MCRP 2-10A.9

Air Intelligence

U.S. Marine Corps

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UNITED STATES MARINE CORPS

FOREWORD

Marine Corps Reference Publication (MCRP) 2-10A.9, *Air Intelligence*, is the first Marine Corps doctrinal publication dedicated entirely to intelligence support to the Marine Air-Ground Task Force's (MAGTF) Aviation Combat Element (ACE). This publication builds upon the doctrinal foundations established in Marine Corps Doctrinal Publication (MCDP) 2, *Intelligence*, and Marine Corps Warfighting Publication (MCWP) 3-20, *Aviation Operations*. It provides tactics, techniques, and procedures (TTP) for air intelligence in support of the ACE and the MAGTF.

This publication describes the unique aspects of intelligence support to the ACE and MAGTF relating to the enemy, weather, and terrain impacting the air domain. It includes doctrinal and scientific fundamentals, multidiscipline intelligence support to the ACE, frameworks for analyzing and understanding enemy air and air defense systems, and guidance on supporting the ACE and MAGTF commander's planning, decision-making, execution, and assessments cycle.

This publication sets the foundation for training requirements, formal schools, organizational structure, and, most importantly, how we provide intelligence support to the ACE and MAGTF in combat. As such, it represents only a starting point and must be continually updated as the state of the art changes. Its users must continue to validate its contents and make recommended changes when more effective techniques or processes are developed.

This publication is not meant to be read alone. Its readers must bookend it on their shelves with Marine aviation doctrinal publications on one side and Marine intelligence doctrinal publications on the other. Intelligence Marines outside the ACE must use this publication to understand how air intelligence can be integrated into their operations. Air intelligence Marines within the ACE must read other MAGTF publications to ensure they are leveraging the full range of MAGTF intelligence capabilities and the Marine Corps Intelligence, Surveillance, and Reconnaissance Enterprise (MCISRE) to support the ACE.

Reviewed and approved this date.

S. E. Gillette

Steve E. Gillette
Colonel, U.S. Marine Corps
Commanding Officer, Marine Aviation Weapons and Tactics Squadron One

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MCRP 2-10A.9 Air Intelligence

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CHAPTER 1. Air Intelligence Introduction and Philosophy

Marine air intelligence is the combination of all-source intelligence, training, personnel, and techniques that assesses the weather, adversary, and terrain impacts to the air domain. While the primary customer of air intelligence support is the aviation combat element (ACE) of the Marine air ground task force (MAGTF), Marine air intelligence is not limited to supporting Marine aviation. Marine air intelligence can also support the MAGTF's command element (CE), ground combat element (GCE), and logistics combat element (LCE) in assessing and analyzing threats that reside within the air domain. This includes providing air intelligence expertise to CE, GCE, and LCE with respect to the impacts adversary air or air defense forces may have on their forces. Marine air intelligence supports the MAGTF by enabling the ACE to persist within an adversary's capabilities while denying adversary power projection capabilities, providing processing, exploitation, and dissemination (PED) for data collected from ACE sensors, and enabling the Marine Corps Intelligence, Surveillance and Reconnaissance (MCISRE) with air and air defense subject matter expertise.

1001. Operational Differences Between the Aviation Combat Element and Ground Combat Element

To understand the unique characteristics of air intelligence, it is first necessary to understand the differences between how the ACE and GCE operate. The different way in which they operate has important implications for how air intelligence organizes, trains, and equips itself.

The principle way in which these major subordinate elements (MSE) differ is their command and control (C2) of attached forces within their assigned battlespace. In the GCE, for maneuver forces capable of achieving MAGTF objectives, battlespace is normally partitioned in a "fractal" manner, with similar character at each echelon. An example of this is found in Figure 1-1. Because structure at each of these echelons is similar in character, their intelligence support requirements are also similar in concept, but generally only differ in scale.

In the ACE, however, airspace is normally managed in a unified manner. Because of both the vast distances the ACE is capable of covering and the high-demand but relatively low-density of ACE capabilities, a unified airspace provides the MAGTF commander with a more efficient allocation of scarce resources as well as a much more responsive ACE. This is achieved through the centralized command of tactical air operations while decentralizing of actual control authority to subordinate agencies, all without the necessity of subdividing an extensive operational area into small zones of action through multiple echelons of command (as it is done in the GCE).

This is accomplished through the Marine air command and control system (MACCS). Under the MACCS construct, the ACE establishes a single tactical air command center (TACC) to command Marine aviation and surface-to-air assets across the area of operations (AO) and balance the employment of aviation assets in support of the Fleet Marine Force. Control of these ACE assets is conducted in a decentralized manner through the direct air support center (DASC) and tactical air operations center (TAOC). This obviates the need to partition the airspace below the senior ACE element/echelon and enables the integrated employment of all ACE assets across the AO in a dynamic manner, responsive to MAGTF requirements.

As a result, the ACE executes command and control of aircraft and missiles through MACCS agencies, not through Marine aircraft groups (MAGs). In addition to the impacts of this unified command and control construct on sortie tasking (through the air tasking order (ATO)) or the command and control of sorties in-flight, a commander may choose to employ a secondary "site command" C2 construct, specifically for sortie-generating activities, where subordinate echelons of command may be tasked only with exercising local site command and control, launching and recovering aircraft, providing mobility and maneuver at the site, sustaining and supporting the site, and site force protection. These site command C2 responsibilities may have no relation to normal organizational charts, with a MAG commander being designated as the site commander for a site with multiple adjacent MAGs or even with the site command responsibilities at the site where the Marine aircraft wing (MAW) itself is located.

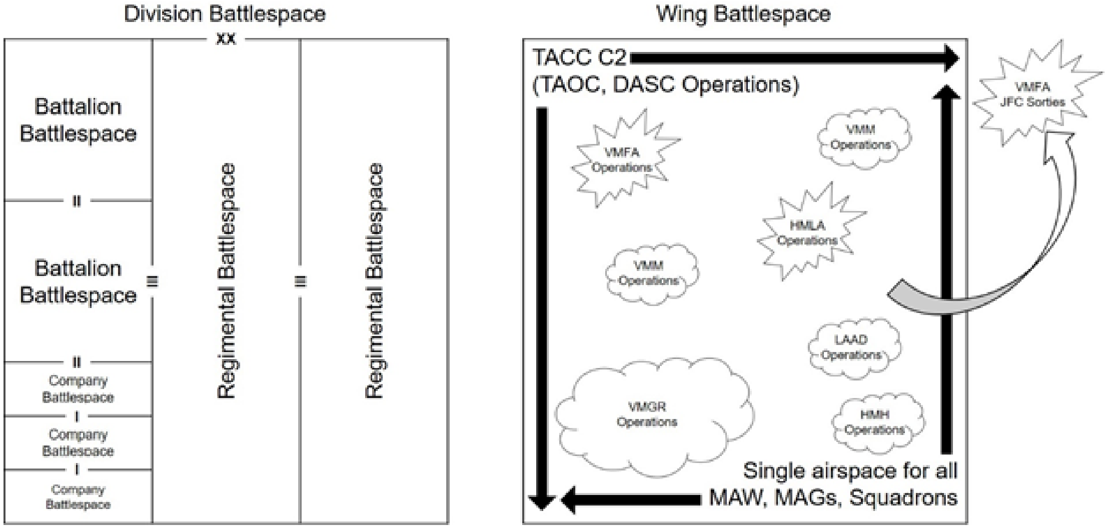


Figure 1-1 example depiction of GCE vs. ACE battlespace

Another consequence of these operational differences, is that the ACE has both fixed and variable costs to support operations. Some support varies in proportion to the size of the ACE, such as refueling capacity. Other support, such as producing an ATO, targeting, intelligence, or airfield operations are fixed whether there are 20 or 200 aircraft in the ACE. The nature of these fixes and variable costs can have a significant impact on intelligence support requirements. Furthermore, Joint doctrine considers some aviation missions inherently Joint, such as the integrated control of air defense, long-range reconnaissance, and long-range interdiction. Consequently, Joint doctrine requires the ACE to make assets available for tasking to the joint force commander (JFC) for these missions. Joint doctrine also recognizes the low-density nature of aviation operations, requiring all sorties in excess of MAGTF direct support requirements be provided to the JFC for tasking in support of other joint force components. This establishes a unique interaction between the ACE and the JFC for theater/joint task force (JTF) fires, apportionment, and ATO development. This enables the ACE to routinely support outside the MAGTF's AO and assigned mission.

The difference in command and control are in large part a consequence of both the ACE's unique time/distance relationship with the battlespace as well as the highly-varied relationship to terrain between sortie-generations activities and sortie execution.

The significant speed with which aircraft can traverse the battlespace gives the ACE a fundamentally different relationship with the AO than the GCE. For example, when it is operationally feasible to sustain a 24-hour-a-day combat air patrol (CAP) from a squadron based at an airfield hundreds of nautical miles and multiple countries away, there is little logic in dividing up airspace by subordinate element. Instead, airspace is divided efficiently by considering what missions are flying and what MACCS agency can control that airspace.

The ACE's unique time/distance relationship with the battlespace also has consequences for its intelligence support requirements and intelligence collection potential. Time factors are compressed in air and air defense operations, increasing the distances considered and decreasing reaction time. These time factors place greater emphasis on combat information of more immediate value as compared to finished intelligence as well as to detailed communication and intelligence planning to ensure responsive collection and dissemination of relevant intelligence. This time/distance relationship also gives the ACE a collection capability not easily achievable by other MSEs as well as generating collection requirements that are often beyond the organic collection capabilities of the MAGTF. Because the ACE allows the MAGTF commanders the ability to observe the battlespace in greater depth than other MSEs, it can be an optimal tool for collection in the deep battlespace for indications and warning (I&W). The same factors, however, mean that targets for many ACE missions, especially interdiction and antiair warfare (AAW), may be located at distances beyond the reach of organic collection means, necessitating increased reliance on theater or national intelligence collection capabilities as compared to other MSEs. Finally, this time/distance relationship has unique consequences for the ACE's relationship to terrain and geographic disposition. The operational flexibility in and decentralized nature of sortie execution is starkly contrasted by the geographic constraints of the ACE in sortie- generating activities (e.g, planning and maintenance). Even the most routine sortie-generating activities require significant centralization and mass. Therefore, while the ACE has more flexibility in maneuver throughout the battlespace, it has much less flexibility in where it can operate from and how long it can operate before it must return to reconstitute combat power.

Because of this, the ACE generally operates out of a small set of forward bases. Throughout history, military aviation has always had to concentrate forces for sortie-generation activities much more than ground forces for similar activities. On one end of the extreme, this has concentrated the entire ACE at a single airfield capable of servicing the MAGTF AO. On the other end of the extreme, such as in World War II, this has still meant a relatively limited set of established and expeditionary airfields across the theater of operations. These differences in command and control and the time/distance relationship between the ACE and the battlespace have important consequences for the operational employment and deployment of the ACE and, therefore, also its intelligence elements.

1002. The Three Alignments of Air Intelligence Support

To meet the unique intelligence support requirements of the ACE, Marine air intelligence aligns intelligence capability and capacity to three distinct operational alignments that offer flexible and dynamic intelligence element configurations**.** The first alignment is to the airspace in which the MACCS commands and controls Marine aviation. The second alignment is to mission planning elements, providing support to commanders responsible for planning aviation and aviation ground operations at squadrons, groups, and wings. The third alignment is to the geographic locations from which aircraft launch and recover and/or where aircraft sensor data is first available for PED. The variations of these three alignments is the principle driver of how the ACE organizes, trains, and equips its intelligence elements and where, across the ACE, this intelligence support is employed.

This framework not only describes the task organization of ACE intelligence elements in past wars but allows ACE commanders to design the optimal task organization of intelligence elements for future operations across the competition continuum, to include the dynamic and distributed operations required by naval operating concepts.

The airspace-aligned intelligence support requirements of the ACE are those that support sensing and making sense of the complete air and air defense intelligence picture as well as related activities, such as intelligence support to campaigning and plans beyond the ATO cycle, and does not normally include intelligence support for specific missions or sorties.

Airspace-aligned intelligence support provides the intelligence support requirements of the TACC. Therefore, airspace-aligned air intelligence support requirements are not dependent on the size of MAGTF element, but must be carried out by the senior ACE echelon, regardless of size or echelon.

Subordinate ACE elements are not generally assigned primary responsibility over portions of the ACE AO and will operate across the entire AO, integrated alongside other ACE subordinate commands. Because of this, subordinate intelligence elements rely on the senior ACE intelligence element to collect, fuse, and analyze intelligence data from throughout the AO. Consequently, the senior ACE intelligence element will normally be responsible for these airspace-aligned intelligence functions on behalf of all subordinate units. In contrast, an S-2 at a battalion assigned its own AO would be expected to collect, fuse, and analyze intelligence data from throughout the battalion AO and to forward that information up to the regimental S-2.

When Marine forces are not assigned a battlespace for any substantial period of time, as in traditional Marine Expeditionary unit (MEU) theater reserve operations (where the MAGTF may have no permanently assigned battlespace) the senior ACE echelon may not have any intelligence support requirements normally associated with the airspace alignment. Airspace-aligned intelligence support is outlined in Marine Corps Reference Publication (MCRP) 3-20F.2 Marine Tactical Air Command Center Handbook .

The mission-aligned intelligence support requirements of the ACE are those that directly support commanders’ planning, decision, execution and assessment (PDE&A) cycle for a specific mission. Commanders at every level have intelligence requirements that necessitate some intelligence capacity and capability directly aligned to that command echelon. Broadly, these include intelligence that informs the direction and execution of assigned missions and the force protection of the unit and subordinate units. This includes the planning of specific missions and sorties within the ATO cycle, whether as one-ship, single-type, model, and/or series (TMS) missions or large integrated aviation packages that bring together multiple squadrons.

At the sortie execution level, mission-aligned requirements include specific and essential capabilities that include the ability to model radar, acoustic, and electro-optical (EO) propagation effects from both terrain and atmospheric conditions for friendly and adversary systems. Additionally, ACE requirements for imagery products place a heavy demand on imagery production and dissemination capabilities. This includes especially imagery-intensive mission planning for offensive air support (OAS) and assault support missions.

The geographic-aligned intelligence support requirements of the ACE are those that are inherently tied to the geographic location where aircraft launch from and recover to and/or where aircraft sensor data is first available for PED. This includes: final intelligence updates as aircrew walk to their aircraft (often hours and sometimes a day after the full mission brief); timely debriefing of aircrew upon return from their sortie (or at intermediate stages throughout the sortie such as between insert and extract or during refueling/re-arming); and the PED of intelligence collected during the sortie (whether this is recorded/transmitted data collected from onboard sensors, the final mission report [MISREP] from the sortie, or the assessment of damage from enemy fire sustained by aircraft during operations).

For site command activities, geographic-aligned intelligence support requirements are those that support local site command and control, launching and recovering aircraft, providing mobility and maneuver at the site, sustaining and supporting the site, and site force protection. A visual depiction of the three alignments and an example support outcome can be found in figure 1-2.

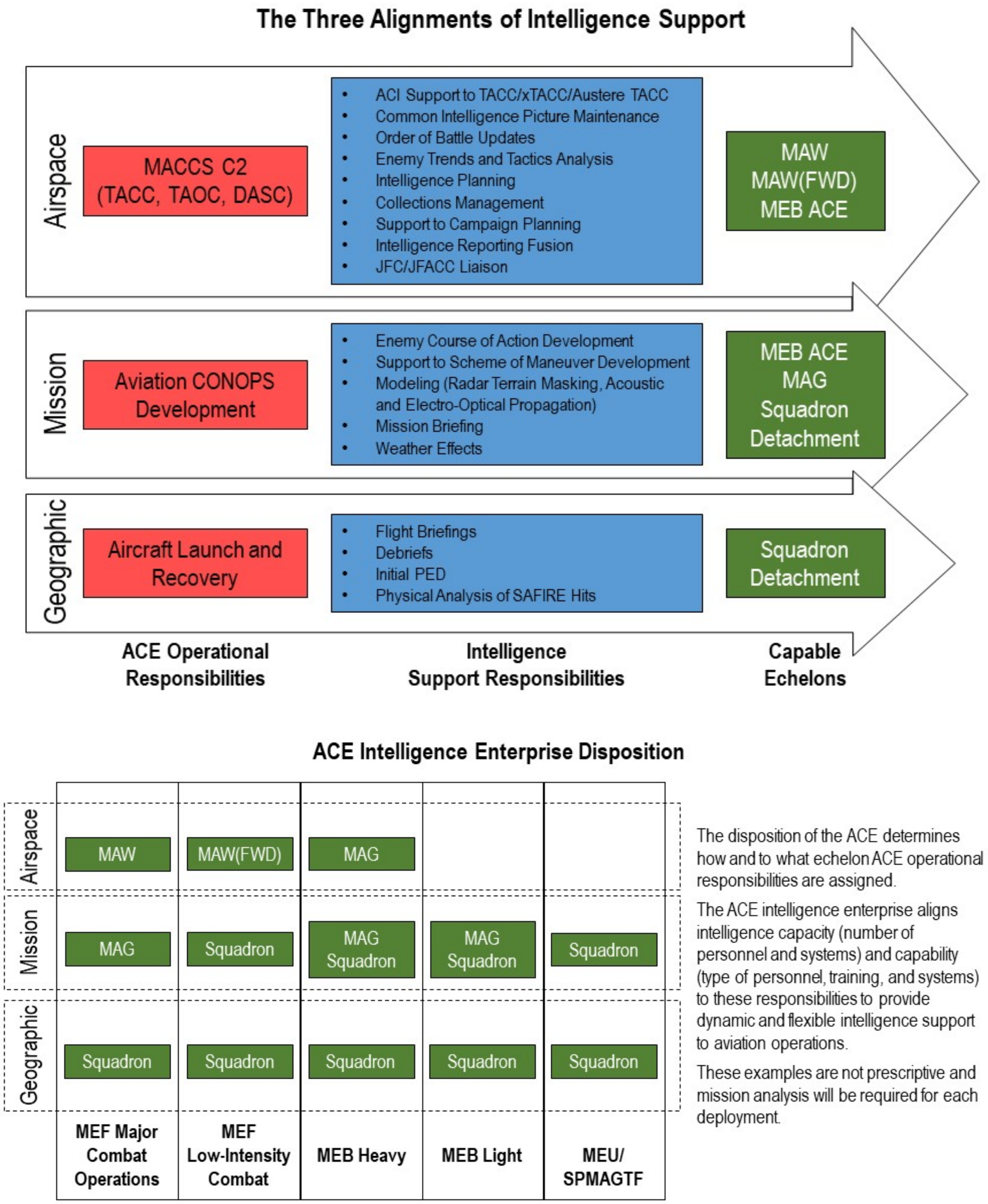
1003. Intelligence Support to the Aviation Combat Element Commander's Decisionmaking Cycle

Air intelligence elements provide these three alignments of intelligence support across five primary phases of Marine aviation’s PDE&A cycle: pre-deployment, planning, pre-mission, in-flight, and post-mission.

Pre-deployment support includes all intelligence support to aviation training as well as all air intelligence training prior to deployment. This includes scenario development tailored to a specific threat or threat capabilities for planned or likely deployments.

Planning support includes all intelligence support to aviation planning and air intelligence planning from receipt of an order (whether warning order [WARNORD] for a deployment, operations order [OPORD] for a campaign, or the daily ATO) to mission briefing.

Pre-mission support includes all intelligence support to aviation briefs and pre-mission activities after the mission plan has been finalized and approved. This includes briefing support to the flight brief(s), final intelligence updates between mission brief and take-off, and coordination activities for any intelligence actions during mission execution.



- ACI Support to TACC/xTACC/Austere TACC
- Common Intelligence Picture Maintenance
- Order of Battle Updates
- Enemy Trends and Tactics Analysis
- Intelligence Planning
- Collections Management
- Support to Campaign Planning
- Intelligence Reporting Fusion
- JFC/JFACC Liaison

- Enemy Course of Action Development
- Support to Scheme of Maneuver Development
- Modeling (Radar Terrain Masking, Acoustic and Electro-Optical Propagation)
- Mission Briefing
- Weather Effects

- Flight Briefings
- Debriefs
- Initial PED
- Physical Analysis of SAFIRE Hits

	MEF Major Combat Operations	MEF Low-Intensity Combat	MEB Heavy	MEB Light	MEU/ SPMAGTF
Airspace	MAW	MAW(FWD)	MAG		
Mission	MAG	Squadron	MAG Squadron	MAG Squadron	Squadron
Geographic	Squadron	Squadron	Squadron	Squadron	Squadron

The disposition of the ACE determines how and to what echelon ACE operational responsibilities are assigned.

The ACE intelligence enterprise aligns intelligence capacity (number of personnel and systems) and capability (type of personnel, training, and systems) to these responsibilities to provide dynamic and flexible intelligence support to aviation operations.

These examples are not prescriptive and mission analysis will be required for each deployment.

Figure 1-2 Examples of air intelligence support via the three alignments

In-flight support includes all intelligence support to aviation in-flight (or during the course of the sortie, to include returning to base to refuel/re-arm or await a call for extraction) as well as intelligence activities during the flight window. These actions may include mid-mission intelligence updates to the aircrew or collection from the aircrew.

Finally, post-mission support includes all intelligence support to aviation and intelligence activities after a sortie has completed. This includes debriefing, MISREP drafting, review, and approval, PED of weapons video, combat assessment, updating the order of battle (OOB), and intelligence support to operational assessments.

1004. Intelligence Task Organization in the Aviation Combat Element

The confluence and divergence of these three alignments in various ACE configurations will drive both the intelligence capacity (i.e., number of intelligence personnel and systems) as well as intelligence capability (type of intelligence personnel, training, and systems) necessary to support each ACE echelon.

If the airspace is partitioned with more than one TACC, such as in a major theater conflict where Marine forces in theater may have multiple, non-contiguous AOs, the ACE requires multiple intelligence elements capable of providing airspace-aligned intelligence support, tailored to the size of the respective TACC's.

When operations are such that one echelon has few mission-aligned intelligence support requirements, the capacity at that echelon may be reduced. For example, in a battlespace where all three echelons (MAW, MAGs, and squadrons) are present but where sortie requirements can be met primarily by mission planning at the squadron level, the group echelon may have very limited mission-aligned intelligence support capacity and capability. In a major theater conflict, where many aviation operations may be highly-integrated operations with multiple squadrons and primary mission planning occurs at the MAG, a squadron may have limited mission-aligned intelligence support capacity and capability.

And finally, when the geographic-aligned intelligence support requirements diverge significantly from mission-aligned requirements and/or squadron headquarters, this capability may need to be detached from normal echelons and placed in general support of multiple units, such as in a flight line intelligence center (FLIC), mirroring the “site command” concept. This can occur during a large movement, as in the 2003 invasion of Iraq, where aircrews may not return to base for many days, overnighting at forward arming and refueling point (FARPs) . Geographic-aligned requirements may necessitate distributed intelligence capabilities during highly distributed operations. Or it may simply be the temporary deployment of a ‘spoke’ that provides an alert line for crisis or contingency. In some cases, this might require the attachment of air intelligence Marines and equipment to aviation ground elements or to specific packages of aircraft so that they may ‘self-deploy’ their intelligence capability.

Intelligence task organization considerations are discussed in greater detail in chapter 7. Figure 1

-2 depicts some examples of how these intelligence support requirements may be aligned to ACE echelons in different combat environments. While the top of figure 1-2 speaks to para 1003 ,the bottom half of figure 1-2 speaks to para 1004 .

1005. Air Intelligence in the Competition Continuum

For aviation operations, there are two broad sources of risk: risk from enemy action (the ‘red threat’) and risk from a mishap (the ‘blue threat’). The red threat is mitigated through intelligence whereas the blue threat is mitigated through operational measures (e.g., safety of flight decisions or control measures). While not always the case, these mitigation measures are often in tension (e.g., an approach into the wind may increase aircraft handling and therefore decrease risk in landing or weapons delivery but it may place the aircraft over a higher-threat area during approach or egress).

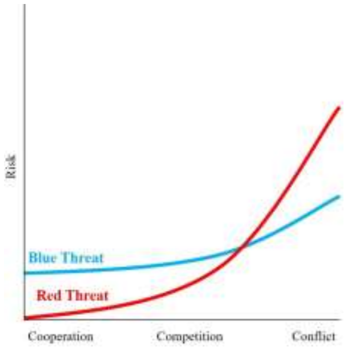


Figure 1-3 Competition Continuum

At the left-side of the competition continuum (see fig. 1-3), during cooperation operations, the red threat is relatively low while the blue threat is comparatively higher. In this environment, operational considerations may tend to override any competing intelligence considerations.

As the competition continuum intensifies, the blue threat rises as the ACE conducts operations that are inherently risky (e.g., more aggressive maneuvers, compressed planning time, or simply larger and more complex operations) and the blue threat increases. However, the red threat increases as well. In low-intensity conflict, where adversary weapon systems may be limited and where US forces possess general force overmatch, the blue threat may remain higher than the red threat. But at some stage, these threats reach a crossover point and the red threat becomes the predominant consideration for risk. This increases both the relative contribution of intelligence tooperations as well as the intelligence support requirements necessary for the commander to balance or mitigate risk.

Consequently, the relative importance of air intelligence varies across the competition continuum. This relative importance should shape both the consideration of intelligence factors in mission planning/execution as well as the intelligence capacity and capability requirements of the ACE across this continuum.

1006. Scientific and Technical Subjects in Air Intelligence

Related to the relative importance of air intelligence across the competition continuum is the scientific and technical nature of air and air defense threats. While advanced ground weapon systems continue to proliferate, air and air defense systems tend to have a greater reliance on the exploitation of science and technology for their fundamental operation. This is likely to remain true for the foreseeable future.

Consequently, the capabilities to understand, collect, and model friendly and adversary air and air defense weapon systems (to include their vulnerabilities and the vulnerabilities that they exploit) necessitate greater emphasis on scientific and technical principals (e.g., electromagnetic spectrum (EMS) theory or the physical and chemical properties of advanced materials) than in many other Marine Corps intelligence sub-disciplines. This is especially true in competition and conflict with peer or near-peer competitors that may have comparable or even superior air and air defense technology systems. A system of these systems (an integrated air defense system [IADS]) increases the complexity of friendly planning exponentially, as discussed in Chapter 5. Air intelligence Marines are required to have a solid foundation of the technical aspects associatedwith the EMS, radar theory, missile guidance laws and schemes, and communication methods in order to properly evaluate the threat. As discussed in chapters 2 and 7, articulating or transferring that information to the supported unit, its aircraft, its weapon systems, or its C2 equipment requires a similarly technical understanding of sophisticated friendly systems and processes, how they will be employed to mitigate the threat, and how they will be affected by the enemy’s weapons, lethal and non-lethal.

CHAPTER 2. Air Intelligence Support to Marine Aviation

This chapter addresses the roles and methods of intelligence support within relevant levels of Marine aviation. It covers both support in the conceptual terms of the six functions of Marine aviation and the MAW hierarchy.

2001. Six Functions of Marine Aviation

The tasks of Marine aviation fall into six functional areas (see figure 2-1): OAS, AAW, assault support, air reconnaissance, electronic warfare (EW), and control of aircraft and missiles. All units within each MAW perform at least one of these functions supported by intelligence.

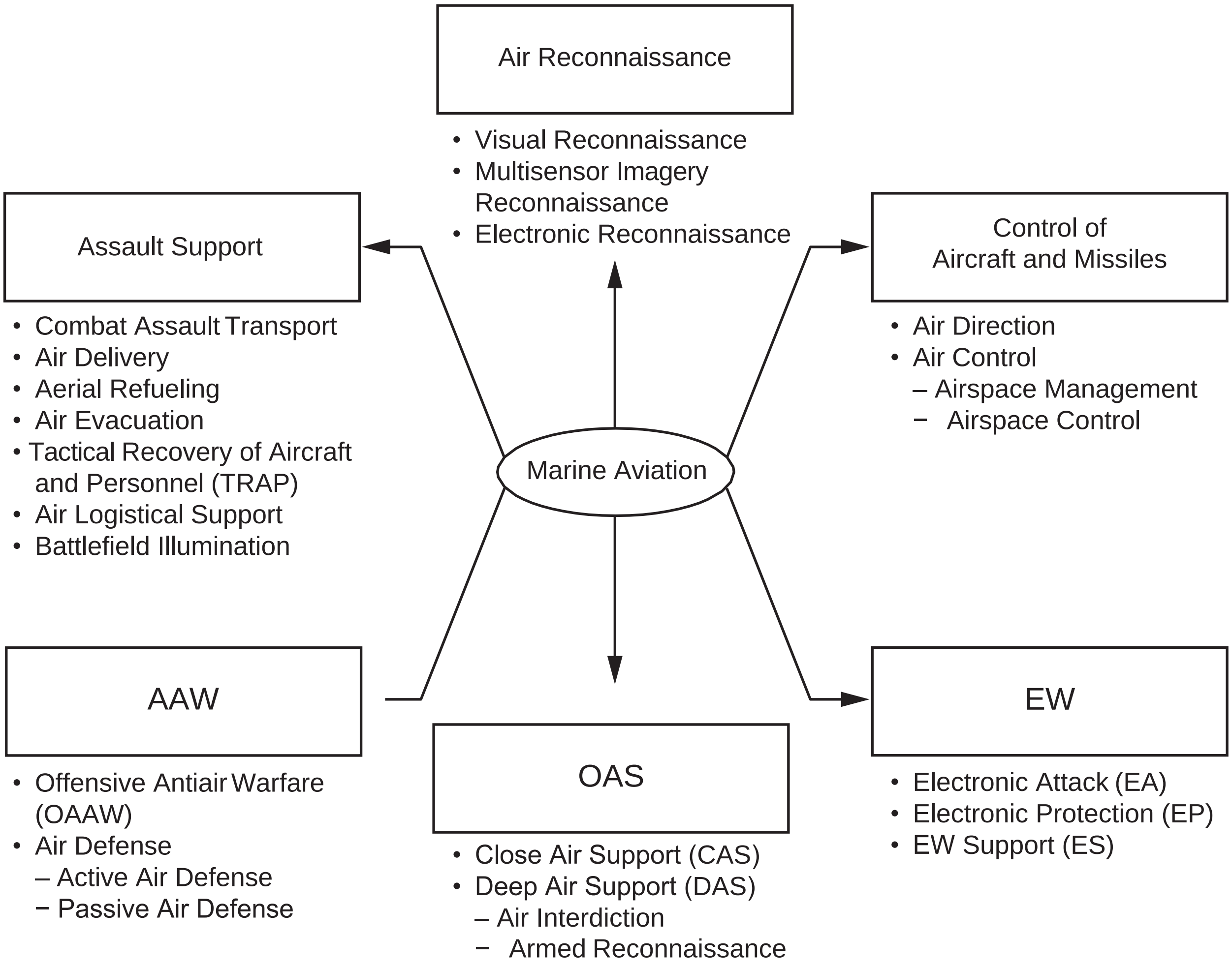
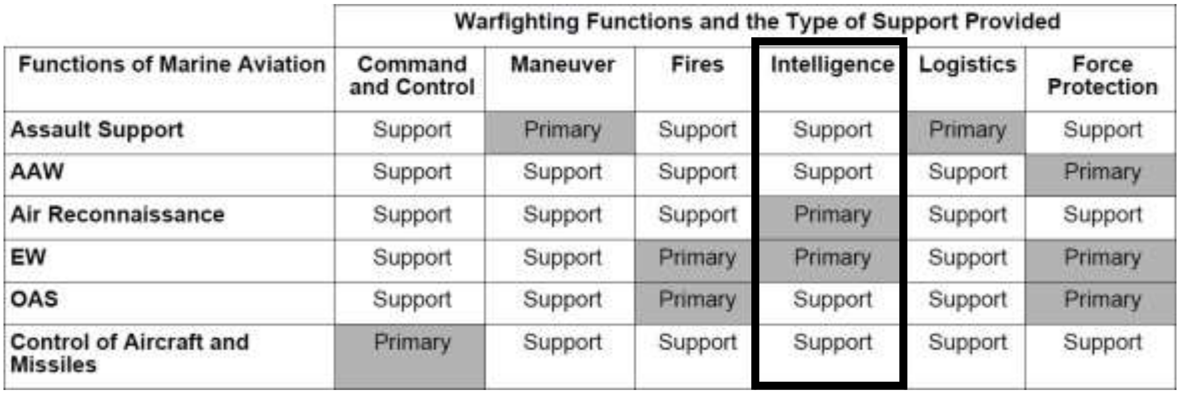


Figure 2-1

Because success in battle requires the integration of many different efforts, Marine aviation is integrated into a combined arms effort focused toward a single objective. Table 2-1 aligns the six functions of Marine aviation with the six warfighting functions, and highlights the role of intelligence in aviation.



	Warfighting Functions and the Type of Support Provided					
Functions of Marine Aviation	**Command and Control**	**Maneuver**	**Fires**	**Intelligence**	**Logistics**	**Force Protection**
Assault Support	Support	Primary	Support	Support	Primary	Support
AAW	Support	Support	Support	Support	Support	Primary
Air Reconnaissance	Support	Support	Support	Primary	Support	Support
EW	Support	Support	Primary	Primary	Support	Primary
OAS	Support	Support	Primary	Support	Support	Primary
Control of Aircraft and Missiles	Primary	Support	Support	Support	Support	Support

Table 2-1

This relationship can be further understood in terms of the intelligence cycle depicted in figure 2-2. Though all intelligence goes through this cycle, a portion requires execution of operations to obtain usable intelligence. For this reason, intelligence as a primary role in aviation operations usually describes the collection efforts of various aviation platforms, as well as some aspects of processing and exploitation. The rest of the cycle is more analytic and administrative in nature, and plays a supporting role in aviation operations.

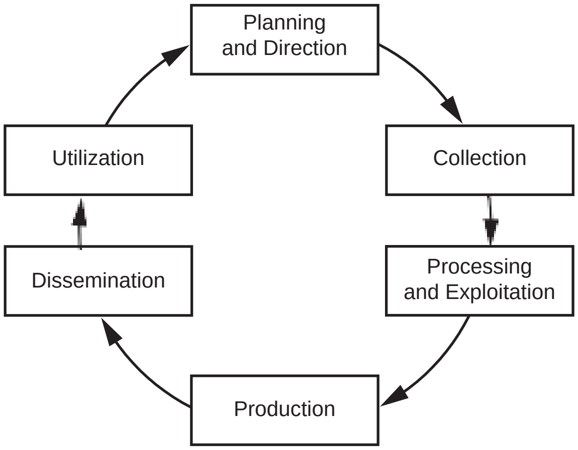


Figure 2-2

a. Intelligence as a Primary Role in Aviation

Because air operations are typically planned well in advance of ground operations, air intelligence collection can often be integrated directly into higher echelon's planning for proper tasking of lower echelon commands – providing proper direction and execution for mission success from the tactical to strategic level.

(1) Air Reconnaissance

Air reconnaissance employs visual observation and/or sensors in aerial vehicles to acquire intelligence information based upon priority intelligence requirements (PIR), an intelligence requirement associated with a decision that will critically affect the overall success of the command's mission. The collection effort can be employed tactically, operationally, and strategically with the focus of Marine Corps assets being more tactical in nature. A number of air reconnaissance platforms can be equipped with sensors to conduct other than visual reconnaissance. The three types of air reconnaissance are visual, multi-sensor imagery, and electronic reconnaissance. These methods can be used to produce geospatial intelligence (GEOINT) and signals intelligence (SIGINT).

(2) Visual Reconnaissance

Visual reconnaissance is the process in which information is collected utilizing the naked eye. Visual reconnaissance can be conducted by any airborne platform and can fill the role in collecting information of friendly and enemy forces as well as providing support to delivery of offensive fires.

(3) Multi-sensor Imagery Reconnaissance

Multi-sensor imagery reconnaissance is used to detect and pinpoint the location of enemy installations, facilities, and concentrations of forces, as well as supporting terrain analysis. Types of imagery produced by Marine aviation sensors include images from standard cameras, targeting pods, EO, synthetic aperture radar (SAR), and infrared (IR) imagery. Platforms by which this is accomplished include F-35B, AV-8B, AH-1Z, UH-1Y, RQ-7B, RQ-21A F/A-18A, F/A-18C, and the KC-130J

(4) Electronic Reconnaissance

Electronic reconnaissance is used to detect, locate, identify, and evaluate enemy EM radiation. Electronic reconnaissance is performed with passive interception equipment that recovers signals and determines signal direction, source, and characteristics.

(5) Electronic Warfare Support

ES refers to the division of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated EM energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations. Electronic warfare support prepares the EM environment for the commander to perform operational missions. Electronic warfare support synchronizes and integrates the planning and operational use of sensors, assets, and processes within a specific battle space to reduce uncertainties concerning the enemy, environment, time, and terrain. Electronic warfare support data can be used to produce SIGINT, provide targeting for electronic or physical attack, and produce measurement and signature intelligence. (JP 3-13.1, *Electronic Warfare*)

b. Intelligence as a Supporting Role in Aviation

Intelligence in a supporting role for Marine aviation takes the form of analytic support for a unit's operations. This support includes, but is not limited to, battle damage assessment (BDA), threat analysis (leadership, doctrine, training and readiness, etc.), line of sight (LOS) profiles (used for weapons employment, observation, and effective use of communication-electronic equipment), strike support, and finished, disseminated imagery products.

At the tactical level, analysis tends to be more product-driven, such landing zone (LZ) studies or target folders, to ensure the safety of aircraft in an unfamiliar environment and accuracy of the operation – weather, enemy, and terrain-based. At the operational and strategic level, products are merely a tool for the assessments that drive the allocation of assets, both dynamic and planned. While this holds true in many cases, there are exceptions depending on level of threat and associated analysis in the AO.

The most significant exception to these general rules is weather. Weather analysis is always in a supporting role, but has an important impact on both friendly and enemy aviation activity. It has the potential to affect everything from safety of flight to weapons employment and sensor capability. Though associated closely with intelligence and integrated into intelligence sections and units throughout Marine aviation, these military occupational specialties have their own requirements, products, and systems to provide support at all levels.

(1) Offensive Air Support

Offensive air support involves air operations that are conducted against enemy installations, facilities, and personnel in order to directly assist in the attainment of MAGTF objectives. Ultimately, the destruction of various enemy assets both in the close and deep battlespace are intended to directly or indirectly affect the enemy's center of gravity.

At a tactical level, intelligence products are the primary form of support to operations. An example of a product is a gridded reference graphic (GRG) for a joint terminal attack controller or forward air controller during a CAS mission. For a deep air support mission, typical products include recognition packs to assist in the identification of priority targets, or target folders with all necessary pre-planned target information.

At an operational and strategic level, products are secondary (and sometimes unnecessary), used mostly to support the communication of one or more assessments that often have a direct impact on planning or targeting, both pre-planned and dynamic during an operation.

(2) Assault Support

Assault support uses aircraft to provide tactical mobility and logistic support to the MAGTF for the movement of high-priority personnel and cargo within the immediate AO (or the evacuation of personnel and cargo). It also includes aerial refueling and battlefield illumination.

There are seven subcategories of as denoted in figure 2-1 with each one requiring varying levels of intelligence support that is highly dependent on the context of the situation. Just as in OAS, intelligence support is product-driven, requiring specialized imagery and topographic products.

(3) Anti-Air Warfare

Anti-air warfare includes the actions used to destroy or reduce the enemy air and missile threat to an acceptable level. It includes the use of fighters, bombers, air defense artillery (ADA), surface-to-air missiles (SAMs) and air-to-air missiles (AAMs), EA, and the destruction of an air or missile threat both before and after it is launched. Anti-air warfare is often primarily conducted at the operational and strategic level, so intelligence support tends to be more analytic (assessment-based) with products tailored to support the delivery of critical assessments.

Individual mission sets within an overall operation can be tactical in nature, but tend to use intelligence products more for their value helping aircrews understand enemy tactics, techniques, and procedures (TTP).

Significant exceptions to this include the SIGINT products produced for EW mission sets used to identify adversary signals. These products themselves are often necessary to support mission execution.

(4) Control of Aircraft and Missiles

This function unites the other five functions through C2 authority over all Marine aviation assets. This is broken down into categories as depicted in figure 2-3.

Air control focuses on the physical maneuver of aircraft to which intelligence provides limited support. Air direction is the authority to regulate the employment of air resources (including both aircraft and surface-to-air weapons) to maintain a balance between their availability and the priorities assigned for their use. Adversary activity and courses of action (COA) play a significant role in how (priority) and when (availability) Marine aviation assets are tasked and retasked. It is the responsibility of intelligence to feed this information to operations through the appropriate channels to drive these decisions.

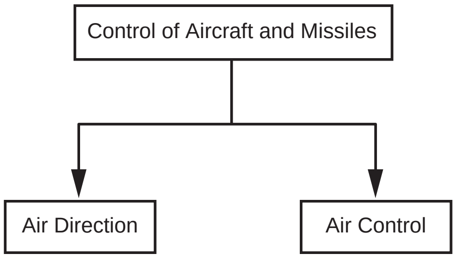


Figure 2-3

2002. Marine Air Intelligence Structure

a. Marine Air Ground Task Force Aviation Combat Element Structure

Intelligence plays a vital role, from the highest level of Marine aviation down to specific tactical mission sets during an operation. While every MAGTF ACE differs, there are three general intelligence formations that support the ACE: the air combat intelligence (ACI), the unit S-2, and the FLIC. Each of these formations will vary in capability and capacity as the mission dictates.

(1) Air Combat Intelligence

The ACE commander and battlestaff (depicted in fig. 2-4) fulfill the role of air direction within the function of control of aircraft and missiles (fig. 2-3) from the TACC. The TACC produces and releases an ATO or Air Plan to be executed by assigned squadrons in a MAGTF operation. While the TACC is most often associated with MAW-level operations, the size and scope of a TACC and the echelon at which it is operated is mission-dependent. Air intelligence supports the TACC through the ACI. The ACI is responsible to the ACE G-2, and serves as the focal point for producing and disseminating aviation-tailored, all-source intelligence during the planning and execution of air operations.

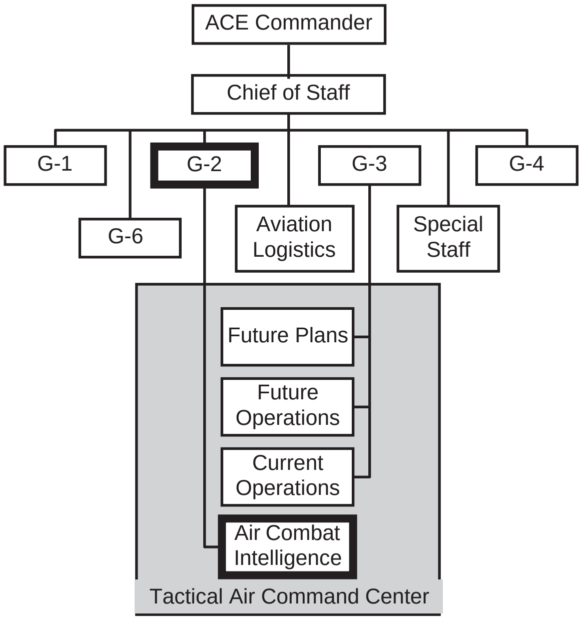


Figure 2-4

The ACI is primarily responsible for airspace-aligned intelligence support requirements that support the overall direction of aviation throughout the MAGTF airspace. Subordinate ACE intelligence sections work with, and through, ACI for all intelligence requirements, production, reporting, and dissemination. Sections within ACI include Production and Analysis, Collections/ GEOINT, Targeting, METOC, and signals intelligence/electronic warfare (SI/EW) as depicted in figure 2-5.

The operations of an ACI are further described in MCRP 3-20F.2.

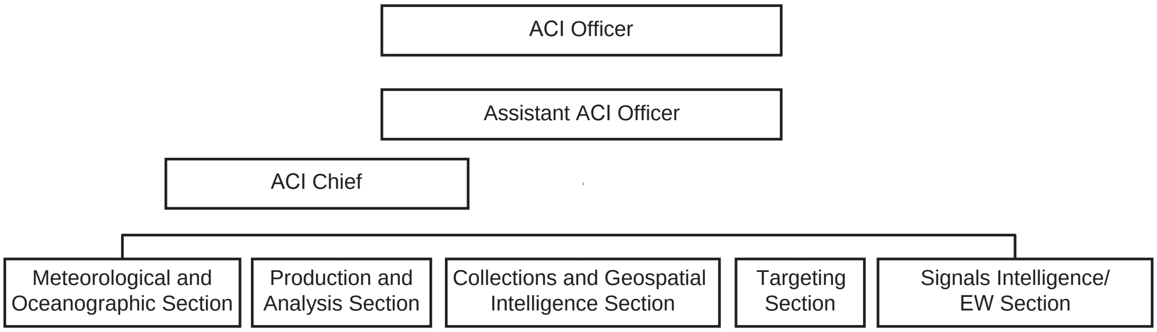


Figure 2-5

(2) S-2 Sections

Subordinate ACE echelons operate S-2 sections. Normally these include MAG and squadron S-2s, although squadron detachments may retain an organic intelligence capability and, when the MAG is the senior ACE echelon, the MAG may operate an ACI rather than a traditional S-2. In most cases, S-2s are task-organized to provide mission-aligned intelligence support. Squadron and detachment S-2s are almost always task-organized to provide geographic-aligned intelligence support.

(3) Flight Line Intelligence Center

The FLIC supports ACE operations at specific forward operating base (FOB) above the single squadron level and up to the MAW echelon when limitations in time, personnel, and/or systems and equipment preclude normal task-organization of intelligence personnel at each squadron, group, and wing (as applicable). When airspace mission, and geographic-aligned intelligence support requirements cannot be efficiently met by assigned intelligence formations at each echelon and unit, a FLIC provides the ACE commander and subordinate commanders with a flexible, scalable, and expeditionary intelligence structure that shares and maximizes the efficient application of available intelligence personnel and resources in a resource-constrained environment at given FOBs.

The ACE employs a FLIC when any of the following limitations require deviation from echelon-based intelligence support and when more than one detachment or squadron is present in a single location:

- Time
- Personnel
- Systems and Equipment

(a) Time

If time is limited between establishing a presence at an expeditionary base and the conduct of operations that require intelligence support, the FLIC can quickly establish the minimum level of intelligence support required to support the first sorties originating from that site. If the total time at an expeditionary base is intended to be limited before forward movement or retrograde, the FLIC provides the ACE commander the ability to quickly establish and displace an intelligence support capability that could service multiple squadrons operating from a single expeditionary site. The FLIC provides a centralized intelligence presence that can efficiently share the limited personnel, systems, and equipment that can be brought to the site or made operational in the limited time available. A FLIC deployed in this manner also provides the smallest intelligence footprint possible to accelerate movement or retrograde from the site.

(b) Personnel

The ACE or any of its elements may have reduced intelligence personnel due to casualties, force deployment caps, limited living or work spaces, reduced signature requirements, hub-and-spoke or disaggregated operations, or other factors. This may be a temporary condition (as when establishing a new expeditionary site) or an enduring limitation. When this occurs, there may be insufficient personnel at each echelon to support mission planning, briefing, execution, and debriefing for the duration of flight operations or for the sorties the site is capable of generating. In these cases, the FLIC can concentrate intelligence personnel at the expeditionary site to provide the full-spectrum intelligence support to multiple supported squadrons.

(c) Systems and Equipment

The ACE or any of its elements may have reduced intelligence systems and equipment (or reduced capability and capacity of available systems and equipment) due to combat losses, equipment attrition, limited cargo space for deploying or forward-positioned forces, a contested cyberspace environment, reduced signature requirements, hub-and-spoke or disaggregated operations, or other factors. In these cases, the FLIC provides the ACE commander a structure that concentrates and optimizes available or effective systems and equipment

(d) Flight Line Intelligence Center Task Organization

The FLIC’s responsibilities will vary in relation to the auxiliary ACE intelligence structure. When a FLIC composites all intelligence personnel and equipment within an ACE or at a location, it inherits all intelligence support responsibilities for the ACE or location. When ACE echelons maintain their own intelligence elements, the FLIC may be tasked with additional responsibilities as required, including debriefing, drafting and dissemination of MISREPs, and PED of collected intelligence.

The FLIC’s composition will be dictated by mission variables.

When the FLIC composites all ACE intelligence personnel and equipment at a location, it is capable of rapidly establishing and building-up intelligence support capability at an expeditionary site, providing centralized intelligence support to all co-located ACE units, and rapidly drawing down and displacing or retrograding, as required.

At a minimum, the FLIC is staffed by one intelligence Marines during flight operations or alert windows in order to: provide last minutes updates to the common intelligence picture (e.g., status or targets, enemy movements, etc.) as aviators and aircrew walk to their planes; capture information of immediate intelligence value (e.g., observations of enemy positions, initial combat assessment feedback, etc.) as aviators and aircrew return from a sortie; and maintain communications with the ACE intelligence element maintaining the common intelligence picture.

(e) Command Relationships

Normally, the FLIC operates at the direction of the ACE commander present on site and as an extension of that commander's intelligence section. Subordinate intelligence personnel may be formally attached to the senior echelon or informally detailed to the FLIC, operating under the direction and staff cognizance of the senior ACE commander's Intelligence Officer, as articulated by relevant orders.

(4) Aviation Combat Element Intelligence Section Task-Organization

Task-organization is important to any element of a MAGTF. However, the modular logic of the MACCS makes task-organization planning especially important in the ACE. This is no less true for ACE intelligence sections. For example, a squadron S-2 might be as small as two intelligence Marines, but for a MEU composite squadron, it may be as large as ten. Or a MAG S-2 might be as small as thirteen Marines, but for a MEB ACE, it may be as large as fifty . This high degree of variance makes troop-to-task analysis critical to ensuring Marine aviation formations are adequately supported by intelligence elements.

Troop-to-task analysis match personnel, equipment, and training requirements to a list of tasks in order to identify the resources necessary for the mission. The outputs of this analysis is a task-organization. The task organization of any unit, element, section, or team—and therefore the factors that are considered in troop-to-task analysis—is determined by two primary requirements: capability and capacity. Capability refers to the ability of a section to accomplish a task. In the simplest cases, this can be thought of as the type of training or equipment required as well as the rank and MOS of the personnel conducting the tasks. Capacity refers to the amount of work that can or is required to be done for a task. In the simplest cases, this can be the number of people and equipment required.

This process is not always linear and some iteration may be required. However, it does follow a logical flow. First the task analysis for a section is required, outlining what the section is required to do to support the unit (directly informing capability analysis). Second, analysis is required to match capacity to task requirements (capacity analysis), ensuring the section plans for sufficient means for what it is required to do.

(a) Capability Analysis

The capability requirement of any air intelligence section is generally derived from the unit and section's mission and both specified and implied tasks. The output of capability analysis is one or more options for the type of personnel, training, and equipment required. For personnel, this may include rank and MOS requirements. For training, this may include schools, courses, on-the-job training, or knowledge of the adversary and battlespace. For equipment, this may include types of equipment and/or that equipment's connectivity to or the availability of external databases and resources.

There are a number of primary factors that must be analyzed to determine a section mission and, therefore, capability requirement:

- The METs to be supported
- The elements of the analytic process required to be conducted
- The level of war being supported
- The nature of the Commander's decisions being supported
- The intelligence topics required to be addressed
- The higher headquarters intelligence support available

The number or variety of METs a unit is assigned provide important information about the tasks an intelligence section will be require to support and, therefore, the capabilities required. The differences in the number and variety of METs between units can also be a key indication of how similar or different capability requirements are between units. For example, an CH-53 squadron and a MV-22B squadron have very similar METs. The capability requirements of the two squadrons should therefore be very similar (all other factors remaining the same).

The type of analysis and steps of the analytic process required of a section also plays an important role in determining capability requirements. For example, an intelligence section at a squadron planning a strike mission may require the capability to conduct detailed tactical analysis of weapons system capabilities. Meanwhile, an intelligence plans section supporting the development of an air campaign requires an understanding of the adversary's operational objectives—but requires little capability to conduct detailed tactical analysis of weapons system capabilities. Similarly, the intelligence plans section may be required to conduct their own analysis of how strategic geopolitical objectives will impact adversary theater air operations. While this analysis is important to squadron intelligence sections, those squadrons only require the ability to synthesize the operational-level analysis of others in the context of their squadron's tactical mission.

Marine units at the Marine expeditionalry force (MEF) level and below are normally considered tactical warfighting organizations and Marine aviation is designed primarily as a tactical instrument, although it can have operational and strategic effects. Understanding this tactical focus is important in understanding both what air intelligence Marines are trained to do and to understand what training is most beneficial to the way those Marines will be employed in combat. For example, assessing the likelihood of a situation escalating into war, while an important question, is not intelligence that informs an aviation unit commander's PDE&A cycle. Such strategic questions, therefore, are not appropriate for an air intelligence element's analysis and reducing the resources available for answering more important tactical questions that higher echelons are not addressing. Air intelligence elements can, however, provide the answers to some of these questions by using the analysis of entities organized, trained, and equipped to answer them (e.g., certain intelligence community (IC) elements).

Closely related to the level of war at which a unit operates, in many situations, especially at the lowest echelons, the decisions actually within an aviation commander's purview may be limited. When the aviation element is not a battlespace owner and it is primarily in a supporting role, the ATO may dictate when and where a squadron will fly. In these cases, the commander may have input into (but not be a decisionmaker for) decisions around when and where the ACE will operate. In this event, the commander's actual decisionmaking authority may be limited to the tactical employment of unit aircraft (the aviation supporting scheme of maneuver (SOM) and employed TTPs). Even when an aviation element is a battlespace owner, the unified nature of airspace control means that the many decisions may still be held at MACCS agencies, and not within the authority of subordinate unit commanders. Considering the decisions available and not available to an aviation unit commander will help refine intelligence support requirements. Intelligence topics are as varied and broad as the elements of a MAGTF. It is therefore neither feasible, nor is it the design of the MAGTF, for any one intelligence section to gain and maintain subject matter expertise on the analysis of all intelligence topics. Within aviation units, intelligence sections are organized, trained, and equipped to provide intelligence support regarding air and air defense topics and to liaise with other intelligence elements of the MAGTF, Joint Force, or IC with respect to other intelligence topics. The scope of topics an intelligence section must address can significantly focus training efforts.

Finally, any intelligence element will have external dependencies. These both facilitate the capability possible at subordinate sections (by providing reach-back or “reach-up” capabilities that would otherwise not be available at all) and present risks to subordinate sections (by placing critical capabilities outside the scope of the subordinate commander’s direct control—competing with other priorities or limited by communication or geo-location restrictions).

Once these factors are analyzed, the section will be able to conduct a task analysis that lists what the section must do to support the unit. This tasks analysis will explicitly articulate the capabilities required but also implies the capacity necessary to meet the capability requirement. Much as with a unit’s mission analysis, this should identify both specified and implied tasks for the intelligence section. The form this takes can be as simple as a list. But, depending on unit or section size and complexity, this list may need to be broken out functionally and/or prioritized. This task analysis becomes the basis for capacity analysis.

(b) Capacity Analysis

The capacity requirement of any air intelligence section is generally derived from the unit’s sustained and surge output ability as well as the degree of intelligence support required to support that output in specific conditions. The output of capacity analysis is generally one or more options for the number of personnel and amount of equipment required.

There are a number of primary factors that must be analyzed to determine a section’s capacity requirement:

- Sortie Generation
- Intelligence watch requirements

- Flight Window
- Number and location of operating sites
- Surge Requirements
- PED requirements
- Threat level
- Collateral responsibilities
- Personnel limitations

At the squadron echelon and below the intelligence support required by sortie is principally determined by three factors: the number of missions flown, the number of crews supported, and the hours flown. Above the squadron echelon these variables still impact intelligence support requirements, but the relationship between intelligence support required and these three factors is less direct than at the squadron echelon and below. During planning before deployment, squadrons and ATO planners often work out “business rules” for what is within normal bounds for ATO tasking of a unit. These planning factors can be used as a planning factor for intelligence section capacity analysis.

Intelligence sections normally require some form of 24-hour intelligence watch that provides the ability to monitor the AO as situations develop. This is essential in situations where aircrew may be called in outside of normal flight window operations for crisis operations or may be required to conduct flight operations at the very beginning of a flight window. In these cases, the intelligence section must be prepared to support on a moment’s notice—and this is often only possible with constant monitoring and situation development. While the need for an intelligence watch increases capacity requirements, personnel in watch positions can also reduce capacity requirements during normal flight windows by updating products or developing briefs that will or may be required during the flight window (e.g., mission briefs for upcoming planned sorties).

The number and locations of operating sites plays a significant role in intelligence capacity analysis and may multiply the requirements of any number of other capacity parameters. While there is almost no limit to the possible configuration of operating sites, the duration and mission focus of the operating sites are the most important factors to consider. Operating from additional sites for short duration may be supportable with only a surge effort while extended durations may require intelligence sections planning for additional capacity. When multiple sites have the same general mission focus, efficiencies may be achievable with a smaller intelligence section, while disaggregated operations may require additional capacity.

The flight window that must be supported by an intelligence section is a significant determinant of intelligence section capacity. This window may be limited by available aircrew or aircraft, operating site limitations, or operational tasking. Flight window analysis must consider planned as well as potential operating sites. For example, while two Marines might be adequate for 24-hour single-site operations, the execution of 24-hour hub-and-spoke operations would require a minimum of four. Flight windows may also vary across sites and all flight windows are not equal. Alert lines may span 24-hours but the aviation capacity may be only sufficient to launch a single sortie. In these cases, with sufficient planning, it might be feasible for one intelligence Marine to adequately support a 24-hour alert. In contrast, a 24-hour flight window that regularly sorties aircraft throughout the day would not be adequately supported by a single intelligence Marine.

Intelligence leaders should plan for a limited ability to surge capacity. This may be required by conditions unanticipated or considered unlikely in planning. Or it may simply be required by a surge in operational tasking. Aircrew have provisions for extending crew days and maintenance sections have the ability to surge readiness rates. Their supporting intelligence sections must plan for corresponding surge capabilities. Surge capacity requirements may also be met with reach-back support. Generally, reach-back support is considered less effective than on-site, organic support. But this shortfall can be mitigated by appropriate task management (e.g., assigning routine or long-term production requirements to a reach-back element). In other cases, this shortfall must simply be accepted.

The requirements for PED vary significantly across TMSs and METs and must factor in constraints such as reporting timelines and crew day. For example, a UH-1Y conducting assault support may have no PED requirements aside from a debrief and MISREP. That same UH-1Y conducting CAS may require significant weapon system video (WSV) exploitation. Similarly, at the most extreme, the PED requirement for an MV-22B sortie may be limited to a two- or three-hour debrief and extensive MISREP. Whereas, at the extreme, the PED requirement for an FA-18 sortie may include an equally-long debrief on top of WSV exploitation and, potentially, exploitation of in-flight video footage, totaling some four or five hours of PED. When these differences are multiplied across the daily sorties generated by a squadron, the cumulative PED requirements of an intelligence section can vary substantially. Planners must also factor in both PED timelines that may be required by intelligence reporting directives and other concurrent intelligence tasks that may be taking place. For example, if theater intelligence reporting directives require MISREPs be submitted within three hours of engine shutdown, an intelligence section may require the capacity to concurrently exploit WSV with one Marine and conduct a debrief and draft a MISREP with another in order to meet this deadline. Additionally, an outgoing sortie may require an intelligence brief at the same time as an incoming sortie is being debriefed.

The degree of air threat in a battlespace is a significant factor in section capacity requirements. A ten-Marine MAG S-2 may be adequate for a permissive operating environment and where the MAG exercises no airspace control. But a similarly-sized MAG deployed against an adversary IADS and responsible for supporting a MACCS may require five times the number of personnel.

Collateral responsibilities require their own capability and capacity analysis. But each detracts at least somewhat from the capacity available for the intelligence warfighting function. These duties may be assigned to specific individuals or as functional areas assigned to the section. Additional rotational duties that support unit operations or force protection, such as “camp taxes” or guard duties may also impact available section capacity.

Finally, in all cases, there are limitations on the number of personnel able to be deployed to a site. This requires commanders to balance capacity across their unit with the consequence that the intelligence section may have an upper limit on the personnel or equipment capacity it can deploy with. Marine units are often positioned in partner or allied nations or aboard ship. There are almost always personnel limitations associated with these basing options. In partner or allied nations, diplomatic agreements may specify the maximum number of personnel allowed in the country or at a specific site. Aboard ship, there are limited berthing spaces. Even when policy limitations on the numbers of personnel may not apply, every individual at an operating site increases risk and logistics support requirements. Even equipment requires lift, maintenance, sustainment, and power —limited resources in any kind of operation. These limitations must factor into capacity analysis.

(c) Task-Organization in Practice

While every deployment will differ, there are five generic scenarios for ACE employment that demonstrate how various ACE intelligence section task-organization fulfills the three alignments of intelligence support discussed in chapter 1.

The first scenario is when a squadron is deployed alone, without a higher headquarters ACE element, such as with a MEU or small special purpose MAGTF ACE. In this situation, it would be rare for the squadron to be assigned airspace for any significant duration of time. Intelligence responsibilities break down as follows:

- Airspace-aligned intelligence support: not required.
- Mission-aligned intelligence support: squadron S-2.
- Geographic-aligned intelligence support: squadron S-2.

The second scenario is when squadrons are deployed under a single higher headquarters ACE element (such as a MAG or a MAW[FWD]) that is not assigned airspace to control. Intelligence responsibilities break down as follows:

- Airspace-aligned intelligence support: not required.
- Mission-aligned intelligence support: MAW(FWD)/MAG G/S-2, squadron S-2.
- Geographic-aligned intelligence support: squadron S-2.

The third scenario is when squadrons are deployed under a single higher headquarters ACE element that is assigned airspace to control. In this situation, the senior ACE element would operate some form of TACC and the senior ACE element intelligence section would operate some form of ACI. Intelligence responsibilities break down as follows:

- Airspace-aligned intelligence support: MAW(FWD)/MAG ACI.
- Mission-aligned intelligence support: MAW(FWD)/MAG ACI, squadron S-2.
- Geographic-aligned intelligence support: squadron S-2.

The fourth scenario is when all three echelons of the ACE (MAW, MAG, squadron) are deployed. In this situation, normally, the MAW will be assigned airspace to control. Intelligence responsibilities break down as follows:

- Airspace-aligned intelligence support: MAW ACI.
- Mission-aligned intelligence support: MAW ACI Future Plans Cell, MAG S-2, squadron S-2.
- Geographic-aligned intelligence support: squadron S-2.

The fifth scenario is when all three echelons of the ACE (MAW, MAG, squadron) are deployed in major combat operations where non-routine missions require large, integrated aviation packages. In this situation, major mission planning primarily occurs at echelons above the squadron. Intelligence responsibilities break down as follows:

- Airspace-aligned intelligence support: MAW ACI.
- Mission-aligned intelligence support: MAW ACI Future Plans Cell, MAG S-2.
- Geographic-aligned intelligence support: squadron S-2.

CHAPTER 3. Science

This chapter provides knowledge of the fundamental principles, terms, and, most importantly, the operational impacts of the science behind flight, the EMS, missiles, weather, terrain, acoustic detection and propagation, space, and the Global Positioning System (GPS). This baseline will provide a working knowledge that air intelligence Marines can apply to the current situation, threats, and friendly forces.

3001. Principles of Flight

Aircraft flight is only possible because of the physics behind flight science and the way they are implemented in aircraft design. The technologies that improve the flight characteristics and maneuverability of aircraft and the scientific foundations that underlie them are important for air intelligence analysis. This will enable air intelligence Marines to better assess weather effects on friendly and enemy platforms and to understanding how technology and features of enemy airframes affect their maneuverability and thus the threat posed to friendly forces. Additionally, this allows analysts to understand the language aviators and aircrew used to describe basic actions in flight and is also critical for comprehending advanced tactical concepts such as within visual range (WVR) tactics and basic fighter maneuvers.

For intelligence Marines supporting fixed-wing platforms, basic concepts of aircraft maneuverability are essential to understanding and assessing enemy air-to-air tactics and weapons employment. Many of these tactics are dictated by an airframe’s flight performance and capabilities relative to the enemy.

The key principles of flight essential to air intelligence include: forces of flight, aerodynamic efficiency, aircraft motions, control surfaces, energy-maneuverability, and airspeed.

a. Forces of Flight

A force is an interaction (push or pull) on an object that changes the state of rest or motion of a body. A force has both a magnitude (amount) and a direction, making it a *vector quantity* (when describing forces, both the magnitude and direction are specified).

There are four forces that act on an aircraft in flight: weight, lift, drag, and thrust (see fig. 3-1). The motion of the aircraft through the air depends on the relative size of the various forces and the orientation of the aircraft. If the forces are balanced, the aircraft cruises at constant altitude and airspeed. If the forces are unbalanced, the aircraft accelerates in the direction of the largest force. The interaction among these forces dictates how the aircraft moves through the air.

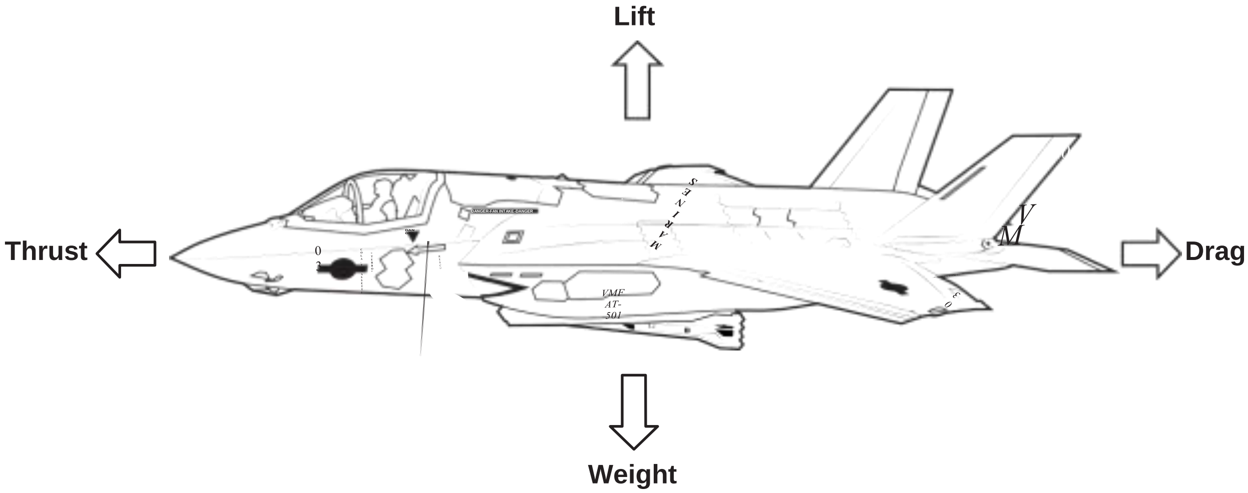


Figure 3-1

(1) Weight

Weight is a force that is always directed toward the center of the Earth. The magnitude of the weight depends on the mass of the aircraft (including the airframe, fuel, payload, and crew). While weight is distributed throughout the aircraft, the center of this weight is the *center of gravity*. In flight, an aircraft rotates about its center of gravity.

For an aircraft to fly, it must overcome two major obstacles: its weight and controlling the aircraft in flight. Both of these problems are related to the object's weight and the location of the center of gravity. During flight, an aircraft's weight constantly changes as the aircraft consumes fuel. The distribution of the weight and the center of gravity also changes. As a consequence, the pilot, or a flight control computer, must constantly adjust the controls to keep the aircraft balanced, or trimmed.

(2) Lift

To overcome the force of an aircraft's weight, it must generate an opposing force: *lift*. Lift is generated by the motion of the aircraft through the air and is perpendicular to the relative air flow (usually perpendicular to the flight direction in straight and level flight). The magnitude of the lift depends on several factors including the shape, size, and velocity of the aircraft. As with weight, each part of the aircraft contributes to the aircraft lift force. Most of the lift is generated by the wings.

As a wing flies through the sky, it deflects air and alters the air pressure above and below it. The curved upper part of the wing lowers the air pressure directly above it. Combined with the high pressure below the wing, the wing is pushed upward. This happens because as air flows over the curved upper surface, its tendency is to move in a straight line, but the curve of the wing pulls it around and back down. For this reason, the air is effectively stretched out into a bigger volume—the same number of air molecules forced to occupy more space (i.e., less dense)—and this is what lowers its pressure. For exactly the opposite reason, the pressure of the air under the wing increases: the advancing wing compresses the air molecules in front of it into a smaller volume (i.e., denser). This difference in air pressure creates lift and forces the wing upward, depicted in figure 3-2.

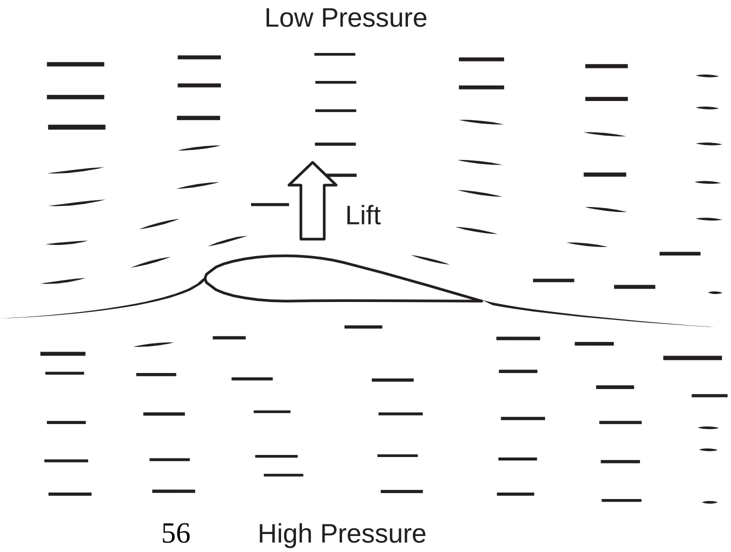


Figure 3-2

Aircraft lift acts through a single point called the center of pressure. As with center of gravity, the center of pressure is the average point of pressure under a wing. The lift provided by an aircraft’s wings helps to solve the weight problem while the distribution of lift around the aircraft is important for solving the control problem.

By manipulating how much lift is generated, and where (i.e., manipulating the center of pressure with respect to the center of gravity), lift surfaces are used to control the aircraft in roll, pitch, and yaw.

As the name implies, in rotary wing aircraft the rotor blades are the primary wings, or lift surfaces. Therefore, lift is provided by the rotors.

Lift can also create drag, known as lift-induced drag. This is drag created when a lift surface redirects the airflow (usually associated with an angle of attack or control surfaces, such as flaps, that are designed to face relative airflow at an angle). The magnitude of lift-induced drag is associated with the angle of the lift surface relative to the direction of airflow.

(3) Drag

As an aircraft moves through the air, the air resists the motion of the aircraft. This resistance force is called *drag*. Drag is directed along and opposed to the flight direction. As with lift, many factors affect the magnitude of the drag force including the shape of the aircraft, the viscosity of the air, and the velocity of the aircraft. Like lift, the collective drag all of the individual components combine into a single aircraft drag magnitude. And like lift, drag acts through its own center of pressure.

(4) Thrust

To overcome drag, aircraft use a propulsion system to generate a force called *thrust*. The direction of the thrust force depends on how the engines are attached to the aircraft. On some fixed-wing aircraft, such as those with short-takeoff capability, thrust direction can be varied to help the aircraft take off in a very short distance. On rotary-wing aircraft, thrust direction is always directed in a downwards direction relative to the rotor or prop rotor (by changing the direction of the rotor, rotary-wing aircraft can create a horizontal component to their trust, propelling them in the direction of the tilt). The magnitude of the thrust depends on many factors associated with the propulsion system including the type of engine, the number of engines, and the throttle setting.

b. Aerodynamic Efficiency

Aerodynamic efficiency is described using two ratios between forces of flight. These two ratios, lift-to-drag and thrust-to-weight, are essential in estimating the maneuverability and suitability of aircraft to different missions, as well as to comparing the relative maneuverability of two aircraft to one another.

(1) Lift-to-Drag Ratio

Lift and drag are both aerodynamic forces, and the lift-to-drag ratio is an indication of the aerodynamic efficiency of the aircraft. An aircraft has a high lift-to-drag ratio if it produces a large amount of lift and a relatively small amount of drag. A high-lift aircraft more easily overcomes its weight, increasing its operational payload for missions. A low-drag aircraft requires low thrust, minimizing the fuel burned. Low fuel usage allows an aircraft to stay aloft for a long time, enabling it to fly long range missions or provide a long on-station time.

(2) Thrust-to-Weight Ratio

Thrust-to-weight ratio is also an operationally important characteristic of an aircraft. Since acceleration is a forward force on the mass of the aircraft, a high thrust-to-weight ratio enables an aircraft to accelerate quickly. Under most flight conditions, an aircraft with a high thrust-to-weight ratio will also have a high value of excess thrust. High excess thrust results in a capability for a high rate of climb in altitude. Having a high thrust-to-weight ratio is an important asset in basic fighter maneuvers and is a key element of supermaneuverability.

c. Aircraft Motions

It is necessary to control the orientation, called the *attitude*, of a flying aircraft in all three dimensions. In flight, aircraft will rotate about its center of gravity, a point which is the average location of the mass of the aircraft. We use rotation in the three dimensions, along the three principal axes (up/down, front/back, and left/right) to describe changes in attitude.

(1) Principal Axes

The yaw axis is defined to be perpendicular to the plane of the wings with its origin at the center of gravity and directed towards the bottom of the aircraft. A yaw motion is a movement of the nose of the aircraft from side to side (i.e., the way a top spins). The pitch axis is perpendicular to the yaw axis and is parallel to the plane of the wings with its origin at the center of gravity and directed towards the right wing tip. A pitch motion is an up or down movement of the nose of the aircraft (i.e., looking up or down). The roll axis is perpendicular to the other two axes with its origin at the center of gravity, and is directed towards the nose of the aircraft. A rolling motion is an up and down movement of the wing tips of the aircraft (i.e., as a log might be rolled over). Figure 3-3 depicts these three axes.

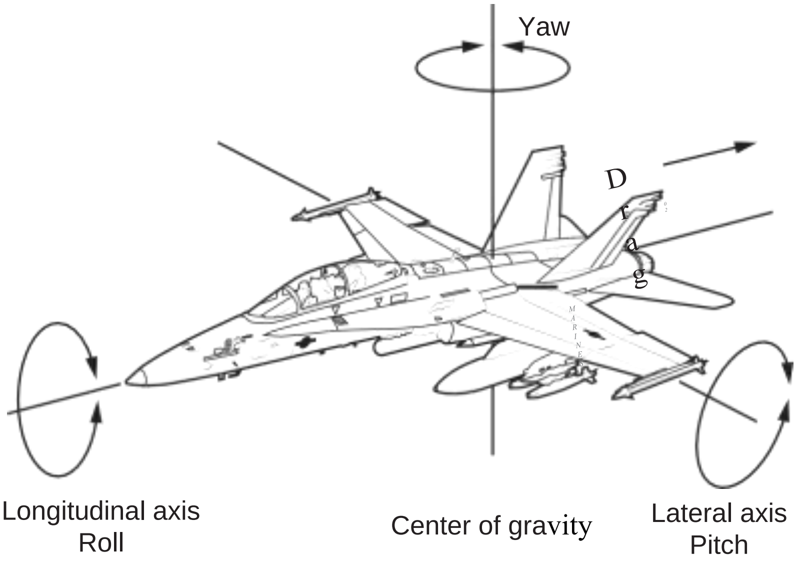


Figure 3-3

In flight, the control surfaces of an aircraft produce aerodynamic forces. These forces are applied at the center of pressure of the control surfaces. These centers of pressure are some distance from the aircraft's center of gravity. The force applied at this distance from the center of gravity produces torques (also known as *moments*) about the principal axes. These torques, in turn, cause the aircraft to rotate. The elevators produce a pitching moment, the rudder produces a yawing moment, and the ailerons produce a rolling moment. The ability to vary the amount of the force and the moment allows the pilot to maneuver or to trim the aircraft as desired.

(2) Banking

One fundamental aircraft motion is a banking turn. This maneuver changes the aircraft heading more easily and rapidly than using yaw alone. The turn is initiated by using the ailerons or spoilers (hinged control surfaces) to roll, or bank, the aircraft to one side. As the aircraft banks, it is no longer oriented parallel to the ground and therefore, the force of lift on its wings does not point directly upwards, but up and to the side, on a diagonal (see fig. 3-4). The sideways component of this diagonal lift is a vector quantity which is always directed perpendicular to the flight path and perpendicular to the wings. As the aircraft is rolled, the lift vector is tilted in the direction of the bank. We can understand the effect on the aircraft by understanding the lift vector's two components. One component is vertical and opposed to the weight force, which is always directed towards the center of the Earth. The other component is an unopposed side force, which is in the direction of the roll, and perpendicular to the flight path.

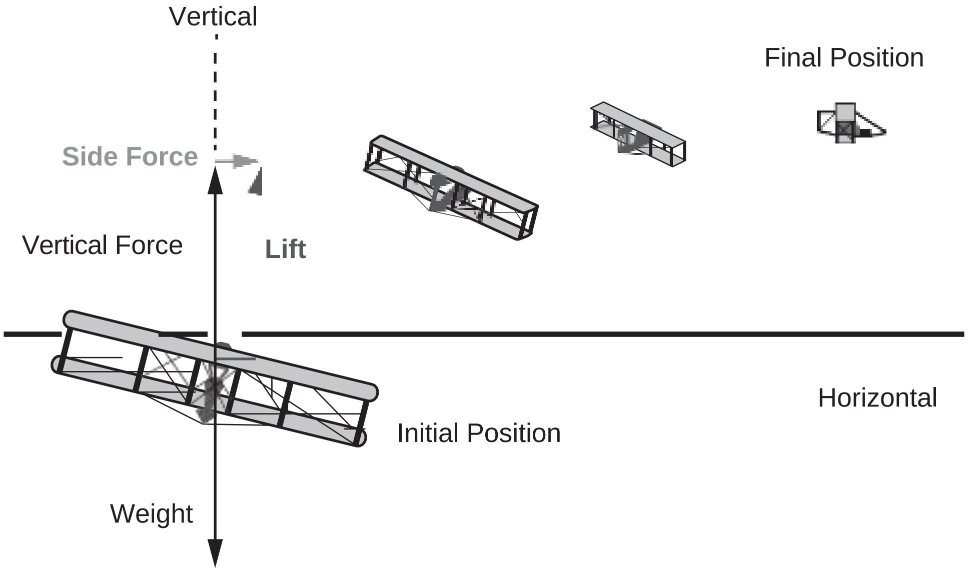


Figure 3-4

As long as the aircraft is banked, the side force is a constant, unopposed force on the aircraft. The resulting motion of the center of gravity of the aircraft is a circular arc. When the wings are brought level by an opposing motion of the ailerons, the side force is eliminated and the aircraft continues to fly in a straight line along a new heading. In a banking turn, the rudder is not the primary control surface used to turn the aircraft but may be engaged to help coordinate the turn (some use of the rudder may be required due to an induced yaw moment, in other words: small rudder inputs are required to balance the turn, but are not responsible for the actual turning action). The aircraft is turned through the action of the side component of the lift force (because some of the lift vector is directed sideways, there is a reduced vertical lift component that must be compensated for or the aircraft will lose altitude as weight overcomes the vertical lift component).

(3) Angle of Attack

The angle of attack is the angle at which relative wind meets a wing (see fig. 3-5). It is the angle formed by the *chord* of the wing (an imaginary line between its leading and trail edges) and the direction of the relative wind (the vector representing the relative motion between the aircraft and the atmosphere). More simply described, the angle of attack is the difference between where a wing is pointing and where it is going. Up to a point, an increase in angle of attack results in an increase in both lift and induced drag. Once the angle of attack becomes too high (this angle varies between aircraft designs), the airflow across the upper surface of the wing becomes detached, resulting in a loss of lift, also known as a stall.

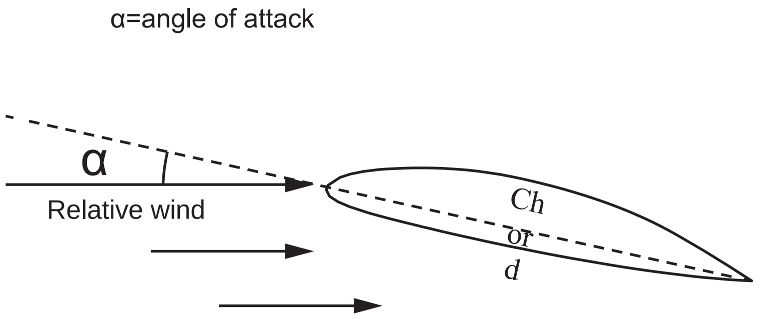


Figure 3-5

(4) Supermaneuverability

Aerodynamic flight refers to maneuvering by manipulating the airflow over the aircraft's control surfaces. *Supermaneuverability* refers to the ability of an aircraft to maintain control and perform maneuvers outside of aerodynamic flight. An aircraft that lacks supermaneuverability will stall when its angle of attack becomes too high or its velocity slows to the point where there is insufficient lift created by its wings or other lift surfaces. An aircraft that possesses supermaneuverability may be able to maintain controlled flight in those instances. A high thrust-to-weight ratio, extra control surfaces (e.g., canards), and thrust vectoring are all important characteristics of supermaneuverable aircraft. These elements combine to allow pilots to maintain control in a stall. A high thrust-to-weight ratio allows the aircraft to hover or stand up on its tail, thrust-vectoring allows the pilot to quickly reorient the aircraft tail, and canards provide stability and lift in extreme angles of attack.

(5) Thrust Vectoring

Thrust vectoring is the ability of an aircraft, missile, or other vehicle to manipulate the direction of the thrust from its engines or motors to control the attitude or angular velocity of the vehicle. It was originally conceived as a way for aircraft to achieve short takeoff and vertical landing (STOVL) and is still used for this function in aircraft such as the AV-8B and the F-35B. But it has tactical advantages when applied in aerial combat. Aircraft and missiles without thrust vectoring rely on aerodynamic control surfaces to turn. Aircraft and missiles with thrust vectoring can dramatically reduce their turn radius by modifying their thrust line and quickly repositioning the rear of vehicle. Thrust is vectored with nozzles in aircraft and exhaust vanes in missiles, as depicted in figure 3-6.

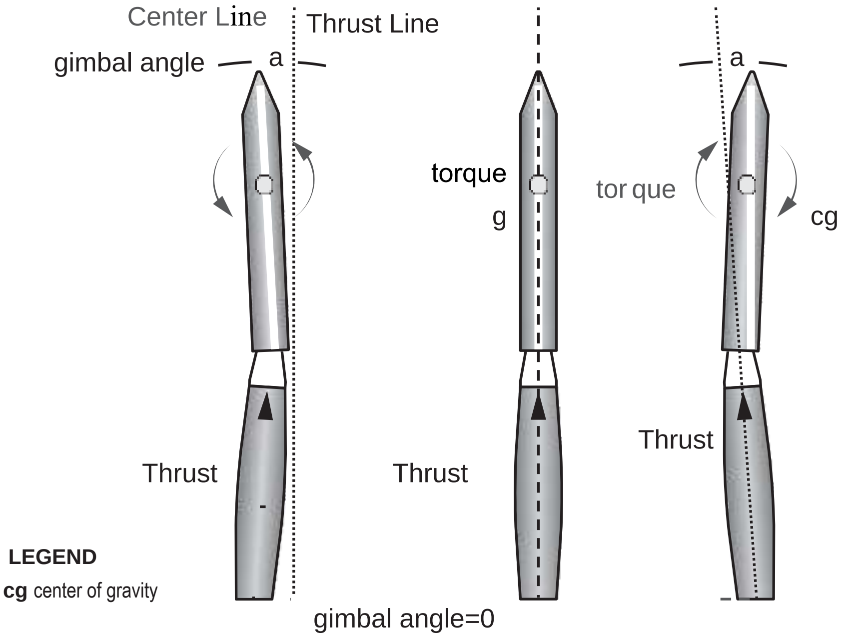


Figure 3-6

There are two different types of thrust vectoring, characterized by the number of dimensions in which thrust can be directed. Two-dimensional thrust vectoring can only direct thrust in pitch. This is the type of thrust vectoring used on the F-22 and achieves most of the tactical advantages of thrust vectoring. To tighten a turn with two-dimensional thrust vectoring, a pilot simply engages thrust vectoring while in a bank. This provides additional torque about the aircraft's center of gravity, turning it more rapidly. Three-dimensional thrust vectoring adds the ability to direct thrust in both pitch and yaw or any combination of the two. This provides additional maneuverability, but it is debated whether or not this generates any tactical advantage for aircraft. All AAMs with thrust vectoring use three-dimensional thrust vectoring and it is crucial to their maneuverability.

While thrust vectoring rapidly decreases the turn radius of the aircraft or missile utilizing it, it does so at the cost of high energy bleed rates. For a missile, this may mean that it could lack the energy to close with the target in the endgame. For an aircraft, this low energy state can leave the enemy with an advantageous energy state if the fight continues. Thus, the advantage of thrust-vectoring in WVR combat is still rooted in pilot skill, appropriate usage, and timing.

d. Control Surfaces

Aircraft flight controls are the means by which a pilot controls the direction and attitude of an aircraft in flight. Flight control systems are subdivided into primary and secondary flight controls. Primary flight controls are required to safely control an aircraft during flight. These consist of ailerons, elevators, and rudder. Secondary flight controls are intended to improve the aircraft performance characteristics or to relieve excessive control loading. These consist of high-lift devices such as slats and flaps as well as flight spoilers and trim systems.

The most basic flight control systems are mechanical and are used in the majority of light, general aviation aircraft. In this design, a collection of mechanical components such as cables, pulleys, rods, and chains transmit the movement of the flight controls to the appropriate control surface(s). These are sometimes called reversible flight controls because movement of the flight control surface also moves the stick in the cockpit

In larger and faster aircraft, the aerodynamic forces become too great for the pilot to overcome without assistance. To aid the pilot in manipulating the control surfaces, hydraulic systems are incorporated to move the flight control surface. These hydraulic systems are controlled through mechanical means in older aircraft, however in almost all modern tactical aircraft, most mechanical components have been replaced with computers and fiber optics to produce control systems which are referred to as fly-by-wire. This provides dramatic weight and fuel consumption savings and improves controllability. These systems are sometimes called irreversible flight controls and, in contrast to reversible flight controls, movement of the flight control surface will not move the stick in the cockpit.

(1) Main Control Surfaces

Movement of any of the three primary flight control surfaces (ailerons, elevator, or rudder), changes the airflow and pressure distribution over and around the aircraft. These changes affect the lift and drag produced by the airfoil/control surface combination, and allow a pilot to control the aircraft about its three axes of rotation.

Ailerons control movement about the longitudinal axis (front to back) of an aircraft. This movement is referred to as “roll.” The ailerons are attached to the outboard trailing edge of each wing and, when a control input is made, move in opposite directions from one another (i.e., the right ailerons move up when the left ailerons move down).

An *elevator* controls movement about the lateral axis (left to right) of an aircraft. This movement is referred to as “pitch.” Most aircraft have two elevators. In some designs, one elevator is mounted on the trailing edge of each half of the horizontal stabilizer. In many tactical aircraft, the entire horizontal stabilizer will change pitch, serving as the elevator. In this design, the horizontal stabilizers are known as *stabiliators*. When a control input is made, the elevators move up or down as appropriate. In most aircraft, the elevators move symmetrically but, in some fly-by-wire controlled aircraft, they move differentially when required to meet the control input demands.

The *rudder* controls rotation about the vertical axis (top to bottom) of an aircraft. This movement is referred to as “yaw.” The rudder is a movable surface that is mounted on the trailing edge of the vertical stabilizer or fin. Unlike a boat, the rudder is not used to steer the aircraft; rather, it is used to overcome adverse yaw induced by turning. In most rotary-wing aircraft, the adverse yaw created by the main rotors is countered by the tail rotor, however some designs use dual, counter-rotating main rotors, eliminating the need for a tail rotor.

A *canard* is a fuselage mounted, horizontal surface that is located forward of the main wing to provide longitudinal stability and control. Depending upon the aircraft, it may be a fixed, moveable, or variable geometry surface and may or may not incorporate control surfaces. The two main design classes for a canard configuration are the lifting canard and the control canard. A *lifting canard* configuration shares the weight of the aircraft between the wing and the canard. A lifting canard generates positive lift (whereas a conventional horizontal stabilizer which generates negative lift). In a *control canard* design, the weight of the aircraft is carried mostly by the wing and the canard is used primarily for pitch control during maneuvering. In other words, a control canard is predominantly a control surface and is usually at 0-degree angle of attack.

In some aircraft control canards are used to make an aircraft less stable in order to make it more maneuverable. In this case, electronic flight control systems compensate for this destabilization.

There are also nonstandard configurations of these control surfaces. In flying-wing designs, for example, there may be no rudder present. In V-tail aircraft (where the vertical stabilizers are tilted outward in a V-shape), the rudder may be referred to as a *ruddervator*, which combines the functions of the rudder and elevator control surfaces. In V-tail aircraft, the ruddervator may be accompanied by traditional horizontal stabilizers, providing elevator control surfaces, or the horizontal stabilizers may be absent altogether.

(2) Secondary Control Surfaces

Secondary Control surfaces provide additional control to the pilot, allowing greater manipulation of an aircraft’s lift or drag than the primary control surface alone. This most often permits the pilot with more control and to fly at lower airspeeds, such as during takeoff and landing.

Flaps are a high-lift device consisting of hinged panels mounted on the trailing edge of the wing (see fig. 3-7). When extended, they increase the camber (i.e., curvature) and, often, the chord and surface area of the wing resulting in an increase of both lift and drag and a reduction of the stall speed. These factors result in an improvement in takeoff and landing performance as the aircraft can maintain sufficient lift at lower airspeeds.

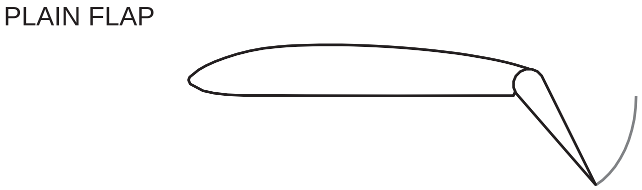


Figure 3-7

Slats are extendable, high-lift devices on the leading edge of the wings of some fixed-wing aircraft (see figure 3-8). Their purpose is to increase lift during low-speed operations such as takeoff, initial climb, approach and landing. They accomplish this by increasing both the surface area and the camber of the wing by deploying outwards and drooping downwards from the leading edge

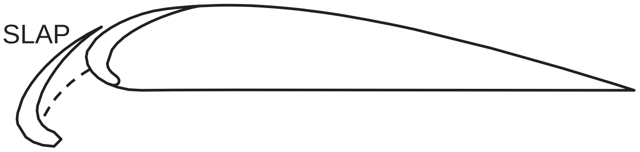


Figure 3-8

Air brakes are high-drag devices that are fitted to many high-performance military aircraft (see fig. 3-9). In most cases, air brakes are fuselage-mounted panels which extend into the airstream to produce drag. An air brake may consist of a single panel or symmetrically mounted pairs of panels. Air brakes may be used during the final approach to touchdown as well as after landing to more rapidly slow the aircraft. Air brakes are used in flight prior to landing to generate drag not to slow the aircraft, but to allow it to fly at a higher throttle setting at a given airspeed and descent rate. There is significant lag between throttle increases and thrust response in jets. A higher throttle setting creates a margin of error for a recovery and go-around.

Figure 3-9

e. Energy-Maneuverability

Energy–maneuverability theory is a model of aircraft performance developed by US Air Force Colonel John Boyd in 1966 that allows the combat capabilities of different aircraft designs to be predicted and compared. It describes an aircraft's performance as the total of kinetic and potential energies or aircraft-specific energy, relating the thrust, weight, drag, wing area, and other flight characteristics of an aircraft within a quantitative model.

(1) Energy-Maneuverability Diagrams

The energy-maneuverability diagram represents the performance capabilities of an aircraft for a given set of flight conditions. The characteristics considered include the maximum lift capability of the wing, aerodynamic drag, structural limits, maximum thrust of the engines, and total weight. Each diagram applies to only a single set of conditions that include altitude, configuration, and weight (these parameters will be specified in each diagram). Figure 3-10 depicts a notional energy-maneuverability diagram. The diagram is comprised of four segments that form a doghouse figure (for that reason, energy-maneuverability diagrams are sometimes also called "doghouse plots"). This figure describes the flight envelope of an aircraft.

The first segment, to the right, is the dynamic pressure or thrust limit. To the right of this line, the aircraft experiences equal drag for any additional thrust and, thus, is not able to accelerate.

The second segment, sloping upwards and left, towards the peak of the diagram, is the maximum G limit. Where this segment peaks represents the maximum instantaneous-turn rate the aircraft can achieve (also called its corner speed). This peak also represents the minimum velocity at which maximum G can be obtained. When below this speed, turn rate is limited by the lift generated by the wing. When above this speed, the structural limit will be reached first.

The third segment , sloping downwards, to the left of the peak, is the lift limit. To the left of the lift limit, the aircraft is not capable of generating aerodynamic lift and will normally experience a stall (supermaneuverable aircraft may be capable of maneuver to the left of this line, under certain circumstances).

The fourth segment, along the x-axis of the chart, is acceleration in a 0-degree turn (i.e., flying straight forward).

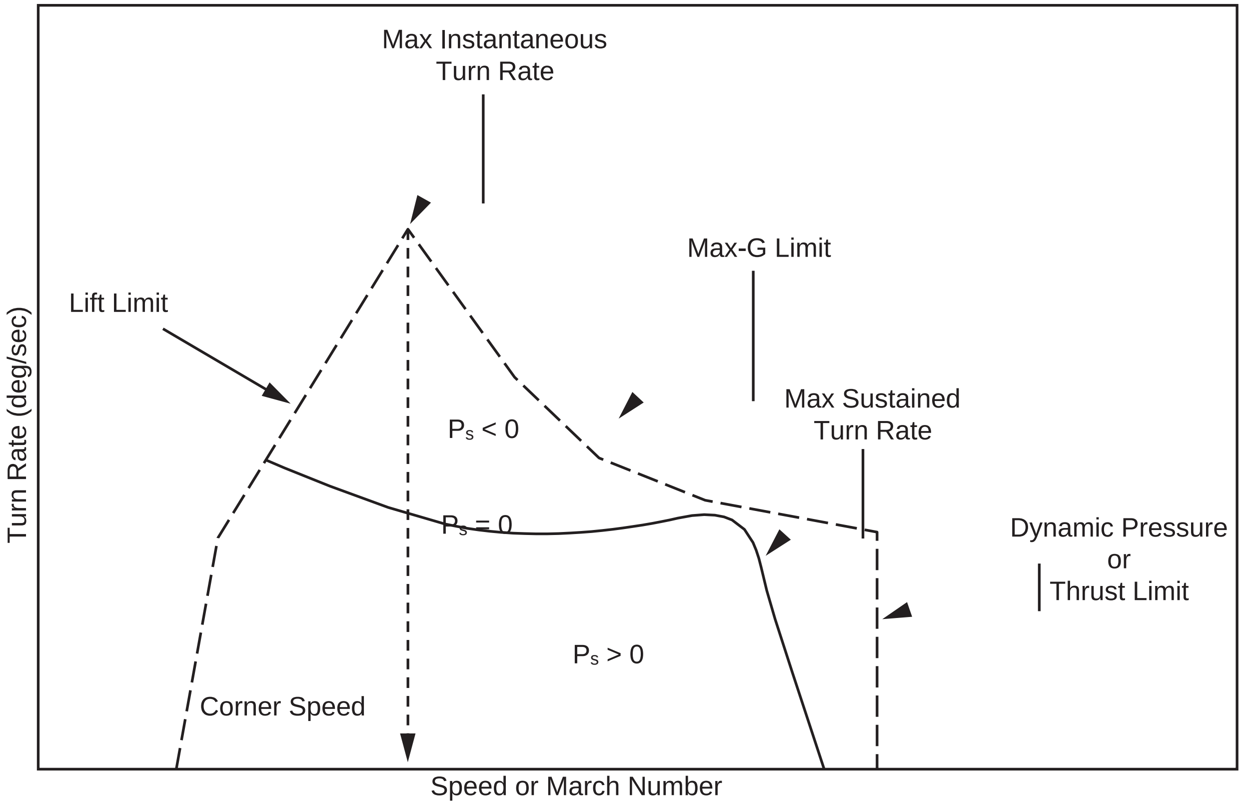


Figure 3-10

Everything under the curve of the energy-maneuverability diagram is within the performance capability of the aircraft. Anything above the curve is beyond the aircraft’s performance limitations.

Within the flight envelope, there is a line representing maximum sustained turn rate, plotting the maximum turn rate at various speeds. Below this curve, the aircraft has excess energy and is capable of longitudinal acceleration (longitudinal acceleration is the change in the aircraft’s velocity along the longitudinal or lengthwise axis of the aircraft). Above this curve, the aircraft is losing energy and longitudinal acceleration is negative, meaning the aircraft is losing or “bleeding” airspeed. Precisely along this curve, the aircraft is maintaining a constant airspeed (zero longitudinal acceleration).

Energy–maneuverability diagrams are often overlaid with additional information that describe other aspects of maneuvers. Most common are turn radius lines and G lines. Turn radius lines are indicated at various intervals and depict how tightly a turn will be achieved at various points throughout the flight envelope. Turn radius lines are depicted from the lower left of the diagram towards the upper right. G lines indicate the G-forces the aircraft will experience at various points within the flight envelope. G lines are depicted from the lower right of the diagram towards the upper left. Figure 3-11 depicts an energy-maneuverability diagram with these lines overlaid on the flight envelope.

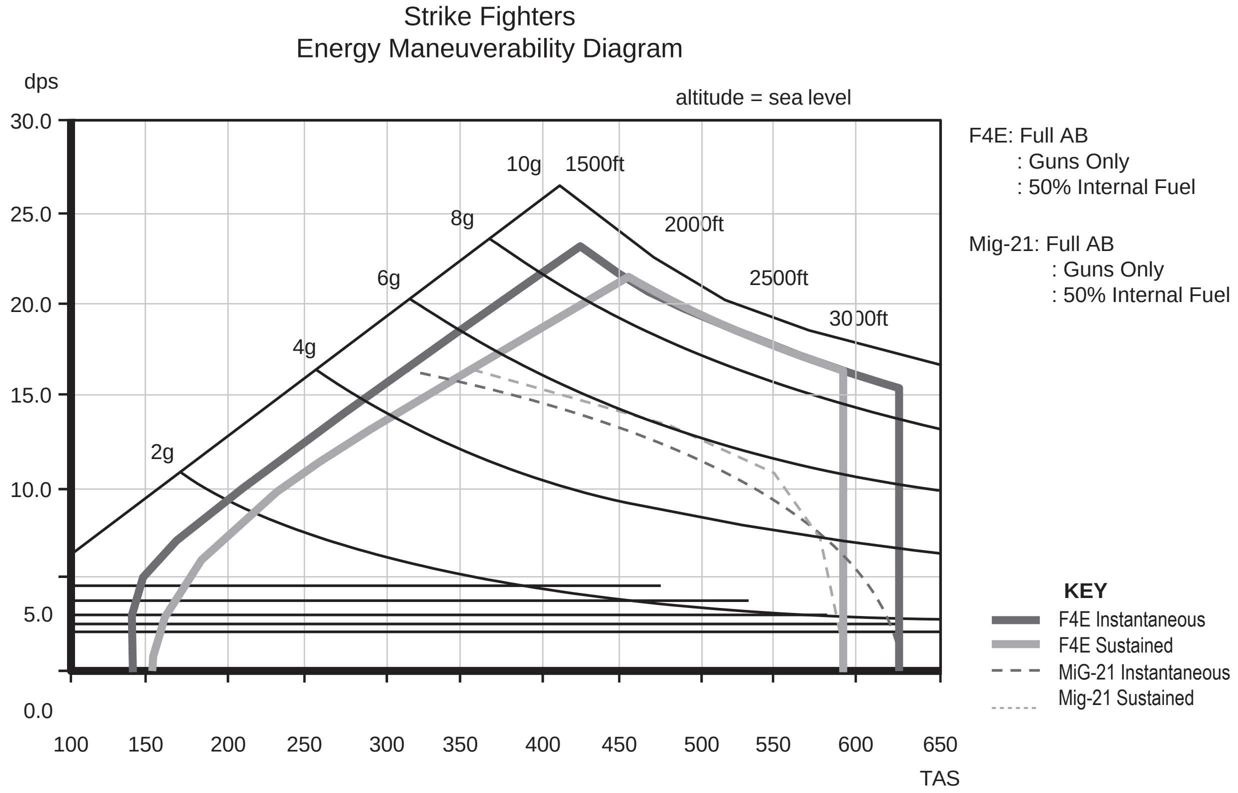


Figure 3-11

(2) Comparing Energy-Maneuverability Diagrams

A single energy-maneuverability diagram is of limited value to the air intelligence analyst as it only describes the performance of a single aircraft. More relevant to the air intelligence analyst’s duties is comparing an enemy aircraft’s performance to friendly platforms. By overlaying the diagrams for the two aircraft, and with an understanding of how to read the diagram, the air intelligence analyst can identify flight regimes in which the friendly of enemy aircraft will have a performance advantage.

Important points to compare are relative positions of the Lift Limit Lines, corner airspeeds, and shape/position of the max sustained turn rates. Aircraft with Lift Limit Lines closer to the Y axis will outperform others in 1-circle fight where the aircraft with the smallest turn radius has the advantage. Aircraft with greater maximum sustained turn rate generally have the advantage in 2-circle fights.

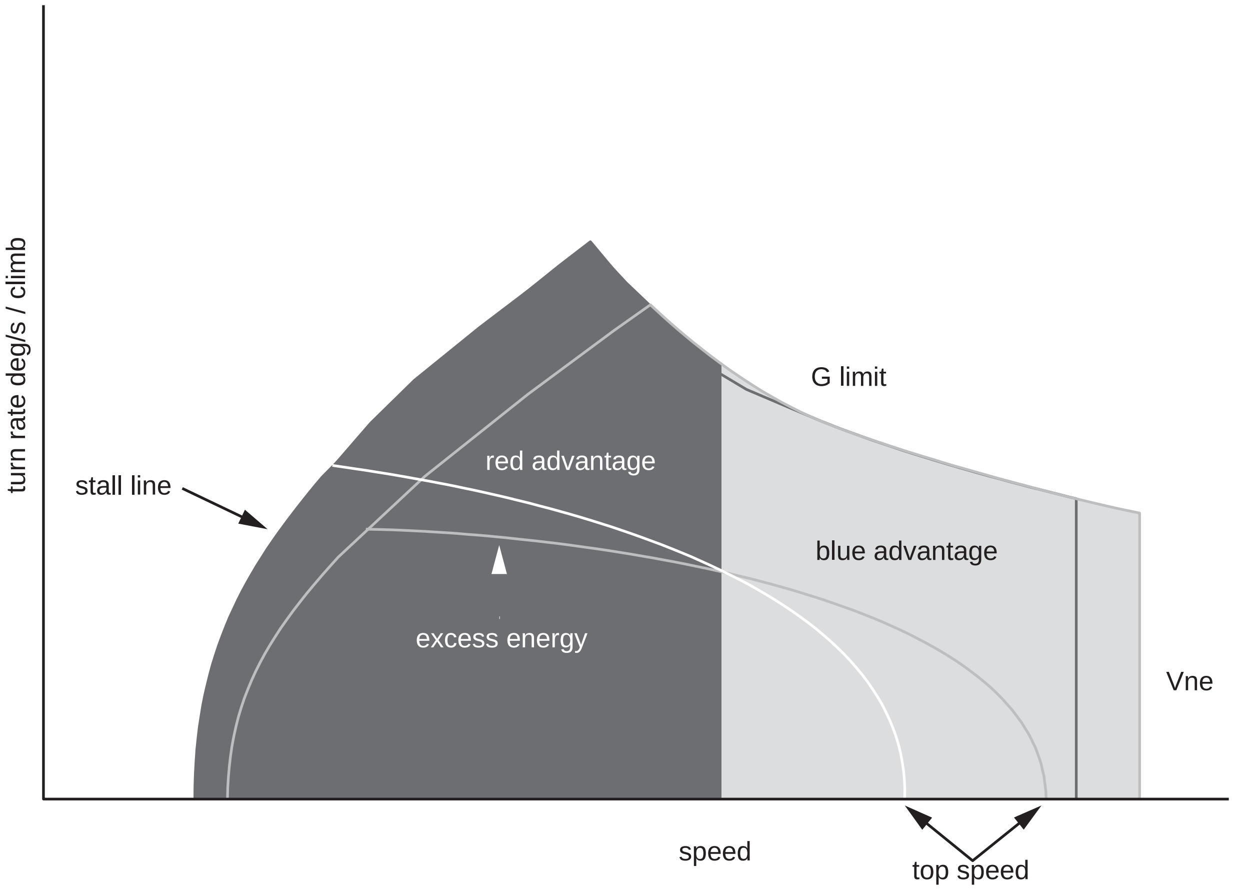


Figure 3-12

(3) Limits of Energy-Maneuverability Theory

Energy-maneuverability theory can be instructive in comparing the performance of different aircraft. But care must be taken in extrapolating the performance characteristics they show into real-world scenarios. Aircrew must translate the fundamental advantages of their aircraft identified by tools such as energy-maneuverability diagrams into effective combat tactics. Choosing the wrong tactic can negate the basic advantages presented by a well-designed aircraft. Furthermore, inflight, aircrew may more intuitively understand the energy tradeoffs created by maneuver and can dynamically transition to different tactics based on their assessment of the enemy’s relative energy state.

Intelligence analysts and aircrew alike should be wary of relying too-heavily on energy-maneuverability theory and energy-maneuverability diagrams for less obvious reasons.

In the decades since energy-maneuverability was developed, a number of factors have altered the performance characteristics important to aerial combat. Advanced weapons capabilities, LO technologies, and advanced avionics enabling faster reaction time may conclude engagements early. Energy-maneuverability diagrams only provide insight into maneuverability of the compared airframes. Despite these factors, energy-maneuverability theory and its diagrams remain central to understanding aircraft performance because they are fairly easy to understand and allow for relatively easy comparison between aircraft.

Intelligence analysis of enemy aircraft’s combat performance must account for more than just how quickly an aircraft is able to orient its nose to a threat while understanding that, in operational circles, energy-maneuverability theory and energy-maneuverability diagrams remain the preeminent tools for assessing enemy aircraft combat performance.

f. Airspeed

Airspeed is generally measured in knots, a unit of speed equal to 1 nautical mile (nm) per hour. Unlike ground vehicles, this speed is measured in several ways. The different parameters for each measurement are important for the air intelligence analyst to understand to comprehend and discuss the flight of friendly and enemy aircraft.

Airspeed is measured through comparisons between air pressure in pitot tubes and static ports. Pitot tubes are devices mounted outside the aircraft and aligned with the airstream to measure the pressure of the air created by the air moving over the aircraft's wings. Static ports are also mounted outside the aircraft to measure static air pressure (the pressure of the air independent of aircraft movement). The pressure difference between these two sensors is used to calculate airspeed.

(1) Indicated Airspeed

Written as knots indicated airspeed (KIAS), this is often the speed displayed on the airspeed indicator in legacy cockpits. Indicated airspeed is the most important airspeed number to a pilot because it defines if the aircraft will fly and will dictate the aircraft’s maneuver and lift performance. Takeoff speeds, landing speeds, and minimum maneuvering speeds are always indicated airspeeds. It is the speed pilots will reference for takeoff and landing and maneuvering flight.

As a consequence, indicated speed is always the primary reference for aircraft flight.

(2) Calibrated Airspeed

Written as knots calibrated airspeed (KCAS), calibrated airspeed is KIAS corrected for instrument and position error. Position error is the main correction to calculate calibrated airspeed. Usually, the error between KIAS and KCAS is minimal and in many modern cockpits, the aircraft will correct KIAS and displayed airspeed in KCAS.

Position error primarily entails how the pressure created by the airflow around the aircraft changes at different angles of attack. Both the pitot tube, measuring dynamic pressure, and the static port, measuring static pressure, are designed for the most accurate readings at certain angles of attack.

The pitot tube assembly is oriented so that it is most accurate at lower angles of attack (i.e., closer to straight and level flight). As the angle of attack increases, the airstream strikes the pitot tube at an increasing angle and causes the airspeed indicator to show a value less than what it truly is.

The static port is oriented so that it is minimally affected by the aircraft (i.e., measuring the static air pressure). Just as with the pitot tube, when the angle of attack changes, the airflow around the aircraft also changes, and in some orientations, this can create a difference in the true static air pressure and the air pressure as measured by the static port.

(3) True airspeed

Written as knots true airspeed (KTAS), true airspeed is indicated airspeed corrected for altitude and temperature. As the temperature or altitude increases, air density will decrease, causing the indicated airspeed to read lower than the true airspeed. Under standard atmospheric conditions (sea level, 15° C, 1013.25 hectorpascal), KIAS will equal KTAS. As altitude increases, the difference between KTAS and KIAS will increase.

(4) Groundspeed

Groundspeed is the movement of the aircraft relative to the ground. It is true airspeed corrected for wind. An aircraft flying at 100 KTAS into a 100-knot headwind (i.e., blowing the opposite direction of aircraft travel) will have a groundspeed of 0 knots. An aircraft flying at 100 KTAS with a 100-knot tailwind (i.e., blowing in the same direction of aircraft travel) will have a groundspeed of 200 knots.

This is the speed that most accurately determines time of flight for a given route.

(5) Mach Number

The ratio of the speed of the aircraft to the speed of sound in the atmosphere (approximately 661 knots in standard atmosphere conditions) is important in describing the compressibility effects of air and the corresponding aerodynamics of aircraft at very high speeds. Because of its importance, it is designated it with a special parameter called the Mach number (M).

The Mach number at which an aircraft is flying can be calculated by where:

$$M = \frac{u}{c}$$

where

M is the Mach number

u is velocity of the moving aircraft

c is the speed of sound at the given altitude

The speed of sound, under any atmospheric conditions, is Mach 1. Generally, at low altitudes and in denser air, this speed will be higher. And at higher altitudes, with less dense air, Mach 1 will be a lower airspeed.

The compressibility of air is a significant factor for aviation at transonic and supersonic speeds. As an aircraft moves through the air, the air molecules near the aircraft are displaced and move around the aircraft. If the aircraft passes at a low speed, typically less than 250 mph, the density of the air remains constant. At higher speeds, the aircraft is moving so rapidly that air molecules cannot move around the aircraft quickly enough and they are compressed, locally changing the density of the air. This compressibility effect alters the resulting force of this air on the aircraft. The effect becomes more significant as speed increases.

Because an airframe is designed to have areas of different pressure (this is how lift is generated), as the aircraft nears Mach 1, there will be small areas of supersonic airflow and other areas of subsonic airflow. As the air accelerates to supersonic speed, this sharp disturbance generates a shock wave that affects both the lift and drag of an aircraft. At speeds well below the speed of sound, all of the airflow remains subsonic and there are no shock waves. At speeds well above the speed of sound, all of the airflow flowing immediately over the airframe remains supersonic and there is a single, large shock wave leading the aircraft in the area where air is being compressed. In the transition area between these regions, there are multiple shockwaves. These regions are called *flight regimes* and they have significant operational impact for aircraft that cross them.

The *subsonic* regime is that range of speeds where all of the airflow over an aircraft is less than Mach 1. While subsonic refers to any speed below Mach 1, the subsonic *regime* is normally any speed less than 0.8 M.

The *transonic* regime is the range of speeds above the point where airflow over any part of the aircraft first reaches Mach 1 (this is known as the critical Mach number). This is normally speeds between 0.8 M and 1.3 M. Compressibility effects are most important in transonic flows and led to the early belief in a sound barrier. Flight faster than sound was thought to be impossible. In fact, the sound barrier was only an increase in the drag near sonic conditions because of compressibility effects. When an aircraft is traveling just above Mach 1, airflow meeting the leading edges of the aircraft is initially decelerated, sometimes causing it to be subsonic. As a consequence, aircraft normally must travel faster than Mach 1 to ensure a consistently supersonic airflow. Because of this and the high drag associated with compressibility effects, most aircraft do not cruise near Mach 1.

The *supersonic* regime is that range of speeds within which all of the airflow over an aircraft is supersonic. While supersonic refers to any speed above Mach 1, the supersonic *regime* is normally any speed from 1.3 M and 5 M.

The *hypersonic* regime is that range of speeds where some of the energy of the aircraft goes into exciting the chemical bonds which hold together the nitrogen and oxygen molecules of the air and aerodynamic heating becomes a significant factor. This is normally speeds above 5 M. At hypersonic speeds, the chemistry of the air must be considered when determining forces on the object.

3002. Electromagnetic Spectrum

The EMS refers to all known frequencies and wavelengths of EM radiation. Electromagnetic radiation is a form of energy that is produced when atoms absorb energy and then release that energy. The absorbed energy causes some electrons to change their location within the atom and, when those electrons return to their original position, an EM wave is produced. Heat, visible light, radio communications, radar emissions, GPS signals, IR emissions, X-rays, cell phone communications, and more are all forms of EM radiation. The EMS encompasses all known forms of this EM radiation.

As depicted in figure 3-13, the EMS spans from radio waves to gamma rays, and many subdivisions in between.

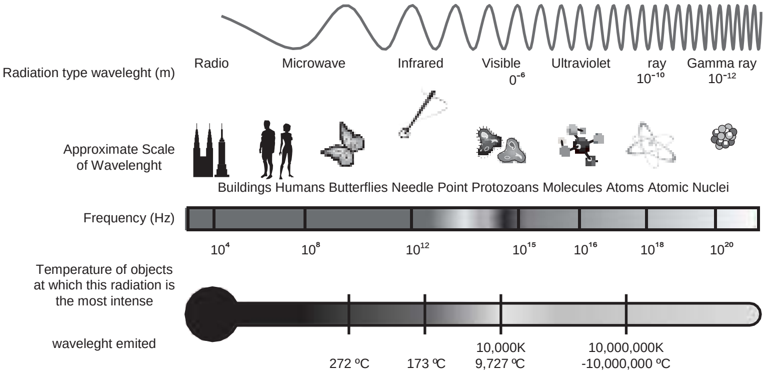


Figure 3-13

Many weapon systems and equipment related to the field of air intelligence are entirely dependent on understanding and utilizing the EMS. Infrared seekers on man-portable air defense systems (MANPADS) or infrared search and track systems (IRSTS), radars for early warning or illuminating a target, voice and data communication between aircraft or jamming that communication, countermeasures such as flares and chaff, and the principles that make aircraft low observable (LO). All of these things rely on understanding and exploiting the principles of the EMS.

The EMS can be complex and entire textbooks can be filled with the science behind it. But certain core principles about how it operates are important to understanding many important features or vulnerabilities of and the operational impacts on friendly and enemy systems.

In many of the examples that follow, radar is be used to illustrate various points. But nearly all the principals discussed below apply equally to other forms of EM energy.

a. Wave Principles

Basic wave principles must be understood to dicuss and understand the operation of systems that utilize the EMS and to understand how certain systems or conditions affect them. All other concepts are built on basic wave principles. To understand many things within air intelligence, from GPS to jamming, from IR missiles to weather effects on weapon systems, one must first understand wave principles.

Waves are an important and fundamental way in which energy is transported through space and time. Mechanical waves, such as waves in the water or sound waves through the air, transport energy through a medium (in these examples, water or the air are the medium). Mechanical waves form when matter is disturbed, such as a rock being thrown into a pond or vocal chords vibrating the air around them.

Electromagnetic radiation, in the form of waves, however, does not require a medium to move from the origin outwards. This enables EM waves to move through the vacuum of space, air, or solid materials. It is important to understand, however, that EM waves in different parts of the spectrum, travel through different media in different ways. For instance, gamma rays can easily travel through most solid media, whereas light waves travel easily through transparent or translucent media (such as the air and water) but not opaque media (such as the brick and cement).

All EM energy travels at the speed of light when in a vacuum (i.e., when there is no medium that it is traveling through). When EM energy does travel through a medium, it slows down slightly. For many purposes, this difference is not relevant. But for others, such as propagation effects, these slight alterations in speed can become significant in many important ways.

(1) Electric Fields, Magnetic Fields, and Polarization

When electric and magnetic fields, coupled together and perpendicular to each other, vibrate, they form an *EM* wave (see fig 3-14). EM waves, as a form of light (both visible light that our eyes can see and invisible light in the form of radio waves, X-rays, etc.) are polarized. *Polarization* is a term that refers to the alignment of the EM field. For example, in figure 3-15, the electric field is vertically polarized.

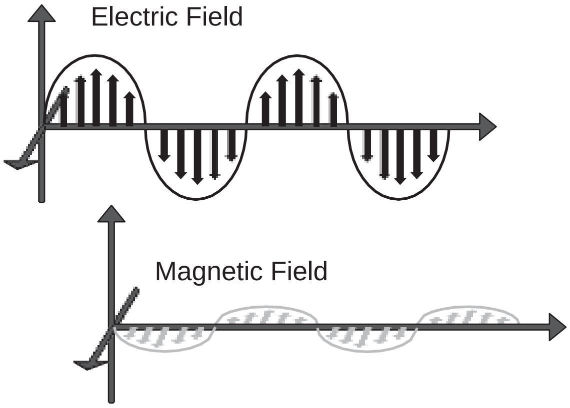


Figure 3-14

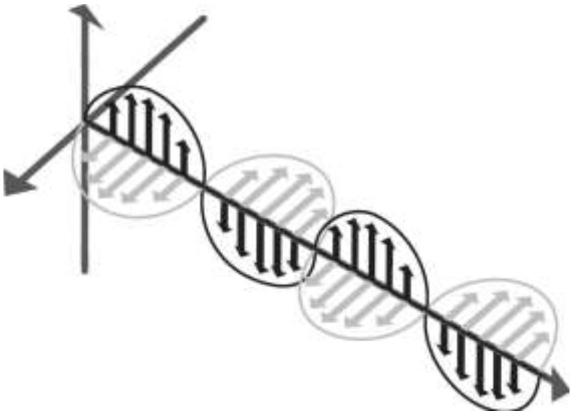


Figure 3-15

In daily life, glare from light reflecting off water or glass is polarized in many different directions. When viewed through polarized sunglasses, only light polarized in one direction (the direction the sunglasses are polarized to allow through), can be seen, reducing glare. In radar operation, antennas are oriented to pick up radar waves polarized in a specific direction. For example, a vertical antenna will best pick up vertically-polarized waves. Waves polarized in a different direction than the antenna is designed for will be received at a reduced signal level.

In this way, the polarization of waves can have significant impacts on the effectiveness of jamming (that should be polarized in the same direction as the target antenna), target detection (if the return signal has an altered polarization), and even the effectiveness of survivability equipment (if the radar warning receiver [RWR] antenna is not polarized optimally based on the threat radar).

Vertical polarization is where the electric field is pointed up or down with respect to the direction it travels. *Horizontal polarization* is where the electric field is pointed left or right with respect to the direction of travel. And *circular polarization* is where horizontally and vertically polarized waves (of the same amplitude and frequency) are transmitted simultaneously, 90 degrees out-of-phase. The result is a polarization that rotates in a circle through space like a corkscrew (see figure 3-16). The direction can be *right-handed circular polarization* (clockwise) or *left-handed circular polarization* (counter-clockwise).

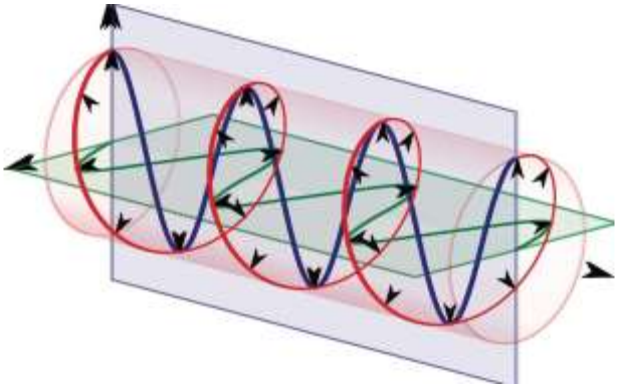


Figure 3-16

(2) Frequency and Wavelength

Because the EMS is so broad, covering everything from radio waves to gamma rays, and because the way in which different parts of the spectrum interact with matter and behave differently under varying conditions, it helps to be able to describe EM energy in ways that enable the spectrum to be broken down into discrete sections and to describe specific EM radiation within those sections. Electromagnetic energy is most commonly described in terms of frequency and wavelength. These two parameters are mathematically linked by the equation:

$$F = \frac{v}{\lambda}$$

where

F is frequency

v is velocity (which, in a vacuum, is equal to the speed of light)

λ is wavelength

Frequency describes the number of complete waves, from crest to crest or trough to trough, in a wave that pass a given point in one second. This unit for frequency is Hertz. A wave that goes through one cycle, from crest to trough back to crest again, in one second has a frequency of 1 Hz. The frequency of the wave depicted in figure 3-17 has a frequency of 2 Hz. Some extremely low frequency waves can have frequencies as low as 3 Hz while some gamma rays can have frequencies as high as 300 exahertz (or 300,000,000,000,000,000,000 Hz).

In radar systems, the optimal operating frequency depends largely on the system’s main functions and primary role. The best frequency to operate in depends on the job the radar is intended to perform. Typically, very long range/early warning radars operate at lower frequencies (longer wavelengths) to increase detection range, while most target tracking radars (TTR) operate at higher frequencies (shorter wavelengths) to increase target accuracy.

Wavelength describes the length of a complete wave: the distance from crest to crest, trough to trough, or any two identical points on a wave. Some waves can be shorter than an atom while others can be as large as the planet. The *period* of the wave is the time for a wave to make one complete cycle.

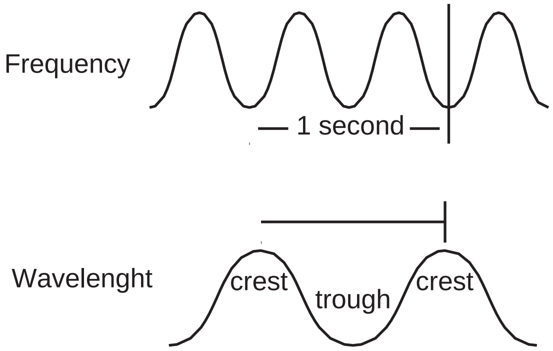


Figure 3-17

(3) Amplitude

Waves can also be measured in terms of their *amplitude*, a measure of how high the peaks and troughs are (see fig. 3-18).

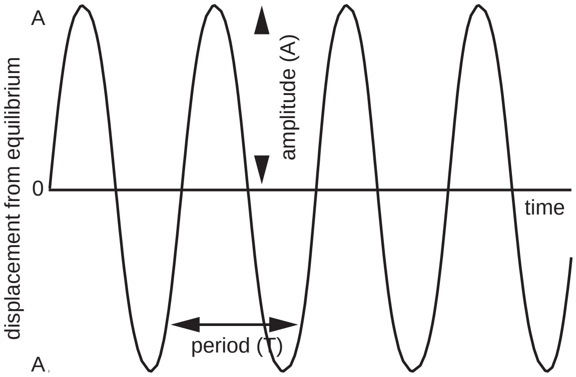


Figure 3-18

(4) Phase

Because EM energy occurs in cycles, parts of a wave are expressed in in terms of *phase* points along the wave, allowing for discussion of different parts of the wave and, more important to its application to air intelligence, discuss waves that are *out of phase*.

Just as with circles, waves are divided up into 360 degrees. Where the strength of the electric field is zero, the wave begins (see figure 3-19). As the strength of the magnetic field grows to its strongest (the crest), the wave is at its 90-degree phase point. This is one quarter wavelength. The cycle continues and the strength of the electric field drops, from its most positive point, back to zero, where the wave is at its 180-degree phase point. This is one half wavelength. Where the strength of the electric field becomes its most negative (the trough), the wave is at its 270 degree phase point. This is a three quarters wavelength. The electric field strength again becomes zero at the 360-degree phase point, where the complete cycle of the wave ends. This is one full wavelength.

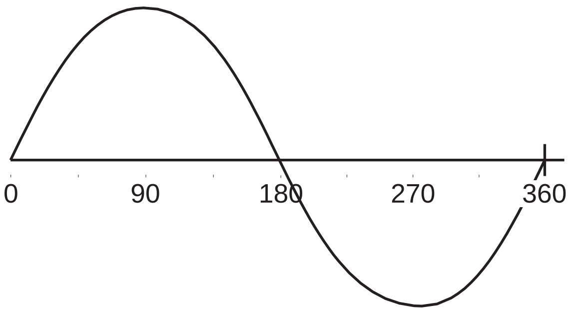


Figure 3-19

Phase points are important for discussing when waves are *in-phase* and *out-of-phase*. Waves that have the same amplitude and frequency and are at the same phase points at the same time will experience what is called *total constructive intereference*. When this occurs, the two waves add together and produce a wave with twice the amplitude and therefore greater energy than one wave by itself. Radar systems rely on total constructive interference when they combine many small transmission elements all creating in-phase waves that combine to produce a much strong wave. *Constructuve interference* can describe any interference where the combined wave is of greater amplitude than the original wave.

Waves that have the same amplitude and frequency and are 180 degrees out of phase (one is at its crest when the other is at its trough) experience what is called *total destructive interference*. When this occurs, the two waves add together and cancel each other out. The term is somewhat misleading, however. The original waves are not destroyed, but their *effect* on the atoms that they encounter is cancelled out. In the case of radar, the reflected energy from an aircraft stimulates the electrons in the atoms of the antenna, allowing the radar system to register a target. If a signal of the same amplitude and frequency, but 180 degrees out of phase, is sent from the target aircraft (a form of jamming), then the effect on the atoms of the antenna by the two waves is cancelled out, no stimulation occurs, and the radar system would register no target. *Destructive interference* can describe any interference where the combined wave is of lesser amplitude than the original wave.

Using this terminology, waves that are out of phase can be expressed either by the difference in wavelength or by degress. In figure 3-20, the two waves are one quarter wavelength, or 90 degrees, out of phase.

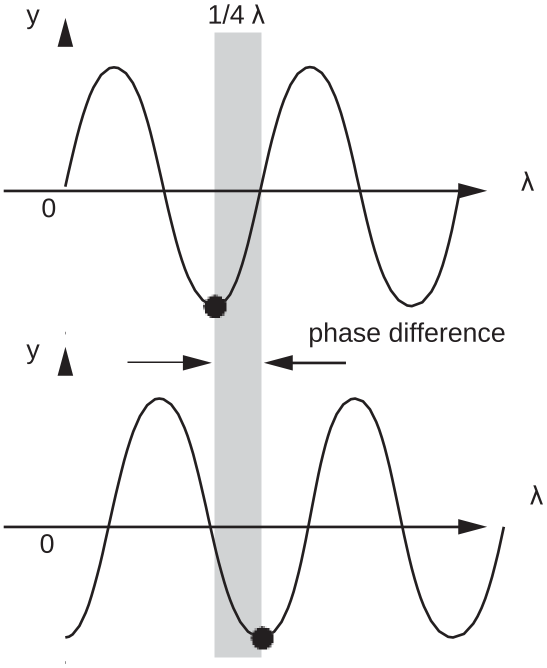


Figure 3-20

Understanding how the EMS is used by weapon systems and other equipment requires breaking down the process into three discrete steps: transmission of signals, propagation of those signals, and target return (or reflection of those signals).

b. Transmission

The first step in the process of using the EMS is transmission of EM radiation, which occurs whenever atoms release energy. When this is done intentionally, such as in radar systems, the transmission is controlled and shaped in a variety of different ways that enable the system to fulfill its function. Transmissions can be continuous or pulsed. They can be of high frequency (HF) or low. They can be of varying power. And they can be modulated.

(1) Modulation

The characteristics of a radio frequency (RF) signal must be changed to transmit information on the signal. This process is called *modulation*. Modulation is accomplished by combining a basic RF signal, called a carrier signal or carrier wave, with a modulating signal that contains the desired information. The resulting waveform is then used to transmit the desired information.

One basic modulation technique is amplitude modulation (AM). The carrier signal is combined with a modulating signal containing information of varying amplitude. Waveforms produced have the same frequency as the carrier signal but with a varying amplitude based on the information from the modulating signal (see fig. 3-21).

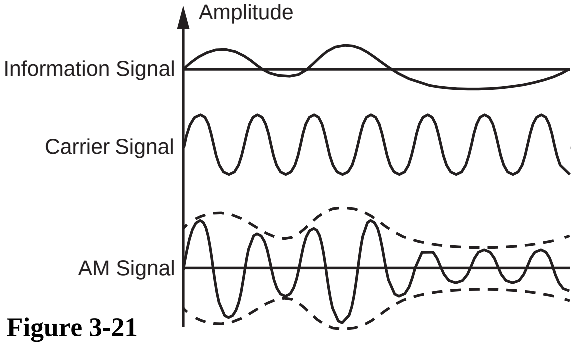


Figure 3-21

Frequency modulation (FM) is another means of encoding information on a carrier wave. Frequency modulation is accomplished by combining the carrier wave with a modulating signal containing information of varying frequency. The waveform produced has the same amplitude as the carrier wave, but the frequency varies based on the modulating signal information (see fig 3-22).

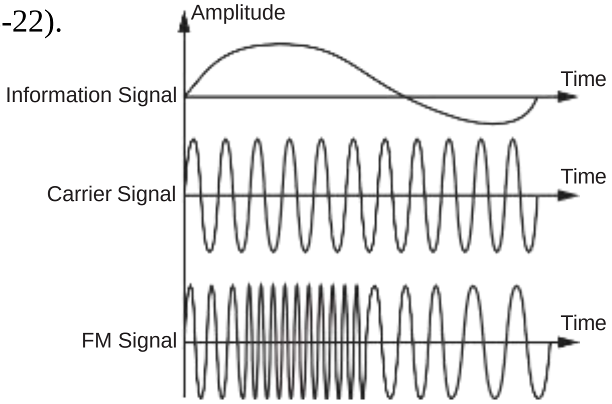


Figure 3-22

A *carrier signal* is simply a basic waveform that is altered (modulated). By altering the carrier signal in a specific way based on input information, the resulting signal can then be compared to the carrier signal. By observing the differences between the carrier signal and the observed signal, the encoded information can be deciphered and understood. For example, audio information is encoded in modulated radio waves that radios can receive, decode, and transform into a sound broadcast by speakers.

Almost any type of information can be encoded into a carrier signal. Sometimes a waveform can transmit information after being modulated by the environment or entity that it interacted with. Radars that exploit the Doppler effect use the frequency changes of the emitted signal to extrapolate the radial velocity of detected targets. In this example, the emitted wave is the carrier signal and, when that wave encounters the target, the radial velocity is “encoded” on the carrier wave and then, when received by the transmitting radar, the frequency shift can be decoded and the target's radical velocity can be read.

(2) Continuous and Pulsed Operation

Some radar systems emit EM energy continuously in what is known as *continuous wave* systems. Other systems rapidly turn the transmitter on and off at set intervals, creating brief bursts of EM energy called pulses. These are known as *pulsed wave (PW)* systems.

Some PW systems have a stable master oscillator that generates a continuous internal reference signal that is not transmitted. When the transmitter turns on, the system uses the internal reference signal to generate a transmitted EM wave. Because the transmitted waves are all generated from the reference signal, the pulses are all in-phase. The term for this is *coherence* and a system that uses this technique is said to be *coherent*.

Pulsed wave systems that do not use this technique are said to be *non-coherent*. Non-coherent PW systems generate a new signal (starting from the 0 degree phase point) each time the transmitter is turned on. Because each pulse is a different phase, there is no way to compare the difference between the transmitted pulse and the received pulse (against an internal reference signal), making doppler signal processing difficult, if not impossible.

In PW systems, the pulse is described in terms of pulse width, pulse length, pulse repetition frequency (PRF), and pulse repetition interval (PRI).

(3) Pulse Width and Length

Pulse width is the duration of the transmission (the time the radar's transmitter is energized during each cycle). Typically pulse width is typically measured in microseconds (one one-millionth of a second). Pulse length is the distance measurement of the pulse's leading edge to its trailing edge.

For radars, pulse width determines ranges resolution, minimum detectable range (also affects maximum detectable range), and Doppler (velocity) resolution. Long pulse duration increases Doppler resolution and the energy of the signal, but decreases range resolution. Short pulse durations result in better ranges resolution but worse Doppler resoltuion and less energy. Frequency and phase modulation techniques can be used to compress the received signal. These techniques retain the extra energy of the long pulse widths as well as the increasesd range resolution and accuracy of the short pulse widths.

(4) Pulse Repetition Frequency and Interval

When EM radiation from radar systems is cut into pulses, the frequency of their repetition and their interval between pulses are inversely related. The higher the PRF, the lower the PRI. The PRF is the number of pulses per unit of time that a PW radar system produces. Pulse repetition frequency is normally measured in Hertz, but it is sometimes also described in pulses per second. Pulse repetition interval is the time from the beginning of one pulse to the beginning of the next pulse, including the pulse itself and the time when no pulse is being emitted, called the *interpulse period*.

A *duty cycle* is a measurement of the percentage of time that a pulsed system is transmiting, a relationship between pulse width and PRI:

$$Duty\ cyc \quad = \frac{pulse\ width}{PRI}$$

(5) Pulsed Systems and Ranging

Almost all radar systems determine the range of targets by determining the time between the transmission of radar waves and the reception of their reflection, the system can determine the range of the target.

When PW systems use this technique, it is called pulse-delay ranging, described by the equation:

$$R = \frac{ct}{2}$$

where

R is range

c is the speed of light

t is the measured time between transmission and reception.

When using this technique, three situations may arise:

Case 1: If the radar transmits a pulse and receives the return from that pulse before it has transmitted another pulse, this is called an *unambiguous range* situation. The range is unambiguous because it is easy to calculate using the above equation, and the time (t) is known *unambiguously*.

Case 2: The radar transmits a pulse, but when the return signal arrives back at the antenna, the radar is in the process of transmitting another pulse. Since pulse systems cannot transmit and receive at the same time and transmission is prioritized over reception, the target return will not be detected. This situation is called *eclipsing*.

Case 3: The transmitted pulse arrives back to the radar after the radar has transmitted at least one additional pulse. This poses a problem for the radar because without additional information, the radar system cannot determine the time between transmission and reception of the pulse because the systems cannot determine which transmitted pulse corresponds to which received target return. Therefore, the system cannot calculate the range. This is called an *ambiguous range* situation.

Because of this aspect of the pulse-delay ranging technique, the lower the PRF and therefore the higher the PRI (a longer time between pulses), the larger the systems maximum unambiguous range. *Maximum unambigous range* is the maximum range of a target that allows the radar to transmit a pulse and receive the return from that pulse prior to the radar transmitting the next pulse, allowing a target to be located. Stated differently, unambiguous ranges are those ranges that will allow round-trip transmit time for the most distant target within the interpulse period. It is important to note that systems can detect targets beyond their maximum unambiguous range, they will simply require additional processing to determine how far away the target is.

With low PRF systems, pulses are timed far enough apart so that range ambiguity and eclipsing problems are rarely an issue. At medium pulse repetition frequencies, those problems become more significant and the radar system has to expend significant resources to overcome them. At high pulse repetition frequencies (HPRF), the problems become extreme; the workarounds are complex and often result in degradation in range accuracy.

Low pulse repeition frequency systems often have ambiguous Doppler reponses, making it difficult to precisely determine the velocity of a target, whereas HPRF systems have unambiguous Doppler reponses allowing for more accurate target velocities. This dynamic makes the selection of PRF a tradeoff between ambiguity in range and ambiguity in velocity.

Staggered PRF is a technique where two or more PRFs are alternated in a fixed sequence, allowing the radar to greatly extend unambiguous ranges.

As a rule of thumb, low PRF includes PRFs less than 4 KHz, medium PRF ranges from 8-50 KHz, and HPRF ranges from 100-300 KHz.

c. Propagation

The second step critical to understanding how the EMS is used is propagation.

As EM waves travel, a number of mechanisms affect the direction of travel and the characteristics of waves. This process is called *propagation*. The mechanisms that make up the process of propagation include attenuation, refraction, diffraction, reflection, scattering, and absorption.

(1) Attenuation and Absorption

Attenuation simply refers to the reduction in signal strength of EM energy. *Natural attenuation* occurs as EM energy spreads out as it propagates outward. Just as the waves created by throwing a pebble into a pond will diminish in size as the wave spreads out, emitted EM energy will spread out as it travels away from the source. This effect is also known as *spreading*. *Atmospheric attenuation,* also called *absorption,* occurs as molecules in the atmosphere absorb some of the energy and transfer it into heat. The amount of energy absorbed depends on the frequency of the energy. Specific molecules in the atmosphere absorb specific frequencies of energy. At frequencies below 10 gigahertz (GHz), atmospheric attenuation is minimal. At frequencies above 20 GHz, it is severe. There are peaks in atmospheric attenuation at 22 GHz and 185 GHz due to absorption by water vapor, and peaks in absorption at 60 and 120 GHz due to absorption by oxygen molecules (see fig. 3-23).

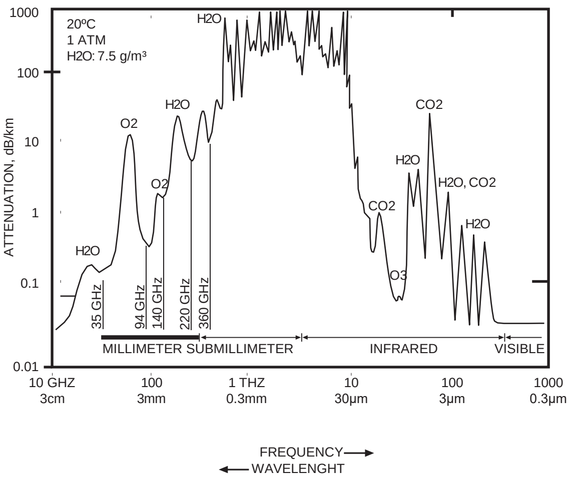


Figure 3-23

(2) Refraction

When an EM wave travels between mediums with different densities, the EM wave bends in the direction of the denser medium because the wave travels slightly slower in a denser medium (additionally, the wavelength will decrease slightly in a denser medium). This is called *refraction*. A common example of refraction is a partially submerged stick appearing bent under water. Because water and air are of different densities, the stick appears bent or disjointed under water. This visual phenomenon occurs because light, as an EM wave, is refracted when it passes between air and water. Likewise, other EM waves, such as radar, also bend when traveling through mediums of different densities.

In the atmosphere, air of different densities creates layers (just as oil floats atop water). These layers are referred to as density gradients. Density gradients and the atmospheric refraction caused by them are typically caused by temperature and humidity differences. Because temperature and humidity fluctuate throughout the atmosphere, the effect of refraction, especially ducting, can be highly variable depending on location and time of day.

There are four basic categories of refraction: standard or normal refraction, super-refraction, trapping or ducting, and sub-refraction (see fig. 3-24).

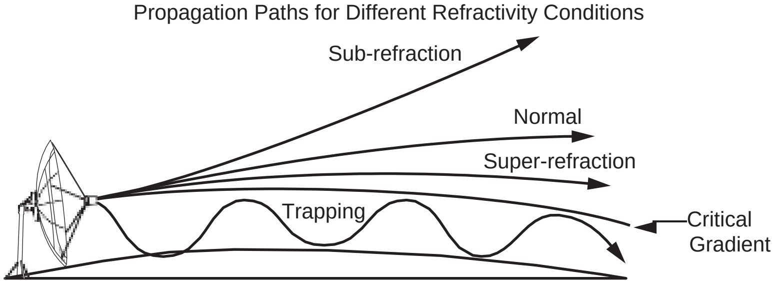


Figure 3-24

In a vacuum, EM waves travel in a straight line without bending. This is called *standard refraction* or *normal refraction*. However, because Earth's atmosphere is not a vacuum and the atmosphere at the Earth's curved surface is denser, the velocity of an EM wave is lower, causing EM energy propagating horizontally to bend down towards the Earth as it is refracted by the atmosphere tracing the earth's curvature. This is also called standard refraction when discussing propagation in the Earth's atmosphere.

When vertical distributions of temperature, moisture, and pressure cause EM waves to bend more toward the surface of the Earth than normal conditions (a negative gradient), it is called *super-refraction*. Super-refractive conditions can extend horizontal radar coverage up to 50 percent above normal ranges.

If the EM wave's downward curvature exceeds the Earth's curvature, the EM wave may become trapped between the Earth's surface and the negative gradient causing the downward refraction. This is called *trapping* or *ducting*. Trapping produces the greatest extremes in radar performance and can significantly extend radar ranges. When trapping occurs between the surface and an overlying region of the atmosphere it is called *surface ducting*. Trapping can also occur in an area above the Earth's surface, between two layers of the atmosphere with different density gradients *(elevated duct)*. Ducting most commonly occurs in areas of high humidity over bodies of water. Ducting presents challenges to effective detection or targeting.

Sub-refractive conditions cause EM waves to be refracted less than normal and travel upward and away from the Earth's surface. Radar waves that are refracted upward offer the smallest ranges and worst opportunity for distant detection.

(3) Diffraction

Diffraction occurs when a wave encounters and bends around an obstacle or slit. The effect is similar to refraction in that the obstacle (instead of a density gradient) causes the wave to bend. In air intelligence applications, this is usually caused by terrain or buildings.

Terrain diffraction occurs when an EM wave encounters a terrain obstacle. Some of the EM wave may experience diffuse reflection, but components of it may also be bent around the obstacle (see fig 3-25). While the cause of terrain diffraction is different from refraction, the overall effect can be the same (causing effect similar to both sub-refraction/ super- refraction).

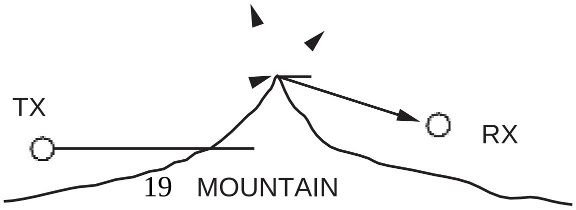


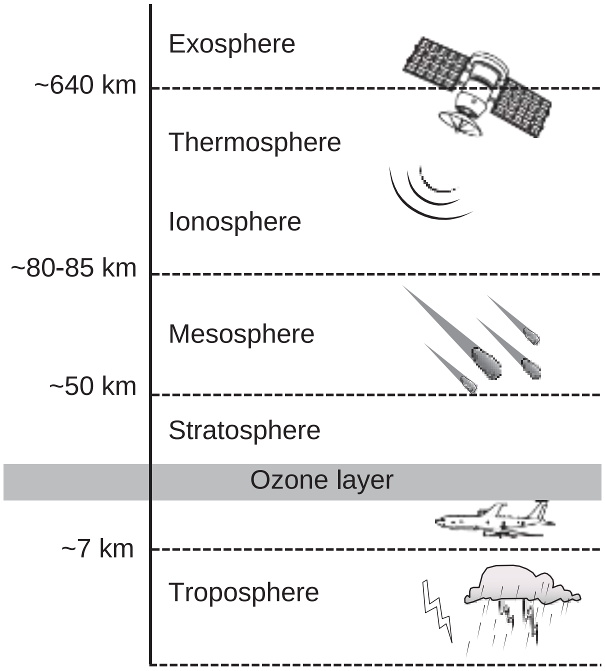
Figure 3-25

(4) Scattering

While refraction occurs when EM waves are diverted from their path in a uniform direction, *scattering* occurs when EM waves are diverted from their path in multiple directions.

Two common forms of scattering include *tropospheric scattering* and *ionospheric scattering* (fig 3-26 depicts layers of the atmosphere).

Figure 3-26



Tropospheric scattering occurs when EM waves, usually in ultra high frequency (UHF) (300 MHz – 3 GHz) and super high frequency (SHF) (3 – 30 GHz) frequencies, are scattered as they pass through the upper layers of the troposphere. Parts of the scattered EM waves are refracted back towards the Earth by the turbulence and varying atmospheric gradients of the troposphere (see fig. 3-27). This can allow receivers hundreds of kilometers away to receive the transmitted signal.

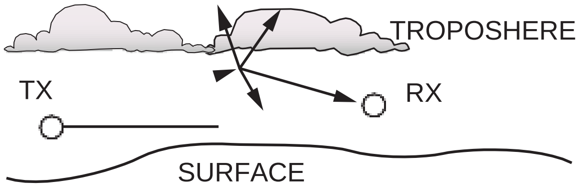


Figure 3-27

The ionosphere is the layer of the Earth's atmosphere where atoms are broken up by sunlight, leading to free electrons. *Ionospheric scatter* occurs when irregularities in the electron distribution within the ionosphere scatters an EM wave, causing most parts of it to be scattered back to Earth. This scattering is uniform enough and takes place over such great distances that the effect is similar to (and may sometimes be described as) severe refraction or reflection. Ionospheric scatter has its most significant effects in the 25 – 100 MHz frequency range. Scattering can also be produced in certain frequency ranges by precipitation and dense clouds. . Frequencies above 5 GHz can experience significant weather clutter.

(5) Reflection

Reflection happens when EM waves "bounce" off an object and travel in another direction. There are two general kinds of reflectors: specular and diffuse.

Specular reflectors reflect EM energy back in a specific, discrete direction (see fig. 3-28). For example, a mirror is a specular reflector for visible light. If light shines on a mirror, it bounces back in one specific direction. Therefore, the intensity of the energy in one specific direction is high while intensities in all other directions are low.

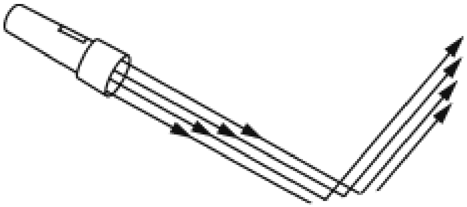


Figure 3-28

Diffuse reflectors reflect EM energy in virtually all directions and are a form of scattering (see fig. 3-29). Therefore, with diffuse reflection, the intensity of the reflected signal in any one specific direction is greatly reduced.

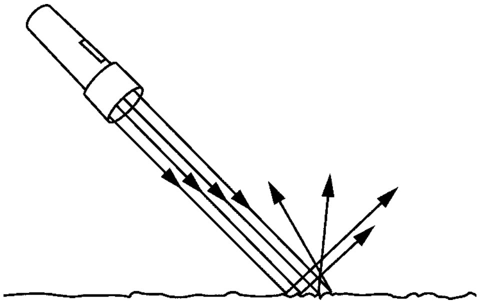


Figure 3-29

Reflection has a number of causes. One is *surface reflection* or *ground reflection* where EM energy reflects off the surface of the Earth (including terrain and water). This can sometimes be seen dramatically in airborne or overhead collection where highly directional emissions (like microwave relays or target tracking beams) can reflect off of terrain, such as a mountainside, and be incorrectly geo-located, sometimes many tens of kilometers from its true location.

(6) Multipath

Reflection, refraction, and scattering, can all cause what is known as a *multipath*. Multipath is caused when a signal arrives at a receiver from two or more paths (see figure 3-30). Only one of these paths (direct) is the shortest and the correct one. The signal received from other paths travel further distances, which can cause range ambiguity, and approach the receiving antenna from different elevations than the true target, which can cause elevation ambiguity.

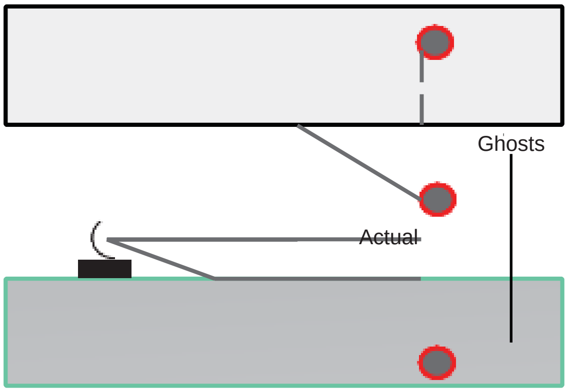


Figure 3-30

Multipath effects are especially problematic near the *radar horizon* (the distance and altitude at which a radar beam raises enough above the Earth’s surface that detection of a target at low level is impossible) where null areas (or *shadows*, where the radar signal does not propagate) and multipath ghosts can make it extremely difficult to detect and maintain an accurate track on targets. This area, near the radar horizon, is called the *multipath zone*. Figure 3-31 depicts multipath effects on radar detection.

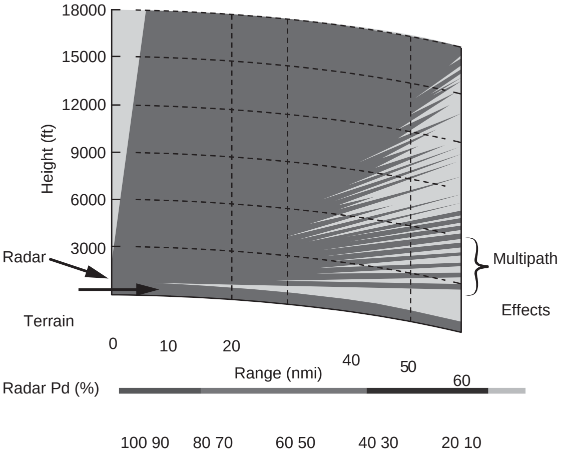


Figure 3-31

(7) Operational Implications

These propagation mechanisms, when all taken together, can significantly affect the capability of systems to transmit and receive EM energy, whether those systems are communications links, radar, or IRSTS. On paper, a system may have the ability to detect out to a certain distance and up to a certain altitude (see fig 3-32) but the reality looks much more complicated (see fig 3-33).

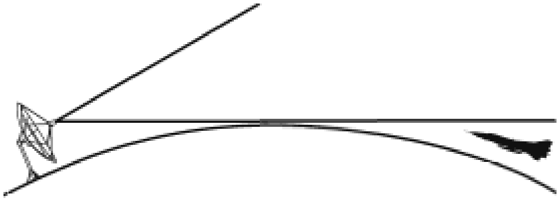
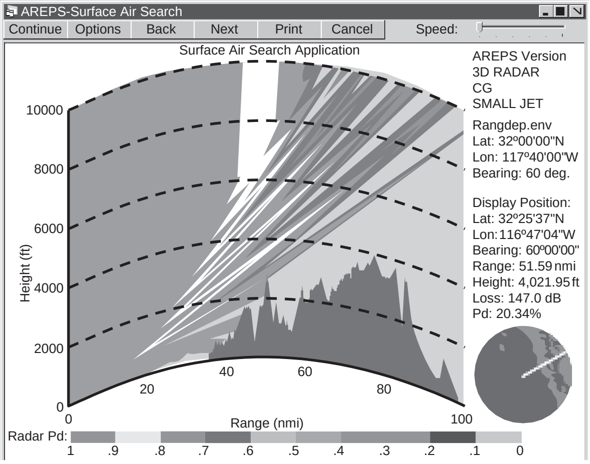


Figure 3-32



AREPS Version
3D RADAR
CG
SMALL JET
Rangdep.env
Lat: 32º00'00"N
Lon: 117º40'00"W
Bearing: 60 deg.

Display Position:
Lat: 32º25'37"N
Lon: 116º47'04"W
Bearing: 60º00'00"
Range: 51.59 nmi
Height: 4,021.95 ft
Loss: 147.0 dB
Pd: 20.34%

Figure 3-33

Propagation mechanisms (and terrain masking) can create areas where a high probability of detection may be much less (or in the case of ducting, much greater) than the radar is theoretically capable of.

This can be exploited in a number of ways. At altitudes where ducts exist, air defense systems.

can have extended ranges, enabling them to detect targets much farther than their capability might suggest on paper. Similarly, ducts enable more effective jamming from longer ranges. Radar shadows (whether created by terrain or refraction) or multipath zones can enable aircraft to approach radars with minimal chance of effective detection or engagement.

Refraction, reflection, and scatter can complicate some systems' ability to reliably detect targets or communicate. But similarly, these propagation mechanisms can be exploited to give other systems the ability to detect, engage, and communicate over the horizon (OTH) and beyond LOS.

d. Target Return

The third step necessary to understand how systems use the EMS is target return. To detect a target, any radar system must receive energy from a target and be able to discriminate that target from unwanted energy returns or clutter.

The strength of the target return is going to be affected by a four-step process: transmission, reflection, reception, and dwell time of the antenna on the target. At each of these steps, a number of variables will affect the strength of target return.

(1) Transmission

The first step affecting strength of target return is transmission.

Energy must be transmitted outward in the direction of the target. This energy will dissipate as the energy travels downrange due to natural attenuation. Increasing the antenna gain or average power will increase the strength of the energy at the target.

Antenna gain is a measure of the directivity of the antenna field pattern as compared to a standard dipole antenna (the simplest class of antenna). Gain is measured by the ratio of (A) the power that must be supplied to the standard dipole antenna to deliver a certain field strength in the desired direction to (B) the power that must be supplied to the directional antenna to obtain the same strength in the same direction. Put more simply: gain describes how well the antenna converts energy into EM waves in a specified direction. Antenna gain is measured in decibels (dB) (see below for a description of dBs).

Energy waves in this specified direction are commonly called "beams." A radar *beam* is normally defined as the energy emitted along an axis in the specified direction (where the power emitted is 100 percent) and extending out to what are known as half-power points. This angular range is known as a beamwidth. The half-power points are normally the limits of the antenna beam with when discussing angular resolution, where the power of the antenna is 50 percent of the power emitted in the specified direction.

The entirety of energy emitted in the specified direction is called a *main lobe*.

(2) Lobes

Because EM radiation dissipates across distance through natural attenuation (growing weaker the farther it travels), radars shape their emissions into beams. Beams can be created by antenna geometry (how antennas are spaced in relation to each other) and by phase shifts (timing of emissions of various transmission elements). These two things create precise regions of constructive interference, making the radar signal extremely strong in a specific desired direction.

This constructive interference, in the intended direction of radar energy, is the main lobe. This is where the maximum EM power is concentrated. But because EM radiation spreads spherically, in every single direction, and the main lobe is only created through antenna geometry and constructive interference, there is EM radiation being emitted in other directions as well (see fig. 3-34). These other lobes of EM energy are called *side lobes*. The side lobe directly opposite the main lobe, which is often the second strongest lobe, is called the *rear lobe*.

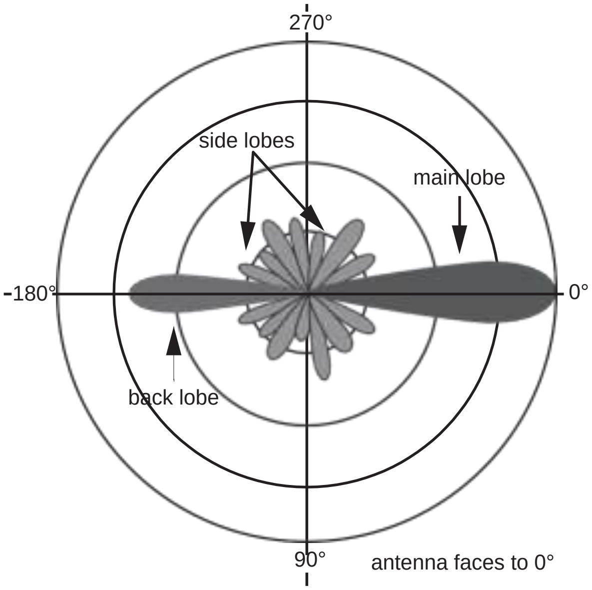


Figure 3-34

Side lobes can be problematic for a number of reasons. The first is that they emit EM energy and can therefore generate a radar return. Because they are not emitting in the desired direction, these radar returns are unwanted clutter (unwanted radar returns, whether from the main lobe or side lobes, are known as *clutter* or *noise*). One common form of this in airborne radars is known as *altitude return* and is side lobe clutter received from the side lobe directly under the transmitter. Relative to other side lobe clutter, altitude return is relatively strong and can be stronger than some main lobe clutter.

The second problem involves concerns about observability. While radars can pick up on radar returns that reflect off targets, some are also able to pick up on the target’s own radar emissions. Side lobes mean that when radars are transmitting, they are detectable not just in the narrow beam in which they are attempting to search, track, or engage, but they are detectable through side lobes as well.

Because EM radiation spreads in all directions, side lobes can only ever be minimized or shielded, not eliminated.

(3) Reflection off the Target

The second step affecting strength of target return is reflection off the target.

The fraction of energy reflected off the target, back towards the radar, is described by the radar cross section (RCS) of the target for a particular observation angle (in both azimuth and elevation) and frequency and polarization of the energy used.

(4) Radar Cross Section

Radar cross section is a measure of how large a particular target appears to a radar at a specific frequency and aspect angle. The more energy reflected back towards the target, the greater the RCS. Radar cross section can vary significantly based on aspect of the target (see fig. 3-35).

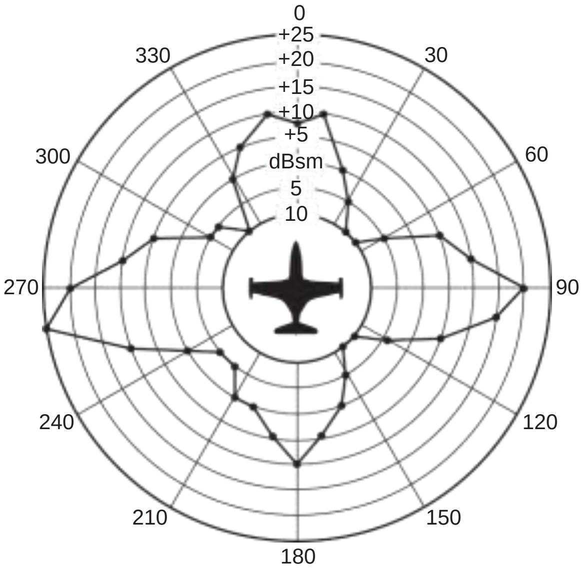


Figure 3-35

Generally, the larger aircraft, the larger the RCS, and thus the earlier a given radar can detect or track it (see fig 3-36). Low observable measures, such as “stealth” design and/or the application of radar-absorbent material radically reduce the effectiveness of most medium- or high-frequency acquisition and TTRs. However, many radars operating in the very high frequency (VHF) and low UHF bands are less affected by these measures. For all aircraft, RCS varies significantly depending on the external weapons load and the aspect angle between the radar and the aircraft.

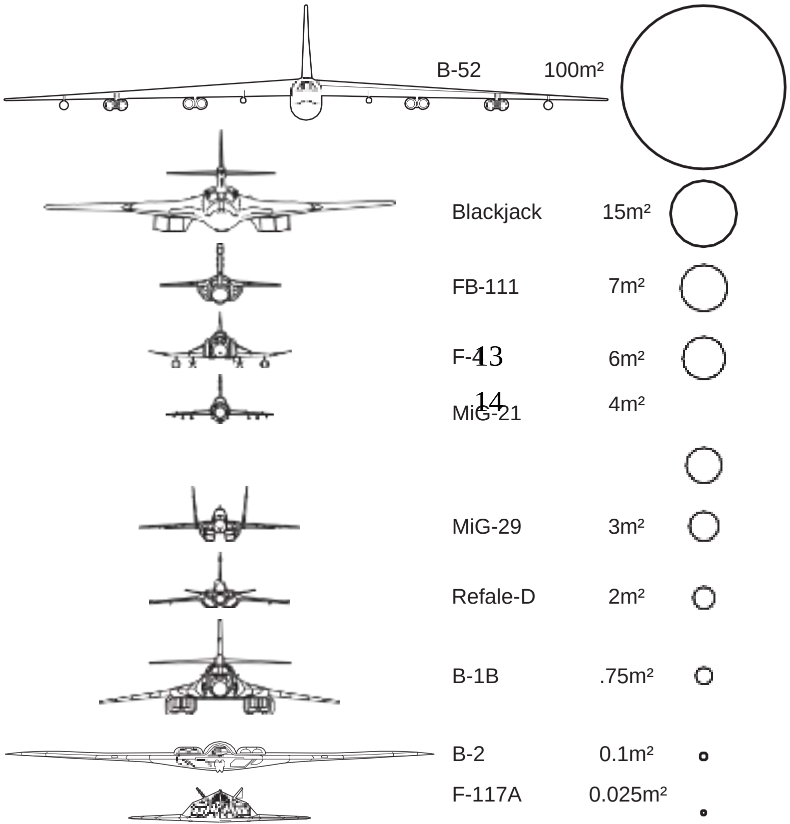


Figure 3-36

Radar cross section is usually expressed in square meters. When expressed in this way, it represents the geometric cross-section of a perfectly reflective sphere (depicted on the right side of fig 3-36) that would reflect the same amount of EM energy as the target. Radar cross section may also be expressed in dB-square meters. When expressed in this way, the measurement is comparing the RCS of a target to the return from a 1 m^2 target. Thus, a target measured as having as RCS of -3 dBsm could also be represented as having an RCS of 0.5 m^2. Table 3-1 demonstrates the conversions between illustrative RCS values.

Table 3-1	
RCS (m^2)	**dBsm**
0.01	-20

0.1	-10
0.5	-3
1	0
5	7
10	10

An important concept in any discussion of the tactical implications of RCS is signal-to-noise ratio. Any radar sensor will receive radar reflections from the target as well as background clutter. This clutter, or noise, must be discriminated from the target return to successfully plot and track a target.

(5) Decibels

The reason the relationship between these two measures is not linear is because dB is a common way to refer to a ratio of numbers through a logarithmic equation. It is useful when comparing numbers with a large dynamic range. Comparing the numbers A and B, the mathematical definition of a decibel is

$$dB = 10 \log_{10} \frac{A}{B}$$

Table 3-2 demonstrates the relationship between certain ratios and decibel level.

Table 3-2	
Ratio of A:B	**Decibel**
1:1	0 dB
2:1	3 dB
5:1	7 dB
10:1	10 dB
100:1	20 dB
1,000:1	30 dB

(6) Reception of Reflected Energy

The third step affecting strength of target return is reception of reflected energy.

After EM energy reaches a target and reflects back towards the source, the reflected energy will spread out again through natural attenuation and be subject to atmospheric attenuation as it travels back to the radar. Larger antennas will intercept more of the energy reflected off the target.

The major obstacle to detecting a target return is the fact that many objects reflect radar signals, not just targets. Signals reflected from targets compete with noise energy (clutter) which is always present in the radar and environment. This clutter must be identified and filtered out for the radar system to isolate and identify its desired target. This can be especially challenging for targets that are small or distant, where the received reflected energy is a fraction of energy reflected from closer or larger targets.

One of the most common ways to reject clutter in modern radars is the exploitation and interpretation of the Doppler effect. Radars that exploit the Doppler effect are called Doppler radars.

(7) Doppler Effect

The *Doppler effect* or *Doppler shift* is the frequency shift of a wave for an observer or receiver moving *relative* to its source, a transmitter or reflector. This allows radars to identify returns that are not moving or are moving more slowly than an intended target (i.e., an aircraft) and disregard those returns.

The Doppler shift is most commonly observed when a siren on a vehicle is approaching, passing, and heading away. When the vehicle approaches, the sound pitch or frequency is higher because each wave crest is emitted closer to the observer than the crest before it, causing each full wavelength to have a shorter distance to travel than the wavelength before it. The cumulative effect is that the waves are compressed, as each one gets an incremental head start on the one before. This causes the wavelength to appear shorter and the frequency to appear to be higher (see fig. 3-37).

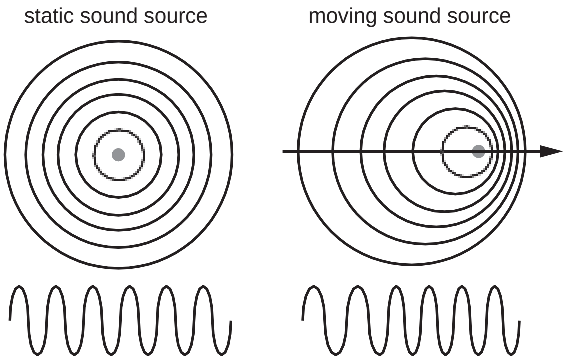


Figure 3-37

The same effect occurs in reverse, as the emitter heads away. Each wavelength is emitted from a further distance, as the emitter recedes, causing each wave to have further to travel, making the perceived waves to be further apart and at a lower frequency.

This is why a siren from a parked vehicle will have a steady frequency while one from a passing vehicle will have a higher frequency as it approaches and a lower frequency as it recedes. When applied to radars and moving targets, this allows a radar to determine the Doppler effect for stationary or slow returns, like the terrain, and filter them out. Even when the radar is moving, such as on an aircraft, it can identify the Doppler shift expected for non-moving targets, like terrain that is approaching, and filter it out.

When discussing velocity as measured by exploiting the Doppler effect, it is important to note that the Doppler effect can only be used to measure radial velocity. *Radial velocity* is the component of velocity that points in the direction of the observer (in this case, the radar receiver). An object's true velocity may be high, but if the radial component is zero, then a radar will not be able to measure that velocity through Doppler shift alone. One example of this is the Moon. While the Moon rotates around the Earth at almost 2,300 mph, it's radial velocity (the rate at which it is heading closer to or further from the Earth) is almost zero. If a Doppler radar were to be used on the Moon, it might be filtered out as clutter.

One of the most significant operational implications of this is a concept known as the *Doppler notch*. Many Doppler radars are susceptible to a *beam maneuver* (also called *notching*) where the aircraft turns perpendicular to the threat radar, bringing its radial velocity as close to zero as possible (see fig. 3-38). Against some radars, this can cause the aircraft to be filtered out as clutter and the system may lose track of the target. The region where this is possible is called the Doppler notch. When coupled with other countermeasures, this can be especially problematic for the radar system and its operators.

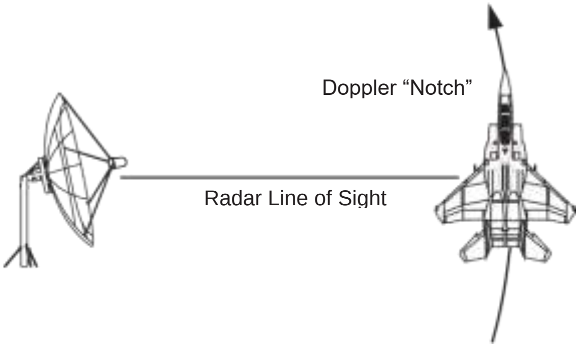


Figure 3-38

(8) Dwell Time of the Antenna on the Target

The fourth and final step affecting strength of target return is time the antenna is looking at or dwelling on the target.

Since all of the above steps (transmission, reflection off the target, and reception of reflected energy) were measured in power (energy per unit of time), but it is energy that determines the ability of the radar to detect a target, the power received must be multiplied by the time receiving that energy. This is called the *dwell time* on a target.

$$P = \frac{W}{t}$$

where

P is power (joules/second)

W is energy (measured in joules)   t

is time (measured in seconds)

In this equation P (power) multiplied by t (time) will give the energy (W) needed in consideration of the other three steps in determining the strength of the target return.

(9) Radar Range Equation

By combining these four steps and the variables involved for each into an equation, it is possible to construct an equation for energy received from a target at a given range. This equation can then be solved for range, which yields an equation for the maximum theoretical detection range of a system. This equation is known as the *radar range equation*.

There are many of versions of this equation, varying in complexity. One example is:

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R_t^2 R_r^2}$$

where

P_r is power or signal strength received

P_t is transmitter power

G_t is gain of the transmitting antenna

A_r is effective aperture of the receiving antenna

σ is RCS

F is pattern propagation factor

R_t is distance from transmitter to the target

R_r is distance from the target to the receiver

Although this equation is not to be memorized, it is useful in seeing how changing one of these variables affects the maximum detection range of a radar system. The consequence of these steps and variables is that:

- Doubling the average power of a system results in a 19 percent increase in detection range.
- Halving the RCS of a target reduces the detection range to 84 percent of the original value.
- Doubling the time the antenna is searching for a target results in a 19 percent increase in detection range.
- Reducing the noise or clutter that the target return is competing with by 50 percent results in a 19 percent increase in detection range.

Atmospheric attenuation, targets not centered in the antenna’s beamwidth, and signal loss through processing within the radar system will also affect return signal strength on top of this equation.

e. Radar

The word radar was originally coined as an acronym for *radio detection and ranging*. In its simplest form: a radio transmitter that produces and emits EM waves and uses the returns from those waves to detect objects. As these waves travel outward from the transmitter, if an object interrupts them, some of the energy will be reflected back towards the radar. The radar system also has a receiver, normally collocated with the transmitter, to be able to detect the returns of this reflected energy. By detecting reflected energy, the radar can determine the presence of an object.

As discussed earlier, reflected energy from an object of interest is called a target return (reflected energy from other objects is called clutter or noise). If the receiver can detect the target returns and distinguish them from clutter, it can determine that there is a target present.

Radar is used extensively in IADS for early warning, target acquisition, target tracking, target engagement, airspace control, and more.

(1) Benefits and Limitations

Exploiting the characteristics of the radio portion of the EMS for radar provides many benefits. Radar provides effective and accurate detection, targeting, and guidance in all weather conditions, at day or night, through clouds, smoke, dust, and darkness. It provides rapid information, practically at the speed of light and at long range (compared to other systems like IR, audio, or EO detection). Based on how the system has been designed, it may be able to derive the following information:

- Azimuth and elevation information based on position of the radar beam.
- Range based on time delay between transmission and reception.

- Range rate based on successive measurements of range information.
- Closure based on observed Doppler shift.
- Size, approximated by RCS.
- Identification based on comparing target return to known libraries of information.

Radar has some limitations, as well. In most cases, radar systems are active. This means they must transmit energy, potentially alerting targets to the fact that they are being targeted and revealing the location of the radar system itself (exceptions to this include antiradiation and passive coherent systems). As discussed above, it is also susceptible to propagation conditions and has range and LOS limitations. It can be engineered against LO techniques (including radar-absorbent material, airframe design, aspect mitigation, and other techniques—although these are often most effective only within specific radar bands). Radar is also non-literal, meaning that it must be interpreted. This means mistakes can be made and both systems and operators can be intentionally misled (e.g., with countermeasures). And finally, many materials reflect radar waves, complicating target detection, recognition, or engagement through clutter and anomalies.

(2) Frequency Bands

To facilitate discussion of radio and radar characteristics, the radio spectrum is traditionally divided up into bands of frequencies. These schemes normally stop at or below 300 GHz because the atmospheric absorption of frequencies above 300 GHz is so great that the atmosphere is essentially opaque (the atmosphere becomes transparent again at the near-IR frequencies).

The two most common schemes for division of the radio spectrum into bands are the Institute of Electrical and Electronics Engineers and the US/European Union (EU)/North Atlantic Treaty Organization (NATO) schemes. Figure 3-39 depicts how these two schemes compare.

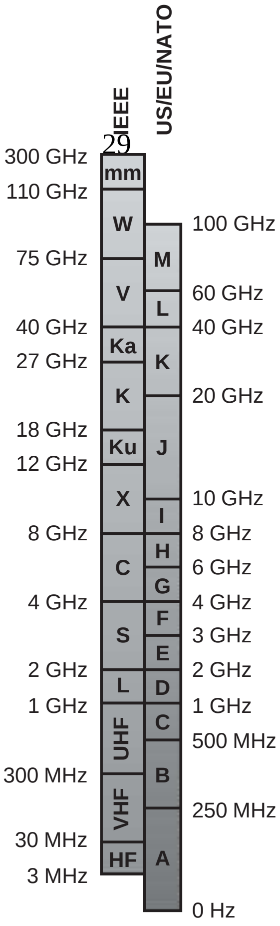


Figure 3-39

Within these bands, frequencies share many characteristics, making it useful to discuss radar systems and their characteristics in terms of the bands they operate in. It is important to keep in mind that newer multi-function radars can blend the traditional radar characteristics and mitigate some of the shortfalls.

Traditional low frequency radar characteristics include: long range, long wavelengths, large antennas, and low atmospheric attenuation, making these systems better suited for long range early warning radars. Traditional low frequency radar systems can often be used in the detection of LO targets because most LO technologies are optimized to defeat or mitigate AI radars that typically operate in higher frequencies.

Traditional medium frequency characteristics include: lower power, less range, shorter wavelengths, smaller antennas, better precision, and some atmospheric attenuation, making them better suited for height finder, ground-control intercept (GCI), and ADA/SAM acquisition radars.

Traditional HF radar characteristics include: even lower power and shorter range, shorter wavelengths, very small antennas, narrow and angular beamwidths, higher precision, and more atmospheric attenuation, making them better suited for fire control radars for ADA/SAMs, fighters, etc.

(3) Radar Antennas

Antenna design is an important factor in determining the operational capabilities of a radar system. There are two commonly used kinds of antennas: parabolic and phased array.

(4) Parabolic Antennas

Parabolic antennas, at their most basic, use a parabolic, or curved, dish as a reflector to shape the transmission of a signal. The emitter can be in front of the dish in an axial or front feed configuration or in the center of the dish, reflecting off a secondary dish back onto the primary dish, in what is known as a *Cassegrain* configuration. When the parabolic dish is oval or has truncated sides (as opposed to being circular), such a configuration is known as a *fan beam* antenna, which creates a beam that is tall or wide in one direction and narrow in another (commonly used with height finder radars). Figure 3-40 depicts a front-feed parabolic antenna configuration on the left and a Cassegrain parabolic antenna configuration on the right.

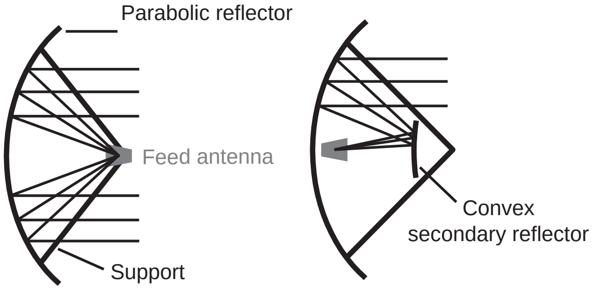


Figure 3-40

(5) Phased Array Antennas

An *array* is a set of transmit/receive (T/R) elements that are operated in coordination to create constructive interference to increase the gain of an antenna in a specific manner and direction A *planar array* is an antenna in which all of the elements are arrayed in a single plane A *phased array* is a mechanically fixed planar array antenna composed of hundreds (an *array*) of feed elements whose *phase* is controlled electronically or mechanically. The number of radar beams, their shapes, and direction can all be changed to tailor the antenna for various functions.

An electronically scanned array (ESA) is a planar phased array that comes in two main types: passive and active. This refers to where the transmitter is physically located. In a passive electronically scanned array (PESA), there is a single, large, high-power transmitter that creates the radar's signal that feeds up the antenna, which steers the beam electronically. In an active electronically scanned array (AESA) antenna, there are many (sometimes thousands) small T/R modules located inside the antenna itself, working in aggregate to create the radar's beam. (At 60 degrees left or right, ESA radars typically lose 50 percent of their power.) Figure 3-41 depicts T/R elements of a PESA radar transmitting in phase to "steer" a beam forward, on the left, and T/R elements transmitting slightly out of phase to "steer" a beam in a specific direction, on the right.

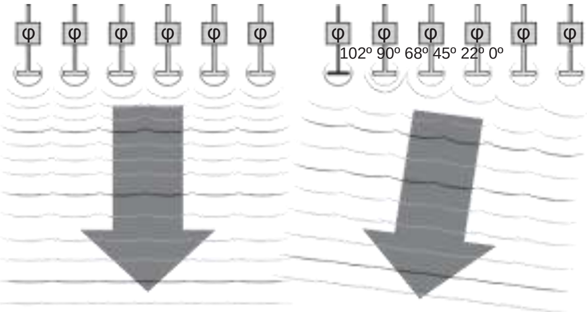


Figure 3-41

Passive electronically scanned arrays have the capability to instantly move their beam from one position to another, which allows the radar to do high quality tracking of many targets. Since the beam points directly at the target for the entire dwell time, the radar can process the sum and difference patterns to do full monopulse tracking of multiple targets, unlike mechanically scanned radars that must not stop moving the antenna during "track while scan" mode (*monopulse* refers to tracking in which the antenna can gather angle information from a single pulse). This effectively blurs the position of the target in the mechanical radar, significantly lowering the quality of the track. The quality of the target track directly affects the probability of a kill for missile shots controlled by the radar. Instant beam movement also allows the radar to perform two functions at once (called dual-mode operations), for example, terrain following during low-altitude attacks while searching for enemy fighters flying at higher altitudes. Some passive phased arrays also have small side lobes to avoid detection and side lobe jamming. Passive phased arrays are moderately difficult to design and manufacture and thus have moderate cost. They also are vulnerable to transmitter failure. If the single transmitter is lost, just like in mechanically scanned systems, the radar no longer functions.

Active electronically scanned arrays have the ability to steer the beam to any point instantly, and can perform true multi-target tracking and dual-mode operation. Active electronically scanned arrays tend to have high effective radiated powers due to the use of many smaller transmitters.

They also have a low system noise figure since the receivers are effectively collocated with the antenna elements. These two factors combine to give some AESA radars extremely long detection ranges. AESAs also have extremely high reliability rates because of their distributed transmitters and having no moving parts. Since they have hundreds of transmitters distributed throughout the array (one in each T/R module), failure of any one transmitter has no tangible effect on the radar's operation. In fact, dozens of T/R modules can fail before the performance of the radar is affected. Because of this "graceful degradation" characteristic, the mean time between failures for AESA radars is often measured in years, not hours. Active arrays require world class design and manufacturing capabilities and are extremely expensive. Only a few countries have the expertise and financial resources to build active arrays.

(6) Antenna Scans

The methods radar antennas use to search airspace for targets are called *scanning*. Each radar system is designed to use one or more radar scan patterns. The ones listed below are the most common.

A *circular scan* provides accurate target range and azimuth information. The antenna rotates 360 degrees about a vertical axis in either direction. Radars using this type of scan generate a fan beam that has a large vertical beamwidth and a small horizontal beamwidth. Since elevation information will normally be provided by height finding radars, the size of the vertical beam is not a limitation. This antenna scan allows the radar to scan large volumes of airspace for target detection.

A *linear scan* is a method used by some radar systems to sweep a narrow radar beam in a set pattern to cover a large volume of airspace. Linear scans can be oriented in a vertical direction for height finder radars or in a horizontal direction for acquisition and TTRs. The narrow beam offers enhanced azimuth and elevation resolution. These sector scans provide coverage at a faster rate compared to other scan types. A *unidirectional* linear scan will scan in one direction, which can be either horizontal or vertical. The unidirectional scan is used when the radar must provide rapid and precise updates on fast-moving targets. A *bidirectional* linear scan will sweep back and forth through a desired vector where the antenna scans in both directions. The vertical sector is used for height finding while a horizontal sector scan provides target acquisition.

A *helical scan* is a unidirectional scan pattern that allows a pencil beam (a beam with an extremely narrow beamwidth) to search a 360-degree pattern. After each complete revolution, the antenna elevation is increased. This scan pattern is repeated for a specific number of revolutions. At the end of the scan pattern, the antenna elevation is reset to the initial elevation and the scan is repeated. A helical scan pattern is commonly used as a target acquisition mode for radar systems with narrow vertical and horizontal beamwidths.

A *raster scan* covers a rectangular-shaped sector by scanning back and forth while changing level. Raster scans are either horizontal raster or vertical raster. The two primary types of scanning used in creating a raster scan are unidirectional and bidirectional. In both methods, each sweep of a sector by the radar beam is referred to as a bar. The unidirectional raster sweeps across a complete bar then returns to the beginning of the bar where it changes the scan elevation (or azimuth) and sweeps another bar. The bidirectional raster sweeps across a complete bar, changes the scan elevation (or azimuth), and sweeps another bar in the opposite direction. The pattern of the bars ensures total coverage of the desired area. At the end of the pattern, the radar beam returns to the starting position and resumes the raster scan. The raster scan is used primarily for target acquisition in air-to-air applications. Figure 3-42 depicts a unidirectional horizontal raster scan.

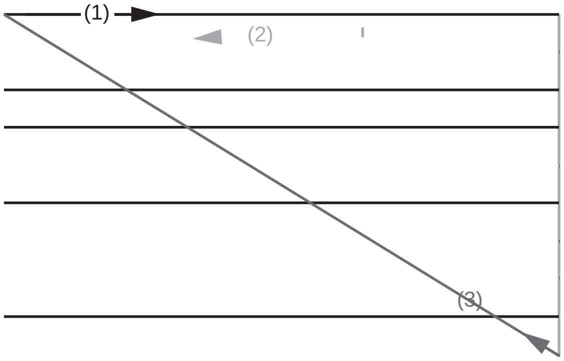


Figure 3-42

A *conical scan* attempts to place the target in the exact center of the scan pattern by spinning a pencil beam in a tight circular pattern. If the beam is not centered on the target, a variable signal will be produced: strong when the beam is aimed at the target, weaker when it is not directly aimed at the target. The radar will then re-orient the beam towards the stronger signal. Only when the target is positioned in the exact center of the scan pattern is a steady signal produced, allowing for accurate azimuth and elevation data. A conical scan is commonly used by radar-guided ADA systems.

Track-while-scan is a scan type that allocates part of the system's power to tracking targets and part to scanning. The central concept is that the sensor itself continues to perform its primary function of scanning while the remainder of the system performs the target tracking function as long as the target remains within the scanned area. The sensor simply provides target position data to the computer subsystem where target velocities and position prediction are calculated. The major advantage of this scanning method is the elimination of the process of target designation from a search radar to a fire control radar. The tracking information is used as a direct data input to the computation of a fire control solution. Therefore, as soon as the target is detected, a fire control solution is available without the inherent delay caused by the designation process.

(7) Signal Processing

After scanning the environment and receiving a target return, the radar system must identify information about the target return. Analysis of EM energy was briefly discussed above with respect to the Doppler effect and using various PRFs to conduct ranging, but is discussed more in depth here.

Eliminating clutter is the primary goal of signal processing—to identify the targets of interest, amongst the noise.

(8) Range Resolution

For a radar to resolve closely-spaced targets in range it must see return from one target, stop seeing target return, and then see the return from the second target. If there is not a break between the two target returns, the radar will not be able to resolve them as separate targets.

If the separation between radar contacts is less than one-half the pulse length, the radar will not see a break between the target returns, and without additional signal processing the radar will not be able to resolve the received returns in range. There may be other parameters (azimuth, elevation, or Doppler) that may allow the radar to break the targets out from each other. As long as two targets are greater than one-half the pulse length apart, the system will always be able to resolve them as distinct targets.

The equation for range resolution is:

$$S_r \geq \frac{c_0 \tau}{2}$$

where

S_r is range resolution distance

c_0 is the speed of light

τ is the transmitter's pulse width

When designing a radar system, design engineers are faced with a compromise. On one hand, maximizing the pulse length would increase the average power, thereby increasing the maximum detection range of the system. This may be the best way to maximize detection ranges, considering the effects of the other ways to maximize average power (increase PRF, peak power, or dwell time). However, simply increasing the pulse length without any additional signal processing power will decrease range resolution capability.

(9) Angular Resolution

Similar principles apply in angular resolution, in both the horizontal (azimuth) and the vertical (elevation). The angular resolution of a radar system is its ability to tell apart two target returns, separated by a given angular distance.

Angular resolution is designated as a beamwidth (θ) that spans from what are known as the half-power (-3 dB) points. The half-power points are normally the limits of the antenna beam with when discussing angular resolution, where the power of the antenna is half the power emitted in the specified direction. Two identical targets at the same distance, between these two points, would normally be resolved as a single target by a radar. Figure 3-43 depicts angular resolution.

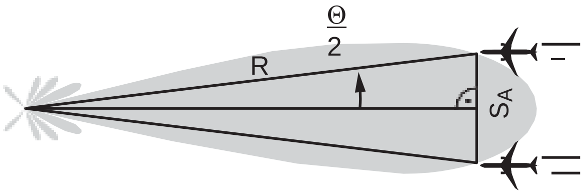


Figure 3-43

The angular resolution equation is:

$$S_A \geq 2R \sin \frac{\theta}{2}$$

where

S_A is angular resolution distance

R is the range from antenna to target

θ is the -3 dB angle (between half-power points)

(10) Radar Resolution Cell

When the principles of range and angular resolution are applied in all three dimensions, they combine in the concept of a radar resolution cell (see fig. 3-44).

Figure 3-44

The radar resolution cell is the theoretical volume of three-dimensional space inside which a radar system cannot resolve discrete targets. Without additional processing techniques (such as resolving differences in target Doppler shifts), a radar system cannot tell the difference between one and many targets sharing the same radar resolution cell.

Because the equations which determine the size of this cell include range to target as a variable, the volume of the radar resolution cell grows at greater distances. This means two identical targets flying in close formation may appear as a single target at greater distances but, as they approach and the resolution cell shrinks in volume, they may be able to be resolved as separate targets.

(11) Other Radar Techniques

Measurement and signature intelligence, electronic intelligence (ELINT), and other disciplines can be used by radar systems to identify targets both by their radar emissions and other characteristics.

Specific emitter identification is a method to unambiguously identify an individual radar by exploiting its unique external signal characteristics. Specific emitter identification measures features of an emitted signal and compares them to a library of known signals. *Specific emitter identification* allows known unique radar systems to be identified and for unknown systems to be uniquely fingerprinted. *Unintentional modulation on the pulse* is a characteristic of a radar's pulse that is unique only to that one radar. While pulses are discussed as having distinct beginnings and ends, a close inspection of a radar pulse will show that is has a rise time (from 0 percent power to 100 percent power) and fall time. The unique rise and fall times of individual transmitters, or unintentional modulation on the pulse, is a recordable signature used by specific emitter identification methods to identify and catalog a specific radar.

Non-cooperative target recognition on jet engine modulation uses the rotation of the blades of a turbine in a jet engine, with variations caused by the geometry of the elements of the engine (e.g., multiple rotors, the cowling, exhaust, stators) to identify the type of jet engine being used by a target of interest (and therefore the aircraft type).

Bistatic, *multistatic*, and *passive coherent radar* (PCR) systems are radars that employ separate antennas to transmit and receive signals. Unlike a monostatic radar that sends and receives signals from the same antenna, these systems' transmitters and receivers are not collocated. Bistatic radars are composed of a single non-collocated transmitter and a single receiver. Multistatic radars are an extension of bistatic radars and employ multiple transmitters, multiple receivers, or both.

Passive coherent radar systems are a special type of multistatic radar distinguished by the use of civilian transmitters of opportunity, including radio or television (TV) broadcast transmitters. Passive coherent radar systems typically rely on civilian transmitters for RF illumination that are not normally regarded as associated with air defense, allowing the PCR system to operate in a clandestine manner. Transmitters and their signals can be described as dedicated or cooperative, meaning the air defense system controls the transmitted signals. Or they may be described as non-cooperative, meaning the transmitter is not controlled by the air defense system. Thus, bistatic and multistatic radars usually employ cooperative or dedicated transmitters, while PCR systems, which rely on FM radio, TV, cellular networks, or other signals of opportunity use non-cooperative signals.

SAR is a radar imaging technique that exploits the movement of an emitter (usually airborne or satellite) aimed at a target, to combine discrete radar returns into a consolidated high-quality image of the target. By combining radar returns as the emitter moves, it is able to (*synthetically*) mimic the quality of a radar with a much larger aperture, hence the name.

Inverse SAR is a radar imaging technique similar to SAR where the movement of the target, not the movement of the emitter, is used to generate high-fidelity information about the target. In some cases, an inverse SAR image can be sufficient to discriminate between various types of aircraft and even the types of missiles they are carrying. *Pulse compression* is an advanced radar technique that blends the radar resolution of short pulses with the low power of long pulses. This has particular application in LO radars. Range resolution of a radar system depends on the bandwidth of the received signal and bandwidth is inversely proportional to the pulse duration. This makes short pulses better for range resolution. Received signal strength is proportional to the pulse duration. This makes long pulses better for signal reception. Pulse compression transmits a long pulse that has the bandwidth of a much shorter pulse by modulating the transmitted pulse (either by frequency or phase). This allows more information to be “encoded” in the pulse, increasing the effective bandwidth. The end result is that peak transmitted power is low (on a long pulse), but range resolution remains the same as if the transmitted power was higher (on a shorter pulse).

f. Infrared

Infrared energy is invisible radiant energy, emitted as EM radiation, by all objects above absolute zero (-459.67 degrees Fahrenheit or -273.15 degrees Celsius) and includes the EMS from 1000 micrometer (µm) (300 GHz) to 0.7 µm (430 terahertz). Objects can reflect, absorb, or transmit IR energy. Figure 3- 45 depicts the relationship between IR energy, visible light, and UV light on the EMS.

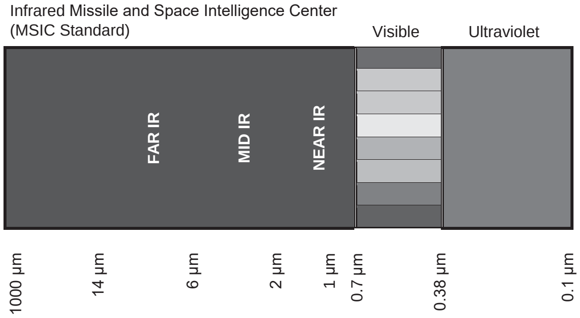


Figure 3-45

Heat is the transfer of energy between two objects or mediums of different temperature. Heat has a number of transfer mechanisms but two of the most commonly experienced are *thermal conduction* (heat transferred by the physical contact of two things, such as the placement of a pot on a stovetop) and *thermal convection* (heat transfer through the movement of fluids—liquids and gasses, such as warm air from a heating vent).

Infrared energy, however, is heat transferred through *thermal radiation*. Thermal radiation is EM energy emitted in the IR spectrum (between radio waves and visible light), caused by the temperature of the object.

The hotter an object is, the more IR energy it emits. And while objects will emit IR energy across a wide portion of the spectrum, the hotter the object, the higher the frequency (and the shorter the wavelength) of maximum emissions (see fig. 3-46 and notice that hotter objects emit more energy and the peak of the energy emitted is of higher frequency and lower wavelength). This makes hotter objects easier to detect and means different portions of the IR spectrum are better for detecting objects of different temperatures.

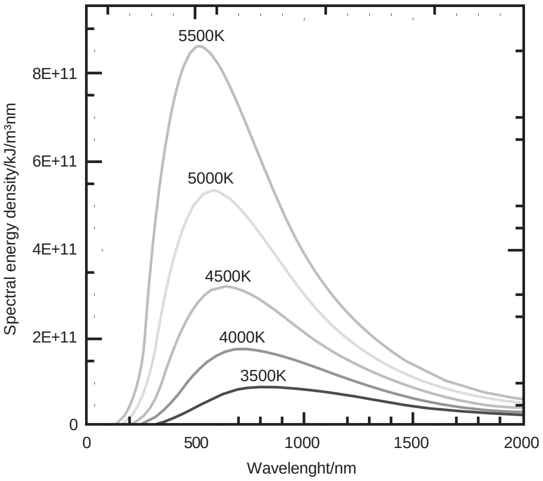


Figure 3-46

For instance, the hot engine of a jet aircraft will have peak energy emissions (*maximum emissivity*) in the 2-5 µm range. The hot exhaust plume will have maximum emissivity in the 4.15-4.20 and 4.40-4.60 µm range. (These spectral regions correspond to significant atmospheric attenuation of IR energy due to carbon dioxide and water vapor, ensuring plume emissions do not propagate very well and contribute less to detection than other sources of IR energy, especially at longer ranges. The extremely hot plumes generated by afterburners spill into spectral regions with much less attenuation, making afterburners an excellent source of detectable IR energy). And aerodynamic heating, the air friction that heats up the airframe or a jet flying at high speeds, will have maximum emissivity in the 8-12 µm range (aerodynamic heating can contribute significantly to an aircraft's IR signature at supersonic speeds).

The 3-5 µm range exhibits much more energy intensity (providing more contrast), making that spectral region ideal for IR detection of aircraft and the main sources of IR energy within those bands (the engine its exhaust plume) the most important for detection (or the most important to mitigate so as to reduce detection).

The use of sensors that detect IR energy have a number of benefits in aviation and air defense. IR sensors are able to see through darkness and can see targets not visible to the naked eye. For example, a well-camouflaged vehicle with a running engine will have a hotter thermal signature than its surrounding. This makes IR sensors ideal for some navigation and targeting. Also, IR sensors are passive, allowing the sensor operator to search for, identify, and lock-on to targets without their knowledge. Additionally, many IR sensors are smaller and less complex than radar systems, making them ideal for mobile, compact, or man-portable systems, such as MANPADS.

IR sensors are not without limitations, however. Many are short-range because of the attenuation that IR energy experiences in the atmosphere (a notable exception are some IRSTS that can detect targets well beyond visual range and can often detect rear-aspect aircraft in afterburner at extreme ranges). Infrared energy is also highly susceptible to atmospheric conditions, with clouds, rain, snow, fog, mist, dust, and other conditions often negatively impacting IR transmissivity. And finally, many IR seekers must have some of their elements cooled, often by exotic materials, making more sophisticated systems expensive and, if the battery coolant unit is unavailable, many systems become useless or can only operate in severely degraded modes.

(1) Infrared Bands

The IR spectrum is broken down by a number of different schemes, each with different terminology for a different number of bands. Figure 3-47 depicts five common schemes, their wavelengths, temperature of maximum emissivity, and bands in which aircraft commonly emit portions of their IR signature.

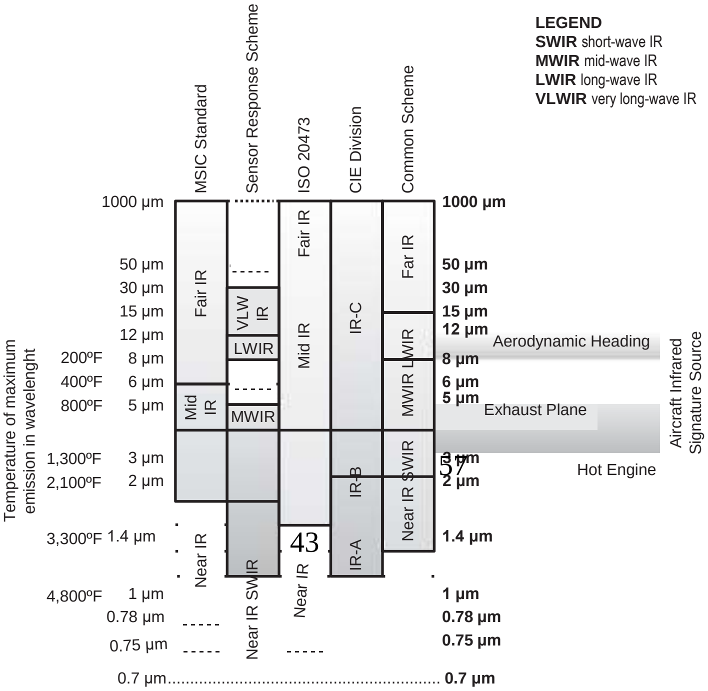


Figure 3-47

For the purposes of air intelligence, the two IR spectrum schemes most useful for understanding friendly and enemy weapon system capabilities are the scheme used by MSIC and the sensor response scheme.

The MSIC scheme is structured around MANPADS sensors and divides up the IR spectrum into: near IR (1-3 µm), mid IR (3-6 µm), and far IR (the remainder of the IR spectrum beyond 6 µm).

The sensor response scheme is largely structured around the response of various IR detectors and divides up the IR Spectrum into near IR(0.7µm), short-wave infrared (SWIR) (1-3µm), mid-wave ifrared (MWIR) (3-5µm), long-wave infrared (LWIR) (8-12µm), and very long-wave infrared (12-30 µm).

The gap between MWIR and LWIR in the sensor response scheme illustrates an important characteristic about the IR spectrum: it has windows and absorption bands.

An *IR window* is an area of the IR spectrum where the atmosphere has high transmissivity and IR energy will propagate easily through the atmosphere. These windows exist in the atmosphere between 0.2-5.5 µm and 8-14 µm. Infrared search and track systems and IR missile seekers operate in these windows.

And *IR absorption band* is an area of the IR spectrum where the atmosphere has high absorption (low transmissivity) and IR energy will be absorbed by atmospheric gasses such as water vapor, carbon dioxide, and ozone. In the 5.5-8 µm band of the IR spectrum, water vapor absorbs a high amount of IR energy and therefore this energy is "invisible" to IR sensors because almost none of it can propagate from the source to the sensor. Figure 3-48 depicts IR transmissivity through the atmosphere.

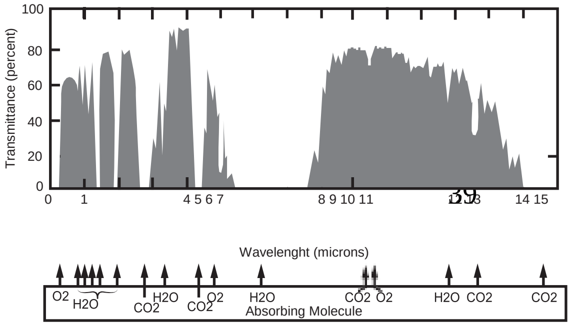


Figure 4-48

Each band has different properties that impact both how well they detect certain objects under varying conditions as well as what materials are required for sensors that detect in a specific band. For example, glass is opaque to the LWIR (8-12 µm) band but it is transparent to the SWIR (1-3 µm) band and it significantly degrades the IR image in the MWIR (3-5 µm) band. MWIR sensors are better for penetrating fog and clouds as compared to other wavelengths, while LWIR sensors have better atmospheric performance. As a consequence, SWIR sensors can use glass in their construction, but MWIR and LWIR sensors must use exotic materials such as germanium and sapphire. Additionally, the MWIR band is less affected by aerosol whereas the LWIR band has longer detection range and is less affected by clouds.

The differences in how different bands within the IR spectrum perform dictate many of the capabilities and limitations of weapon systems and how their sensors perform under different conditions and for different tasks

(2) Sources of Infrared Energy and Target Detection

Because IR energy is emitted by all objects above absolute zero, everything is a source of IR energy. Clouds, terrain, the Sun (including reflections off of water), fires, and many manmade structures and facilitates.

Engines, exhaust nozzles, portions of the airframe surrounding the engines and exhaust, and (for aircraft flying at high speeds) the nose and other leading edges of the airframe all produce IR energy on aircraft detectable by IR sensors.

Infrared sensors rely on IR contrast to seek and track targets. *Infrared contrast* relies on temperature differences between the target and background. These differences come from radiated and reflected heat energy. Infrared sensors detect the energy transmitted by an object based on its temperature. The amount of energy an object releases or stores is determined by its absorptivity, thermal conductivity, and thermal capacity. The amount of energy transmitted depends on the object's properties, temperature, surface reflectivity, and angle of illumination. An object may be a passive emitter, emitting stored energy, or active, generating its own heat (e.g., an engine).

The altitude at which a seeker is operating, whether a MANPADS gunner in a mountain or an AAM on an aircraft at high altitude, will impact the ability of an IR seeker to lock-on to a target. Since the air at higher altitudes is generally colder and dryer than at sea level, the IR seeker will perform better than when fired from a sea-level location. Specifically, seekers operating in the near-IR region of the spectrum may experience as much as a 30 percent increase in lock-on range for a given target due to the increased atmospheric transmission at high altitude.

Just as with radar, unwanted IR energy detected by a sensor is called clutter.

For IR seekers to discriminate a target from clutter and to then track the target within its field of view (FOV), the IR energy being absorbed by the seeker must first be modulated. Most frequently, this is done with a reticle, placed in front of the seeker, which can then modulate the incoming energy either by amplitude or frequency, depending on the design.

The energy gathering system on an IR seeker is designed to have a FOV within which it gathers the most IR energy. The seeker processes this input data to maintain the target in the FOV as the missile flies, and in this manner measures either the angle or the change in the angle of the LOS as the missile tracks the target. Mounting these energy-gathering systems on a gyro-stabilized platform provides an inertial reference for making angular measurements. This also ensures that rapid missile motions due to flight instabilities are compensated for. In doing so, the seeker can accurately measure the slowly changing angle between the missile and target due to the closing motion and intentional maneuvers for the aircraft.

A target within the seeker FOV emanates a steady source of IR energy, which is then transmitted through lenses and is usually reflected first off of a primary and then a secondary mirror onto a reticle. Seekers will have both an instantaneous field of view (IFOV), which is the region the detector elements are looking at a given time, and a total field of view (TFOV), which is the area accessible to the seeker over the course of its scan pattern. The IFOV and TFOV may be the same for some systems. Narrower IFOVs are less susceptible to decoys and clutter because they are collecting energy only from a small area of the sky. Larger TFOVs allows for better initial acquisition capability.

The steady IR energy emitted by a target is modulated into a pulse of IR energy that is then focused onto a detector element. The detector element simply converts the IR signal into an electrical signal that is then sent to the signal processing section of the seeker head and derives guidance commands that are sent to servos controlling the canards on the missile body. The deflection of these canards allows the missile to remain on boresight with the target and fly to its intercept point.

Other methods of target discrimination combine IR elements with non-IR seeker elements. *Negative-ultraviolet* tracking utilizes an additional detection element independent of the IR detection elements and exploits the fact that aircraft appear as a dark spot against a (bright) UV sky background. The reason targets appear dark is that they absorb UV radiation from their surroundings and reflect or scatter only a small fraction of it. A UV target detector therefore senses a target's presence as a decrease in received energy relative to the target's background. This is called "negative contrast." Large objects in the scene are rejected by virtue of their size. The target aircraft, flares, and clouds will all emit a positive IR signature. In the UV spectrum, flares, clouds, and the sky background all emit a positive UV signature while target aircraft will provide a negative UV signature, allowing systems incorporating this technique to easily identify the target aircraft.

Imaging infrared is a system where the IR/UV sensor is a focal plane array that is able to "see" in IR, much like the charge-coupled device in a digital camera. This requires much more signal processing but can be much more accurate and harder to fool with decoy countermeasures.

In addition to being more flare-resistant, imaging infrared seekers are also less likely to acquire lock onto the Sun.

(3) Irradiance in Infrared Sensors

Infrared sensors normally utilize three significant measurements if IR irradiance that describe their sensitivity, noise equivalent irradiance (NEI), minimum detectable irradiance (MDI), and minimum trackable irradiance. *Irradiance* is a measurement that describes the flux or power received at a surface. When discussing IR sensors, this term helps describe a sensor's ability to discriminate a target or targets from noise and other clutter.

Noise equivalent irradiance is the measurement of the average noise in the seeker as caused by internal sources and ambient noise. Even under ideal conditions, any electronic sensor will experience some level of noise simply from the functioning of the electronics and ambient noise in the environment. To remove this baseline noise, IR sensors sets a "gate" or a cut-off, below which IR energy is not processed. Only IR energy above the level set by the NEI gate for that sensor has the potential to be detected.

Minimum detectable irradiance establishes the maximum IR power detectable by a sensor. Aside from internal noise, IR sensors must deal with ambient IR energy from the sun, terrain, and other clutter. In order to limit the energy sources the detector must discriminate (i.e., potential targets) the MDI level represents a signal-to-noise ratio required before a source of IR energy is processed as a potential target. Minimum detectable irradiance is the parameter that allows the system to reduce the susceptibility to ambient IR energy and focus on IR energy sources considered to be a valid potential targets.

Minimum trackable irradiance is the threshold above which a sensor can continue to track a target. Some sensors can continue to track on a target even after its irradiance has dropped below the MDI. This loss of intensity can be caused by a target moving farther away or reducing engine power. If a sensor is capable of this, it must set a threshold below MDI above which it can continue to track the target. The threshold for MTI will normally be slightly less than the minimum detectable irradiance, but must remain above NEI. The terms MTI and MDI can sometimes be used synonymously when the described sensor lacks the ability to continue tracking targets below MDI.

(4) Infrared Search and Track Systems

Infrared search and track systems are a type of sensor that uses IR radiation for detection and targeting purposes. Like other IR sensors, IRSTS are passive and their search and track patterns cannot be detected. Because of the characteristics of IR propagation through the atmosphere, IRSTS are optimized for fighter aircraft. The high altitudes are cold (providing excellent heat contrast), dry (minimal water vapor absorption of IR energy), thin, and contain minimal aerosols (minimizing other propagation problems for IR energy), which maximize IRSTS capabilities. Infrared search and track systems allow for enhanced emission control where the aircraft can still maintain situational awareness and even engagement ability without utilization of its own AI radar. This can force opposing aircraft to increase their emissions to actively search for the IRSTS-equipped aircraft, making themselves more susceptible to antiradiation weapons or passive radar detection. When combined with data links and radar tracks from aircraft with increased stand-off, IRSTS-equipped radars can significantly increase survivability and lethality. Infrared search and track systems also mitigate all radar-based LO technology (although IR suppression on LO aircraft will still reduce observability to IRSTSs).

Infrared search and track systems are also difficult to jam by nature. Electronic warfare capabilities are ineffective and the range, size, and detectability of IRSTS and the aircraft that carry them make it extremely difficult to jam with directed energy (e.g., in the same manner that the directional IR countermeasure system is able to jam IR seekers on MANPADS).

g. Electro-optical

Electro-optical sensors and systems utilize EM radiation emitted by all objects above absolute zero to form some image of a target scene. These sensors operate in a relatively small portion of the EMS.

Electro-optical sensors detect targets by using visual, near IR, and far IR imaging. *Visual imaging* is the contrast between target and background reflectivity of visual light. Infrared imaging is discussed above.

Electro-optical sensors primarily rely on visual or IR *contrast* to seek and track targets. *Visual contrast* relies on differences in albedo (reflectance) of visual light between the target and the background. These differences come from the roughness, color, shape, and size of the target and background, as well as solar and lunar illumination levels and angles. Objects can range from specular reflectors (as in the case of a mirror), which reflect light well but only in a limited direction, to diffuse reflectors (such as matte or flat paint), which reflect incident light in many directions but at relatively weak levels.

Contrast differences between the target and background are expressed three ways: inherent, apparent, and threshold.

Inherent contrast is measured as if the observer is right at the target, at a distance of zero.

Apparent contrast is a measurement of the contrast differences from a given distance from the target. The contrast difference is always reduced as the sensor moves away from the target.

Threshold contrast is the minimum amount of energy difference required by a sensor. The sensor in question can be night-vision devices (NVD), an IR targeting pod, an IR guided missile, or the seeker on the front of a laser-guided bomb. The threshold contrast value won't change for a given sensor because it is built into the design of the sensor. But the threshold contrast seen by the sensor will change based on the target and background values and weather conditions in the target-background path.

Just as with any form of EM energy, a number of parameters factors into the ability to detect targets with EO sensors.

Aerosols or haze (particulates in the air such as smoke or dust), wind speed (especially when it carries aerosols), temperature gradients (which cause refraction of light), precipitation (including fog and mist) and sea spray, available light (which can be affected by cloud cover or time of day), and absolute humidity (which provides a measure of the most significant molecules—water—that will attenuate visible light across long distances) all affect a sensor's ability to detect targets at a distance.

The target scene's complexity (a camouflaged vehicle in a tree line as opposed to a building in an open desert) and the contrast and size of the target also factor into an EO sensor operator's ability to find a target and discriminate it from its background.

Software is available to predict the impact of these factors on specific EO sensors in the form of an electro-optical tactical decision aid (EOTDA) that predicts the range that a target will be distinguishable by an EO sensor at a specified altitude. EOTDAs are highly useful to support friendly operations but can also estimate the enemy's sensor performance as well. Figure 3-49 is an example EODTA.

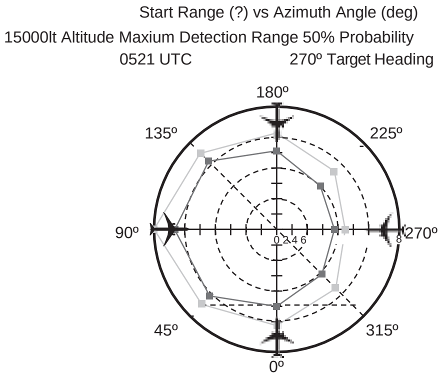


Figure 3-49

h. Lasers

The word laser originated as an acronym of “light amplification by stimulated emission of radiation,” Lasers emit EM energy in visible and near-visible bands of the EMS through an optical amplification process.

Lasers differ from other light in that laser light is coherent. Lasers have spatial coherence, which is a measure of how well a wave maintains the same amplitude (i.e., does not spread) over a distance. Lasers can also have temporal coherence, which is measure of how monochromatic a color is, meaning that lasers can emit light in a very narrow spectrum (i.e., one color).

Propagation mechanisms influence lasers just as with any form of EM energy. The most commonly experience visual propagation phenomenon is a mirage, where light waves bend to make on object appear above the horizon, sometimes also appearing as though it were shimmering (a form of mirage sometimes called heat haze).

Lasers have a number of military applications:

- Ranging
- Illumination
- Guidance and designation
- Weapons
- Communication

(1) Ranging

Using the same principles as in radar ranging, lasers can be used to measure the distance to a target. By measuring the time a laser pulse takes to travel to a target, reflect off of it, and return back, very accurate range measurements can be made very rapidly.

Military-grade laser rangefinders can be accurate within 5 m or more and are operable to ranges from 1.6-26 nm, depending on size, weight, and application. Laser rangefinders can generate targeting-quality position data to pass to other weapon systems or use for on-board weapons. When multiple measurements are made over time, range rate can be measured and therefore ranging lasers can also measure an object's velocity.

Laser ranging can be used on optical sensors, to identify range to target, on proximity fuzes to determine when to detonate a warhead, and in light detection and ranging (LIDAR) sensors. Light detection and ranging is a special kind of laser ranging that measures the distance to an object using laser pulses. It is similar to radar in concept but uses the optical region of the EMS. Very accurate topographic measurements can be made using LIDAR.

(2) Illumination

Visible and invisible (often IR) lasers can be used to illuminate a target. This can allow rapid cueing and acquisition.

Non-military lasers can also be used for illumination, allowing an observer to direct a weapon system onto an aircraft, either by manually pointing the laser, or by attaching it to more powerful optics, potentially allowing one system to visually designate an aircraft for all over optically-guided systems within LOS.

(3) Guidance and Designation

Lasers can be used to designate targets in much the same way as radar. A laser illuminates a target and a seeker uses the reflected laser energy off the target to guide the weapon onto target. This is common in precision-guided munitions (PGM) as well as laser beam rider (LBR) MANPADS. Most designation lasers are invisible to avoid alerting the victim to the fact that they are being targeted.

Laser designators can be "coded" to better ensure that the weapon is picking up on the desired designation signal and to increase resistance to some laser countermeasures. Altering the PRF (setting the designator to illuminate with a specific PRF and the weapon seeker to track onto that same specific PRF) is a common way to code laser designators.

Countermeasure systems have been developed to detect laser designation and disrupt the kill chain, usually through reduction of the energy reflecting off the target. This can be done by as scattering the laser beam (diffusing its energy and creating a larger, weaker reflection), by repeating the laser beam (i.e., in the same was as digital RF memory equipment repeats radar signals) or through other attenuating or absorptive means.

Laser guidance is applied on weapon systems ranging from rockets to missiles, bombs to cruise missiles, and even artillery rounds.

(4) Weapons

Laser weapons are divided into three main categories:

- Non-weaponized lasers
- Anti-sensor and anti-personnel lasers
- Structural damage lasers

Non-weaponized lasers are typically commercial-off-the-shelf devices that operate within the visible spectrum. These lasers can be menacing to aviators and aircrew due to their power, low cost, wide availability, ease of concealment, and portability. Although these lasers are not designed as weapons, their power output is high enough to disrupt and/or deny vision and, in rare circumstances, cause eye damage.

Anti-sensor lasers, such as on the directional IR countermeasure system, can be used to overload EO and IR sensors, temporarily or permanently damaging them or manipulating the sensor by providing it false targets or otherwise causing it to fail to successfully track its target. Other effects on sensors include target obscuration, loss of sensitivity (gain), image blooming/saturation, temporary shutdown, and permanent loss of partial FOV. Sensors equipped with video tracking capability are susceptible to tracking errors or total break-lock. Image intensifying devices such as NVDs are particularly susceptible due to their intended purpose of amplifying small amounts of illumination.

While structural damage laser weapons are still mostly in development stages, directed energy weapon systems that use lasers can create highly destructive effects by super-heating parts of a target (whether an inbound munition or a fighter aircraft), causing it to ignite, detonate or explode, or otherwise suffer catastrophic damage.

A number of schemes exist to divide lasers into classes based on their wavelength and maximum power.

(5) Communication

Lasers are also used for communications, establishing directional links between nodes. Similar to fiber-optic cables, but using light propagation through the atmosphere (or space), lasers can transmit modulated energy which can then be decoded by the receiving station.

3003. Weather

Weather provides some of the most significant impacts to operations of any factors. As seen with the EMS, radio, radar, IR, and EO systems all experience propagation effects that are, in part, dictated by the weather and atmospheric conditions. Weather impacts friendly and enemy aviation and air defense systems equally.

Weather impacts can affect the overall effectiveness of friendly and enemy forces in a variety of ways. Weather impacts affect detection, tracking, and guidance for EO, IR, and radar systems. Cloud cover can impact NVD effectiveness while thermal crossover can render thermal optics temporarily impaired. Weather can also affect other operations of a system, causing excessive heating or reducing the lift produced. The personnel operating that equipment will also be affected by weather extremes, becoming less effective or responsive or having higher attrition rates. System performance factors such as range and payload can be reduced with lift as affected by altitude or air density, temperature, and humidity. And in the most extreme weather conditions, the ability to shoot, fly, or otherwise operate may be temporarily halted entirely by operational limits.

a. Weather Factors

Weather factors include visibility, wind, precipitation, cloud cover/ceiling, temperature, humidity, atmospheric pressure, sea state, and turbulence.

(1) Visibility

Visibility in aviation terms normally refers to horizontal visibility. It is impacted by a number of factors but is normally measured in nm or statute miles (there are 5,280 ft in a statute mile and 6076.12 ft in a nm). For example: “visibility is 3 nm.”

The effect from obscurants is due to particle size and density. Airborne constituents such as sand can damage or destroy the protective cover on sensors. The effect of blowing sand or dust is similar to that created by snow, except that the particulates are far less reflective and much larger. This is known as a “brown-out.”

Brown-outs can pose significant challenges to IR seekers or sensors because these particulates can completely block the near-IR light from striking and reflecting from the terrain. Since there is less luminance, the scene is darker and during vertical helicopter operations or strong winds and there can be a total block of near-IR radiation.

Airborne dust reflecting available light at night (such as that from a flight deck) can reflect and scatter so much of the incident light that NVDs may become unusable. In general, IR sensors can still operate when impacted with smaller particles. However, sand, dust, and battlefield obscurant effects are similar to those of rain, fog or clouds in that larger particle sizes will result in scattering. Unlike precipitation, which can create a uniform temperature over a period of time, the effects of sand or dust diminish as soon as their atmospheric concentration diminishes. Natural visibility restrictions (fog, haze, precipitation, dust) degrade laser performance by increasing attenuation.

Illumination is critical in planning operations where NVDs are used or on operations timed to use only available light. Natural light values vary as a function of the position of the Sun, Moon, stars, and clouds. Variables such as altitude, cloud cover, terrain-produced shadows, visibility, and direction of vehicle or aircraft movements in relation to the Sun or the Moon can also affect light level availability. When considering artificial illumination, whether overt (visible light) or covert (IR illumination), weather can impact the effectiveness of the illumination as well. Low cloud ceilings will limit the area covered and effective time of the flares but cloud cover at a certain altitude can enhance the effects of artificial light due to cloud base reflection. Rain, snow, or fog can reduce flare effectiveness. Snow- or sand-covered terrain also reflect both natural and artificial light. See the astrological data section below for more information about lux and nighttime illumination considerations for operations.

(2) Wind

Winds affect EO sensors by increasing the density of particles in the air. Winds can impact IR sensor performance as well because it decreases thermal contrast, which in turn reduces the sensor's image quality. If a target is self-heated (such as a vehicle with a running engine), wind can remove heat from surrounding objects while the target is replacing any heat lost to the wind with more heat. In that case, an IR sensor can actually see the target better. And finally, winds can impact the flight of both guided and unguided munitions.

Surface winds, especially cross-winds, affect aircraft control near the ground during take-off and landing. They also affect ground speed for low level flights. Strong winds can reduce the effectiveness of units downwind by blowing dust, smoke, sand, rain, or snow on them. Forces upwind generally have better visibility and can advance more easily. Winds in excess of 35 knots can cause injury to personnel, damage materiel and structures, create false radar returns, and reduce visibility because of blowing sand, dust, and other battlefield debris.

Winds aloft (at flight altitudes) always affect navigation and fuel consumption. Winds are generally must stronger and faster at higher transit altitudes, making downwind flights much quicker and upwind flights much slower.

(3) Precipitation

Rain, sleet, or snow degrades visual and IR target acquisition and tracking, and attenuates radar signals. It can also impact unit performance through trafficability, visibility, and personnel effectiveness. Heavy rains, sleet, and snow can make some unsurfaced, low-lying, and off-road areas impassable. In addition, both rain and snow can drastically reduce personnel effectiveness by limiting visibility, causing discomfort, increasing fatigue, and creating other physical and psychological problems.

Like clouds, rain effects are difficult to forecast because of the variation in droplet size and density. Absorption, scattering, clouds, and fog are all considerations. Light rain or mist cannot be readily detected using NVDs. These sensors may not see rain until the rain rate is higher. This is why pilots flying with NVD's are sometimes unaware that they are flying in rain until the precipitation gets heavy. Contrast, distance estimates, and depth perception are affected due to light scattering and a general reduction in light level. Contrast changes due to wet surfaces after rain ceases may alter detection capabilities (sometimes improving them). Rain has similar effects as fog. Since droplet size is larger than fog, there is more absorption, although some information can still be gained through light rain or mist. Heavier rain causes significant attenuation. However, as rain cools the background during the day, thermally significant objects will tend to stand out conspicuously. Rain droplets can cause beam spread or beam wander for lasers, reducing or eliminating the signal strength from the designator to target area (or vice versa). Snow. Snow occurs in a wide range of particle sizes and geometries. Snow crystals are generally large in comparison to the wavelength of visible, near-IR, and far-IR radiation and easily blocks or scatters those wavelengths. However, due to its lower particle density, snow normally degrades thermal signatures less than fog and rain. Density of the flakes (light snowfall versus heavy snowfall) determines how much illumination and luminance is blocked, and thus how much degradation occurs to the EO/NVD image. Snow can be of help, however, in that it reflects available light and, under certain conditions, can add a degree of depth perception to an otherwise washed-out scene. Snow is also similar to that of dust and sand in that landing in snow can cause a white-out that effectively blocks the EO/NVD image. Contrast, distance estimates, and depth perception are affected due to light scattering and a general reduction in light level.

The effect of snow on IR equipment depends on flake size and density. Most of the attenuation in the far-IR spectrum is caused by scattering of the thermal energy. For snow on the ground, the degree of attenuation depends upon how long the snow has been on the ground. If the snow has been there long enough, it can cool the ground surface to reasonably uniform temperatures and attenuate the IR image. Snow also causes attenuation for laser systems; as with rain, the heavier the precipitation, the worse the attenuation.

The dew point is the temperature to which a given weight of air must be cooled at constant pressure and constant water vapor content in order for saturation (precipitation) to occur. When this temperature is below freezing, it is sometimes called the frost point. The dew point serves as a warning of possible icing conditions. It is a key measurement in computing density altitude.

Icing on lifting surfaces, such as wings and rotor blades, negatively affects the aerodynamics of the aircraft and can be extremely dangerous. Icing is also a problem with electronic systems that depend on ice-free antennas for optimum operation.

Extreme weather that includes thunderstorms and lightning is hazardous to flight operations, refueling, and rearming and can deny areas of airspace.

(4) Cloud Cover/Ceiling

Overcast skies degrade visual acquisition and tracking. A low overcast limits the effectiveness of aerial illumination devices, such as flares. And clouds limit the use of NVDs by blocking natural light from the Moon and stars.

Ceiling, when referring to cloud ceiling (as opposed to the service ceiling of an aircraft), is the altitude of the base of the lowest clouds that cover more than half the sky. Ceiling is measured in feet or be “unlimited” when the sky is mostly free of cloud cover or there are insufficient clouds to impede visual flight rules operations.

Cloud cover refers to the fraction of the sky obscured by clouds. Both cloud ceiling and cloud cover are important and distinct terms in intelligence preparation of the battlespace (IPB).

Because of the variation in particle size, it is difficult to predict how clouds affect NVD and IR performance. The effect of clouds is dependent on season, cloud type, and water vapor content. Because warmer air holds more moisture than colder air, summer clouds generally have higher water content than winter clouds. Thick clouds are more easily seen with NVDs, particularly when viewed against the night sky. But the same clouds also reduce illumination that strikes the ground, reducing the illumination available for NVDs. Thin, wispy clouds generally have no effect on NVDs but can also mask thicker clouds behind them, leading pilots to progress into thicker cloud walls without warning. Even when thicker clouds are detected, pilots may have a hard time discerning their distance.

Although clouds can decrease illumination and the resulting luminance from the Moon and stars (or eliminate it in the case of a solid overcast), they can also reflect enough cultural lighting to help offset the loss of lunar illumination. Shadows caused by broken or scattered cloud layers blocking the Moon's illumination can be seen on the terrain, blocking potential obstructions and causing the perception of bodies of water or forested areas where they don't actually exist.

Infrared radiation is scattered when its wavelength is less than or equal to the diameter of the particle (frequently the case with clouds that contain larger droplets). Water molecules also easily absorb far-IR energy. Thermal shadows are formed when a thermal source (usually the Sun) is blocked by clouds for a long enough time to create thermal differences. The thermal shadows usually dissipate shortly after sunset or if the Sun is obscured by clouds. Total cloud cover for days can degrade IR performance by producing a washed-out effect (when all temperatures are similar). However, the washout condition can be desirable if a non-natural feature (like a tank) has its own heat source, which tends to stand out strongly. Similar to the effects seen with EO/NVD sensors, laser systems require a cloud-free LOS.

Fog has similar effects to those of clouds. The particle size varies from 2 to 20 μm, which is similar to clouds, although fog has fewer particles and a smaller range of particle sizes than clouds. Since fog tends to stay close to the ground, it presents a greater hazard to rotary-wing aircraft as compared to fixed-wing aircraft. Fog can mask or partially mask ridges or other navigational features making it difficult to navigate. Pilots often detect the presence of fog by noting a gradual decrease of intensity of ground lighting. Many of the same effects are also seen with IR devices. Fog particles have the greatest distribution in the 5 to 15 μm range, which will produce a 100 percent scattering effect for IR devices. However, even with these negative effects, IR devices can still identify hot spots such as fires, operating factories, etc. Just as with clouds, laser systems require a cloud-free LOS, which fog will inhibit.

(5) Temperature

High temperatures can reduce air density, reducing the lift aircraft can achieve and reducing performance. High temperatures can also degrade the effectiveness of electronic systems, and very low temperatures may affect mechanical devices. And extreme cold produces detectable ice-fog exhaust trails from certain weapon systems and vehicles.

Most manmade and natural objects undergo continual temperature changes that follow predictable trends. But because of the variations in emissivity values and variations in the background, individual target objects and their backgrounds heat and cool at different rates during the diurnal (i.e., 24-hour) cycle. Because of this, there are periods within the diurnal cycle when the temperature of one can equal the temperature of the other (see fig. 3-50). These periods are referred to as diurnal or thermal crossover.

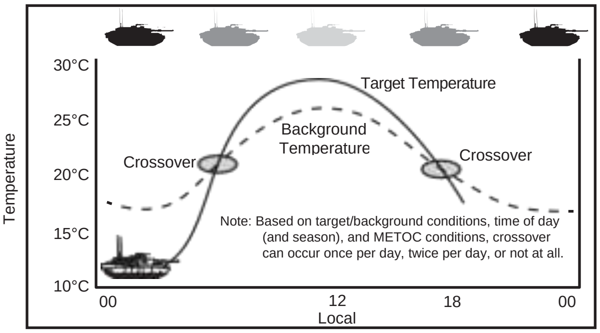


Figure 3-50

(6) Humidity

Moisture in the air reduces the air density, causing reduced lift and reduced aircraft performance. Moisture also affects the refractive index and may degrade radar effectiveness. Water vapor is the most influential absorbing gas (over oxygen and ozone) as well as the most variable when discussing EO systems. There are two terms associated with water vapor content: relative humidity (the common measurement used in the METOC community for discussing humidity) and absolute humidity. Relative humidity is a ratio that expresses the amount of moisture in the air compared to the maximum that can be held at that temperature. Absolute humidity is the amount of the mass of water vapor present in a given volume of air (measured in grams per cubic meter).

The effect of absolute humidity on NVDs varies according to particle size and density. Wavelengths used by NVDs tend to pass more readily through an area of high absolute humidity as long as particle sizes are small (as found in humid air, light rain, and fog). The larger the particle size, the more the effect on visual sensors. Infrared sensor performance can be predicted to a certain degree by knowing the absolute humidity value in the area of interest (AOI). The greater the humidity, the greater the amount of water vapor present, and the greater the IR absorption. Most users of IR sensing equipment consider 20 g/m3 to be a “show stopper,” but this threshold can go as low as 12 g/m3. High levels of humidity also contribute to attenuation of laser energy, limiting the effectiveness of laser-designation for targeting or ranging purposes.

(7) Atmospheric Pressure

Density altitude, or DA, is an indication of how well the aircraft will perform based on the density of the air. Just as an aircraft has fewer air molecules of air to push against as it gets higher into the atmosphere (as the air thins and becomes less dense), high temperatures can mimic this effect (warmer air has less density). In hot areas with an altitude of only a few hundred feet mean sea level (MSL), aircraft can experience the same performance as though they were flying in a cooler area of a few thousand feet MSL. This is a critical measurement that determines if an aircraft has enough lift capability and performance to get off the ground. Too much density altitude limits fuel, weapons, and passenger loads.

Pressure altitude, or PA, is the indicated altitude when an altimeter is set to the baseline pressure setting of 1013.25 mbar/hectopascal or 29.92 in of mercury (Hg), is equivalent to the air pressure at 0 ft MSL in the international standard atmosphere. Pressure altitude is primarily used in aircraft performance calculations and in high-altitude flight, above the transition altitude. This affects aircraft engine performance.

Transition altitude is the altitude above which altitude is measured by pressure altitude. Altitudes above TA are referred to as flight levels. Below the transition altitude, altitude is measured by height above MSL or height above ground level. In the United States, for example, the transition altitude is at 18,000 ft MSL. An aircraft flying at this altitude would report its altitude as FL180. An aircraft flying at 5,000 ft MSL would report its altitude as 5,000 ft MSL. transition altitude in some parts of the world can be as low as 3,000 ft MSL.

(8) Sea State

Sea state refers to the general condition of the surface of an area of open water, affected by wind waves and swell. Sea state takes into account parameters such as wave height, period, and power. Sea state can affect the ability for ships to launch and recover aircraft, the ability to conduct other non-flight operations aboard ship (such as maintenance, refueling, or re-arming), and the safety of low altitude flight over the water.

b. Operational Weather Terminology

A limited set of operational weather terms that incorporate or relate to the operational impact of many of the above weather factors are important to know.

A meteorological terminal aviation routine weather report (METAR) is a format for reporting forecasted weather, generally for airfields and weather observation stations. They are normally issued every 30-60 minutes. METARs generally consist of information on temperature, dew point, wind speed and direction, precipitation, cloud cover and heights, visibility, and barometric pressure.

A special meteorological terminal aviation routine weather report, or SPECI, is issued when weather conditions change significantly from a METAR.

A terminal aerodrome forecast, or TAF, is a format for reporting forecasted weather, especially for airfields. They are generally issued every 6 hours, cover a 24-hour forecast period, and encompass an area 5 statute miles around the airfield.

Instrument flight rules, or IFR, refer to rules that govern flying where the pilot relies on the instruments inside the aircraft to provide location, and relies on air traffic control (ATC) to provide separation by positive control.

Visual flight rules, or VFR, refer to rules that govern flying where the pilot can see and be seen in the environment and to navigate safely. These rules are tied to visual meteorological conditions.

Instrument meteorological conditions, or IMC, are “meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, less than minimums specified for visual meteorological conditions” (JP 3-04, Joint Shipboard Helicopter and Tiltrotor Aircraft Operations). For example, “less than a 1,000 ft ceiling and/or less than 3 nm of visibility.” Instrument meteorological conditions necessitate flying with an instrument flight rules flight plan.

Visual meteorological conditions, or VMC, are “weather conditions in which visual flight rules apply; expressed in terms of visibility, ceiling height, and aircraft clearance from clouds along the path of flight” (JP 3-04). For example, “better than 1,000 ft ceiling and 3 nm of visibility.” Visual meteorological conditions allow for visual flight rules flight operations.

3004. Terrain

The science related to terrain and its impacts is different from military aspects of terrain (key terrain, obstacles, cover and concealment, observation and fields of fire, and avenues of approach), although the science applies to it and the IPB process.

a. Climatology

Climatology can have significant impact on almost all aspects of operations, from the suitability of LZs and the intensity of brown-outs or blown debris that might impact friendly or enemy forces' SOM or that might alter the supporting or attacking aviation SOM. A number of factors must be taken into consideration both on friendly and enemy forces, including ground, air defense, and aviation forces.

(1) Soil Composition

Especially when combined with weather effects, soil composition can offer or deny terrain as maneuver space (both to friendly and enemy forces), can affect force protection (e.g., the protection offered by berms or sandbags), and has targeting implications. Soil composition can also significantly impact LZ suitability, making an otherwise suitable zone less safe because of brown-out concerns or unsuitable because it cannot support the weight of an aircraft (e.g., soft mud).

(2) Topology

Topographic relief can provide mechanical and tactical advantage or disadvantage to maneuver. Significant topography can hinder an enemy's ability to maneuver into position or slow a friendly force's movement (necessitating different LZ selection or requiring additional air support in the form of fires or logistics). Significant topographic features can also terrain-mask enemy from friendly observation and fires or mask friendly forces from enemy observation and fires. Micro-topographic features can impact suitable firing sites for weapon systems, emplacement sites for sensors, and LZs for aircraft.

Terrain topology can also have significant impacts on sensors of various types. For EO and IR sensors, terrain slope can create shadows as well as reflections that impact both visible and IR contrasts and can make detection of targets challenging.

For ELINT sensors, the location of the collection asset with respect to the terrain and the emitter can dramatically impact the picture of the battlespace when terrain bounce occurs. As an example, if a ground-based radar emits a highly-directional pencil beam (e.g., a target illumination beam) horizontally at a low-flying target, portions of that beam will pass the target and, if they encounter a mountainside, will reflect upwards. An airborne collection asset might receive this signal and geo-locate the emitter on the mountainside where the reflection originated, tens of kilometers away from the true location of the emitter (these same terrain bounce principles can also be exploited for jamming).

(3) Rivers and Lakes

Moving or standing bodies of water guided or influenced by terrain and possibly manmade structures can provide an obstacle to movement and typically require mobility enhancement or amphibious capability to negotiate. As a consequence, rivers and lakes can facilitate targeting of enemy forces that are slowed, blocked, or canalized by them, or dictate LZ selection for friendly forces limited or unable to cross them.

(4) Watersheds and Deltas

Watersheds are areas where multiple sources of surface water, such as streams, rivers, lakes, converge at a point of lower elevation to join into another (or single) body of water such as a river, lake, wetland, or ocean. Deltas are the opposite, where a single body of water, such as a river, splits and spreads out into multiple bodies, including smaller rivers or wetlands. These can influence terrain beyond what is annotated on maps and charts and affect maneuver space. Shallow deltas or watersheds tend to have a greater chance for standing water and steep watersheds or deltas tend to have a greater chance of flashfloods.

(5) Vegetation

Vegetation factors heavily in determining battlespace effects for maneuverability, force protection (e.g., concealment, observation, and detection), employment of predominantly direct fire, and target acquisition systems.

b. Mountain Operations

Mountains are areas which rise at least 2,000 ft above their surroundings and include two or more zones of climate and plant life; they make up 20% of the Earth's landmass, and they have unique considerations for aviation operations.

The terrain effects experienced during mountain operations affect aircraft performance, pilot performance, and create flight conditions rarely experienced elsewhere.

(1) Winds

Over water or flat landmass, wind is generally regarded as being two-dimensional and having a vector, with a direction and strength. This simplified model of wind is not sufficient when flying in mountainous terrain. In mountainous areas, winds contain both a vertical and horizontal component. As an example, a 10-mph wind hitting a 45-degree slope will produce a 700 foot per minute climb.

Mountainous terrain creates what is known as a boundary layer, a blanket of laminar air with a vertical component, which flows next to the terrain. It is the most stable wind in close proximity to terrain, and is the wind that aircraft have to pass through to reach a landing zone. The boundary layer is usually 50-150 ft thick. The stronger the winds, the thicker the boundary layer.

As air flows up the side of the mountain, there will be a division point where it will become downflow and turbulent on the leeward (the side of the mountain that is downwind) side of the terrain. This division is known as the demarcation line. Since winds in the mountains move in three dimensions, the demarcation line is also three dimensional and changes based on wind speed, terrain slope, and wind orientation to the terrain. In light winds, the demarcation line is at a shallow angle. As wind speed increases, the demarcation line will steepen vertically and move closer to the crest of the hill, increasing the size of the downflow region. Similarly, steep terrain will create a steeper vertical demarcation line as compared to rounded terrain. The area of downflow will be larger or smaller based on the terrain feature's orientation relative to the wind. An aerodynamically shaped and orientated terrain feature will have a smaller area of downflow. Airflow in mountainous terrain consists of:

- Prevailing winds
- Local winds
- Valley winds

Prevailing winds are steady winds associated with a particular geographic region. They are relatively constant in speed and direction and become more consistent at higher elevations.

Local winds are generated by localized phenomena such as topography, water masses, and convection.

Valley winds consist of converging winds, diverging winds, and funneling winds. Converging winds occur when terrain funnels winds from two different directions into the same direction. When this occurs the resultant wind speed can approximate the sum of the two converging winds. Diverging winds are the reverse, where one wind is split, causing the diverging winds to slow (their speed summing to approximately the speed of the source wind). Funneling winds occur when a large wind front is funneled into a smaller area (or in reverse, from a smaller area to a larger one), causing the wind to accelerate much in the way placing a finger on a garden hose causes the water to spray out at a greater speed as it is forced through a smaller opening.

(2) Illusions

The mountain environment is unfamiliar and demanding. The terrain provides limited references to the horizon that can cause a number of illusions that make flight difficult, if not dangerous. The up-slope illusion is caused when flying up-slope where the perceived horizon is above the true horizon, causing a tendency to climb and decelerate when flying towards rising terrain. The down-slope horizon is caused when flying down-slope where the perceived horizon is below the true horizon, causing a tendency to descend and accelerate when flying towards falling terrain.

The cross-slope illusion is caused when the perceived horizon is not parallel to the true horizon (i.e., the terrain is sloping down or up, causing the horizon to appear sloped). This has a tendency to cause an undesired bank angle due to a lack of usable horizon.

The scale illusion is caused by a lack of reference to objects of known size. This can lead to incorrect judgments in distance as well as size estimation (especially for landing zones).

3005. Acoustic Detection and Propagation

Understanding the principles of sound propagation and detection, combined with software that can produce acoustic detection tactical decision aids, enables planners to determine the acoustic detectability of their aircraft under a variety of conditions (flight profiles, atmospheric conditions, terrain, etc.) and plan operations accordingly.

Just as with propagation of EM waves, *acoustic propagation* refers to the movement of sound waves from one place to another and what happens to them in between. While sound is not an EM wave, it is still a wave and therefore, basic wave principles still apply.

Just as with EM waves, the speed of sound varies with the density of the medium in which it travels. Because sound is made of the compression of the medium in which it travels, it also varies with the compressibility of that medium. The equation for this calculation is

$$c = \sqrt{\frac{K_s}{\rho}}$$

where

c is the velocity of sound

K_s is the coefficient of stiffness (a measurement of compressibility) of the medium

ρ is the density of the medium

For example, at sea level, in 20 degrees Celsius (68 degrees Fahrenheit) dry air, sound travels at approximately 343.2 m/s (1,236 km/h or 768 mph).

a. Propagation

The propagation of sound through the atmosphere is a complex process. Sound absorption happens normally through classical losses (the change of acoustical energy into heat) and molecular relaxation losses (the change of acoustic energy into internal energy within the air molecules themselves). These losses are relatively well understood and are functions of

- Temperature
- Humidity
- Atmospheric pressure

Losses are affected by numerous external factors as well, such as:

- Temperature gradients
- Humidity gradients
- Wind
- Wind gradients
- Level of turbulence

Acoustic propagation is further complicated by the random variation in space and time of the temperature, wind, and turbulence level. The manner in which these external factors affect propagation is less well understood but can be significant.

There is significant variation in propagation under different conditions for distances beyond a few hundred meters. The consequence is that an aircraft that is inaudible from a given distance at one point in its flight path may be audible from that same distance elsewhere (or if it is flying the same flight path at different hours of the day or on different days). Or, an aircraft flying at a given altitude and location may be audible from a given distance in one direction but inaudible from the same distance in another direction.

Sound pressure level is measured in dB, which, as a logarithmic representation of a ratio, compares the measured sound to the threshold of human hearing (which is 0 dB). Table 3-3 depicts the dB level of common sounds.

Table 3-3

dB	Sound
0 dB	Mosquito flying 3m away
20 dB	Watch ticking
30 dB	Whisper in a library
60 dB	Conversation
70 dB	Car running
120 dB	Rock Concert
130 dB	Jet engine 30m away

b. Detection

Acoustic detection of aircraft can take place at formal listening posts (LP) or informally when an astute enemy detects approaching forces. These LPs can be equipped with the simple human ear or augmented with technology that can aid in identifying the sound and, through measuring the differences in time of arrival of the sound, either at one LP or at many, can identify the source direction and/or triangulate the source location.

Generally, rotary-wing aircraft produce low-frequency sounds that travel long distances and can be detected by sensors from 5 to 30 km away. Fixed-wing aircraft produce a much wider range of sounds and at much more variable differences, with small low-flying UASs easily masked by terrain and large multi-engine jets producing loud, broadband sound sometimes audible at great distances.

This information can be fed back to a formal air surveillance (ASV) site through simple radio call, be integrated through data link into an air picture created by other sensors as well, or be related through a simple telephone or radio call to another individual.

Factors that determine acoustic attenuation and thus detection can be broken down into three main categories: source characteristics, geometric spreading atmospheric effects, and surface effects.

c. Source Characteristics

Source characteristics are the features of the sound that factor into how it propagates and therefore the likelihood of it being audible at given distances.

(1) Sound Volume at Source

Most obviously, the louder the source volume, the more easily the sound will be detectable at a distance. Volume is not everything, however; frequency, directivity, and distribution all play important roles.

(2) Source Frequency

Higher frequencies tend to attenuate more than lower frequencies through most atmospheric conditions. This can cause a louder, HF sound, to be less audible at a given distance than a quieter, low frequency sound.

(3) Source Directivity

Directivity includes both:

- The degree to which the sound is directed to the observation point (e.g., the engines of an inbound jet are quieter than the engines of an outbound jet at the same distance because the sound is directed towards the observer for an outbound jet).
- The apparent direction the observation point observes the sound (e.g., the manner in which it is reflected towards the observer from a direction other than the source—see non-linear propagation of sound, below).

On aircraft, this can be altered (both enhanced and diminished) by major factors such as aspect (i.e., inbound versus outbound) but also by everything from exterior weapons and stores, landing gear deployment, flap settings, surrounding terrain, and more.

(4) Source Size

Source size also plays a role in the nature of the sound generated and how it propagations. Sound does not propagate linearly. Each point in its propagation is a new (and weaker) source for additional propagation. This is why it is possible to hear a sound from around a corner (see fig. 3-51) but a light source cannot be seen from around a corner (light propagates linearly). Variation in atmospheric conditions also cause sound to scatter.

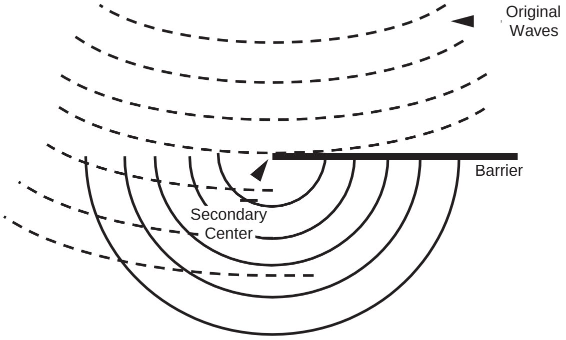


Figure 3-51

This also causes sound waves to destructively and constructively interfere when in a complex reflectivity environment, such as close to the ground. When sound is emitted from multiple locations, the constructive and destructive interference can have unpredictable effects, making the sound more detectable in some places and less detectable in others.

A small source will generate sound from one single point. A large source will generate sound from a number of different points. For example, a small single-engine jet emits sound from a relatively small area. A large, multi-engine bomber emits sound from a number of engines across a wide wingspan, creating sound across a larger area.

The effects of source size tend to be minimal when there is a clear LOS to the observer, such as with a high-altitude aircraft; however, the effects of varying source sizes can be more noticeable when the LOS is less direct, such as at low-altitudes and/or with rugged terrain in the LOS. The result can cause low-altitude sound sources to fade in and out based on changing reflections, distance, and constructive/destructive wave interference changes.

d. Distance and Geometric Spreading

After source characteristics, the way in which sound waves travel across distance must be considered. Just as with EM waves, sound weakens as it travels over a distance.

While sound attenuation and propagation is incredibly complex and there are still no mathematic models to precisely predict it, noise generally dissipates in proportion to the square of the distance (i.e., at 2 nm, one quarter of the noise perceptible at 1 nm remains). This is called *geometric spreading*.

(1) Types of Spreading

Geometric spreading happens in two ways: spherical and cylindrical.

Spherical spreading occurs from a point source due to sound radiating equally in all three dimensions (see fig. 3-52). This is the type of spreading most relevant to aviation as aircraft can be considered point sources for most situations.

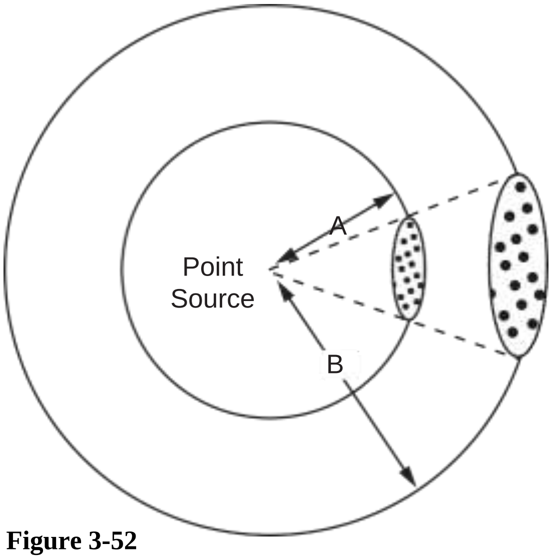


Figure 3-52

Cylindrical spreading describes how sound spreads from a linear source like a highway (see fig. 3-53). Because sound is being emitted continuously across the line, it behaves as though it were spreading only in two dimensions. As a consequence, sound is normally reduced half as much for a linear source than as for a point source over the same distance. This normally has little application to aviation but may have minimal application to airfields where aircraft may be operating across a long flight line or for large, linear (either long or wide) formations of aircraft.

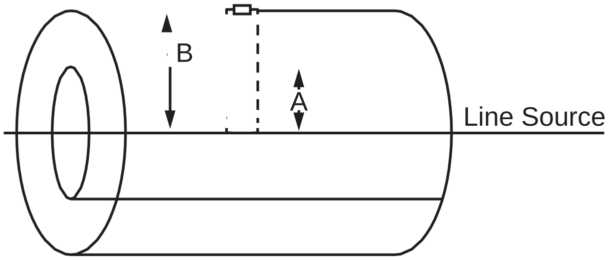


Figure 3-53

While some propagation mechanisms may make aircraft more audible at longer distances (due to effects such as sound shadows or constructive interference) geometric spreading causes sound to be weaker the further it is from the source, all other things equal.

e. Atmospheric Effects

Atmospheric effects fall into two main categories: attenuation through atmospheric absorption (which is effected by factors such as temperature and humidity) and wind and temperature gradients.

(1) Atmospheric Absorption

Sound is absorbed by the atmosphere through molecular relaxation and viscosity effects.

Molecular relaxation occurs as sound energy compresses air and, in the process, vibrates and rotates air molecules. This is used to carry the sound wave outward, but it is kinetic energy expended on exciting air molecules, which means that energy is then sapped from the sound wave as it expands.

Viscosity effects describes the energy-loss process where air molecules bump into each other as the compressed air wave moves through the atmosphere. This contact between molecules creates small amounts of friction and heat that also sap energy from a sound wave.

A number of factors affect how much energy these two mechanisms sap from a sound wave and therefore how much attenuation sound waves experience in different atmospheric conditions. Greater air density tends to increase the intensity of the sound (reduced attenuation). Therefore, lower temperature environments or aerosols that increase air density will result in less attenuation.

As humidity increases, to a point, so does absorption. Beyond that point, however, absorption is reduced. That point of maximum attenuation through humidity changes with the frequency of the sound, but 10-30 percent relative humidity corresponds with maximum attenuation for a wide range of frequencies.

Precipitation (e.g., fog, rain, snow) in itself has minimal effect on propagation. The humidity associated with that precipitation, however, will affect propagation through ambient sound (e.g., rain falling) or albedo (e.g., water, snow). Clouds can reflect noise (reducing it if they are between the source and observer; or aiding in detection if they reflect the sound to the observer.).

(2) Wind and Temperature Gradients

Just as with EM waves, the density of the medium affects the speed of sound waves and as the speed of the wave changes through gradients, it can experience refraction.

Because wind does not blow evenly (air next to the ground or obstacles, such as buildings or trees, moves more slowly than air at higher altitudes), wind will always cause a wind gradient (see fig. 3-54). This causes sound waves traveling upwind to be refracted upwards (and experiencing more attenuation) and sound waves traveling downwind to be refracted downwards (and experience less attenuation). Cross-winds can also change the perceived direction of a sound source.

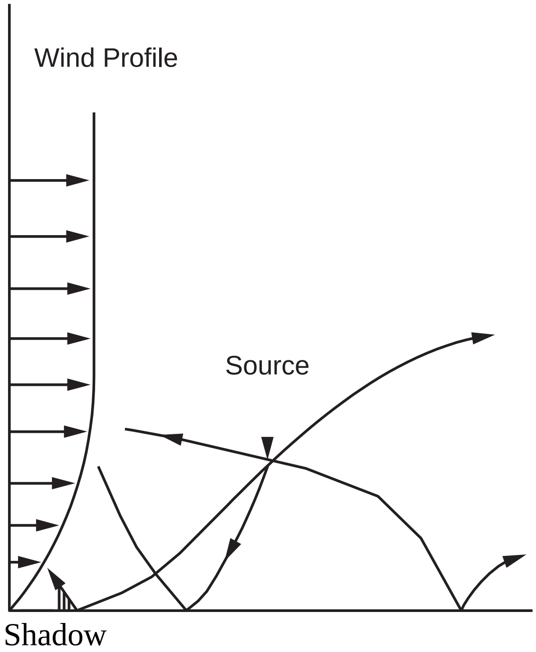


Figure 3-54

Temperature gradients work the same way on sound waves as they do on EM waves. One common example of this is temperature inversions (where high altitude temperature is warmer than at lower altitude). Temperature inversions commonly happen in the winter or near sunset and will tend to refract sounds downwards, sometimes across extreme distances (see fig. 3-55).

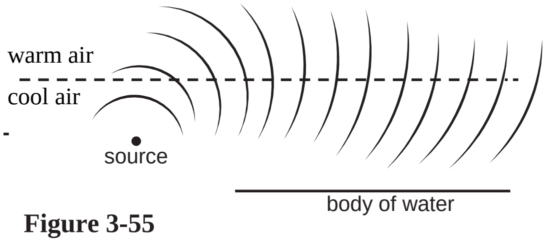


Figure 3-55

f. Surface Effects

Ground reflection and absorption is the last major consideration in sound propagation.

Ground reflection is expressed in terms of albedo. *Albedo* refers to the proportion of a wave (in this case, sound) that is reflected by a surface. The acoustical “hardness” or “softness” of surfaces affect how well they will reflect sound. Acoustically “hard” surfaces (smooth, hard surfaces like roads, runways, or packed desert floor) will reflect sound more effectively. Acoustically “soft” surfaces (rough, soft surfaces like thick grass or foliage) will reflect sound less effectively (including more diffuse reflection as well as more absorption).

Ground absorption is highly dependent on the relative angle to the source. For example, there will be a maximum absorption effect for sources at the horizon, whereas sources 7 degrees or more above the horizon will experience minimal absorption from ground sources.

Shielding barriers such as trees, buildings, and terrain will contribute to absorption. These are most effective at attenuating sound when close to the source or the observer. For example, if the source and observer are 100 ft apart, a tall wall 10 ft from one or the other will attenuate the source more than if the wall is an equal distance between the two. Additionally, the absorption effect from shielding barriers on the ground diminishes the higher in altitude the source is.

3006. Space

The US military is more dependent on satellite support than other countries, which makes its various space systems lucrative targets for an enemy to exploit. Every aspect of expeditionary warfare relies in part on space: intelligence (imagery or electronic surveillance), navigation and targeting (GPS-guided munitions), communications, and control of UASs.

The MAGTF and Marine aviation rely extensively on space-based assets for force enhancement and situational awareness, including intelligence, surveillance and reconnaissance (ISR), detection and tracking of missiles, environmental monitoring, weather data and forecasting, communication, and positioning, navigation, and timing (PNT). Other aspects of space outside human control, such as astronomical data, can be equally important.

a. Space Systems

Space systems are composed of three segments: space, ground, and link. The space segment includes satellites, space stations, and space lift vehicles. The ground segment includes fixed and mobile land-, sea-, or airborne equipment used to interact with the space segment. And the link segment is the data transmitted between the ground and space segments.

(1) Space Segment

Satellites predominately reside in one of four identified Earth orbits. The terminology used to describe these Earth orbits attempts to categorize these orbits according to three parameters: altitude, inclination (measured from the Equator, see fig. 3-56), and eccentricity (orbital shape). Other orbits not covered in this section are polar orbits, sun synchronous orbits, and transfer orbits such as cislunar orbit and the highly eccentric orbit.

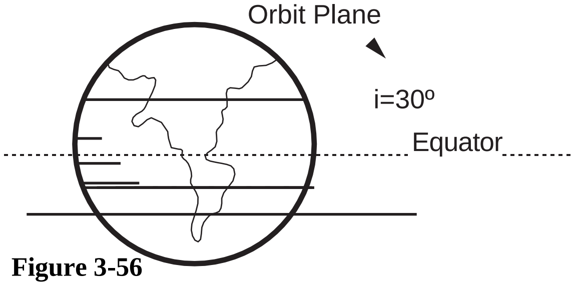


Figure 3-56

Low Earth orbit refers to both circular and elliptical orbits with altitudes up to approximately 2,000 km (1,080 nm and orbital periods (time to complete a single orbit) from 88 minutes approximately 2 hours. Satellites residing in low Earth orbit are usually meteorological, imagery, or manned space vehicles.

Medium Earth orbit refers to both circular and elliptical orbits with altitudes from about 2,000 to 20,000 km (1,080 to 10,800 nm) and orbital periods ranging from approximately 2 to 12 hours. This term is frequently used to identify the semi-synchronous circular orbits used by PNT spacecraft, such as the US Navigation Satellite Timing and Ranging (NAVSTAR) GPS or Russia's Global Navigation Satellite System.

Highly elliptical orbit is sometimes called a Molniya orbit (named after the orbit of a Russian communications satellite). It is commonly used for communications and launch detection satellites with coverage of the far northern latitudes. A standard highly elliptical orbit (Molniya orbit) is a semi-synchronous (12-hour period), elliptical (40,000 by 1,000 km or 21,600 by 540 nm) orbit inclined at approximately 63 degrees to the Equator.

Geosynchronous Earth orbit refers to a circular orbit with an altitude of 35,750 km (22,200 nm), near-0-degree inclination, and a 24-hour period. This allows the spacecraft to appear to remain above a specific ground location. Geosynchronous orbits can be elliptical and/or highly- inclined but not necessarily geostationary (a circular orbit directly above the Equator). Satellites in a geosynchronous orbit are typically communications satellites, relay satellites, and launch detection satellites.

(2) Ground Segment

The ground segment is defined by the ground station operations including transmission and reception of signals for telemetry, tracking, and commanding of the space nodes and space launch functions. In addition, the ground segment includes satellite communications (SATCOM) transmission and reception devices such as GPS receivers and data reception stations for receiving imagery or other data.

(3) Link Segment

Both the ground segment and the space segment nodes are tied together by information conduits called links. These links are classified as control or mission links. Control links command the satellite and its sensors while mission links carry operational data to or from the satellite.

(4) Astrological Data

The position of the Sun and Moon and their rise and set are significant factors in operational planning. Commonly called solar/lunar almanac prediction data, this information can provide important details on light levels to mission planners.

When the Sun crosses the horizon, this is sunrise and sunset. When the Sun is 0-6 degrees below the horizon, this is civil twilight. During civil twilight, most terrestrial objects are visible to the human eye and artificial light (illumination or night vision optics) is usually not required. When the Sun is 6 degrees below the horizon, this is known as begin morning civil twilight or end morning nautical twilight and (after sunset) end evening civil twilight or begin evening nautical twilight. When the Sun is 6-12 degrees below the horizon, this is nautical twilight. During nautical twilight, most terrestrial objects are not visible to the human eye without artificial light but the horizon is still clearly visible and it may still be possible to see silhouettes of objects in the sky, such as an aircraft, without artificial light.

When the Sun is 12 degrees below the horizon, this is known as begin morning nautical twilight or end morning astronomical twilight and (after sunset) end evening nautical twilight or begin of evening astronomical twilight. When the Sun is 12-18 degrees below the horizon, this is astronomical twilight. During astronomical twilight (in areas with low or no light pollution) astronomers can make most observations of point sources, such as stars. Observations of the faintest stars or other astronomical items may not be possible until the Sun is 18 degrees or more below the horizon, night. Astronomical twilight has limited military operational impact. Figure 3-57 depicts the day, twilights, dusks, and night.

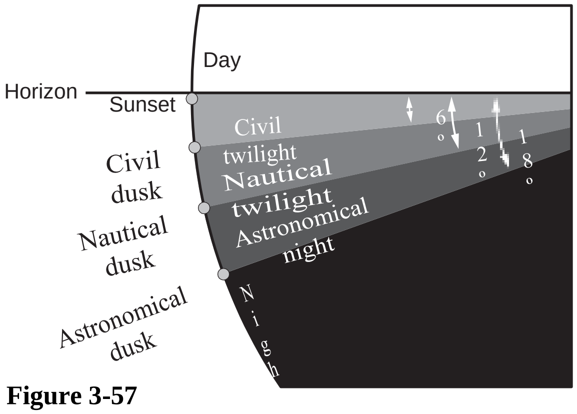


Figure 3-57

The position of the Sun is critical to illumination during the night, but even more so is the position and phase of the Moon.

When discussing nighttime illumination levels, especially in the context of NVDs, the measurement of lux is important. *Lux* is a measurement of *luminous flux*, which is the power of light as perceived by the human eye.

Under NVDs, nighttime illumination levels are divided into two categories: high light level (HLL) and low light level. The threshold between the two (the lowest lux considered HLL) is 0.0022 lux, which is the equivalent energy produced by a 23 percent Moon disc that is 30 degrees above the horizon. By comparison, starlight alone provides approximately 0.00022 lux, one tenth of the HLL threshold. During low light level conditions, older NVDs have reduced effectiveness. Newer NVDs may have lower operational thresholds.

Nighttime illumination is produced by the stars, cultural or city lighting, the Sun (during twilight period), and the most significant source of nighttime illumination, the Moon.

The illumination produced by the Moon (which is a reflection of approximately 7 percent of the Sun’s light) varies with Moon phase/lunar cycle, Moon angle, lunar albedo (a measure of the reflectiveness), and the distance from the Earth to the Moon.

Because these factors vary over the course of the night and their timing during the night varies over the course of the lunar cycle, a light level planning calendar (fig. 3-58) allows aviators to predict the light level and therefore the effectiveness of their NVDs throughout the night period.

Factors including cloud cover, humidity, haze, dust, terrain, and shadows can all degrade illumination levels.

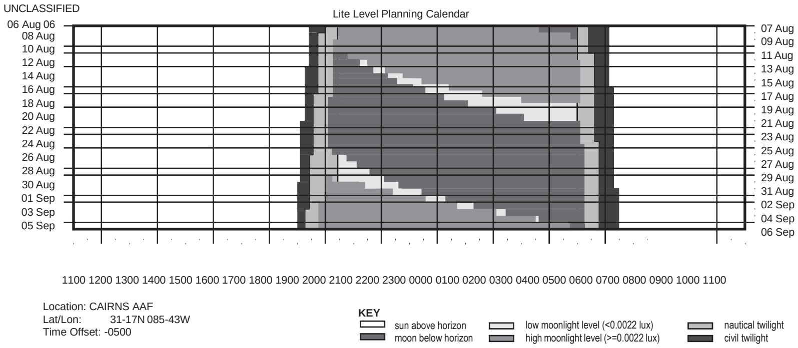


Figure 3-58

3007. Global Positioning System

Global positioning system is both a generic term to refer to global navigation satellite systems that provide PNT, as well as a term that specifically refers to the US NAVSTAR GPS satellite constellation that provides GPS signal to civilian and military users.

Other global navigation satellite systems in existence or development include the Russian Global Navigation Satellite System, the EU Galileo system, and China’s BeiDou system. Additional navigation systems exist that only cover parts of the globe or provide non-satellite-based PNT.

The NAVSTAR GPS is a space-based system that provides positioning and timing data to users worldwide. The data that it provides has become essential to the conduct of military operations. It also contributes to transportation efficiency, safety in the civilian sector and to the timing, and recording of financial transactions. The system, which includes a constellation of satellites, was developed and is operated by the Department of Defense (DOD) in consultation with the Department of Transportation and several other federal agencies.

The NAVSTAR GPS began operations with a full constellation of satellites in 1995. In the years since then, GPS has become vital to military operations and is used by all branches of the armed services to guide troop movements, integrate logistics support, and synchronize communications networks. In addition, US and allied forces use GPS signals to guide munitions to their targets and to locate military personnel in distress.

The NAVSTAR GPS is a global network composed of three segments: satellites that transmit military and civilian GPS signals, systems on the ground that control the satellites and support the signals (ground control systems), and receivers that make use of the broadcasted signals (see fig. 3-59). Each of those signals includes positioning and timing information that enables users with GPS receivers to determine their position and the exact time 24 hours a day, in all weather.

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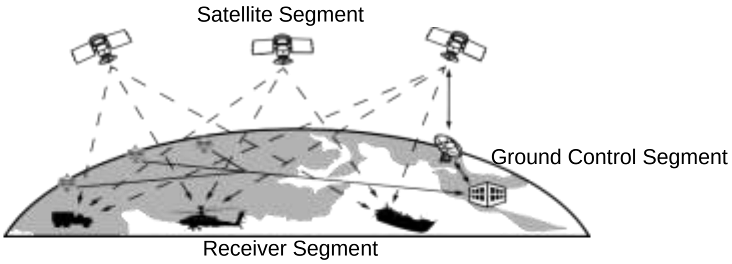

Figure 3-59

a. The Three Global Positioning Systems Segments

All three segments of the GPS are necessary to enable users to determine their location accurately without interruption. Most GPS users are familiar with both the space segment—the constellation of satellites orbiting the Earth—and the receivers that use the satellites' signals to determine individual locations. The workings of the ground control system, which continuously monitors the health of the satellites and adjusts their signals to eliminate errors in time and position, are less well known but no less necessary for the proper operation of the overall system.

(1) Satellites

The GPS space segment is a constellation of at least 24 satellites that transmits signals with data on each satellite's position and the time. Currently, there more than 24 satellites in orbit. They are arranged into six orbital planes, each inclined 55 degrees from the Equator. Each orbital plane contains at least four unevenly spaced satellites orbiting the Earth twice a day at an altitude of 10,898 miles. Satellites move continuously through their orbit in the same direction as the Earth's rotation. They orbit the Earth twice in 23 hours, 56 minutes, and 04.091 seconds solar time or one 24-hour sidereal day (sidereal is a time scale that is based on the Earth's rate of rotation measured relative to the fixed stars).

The satellites are spaced in such a way that a minimum of four satellites are in view to users worldwide at any given time. This arrangement enables users with an unobstructed view of the sky and appropriate receivers to determine their position accurately.

The satellites transmit at least two types of signals with the same time and position information. One set of signals is encrypted and is available only to military users. The other, unencrypted civilian signals are available to all users.

(2) Ground Control System

The ground control system tracks the GPS satellites and periodically updates the information that they transmit to Earth. This segment includes two master control stations, the primary one in

Colorado and an alternate one in California. In addition, four ground antennas that can send commands up to the satellites and six dedicated monitoring stations are stationed around the world.

The monitoring stations receive information from each GPS satellite as it orbits the Earth roughly twice a day. That information is then sent to the master control station, where it is processed to identify inaccuracies in the time and position data. Despite the fact that the clocks aboard the satellites are extremely accurate—they have even been adjusted to take into account the effects of relativity on the clocks aboard the satellite, as opposed to identical clocks on Earth—tiny errors in time can result in measurable errors when determining location (an error of 1 billionth of a second can result in location errors of 1 ft). Because the clocks can accumulate errors of up to 10 billionths of a second per day—creating location inaccuracies of up to 10 ft—the Air Force computes and uploads time corrections for each satellite daily using the ground control system. In addition, satellites drift from their prescribed orbits and, as a result, their actual positions differ from predicted ones. Corrections that need to be made to an individual satellite's transmitted position are also relayed back up to the satellites once per day via the ground antennas.

(3) Receivers

Military and commercial GPS receivers are installed on ships, aircraft, vehicles, and are carried by individuals. Military GPS receivers are designed to use the encrypted GPS signals that are available only to authorized users, including military and allied forces and some civilian agencies. In contrast, commercial receivers use the civilian GPS signals, which are publicly available worldwide.

The military fields many types of GPS receivers that have been optimized for its use. In the past decade, as advances in technology have facilitated the development of smaller and lighter GPS receivers, it has become possible to embed them in precision-guided munitions, such as cruise missiles and guided artillery rounds, as well as in unmanned aerial vehicles (UAVs).

b. Satellite Signals

Each GPS satellite broadcasts carrier signals on two spread-spectrum radio frequencies. The satellite's onboard atomic clocks generate a fundamental frequency of 10.23 MHz multiplied by a factor that produces the actual carrier frequency.

The Link 1, or L1, RF carrier frequency is generated by multiplying the fundamental frequency by 154. It is centered at 1575.42 MHz and has a bandwidth of 20.46 MHz. The majority of the intensity of the signal lies at 1575.42 MHz (±10.23 MHz). The signal wavelength is 19 cm.

The Link 2, or L2, RF carrier frequency is generated by multiplying the fundamental frequency by 120. It is centered at 1227.60 MHz and has a bandwidth of 20.46 MHz. The majority of the intensity of the signal lies at 1227.60 MHz (±10.23 MHz). The signal wavelength is 24 cm. Link 3, or L3, centered at 1381.05 MHz, is used for nuclear detonation detection.

Link 4, or L4, centered at 1379.913 MHz, is being studied for ionospheric correction (irregularities in the ionosphere can cause interference with or loss of the GPS signal in some areas).

Link 5, or L5, centered at 1176.45 MHz, is proposed for use as a civilian safety-of-life signal.

(1) Data Sequences

Each GPS satellite develops several binary data sequences transmitted from the GPS control segment. These sequences are the coarse/acquisition (or C/A) code, the precise (or P) code, and the Navigation Data Message.

The C/A code is sometimes referred to as the standard (or S) code or the L1 Civilian (or L1C) code. It has also been called the clear access code. It is broadcast by all GPS satellites on the L1 carrier wave.

The P code is sometimes referred to as the protected code. It is broadcast by all GPS satellites on both the L1 and L2 carrier waves. The P code can be encrypted by the satellite creating a Y code, producing a P(Y) code or encrypted code.

The M code is designed to replace the P(Y) code and provides superior jamming resistance to the P(Y) code through higher gain (more directional) broadcasts.

c. How GPS Works

GPS works by timing how long it takes the radio signals from its satellites to reach a specific location on Earth. Each satellite continuously broadcasts the time and its own position, and GPS receivers calculate the delay between the time when the signal left the satellite and when it reaches the receiver. That time delay, when multiplied by the speed of light, determines the receiver’s distance from the satellite.

A GPS receiver could, in theory, calculate its three-dimensional position by measuring its distance from three different satellites simultaneously. To be more accurate, a GPS receiver could use a fourth satellite to calculate its position. As the number of satellites increase, so does the accuracy of the location.

Although the Air Force monitors the data that each satellite transmits to ensure its accuracy, errors in determining location can be introduced as the satellite's signal travels through the atmosphere and because the clocks on the satellite and those in the receiver are not synchronized exactly. Satellite geometry is also important because a GPS receiver determines its position by triangulation; the more widely dispersed the satellites are, the more accurately a receiver will be able to determine its position.

Several points should be noted about how the system works. First, there is no interaction between the satellites and the receivers. That is, the satellites send out military and civilian signals that are available to all receivers that can decode them. The receivers merely process the information received from the satellites; they do not send signals back to the satellites or to other systems. To process the data that the satellite or satellites are transmitting, a receiver must first "acquire" a signal from one or more GPS satellites in view. Once the receiver has acquired and identified signals from a GPS satellite, it can more easily continue to process the data from (or "track") the signal.

Second, because the receivers determine a user's location on the basis of triangulation, any errors introduced into the distances calculated from the satellites result in errors in determining the location of the receiver. Receivers can cancel out any errors introduced by atmospheric interference by using information from signals on two different frequencies transmitted by the same satellite. Such a capability has been available to military users from the system's inception (because each GPS satellite has always transmitted military signals on two different frequencies), although not all military receivers were capable of processing both signals. Until recently, however, civilian receivers did not have this ability because older GPS satellites transmitted the unencrypted civilian signal on only a single frequency. Global positioning system satellites launched since 2005, however, have transmitted two civilian signals on the same frequencies as the military signals, enabling civilian receivers to calculate a user's position with greater accuracy (one source estimates an accuracy of 74 ft using a single frequency, as compared with 28 ft using two frequencies).

Finally, because the receiver calculates its position on the basis of triangulation and because data transmitted by each satellite include some degree of error, receiving data from more satellites enables the receiver to cancel out more of the errors and calculate a more accurate position. Thus, the greater the number of satellites in view, the greater the accuracy of the calculated position. However, some locations, such as urban settings and hilly or mountainous terrain, offer only obstructed views of the sky. In those circumstances, obtaining signals from even three satellites at one time might be difficult. In such situations, the GPS user often must augment the signals with information from sources other than GPS to determine a position accurately.

d. Interference with Global Positioning System Signals

Reception of GPS signals by receivers on Earth can be easily disrupted, intentionally or unintentionally. One reason is that the signal from space is extremely weak by the time it reaches the Earth. A received GPS signal has approximately 10^{-16} Watts of power (0.0000000000000001 Watts), which is the equivalent to the amount of light received in Los Angeles from a 60 Watt light bulb in New York City. Consequently, the signal can be masked unintentionally by other RF signals in the vicinity (for example, cell phone traffic and TV broadcasts), by ionospheric irregularities, or intentionally by deliberate jamming.

Global positioning system jamming is accomplished by generating a signal with enough power to overwhelm a weaker signal. Although the military GPS signals are encrypted and are not easy to replicate, they can be easily masked by stronger signals of the appropriate frequency. As an example, a jammer broadcasting 1 Watt of power at the appropriate frequencies could theoretically prevent a military receiver 60 km away from locating and acquiring a GPS signal. Once the receiver has acquired and locked on to the military signal, the same 1-Watt jammer would need to be within 30 km to cause the receiver to lose track of the signal.

Such a jammer could be as small as a soda can and easily be carried by an individual. A larger, but still portable, 10-Watt jammer could prevent the same receiver from acquiring a GPS signal at a distance of 200 km and could cause the receiver to lose track of the signal at 90 km.

The most common jammers likely to affect GPS reception are those emitting radio signals over a relatively broad band of frequencies. Because the GPS signals are so weak by the time they reach the Earth, very weak jammer signals can mask the signals from the GPS satellites. Jammers that generate signals of higher power can adversely affect GPS receivers at greater ranges. Because more powerful jammers need larger power supplies, however, they are more expensive and easier to detect and attack.

Jamming of the GPS L1 and L2 navigation downlink signals is the most prevalent target for downlink jamming. These broadcasts are susceptible due to the very low powered received signal strength.

Global positioning system received signals are susceptible to jamming at and near the Earth's surface, especially the C/A code, which is used to acquire the P(Y) code in most instances (some receivers are capable of direct P(Y) code acquisition). Once a receiver has acquired and is locked onto the P(Y) code the amount of jamming must increase for the receiver to lose lock and subsequently lose tracking.

On the basis of reviews conducted in the late 1990s, the DOD decided to take several measures to make it harder for enemy forces to prevent military users from taking advantage of GPS signals in the future. Those measures included:

- Enabling future GPS satellites to transmit new military signals (designated M code) that would cover a wider frequency range and be separated in frequency from the civilian signals.
- Developing satellites capable of transmitting military signals at higher power.

The purpose of those measures was to make it more difficult for enemy forces to use jammers capable of masking GPS signals from significant distances. The jammers work by broadcasting noise that covers the same frequency range as the signal from the satellite. To generate noise over a wider frequency spectrum, the enemy is forced to use more powerful jammers to attain the same effective range. Such jammers require larger and bulkier sources of power, which makes them larger and more expensive. By transmitting a stronger and broader GPS signal from space, the DOD hoped to force enemies to transmit stronger jamming signals, which would make them easier to locate and attack.

Global positioning system signals can also be contested by spoofing. *Spoofing* is the enemy's attempts to duplicate or imitate GPS signals. Spoofing requires that the enemy have a knowledge of the received satellite phase and frequency at the targeted receiver antenna. The proper carrier frequency and timing code phase plus a sufficiently higher power output will allow a deceptive jammer to establish a false lock with the receiver. The enemy must know which satellites are being tracked and the position and velocity of the receiver to create a false signal with the correct Doppler shift. Once false lock is established, the spoofer can manipulate the duplicated navigation signals to cause navigation errors.

(1) Positioning, Navigation, and Timing in a Global Positioning System-Contested Environment

Because of military reliance on GPS-enabled PNT, many enemies plan to deny or otherwise contest the use of GPS. A number of techniques and technologies exist to mitigate these risks.

The first is improving the ability to track a GPS signal in a contested environment. This is largely achieved through antenna design and anti-spoofing.

To filter out jamming signals, larger external antennas have been developed for use with handheld GPS equipment as well as antennas on aircraft and vehicles.

Spatial filtering antennas have been developed to filter out interference from ground-based jammers. Ground-masking antennas limit the jamming effects of ground-based jammers regardless of the signal's angle of arrival by masking the antenna from signals that don't originate from space.

Controlled reception pattern antennas have been developed to provide anti-jamming protection, primarily for aircraft. The antenna has the capability to form "nulls" (through destructive interference) in the reception pattern in the direction from which the jammer's energy is arriving, reducing the effectiveness of jamming signals.

Antispoofing is a method used to prevent possible enemy imitations of the GPS signal. Encrypting the P code creates the Y code, which can only be processed by GPS receivers with a valid crypto key. This encrypted code is difficult to imitate. It is important to understand that the P code and the Y code are not two separate codes; one is the encrypted version of the other. A GPS receiver without a valid crypto key cannot process the Y code and will be limited to measurements from the C/A code. The C/A code is totally unaffected by the P code encryption. This is why the C/A code is very susceptible to deception jamming.

The second way to mitigate the risks of GPS jamming is the use of non-GPS PNT techniques.

Inertial navigation systems use gyroscopes, accelerometers, and computers to take an initial validated location (potentially acquired by GPS outside the battlespace affected by jammers) and, based on *inertia* (the resistance of any object to change in its state of motion—i.e., slowing down, speeding up, changing elevation, or turning) acting on those gyroscopes and accelerometers, calculating how far from that initial validated location the inertial navigation system (INS) has moved and in what directions, allowing the system to estimate (sometimes with great precision) its current location. Because of small errors in measurements and calculations, INS systems tend to "drift" and become less accurate the more movement and time there has been since a last validated location.

High integrity GPS, known as iGPS, augments normal GPS equipment with location information from the Iridium SATCOM network to potentially produce a higher fidelity location in GPS-contested environments.

Tactical air navigation system, or TACAN, is a military navigation system that provides bearing and distance (slant-range) to a ground or shipborne station, allowing an aircraft receiving the tactical air navigation system signal to calculate its own location, relative to the location of the emitter. For shipborne systems, this can allow navigation back to the ship or for patrolling the area around the ship. For ground-based systems, a known location can allow the aircraft to calculate its current location based on the signal.

Finally, utilizing identifiable terrain or manmade features to navigate using a bullseye system can enable aircraft to identify their rough location. This can be as simple as navigating along a highway or as complex as using SAR to identify a significant piece of infrastructure with a known location to be able to extrapolate the aircraft's relative location.

Ultimately, realistic training that simulates GPS-contested or GPS-denied environments provides the best preparation for operating in a GPS-contested battlespace.

3008. Low Observable

LO technologies are commonly referred to as "stealth" or "stealthy. LO technologies cannot make vehicles invisible; only harder to detect and at shorter ranges.

LO techniques are forms of passive countermeasures: structural measures or tactics designed to mitigate the enemy's ability to observe an aircraft throughout the kill chain, enabling LO aircraft to break the kill chain.

LO measures are about more than just RF signature reduction. They are implemented to reduce the signature of an aircraft (or other weapon system) to any sensor so as to improve its survivability, allowing it to conduct missions in areas that might otherwise prove lethal, pose unacceptable risks to non-LO aircraft, or simply to improve survivability of an aircraft in any threat environment. This does not always mean LO aircraft remain undetected. As long as the kill chain is disrupted, LO technology has served its purpose. For example, if an LO aircraft is visible to low-frequency early warning radar, but a weapon system's higher frequency fire control radar is unable to acquire it and develop a firing solution, then the kill chain has been broken and the LO technology and/or tactic has succeeded.

This distinction is important as a number of LO principles and technology can be used to upgrade conventional aircraft with features that reduce their RCS, increasing survivability while not attaining what would generally be considered "stealth." For example, IR suppression devices are fitted to many modern helicopters while many non-LO fourth generation fighters have been updated with LO features like radar absorbent paint or RCS-reducing canopy coatings.

LO tactics and technologies are not a silver bullet. They have significant drawbacks. First, LO aircraft are very complex and expensive to research, develop, build, and maintain. Secondly, LO measures often impose limits on payload, range, and performance of an aircraft as compared to similar non-LO aircraft. Third, many LO characteristics are delicate or short-lived and must be treated with care, repaired, or re-applied regularly, increasing the maintenance requirements over non-LO aircraft. And finally, because of the cost of LO and the therefore limited production, it is not a foregone conclusion that one nation, armed with a small number of LO aircraft will necessarily prevail in a conflict with another nation that has a comparatively high number of non-LO aircraft.

LO measures are broken down into six categories:

- RCS reduction
- RF emission reduction
- IR reduction
- Acoustic reduction
- Visibility reduction
- LO tactics

a. Radar Cross Section Reduction

It is no coincidence that RCS reduction is often mistakenly thought of as the entirety of LO technology. It was the advent of radar during World War II that caused air defense operators, aviators, and aircraft manufacturers to first note that some aircraft were easier to detect while others were more challenging to observe on radar scopes. While radar-based LO technology did not take off in earnest until decades later, the first experimentation with LO aircraft design took place with Germany during the 1940's and the first significant studies into RCS reduction took place with Russia in the 1960's.

Radar cross section reduction focuses on reducing an aircraft's RF signature to active collection efforts (i.e., active radars). The RCS of an aircraft is mostly a product of:

- Aircraft geometry (shape)
- Aircraft material (especially the skin)

- Position of the radar antenna relative to the aircraft (i.e., aspect)
- Angular orientation of the target relative to the radar antenna (e.g., is the radar looking at the aircraft nose-on, from the bottom, from the top?)
- Radar frequency
- Radar antenna polarization

Table 3-4 depicts illustrative RCS figures for various targets. These figures are approximate unclassified figures of the front-aspect RCS of a “clean” (i.e., no external stores) airframe in the X-band (8-12 GHz). True RCS figures are classified and RCS varies significantly with respect to aspect. Table 3-4 is only for illustrative purposes.

Table 3-4

Target	**RCS (m^2)**
B-52 Stratofortress	100-125
C-130 Hercules	80
F/A-18C/D	1-3
F/A-18E/F	0.1
B-2 Spirit	< 0.1
F-117A Nighthawk	< 0.025
Bird	0.01
F-35 Lightning II	0.0015-0.005
F-22 Raptor	0.0001-0.0005
Insect	0.00001

A reduced RCS does not render aircraft invisible to radar, but complicates detection and, in most cases, significantly reduces the range at which a radar system can detect the aircraft. A notional radar system capable of detecting a 1 m^2 RCS target at 200 nm would be able to theoretically detect a 5 m^2 target at 299 nm. Meanwhile, a 0.1 m^2 target would be detected at 112 nm and a 0.001 m^2 target would be detected at 36 nm.

It is important to remember that most RCS reduction is only effective against certain radar bands. In practice, RCS reduction techniques most often target HF AI radars operating in the X and Ku bands.

There are four basic methods of RCS reduction:

- Shaping.

- Airframe materials
- Passive cancellation
- Active cancellation

(1) Shaping

Shaping or the geometry of an aircraft refers to the physical design of the airframe. Low observable shapes are not necessarily smaller but have geometry that deflects radar energy in directions other than the source. In principle, LO geometry seeks to minimize EM reflections back at the emitting radar by reducing reflective surfaces and maximizing deflection in irrelevant directions (i.e., away from radars). The most important geometric factor contributing to RCS is the edge configuration of an aircraft. Therefore, most RCS reduction is focused on reducing or manipulating edges throughout the airframe. Because of this, while LO features can be added to non-LO airframes, true radar-based LO must be designed into an aircraft from the beginning. Propellers and jet turbine engines reflect significant amounts of radar energy. Therefore, propellers are avoided and jet engines are hidden behind intake ducts, either behind an S-bend or covered with baffles.

Low observable airframes can also use radar-transparent skin in areas with what are known as re-entrant triangles underneath. Re-entrant triangles are also called concave polygons that have at least one internal angle that is greater than 180 degrees, like a polygon with a side pushed-in. This traps radar waves and prevents them from reflecting out of the airframe or drains energy as they reflect so that any returned energy is weaker and less detectable at a distance.

Low observable aircraft also usually angle the vertical stabilizers on the tail. The sharp corners and right angles of conventional tail design acts as a corner reflector which returns energy very efficiently. Another alternative is to eliminate the tail entirely, as in a "flying wing" airframe. The surfaces and edges that cannot be eliminated can be rounded to eliminate angles to reflect back at the emitting radar. Additionally, parallel alignment of surfaces or edges (i.e., designing the leading edge of the wing and tail at the same angle) deflects radar waves in a very specific direction, away from radars for most aspects, instead of returning a diffuse signal (part of which will return to the emitting radar). Parallel alignment gives rise to the characteristic serrations of landing gear doors and weapons bays in many LO airframes.

Internal stores hide the many angles of non-LO munitions, other equipment, and the pylons they attach to inside an LO airframe.

Mechanically scanned radars are usually traded for ESA radars (or no radar at all) as the antenna on a mechanically scanned radar itself is an ideal reflector (by design for emitted signals, but also incidentally for reflected signals).

(2) Airframe Materials

Selective use of the following materials can reduce the overall RCS of an aircraft:

- Non-metallic
- Radar absorbent
- Radar reflective

Using non-metallic material, such as certain dielectric composites that are transparent to radar, provides less material on the airframe to reflect radar waves. In some locations, this can be used to allow radar waves to entirely pass through parts of the airframe. In others, it can allow radar waves to get trapped inside re-entrant triangles beneath the skin.

Selectively applying radar-absorbent material to parts of the airframe, especially edges of metal surfaces or other high-RCS components that cannot be eliminated, can offer additional RCS reduction. The goal of radar-absorbent material is to absorb radar energy (i.e., convert it into heat) to weaken what energy is deflected or returned. Certain magnetic materials, glass-reinforced plastics, and carbon composite have radar absorbent characteristics and can be used in parts of airframe construction or cured into the skin of the aircraft. Additionally, “iron ball paint” contains microscopic balls of iron that resonate with RF energy that strikes it, dissipating much of the energy as heat (allowing very little to be reflected or deflected).

Counter-intuitively, selective application of radar reflective materials can reduce aircraft RCS. The two places this is seen most commonly is in the cockpit canopy and the radome. Radar waves normally enter the cockpit or the radome and reflect off the complex shapes and angles within, producing a significant radar return. Coating canopies with a thin transparent conductor (like vapor-deposited gold or indium tin oxide) causes the radar to reflect off the controlled shape of the canopy which contributes less to RCS than the interior of the cockpit would. Constructing radomes out of materials that are transparent to the on-board radar but are reflective to threat radars produces a similar result.

(3) Passive Cancellation

In principle, passive cancellation creates a target return that causes destructive interference with other elements of the target return. For example, creating reflective surfaces one-quarter wavelength behind other reflective surfaces, causing a second target return 180 degrees out of phase with the first target return.

In practice, this is extremely difficult to apply to airframes and generally not considered a viable technique for RCS reduction of aircraft.

(4) Active Cancellation

Active cancellation includes any technique where an aircraft emits a signal intended to cause destructive interference with the target return. This is a form of jamming. When employed on LO aircraft, active cancellation is risky because if it is not done precisely and under the correct conditions, it can actually increase the radar signature of the aircraft, facilitating enemy targeting.

b. Radio Frequency Emission Reduction

Where RCS reduction sought to reduce the RF signature of an LO aircraft to active collection, RF emission reduction seeks to minimize the RF signature of an LO aircraft to passive collection. This is done through the reduction of:

- Radar emissions
- Data and voice communications

(1) Radar Emission Reduction

Radar emission reduction can be accomplished through the use of:

- Passive sensors and/or laser designators
- Low probability of intercept (LPI) radar

Passive sensors, such as EO or IR (including forward-looking IR sensors and IRSTS) can enable LO aircraft to search for and acquire their target (whether on the ground or in the air) and, in some cases, compute a fire solution and deliver ordnance, all without the use of radar. When combined with GPS- or laser-guided munitions, beyond visual range IR missiles, or radar illumination from a separate platform, this can significantly increase a LO aircraft’s survivability and lethality.

When passive sensors cannot be used, LPI radars provide LO aircraft with similar capabilities to conventional radars while still reducing overall radar emissions.

Low probability of detection refers to emissions designed to prevent a threat from detecting a signal at all, usually through low-power emissions.

Low probability of exploitation refers to emissions designed to prevent a threat from decoding, spoofing, or position monitoring, usually through encryption.

Low probability of intercept refers to emissions which have a low probability of both detection and exploitation.

Low probability of intercept radars are designed to prevent detection from RWR equipment by using pulse compression, frequency hopping, FM continuous wave transmission, minimum power, highly-directional beams, and significant side lobe reduction/shielding. Electronically scanned array radars better control side lobes and their fast-moving beams allow for search patterns that complicate detection by RWR equipment.

(2) Data and Voice Communication Reduction

By applying the similar LPI techniques to data and voice communication emissions, LO aircraft can reduce the power of the emissions. This may reduce the range at which these LPI communications are available.

Additionally, higher-power communications (such as non-LPI data links) can be received by LO aircraft who do not transmit, allowing LO aircraft to receive an air picture from systems such as an Airborne Warning and Control System (AWACS) without increasing their own RF emissions.

c. Infrared Reduction

Infrared signature reduction most often focuses on the reduction of the exhaust plume signature (hot air expelled from the engine). This can significantly increase survivability of helicopters against MANPADS or reduce the ability of enemy IRSTS to detect some fighters.

This can be accomplished through non-circular exhaust outlets that maximize the mixing of hot exhaust with cool ambient air. Other techniques include internally mixing cool ambient air with exhaust before expelling it, circulating coolant near the exhaust to cool the plume, or venting the exhaust over a wing surface to shield it from ground observers.

d. Acoustic Reduction

Acoustic reduction is much more difficult to achieve with aircraft. The limited reduction possible with current technologies and the fact that acoustic detection is much less of a threat than detection through other techniques means that acoustic reduction may not even be attempted for many LO aircraft until the distant future. In most cases today, acoustic signature reduction is limited to mission planning efforts to model the acoustic signature of an aircraft or simply gaining standoff (horizontal and altitude) from observers.

The even spacing of helicopter rotor blades produces greater noise in a given frequency because of the harmonics of the rotors, creating constructive interference in certain frequencies.

Therefore, LO helicopter designs may incorporate uneven or staggered spacing.

Other design techniques may include the partial isolation of mechanical noises (for example, by rubber mounting of mechanical parts to absorb noise or special sound-absorptive coating of parts of the skin) to prevent vibrations from being spread across an entire airframe.

e. Visibility Reduction

Visibility reduction includes efforts to mask LO aircraft themselves or their observable effects. LO aircraft may use dark and disruptive paint schemes or predominantly operate at night. Matte paint can be used as it serves as a diffuse reflector, limiting the risk of observation by sun glint or glare. And finally, contrail mitigation can reduce the contrails produced by an LO aircraft, notify the pilots of contrail so that they can change altitudes, or simply be factored into mission planning so as to fly under conditions or in a flight profile that minimizes or eliminates contrails. (Contrails are produced by water vapor from engine exhaust that freezes in the cold ambient temperatures at high altitudes and creates long, linear clouds that can make an aircraft easily detectable.)

f. Low Observable Tactics

The final LO measure is LO tactics. For LO aircraft with significant RCS reduction at certain aspects, flight paths can be planned that present enemy radars with the lowest RCS possible. Aircraft can also exercise detection avoidance tactics, flying outside the detection range of enemy systems (whether beyond the system limits or in terrain-masked regions at low altitudes). Or, when forced near or within the detection or engagement zone of an enemy system, mission planners may select a flight path which maximizes exploitation of the Doppler notch. And finally, aircraft can use other systems, outside of enemy engagement ranges, to illuminate targets so that aircraft within those engagement ranges can successfully target the enemy with minimal exposure to themselves.

g. Mitigation of Low Observable Technology

Even with the most advanced implementations of LO possible today and in the near future, there are a number of measures that can be taken to mitigate the advantages these provide.

Advanced IR sensors, such as IRSTS, provide some ability to detect and engage LO aircraft. Over-the-horizon radars that bounce HF signals off of the ionosphere can take advantage of the fact that today’s LO designs must be engineered to mitigate in certain aspects and angles. As the predominant threat to LO aircraft remains to be nose-on from the same or lower altitudes, many LO aircraft utilize geometry that has a higher RCS from low-frequency radar bands arriving at the aircraft from above (as is the case with sky-wave OTH radars).

Rapidly advancing computing power is being paired with legacy lower frequency early warning radars and being integrated into new lower frequency designs, too. This allows these systems to more effectively detect, and in some cases target, aircraft designed to be LO in the X and Ku bands. Furthermore, some of these systems are not detected by RWR equipment, denying the victim the ability to respond with tactics, weapons (i.e., antiradiation missiles), or electronic countermeasures (ECM).

Advancing computing power is also making information fusion (including plot fusion for radar sensors as well as the fusion of information from other types of sensors) increasingly within reach of potentially hostile countries. This will work to increase the ability of the enemy to exploit the marginal returns from LO aircraft and reduce the survivability that LO techniques offer today.

Lastly, many radar-based LO techniques are designed to defeat monostatic radars (with collocated transmitters and receivers). Bistatic, multistatic, and passive coherent radars reduce the advantage that today’s LO technologies offer.

CHAPTER 4. Multi-Discipline Support to Air Intelligence

4001. Signals Intelligence

The Marine Corps uses the EMS to command and control operating forces, acquire targets, guide weapons, and direct supporting arms. The EMS is also used to collect, process, and report intelligence, and to support other administrative and logistics operations. Most facets of aviation operations involve the use of some device or system that radiates or receives EM energy via air waves, metallic cable, or fiber optics. Radios, radars, sensors, smart munitions, telephone systems, and computer networks use EM radiation. All levels of aviation depend on these systems and their inherent use of the EMS.

Signals intelligence is “a category of intelligence comprising either individually or in combination all communications intelligence (COMINT), ELINT, and foreign instrumentation signals intelligence, however transmitted” (JP 2-0, *Joint Intelligence*). Signals intelligence is intelligence gained by exploiting an adversary’s use of the EMS with the aim of gaining undetected firsthand intelligence on the adversary’s intentions, dispositions, capabilities, and limitations.

a. Communications Intelligence

Communications intelligence is “technical information and intelligence derived from foreign communications by other than the intended recipients” (JP 2-0).

b. Electronic Intelligence

Electronic intelligence is “technical and geolocation intelligence derived from foreign non-communications EM radiation emanating from other than nuclear detonations or radioactive sources” (JP 2-0). Electronic Intelligence consists of two subcategories; operational electronic Intelligence (OPELINT) and technical electronic intelligence (TECHELINT).

c. Foreign Instrumentation Signals Intelligence

Foreign instrumentation signals intelligence is “a subcategory of SIGINT consisting of technical information and the intelligence derived from the intercept of foreign EM emissions associated with the testing and operational deployment of non-US aerospace, surface, and subsurface systems.” (JP 2-0). Foreign instrumentation signals intelligence is primarily strategic in nature and is not addressed in this manual.

d. Concept of Employment for Aviation

Signals intelligence can be used to support numerous aviation operations. Enemy forces that use the EMS for communications or other systems can be exploited by numerous assets and entities.

These can be tactical or strategic in nature, but typically have various means to find, fix, and finish adversary forces. Signals intelligence is just one discipline for intelligence exploitation.

e. Commander's Signals Intelligence Requirements

Aviation Combat Element Commanders and intelligence staff should formulate and disseminate intelligence requirements for aviation support for integration into MAGTF collections management.

Signals intelligence requirements from the ACE should be validated and consolidated in order to coordinate with the radio battalion to determine where national resources may be applied to aid in answering MAGTF requirements. The radio battalion is typically in general support of the Marine Expeditionary Force and is the Marine Corps unit with the most direct access and requisite expertise to facilitate leveraging national SIGINT capabilities. Intelligence requirements from the ACE may already have parallels that have been prioritized under the National Intelligence Priorities Framework and that are part of a national collection management strategy. Where possible, the radio battalion may be able to aid in applying external resources to ACE requirements through coordination with the National Security Agency Representative at the geographic combatant commander GCC, the Marine Cryptologic Office, and with the Marine cryptologic support elements.

f. Radio Battalion Support

Radio battalions are the Marine Corps' organic SIGINT/EW support agencies, with their primary mission to provide tactical support to the MAGTF commander. This support is vital in ensuring that Marine aviation has the most current and relevant support needed for a squadron's specific mission. As a gateway to the national SIGINT architecture, radio battalion is uniquely positioned to work with units to properly request and leverage national- and theater-level SIGINT support for various echelons within the ACE. Air intelligence Marines can leverage Radio Battalion support through ACE SI/EW Marines, when present, or through higher headquarters intelligence sections.

g. Detachment Support

The radio battalion can provide survey, collection, processing, exploitation, production, and dissemination support to the ACE in support of the functions of Marine aviation. Proper mission analysis will determine the capabilities of the detachment fielded to support the ACE, but at a minimum is likely to include analysis and reporting through approved IC dissemination

As an example, the radio battalion may be relied upon to aid in EW planning with pre-mission intelligence support as well as the post-mission evaluation of ES information.

h. Training Support

Marine aviation units conducting routine or special training in garrison should actively seek to incorporate radio battalion personnel when practicable. Integrating SIGINT during training evolutions will build the unit cohesiveness needed for when Radio Battalion detachments support aviation deployments. This integration will also build the squadron's awareness of the specific authorities that radio battalion operates within as part of the US SIGINT System.

i. National-Level Signals Intelligence Support

Requests for national SIGINT support should be directed to the Radio Battalion detachment, the Radio Battalion, or the ACE SI/EW Officer. If none of these are available, the Marine Cryptologic Office can assist ACE units seeking coordination with the National Security Agency. Unit intelligence requirements that are not directly represented by Intelligence Needs articulated through the National Intelligence Priorities Framework and then into the National SIGINT Requirements Process are unlikely to be apportioned to a national mission. Direct coordination with the Radio Battalion is the most likely method of gaining access to external SIGINT resources to answer local requirements.

j. Signals Intelligence Support to Mission Planning

Signals intelligence support to aviation mission planning is achieved through the use of COMINT and ELINT information. Communications intelligence information can help to determine enemy force composition, disposition, and location if unknown. Electronic intelligence can give insight to threat emitters in the battlespace or near proposed friendly force ingress and egress routes. Effective SIGINT integration with IPB can help to identify likely threat and neutral emitters as well as ranges at which they are likely to be able to communicate and operate in the battlespace. This can contribute to a thorough understanding of the means of communication for threats in the battlespace as well as mission support to orient friendly EW missions.

4002. Geospatial Intelligence

Geospatial intelligence is "the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. Geospatial intelligence consists of imagery, imagery intelligence [IMINT], and geospatial information" (JP 2-0). There are several disciplines, with the primary military occupational specialty-trained disciplines in the Marine Corps focused on topographic intelligence and IMINT.

a. Imagery Intelligence

Imagery intelligence is "the technical, geographic, and intelligence information derived through the interpretation or analysis of imagery and collateral materials" (JP 2-0). Imagery intelligence is the visual representation of intelligence products. This capability can be found at many levels of Marine aviation in both direct and general support of a unit or operation. Within most imagery sections, the two subsets are production and collections. Production is the main function of the Marine Corps IMINT structure within aviation. Besides producing finished imagery, this is also where most of the RFIs are handled. Collections plays a smaller role because the Marine Corps owns very few IMINT collection assets, and the ACE often does not own battlespace. For these reasons, collections within Marine aviation often exists primarily as a liaison to MEF and the joint force air component commander (JFACC) as an advocate for ACE collection requirements.

(1) Marine Corps Organization

Every unit within the MAW is staffed according to its assigned METs. At the MAW there are a small number of trained IMINT Analysts that are directed to support IMINT collection needs and products requested by subordinate units. Marine Aircraft Groups are largely staffed with Intelligence Specialists (MOS 0231) whose focus is primarily all-source analysis with less of a focus on technical skills. Imagery Analysis Specialist (MOS 0241) and capabilities are usually not present within a MAG as they are pushed to specific squadrons for support to the squadron's organic collection assets and production requirements.

The only units in Marine aviation normally staffed with an organic IMINT collection capability are F-35 B/C and UAS squadrons. From the squadron level, IMINT Analysts are able to support the EW, OAS, and AAW functions of Marine aviation with imagery products including target folders, GRGs, kneeboard route planning, battlespace assessments, and BDA.

(2) Systems and Assets

There are numerous systems at different classifications necessary for the collection, processing, and exploitation phases of the intelligence cycle.

Despite its accessibility and overall versatility, commercial imagery from commercially-available programs has limitations that can affect the quality of support provided, most notably the clarity of their images as measured by the National Imagery Interpretability Rating Scale. National Technical Means is available when the intelligence section determines the need for greater image resolution. Details on National Technical Means and its capability reside at higher levels of classification.

Especially notable, commercially-available imagery or imagery analysis conducted by untrained personnel can result in significant safety-of-flight hazards and have resulted in mishaps in the past.

Organic assets are useful to satisfy high priority needs without the use of outside entities such as the National Reconnaissance Office or MEF. The intelligence section will provide a collection plan and then the sortie will satisfy the mission and provide the collected information back to the intelligence section for exploitation and dissemination. Overall the process can take hours instead of days.

b. Topographic Intelligence

Topographic intelligence surveys, plots, and exploits raw geospatial data. Topographic intelligence augments imagery capabilities with a more accurate understanding of the terrain depicted. Topographic support can also stand alone, for example, providing data on soil composition as well as three-dimensional terrain surveys. Topographic Marines usually reside an Intelligence Battalion or other ground unit, but can be requested for aviation support.

(1) Topographic Products

The GRG is an overhead image of the tactical battlespace. On this image, the analyst generates a sectioning and sub sectioning of the roads, buildings, or other identifiable objects. This is overlaid with the Military Grid Reference System that allows rapid communication between air and ground assets concerning locations, movements, fires, etc.

Another common product is an elevation study. This is a colorized rendering of the elevation from highest to lowest. The product is typically used as a collision-avoidance planning measure; however, it can be applied to other products such as terrain masking graphics.

Slope studies may also be produced from the same data utilized for elevation studies. This product is useful for determining the suitability of LZs. This product is a graphic representation of the change in elevation of the bare earth and at what rate that change occurs (shown in degrees or percent).

A soil composition study greatly increases the clarity of the picture created for the aviation planner used to assist in landing an aircraft safely. The soil information can inform payload or lift planning factors or the likelihood of brownouts.

Until recently, these products have only been available to a pilot in the cockpit via handheld prints on knee boards. Innovations in information management have begun putting the data displayed on these products into the pilot’s navigational display and handheld tablets.

4003. Human Intelligence and Counterintelligence

a. Human Intelligence

Human intelligence (HUMINT) is the collection of information by a trained HUMINT collector, from people and their associated documents and media sources to identify elements, intentions, composition, strength, dispositions, tactics, equipment, personnel, and capabilities. It uses human sources as a tool and a variety of collection methods, both passively and actively, to gather information to satisfy the commander’s intelligence requirements and cross-cue other intelligence disciplines.

Human intelligence tasks include but are not limited to—

- Conducting source operations.
- Liaising with host officials and allied counterparts.
- Eliciting information from select sources.
- Debriefing US and allied forces and civilian personnel including refugees, displaced persons, third-country nationals, and local inhabitants.
- Interrogating EPWs and other detainees.
- Initially exploiting documents, media, and materiel.

b. Counterintelligence

Counterintelligence (CI) plays a significant role in supporting the force protection of the MAGTF and it’s ACE. It includes active and passive measures intended to deny the enemy valuable information about the friendly situation; activities related to countering hostile espionage, subversion, and terrorism; and directly supports force protection operations by helping the commander deny intelligence to the enemy and plan appropriate security measures. Like other intelligence disciplines, CI/HUMINT takes place across all three levels of war (strategic, operational, and tactical) as well as during peacetime. Human intelligence and CI operations include military operations by all the services in areas they are deployed to as well as non-military operations by other elements of the IC in areas of the globe where there may be no US military presence. Human intelligence and CI elements, whether adjacent or external, can provide a range of intelligence information pertinent to the ACE, including landing zone studies, enemy TTPs from source operations or interrogations, and information regarding foreign capabilities through the debriefing of human sources.

Aircraft are technologically sophisticated, expensive, and difficult to replace. The ACE often operates from relatively static positions that may be widely dispersed (i.e., separate airfields), have large signatures, and are in close proximity or supported by indigenous personnel. This garrison activity includes activities such as air show participation. This makes the ACE a lucrative target for foreign intelligence entities, saboteurs, or enemy attack. These factors make CI support critical for the ACE in order to identify and counteract these threats. For these reasons, the ACE may have CI/HUMINT teams attached or placed in a supporting role to enhance force protection.

c. Counterintelligence/Human Intelligence Terms

A number of CI/HUMINT terms are useful for air intelligence Marines to understand in order to maximize the CI/HUMINT support to air intelligence and, consequently, aviation operations.

A notice of intelligence potential (NIP) is used to inform the US IC of the availability of an information source of potential intelligence value, as well as to notify the IC of what agency has responsibility for that source and how to forward questions and RFIs to that agency. Notices of intelligence potential serve to inform the air intelligence Marine of new sources or opportunities that may potentially answer ACE intelligence requirements. Air intelligence Marines should work with their local CI/HUMINT element to reply to any NIPs of interest with a Source-Directed Requirement (SDR), providing any intelligence requirements and necessary air intelligence context that the source may require to fully answer the requirements.

An SDR is an intelligence requirement directed towards a specific approved source based on that source’s potential to provide information of intelligence value. A SDR helps to both focus a CI/HUMINT element’s collection as well as increase the likelihood that the questions within an SDR will be answered. Although an SDR is directed toward a specific source, any collection element can respond to that SDR if that element has access to pertinent information.

The CI and HUMINT Requirements Reporting and Operations Management Environment system provide a centralized tasking and reporting of DOD HUMINT resources worldwide, allowing for receipt of NIPs and submission of SDRs. Through this system and/or MAGTF HUMINT Marines, air intelligence Marines can maintain awareness of HUMINT intelligence reports, NIPs, and SDRs, as well as existing HUMINT collection requirements.

Air intelligence Marines should also be aware of the Foreign Military Intelligence Collection Activities, or FORMICA, program and the many opportunities and situations that they will have to participate in and benefit from it. The Foreign Military Intelligence Collection Activities program is the overt debriefing, by trained and certified DOD HUMINT collectors, of all DOD personnel who have access to information of potential foreign intelligence value. Select participation of ACE Marines, especially aviators and aircrew (including during garrison operations, official travel aboard, exercises, and deployed operations), can contribute significantly to current MAGTF intelligence requirements, IC requirements, and even answer intelligence requirements for future MAGTFs that may rely on that intelligence, especially as it pertains to tactics and training analysis.

Counterintelligence can also assist in development of evasion plans of action or, identification of areas of least threat that facilitate escape and evasion.

See Field Manual 2-22.3, *Human Intelligence Collector Operations*, and MCRP 2-10A.2, *Counterintelligence/Human Intelligence*, for more information about CI/HUMINT.

4004. Technical Intelligence and Foreign Material Exploitation

Technical intelligence and foreign material exploitation is intelligence derived from the collection processing and exploitation of data and information pertaining to foreign materials and equipment, assessing foreign scientific and technical capabilities for the purpose of preventing technological surprise, and developing countermeasures to neutralize an adversary's technological advantages. The technical intelligence mission ensures that the warfighter has a clear understanding of the full technological capabilities residing in the enemy's equipment. With this knowledge, the aviation planner adopts countermeasures, operations, and tactics, as necessary, to be successful in any assigned mission.

At an operational and tactical level, technology is changing how we organize, train, and develop leaders, and conduct operations. Advances in electronics, communications, automation, reconnaissance and surveillance, contamination avoidance, PGMs, and the exploitation of space-based capabilities have increased the lethality, range, accuracy, and reliability of our weaponry. Operational and tactical commanders rely on this technological advantage to successfully synchronize and execute complex modern Marine Corps operations. Technical intelligence and foreign material exploitation is the key to the early identification of an adversary's technical capabilities and the development of countermeasures for the operational and tactical commander.

CHAPTER 5. Threat to Aviation Operations

5001. Integrated Air Defense Systems

An IADS is a group of sensor systems, weapon systems, command, control, communications, computers, and intelligence (C4I) systems, and the humans that operate them with the collective mission of protecting a defined area, target, or group of targets from airborne intrusion or attack. As a result, an IADS is a system of systems.

An IADS can be strategic or tactical. Their specific role and type of asset being protected determines the category.

Strategic IADS are designed to protect fixed airspace, such as areas overlying borders, commercial and industrial areas, high-value assets (e.g., nuclear facilities), population centers, or fixed military facilities. These air defense systems generally use fixed or mobile assets from peacetime garrisons and centralized control as the primary means of operation.

Tactical IADS are designed to provide point defense as well as protect ground force maneuver formations such as troops, tank formations, and rear echelon elements. In some countries, weapons and sensors designed for tactical air defense are often deployed as fixed elements of strategic air defense systems. For example, a mobile tactical SAM system deployed to augment low altitude defense while protecting a command center or an airfield and its facilities.

For every threat within an IADS, the air intelligence analyst is fundamentally concerned with it’s: mission, observability (by friendly forces or collection measures), maneuverability (both throughout the battlespace and during engagement), and vulnerability (to countermeasures or weapon systems).

An IADS is the organized and regular combination of procedures and resources dedicated to defend specified airspace and priority assets against attacks by enemy aircraft and ordnance. The system coordinates the employment of doctrine, tactics, procedures, equipment, and C3 networks that interact to detect, identify, track, assign, engage, assess, destroy, nullify, or reduce the effectiveness of attacking aircraft or ordnance.

This includes the use of land-, sea-, and air-based resources of national or non-state entities dedicated to defending specified airspace and prioritized assets against intrusion or attacks by enemy aircraft and missiles. An IADS has the ability to defensively counter airborne threats through the use of diverse sensors, weapons, and countermeasures. The effectiveness and reach of an IADS, whether strategic or tactical, is dependent on the efficient interaction of the system’s sensors, weapons, countermeasures, and C3 equipment. This integration supports the air defense system's objective of repulsing, or engaging and destroying, enemy air threats at the greatest range possible from defended airspace or entities, and retaining the ability to re-engage the target if initial engagement is unsuccessful.

An IADS is a single entity; a system of systems, with a unified command structure and purpose. Integration of assets into the IADS helps avoid missing targets, redundant engagement, and fratricide, enabling the most practical and timely allocation of weapons to threats, and, ultimately, making the composite effect far greater than the sum of the individual weapons' effects. An enemy IADS increases situational awareness.

In short, the mission of an IADS is to engage and destroy targets at the earliest possible time, with the most capable system, while retaining the ability to engage subsequent threats.

a. Integrated Air Defense System Components and Functions

An IADS is comprised of three major components:

- Sensors
- Weapon systems
- C4I entities

When these entities are combined with human operators and decision makers, they fulfill the three basic functions of an IADS—

- Air Surveillance
- Battle Management
- Weapons Control

An IADS is designed to perform these three functions in order to repel enemy intrusions into their airspace. By performing these three functions, an IADS creates a kill chain (the flow of events that must occur to successfully engage a threat).

The three functions are synergistic, but the critical process is engagement. It certainly becomes more difficult to engage if the air surveillance and battle management functions are performed poorly or are degraded through attack. That said, the air surveillance and battle management functions can be executed flawlessly, but if the IADS cannot effectively engage enemy aircraft, the successful execution of the other two functions is meaningless. The mission, and therefore, the final measure of success for any air defense system, is its ability to engage threats.

Kill chains differ for individual weapon systems and across different IADS. The generic IADS kill chain is depicted in table 5-1.

Table 5-1. The Integrated Air Defense System Killchain

Basic Function	Kill chain Step	Description
Air Surveillance	I&W	Many functions within the IADS kill chain are enabled by I&W of an impending attack (i.e., the activation of ASV sites, raising of alert status, and forward deployment of forces)
	Detect	Detection is the first requirement of an IADS. Detection may be performed by EW radar, passive detection systems, weapon systems, or visual sighting. Detected threats generate radar plots. Several plots become a track. Track data then gets entered into the C2 structure in one of two ways: the operator can manually extract the radar data and pass it up-channel, or the radar may have special hardware/software to automatically extract the data.
Battle Management	Identify	Once a target is detected, the detecting system will attempt to identify it as friendly or hostile, establish track data, and pass it to the filter center and to a senior AD command center.
	Track	Track correlation and track maintenance takes place primarily at the filter center. The filter center receives target data from many sources and assigns a correlated track identification. Correlated tracks are the results of human and computer interaction to resolve duplicate tracks from different sensors, false tracks, and friendly versus hostile and other ambiguities. The correlated track data are passed to the weapons unit CPs and up echelon.
	Assign	Battle management begins with an analysis of the overall air picture and includes threat evaluation, deciding whether to engage a target, authorizing engagement, and selecting weapons types. Each target or track is analyzed and a weapons system is assigned against the target based on the priority/type of target, the availability and condition of a specific weapon system, or on predetermined rules of engagement (ROE). After this has been accomplished, the track data and engagement authorization is passed to the weapons control unit for prosecution.

Weapons Control	Engage	After receiving a target assignment from a higher echelon, the weapons control unit must pair specific threats with specific weapons and execute the engagement.
	Assess	Each weapon system reports its status and engagement results to the weapons control unit so the commander can direct the engagement of additional threats or re-engage the original threat if the engagement was unsuccessful.

In analyzing the effectiveness of an IADS, it is important to remember that these are largely independent steps, each with separate degrees of effectiveness, and each of which relies on the previous step to be completed successfully and thus relies on the degree of effectiveness of the previous step. Thus, the kill chain can be viewed as a sequence of independent variables and the overall effectiveness of an IADS can be conceived of as the combination of these variable.

The consequence of this is that the effectiveness of an IADS is, conceptually, the effectiveness of each step in the kill chain, multiplied by the effectiveness of the others.

Thus, if a kill chain is seven steps and each step is 80% effective, the overall effectiveness of the IADS (which can also be conceived of as probability of kill, or P_k) is 21%. If the chance of success for each step is 90%, the total P_k is still only 48%.

Similarly, if a kill chain is highly effective (99% at six out of seven steps) but one step has only a 25% effectiveness rate, the overall success rate will be mathematically bounded by the most ineffective step. In this case, overall P_k would only be 23.5%.

Thus, it becomes easy for an analyst to overestimate the effectiveness of an IADS without factoring in its sequential nature.

The analysts must also keep in mind that IADS effectiveness is time based. The likelihood of success at any stage of the kill chain rises the longer threat aircraft are present in the detection or engagement zones.

For example, imagine an IADS that only has a 10% overall effectiveness rate at completing a successful intercept within two minutes. A threat aircraft exposed to the IADS for only two minutes will have a 90% chance of surviving (i.e., not being successfully engaged). In that same IADS, if that aircraft is exposed for 20 minutes, it will only have a 35% chance of survival (i.e., 65% chance of being successfully engaged). At 30 minutes of exposure, the chance of surviving that IADS drops to 21%. At 40 minutes, only 12%.

It is important to note that it is impossible to know the precise effectiveness of an IADS (the numerous and constantly changing variables, including human factors, make knowing a precise effectiveness rate impossible). Therefore, it is the overall relationship between independent steps of an IADS kill chain that the analyst must understand and account for, not any specific mathematical figures or equation.

5002. Air Surveillance

There are five basic elements of the Air Surveillance (ASV) function of an IADS:

- Detection
- Track initiation
- Track identification
- Track correlation
- Track maintenance

These five elements occur during different levels of ASV processing: primary, secondary, or tertiary. Because each IADS is unique, it is important to note that these five ASV functions may not always be a linear process. Integrated air defense echelons often have different names in each enemy nation that depend on the air defense system's design, a country's doctrine, or its defense strategy.

a. Processing

(1) Primary Processing (Detect)

The first requirement of the IADS is to detect targets. It does this first by searching a volume of airspace for potential targets. Detection occurs when a sensor system senses a potential target, and tends to be associated with a single sensor event. This creates a radar plot, a target return within a single radar resolution cell, usually after clutter has been removed. It represents a single radar observation from a single target return. Multiple plots must be made to generate a radar track. If this does not occur, the system may discard the plot as an anomaly or clutter or, if the plot is identified as a target, the system may only have low-fidelity information on bearing, range, azimuth, airspeed, and elevation.

Sensor systems responsible for detection are broadly divided into two categories: active or passive sensors. If detection results in a two-dimensional or three-dimensional target plot (i.e., some combination of target location, elevation, heading, range, or velocity) in a digital format, then plot extraction occurs and the IADS has started its first step towards a useful ASV picture.

(2) Secondary Processing (Track Initiation and Identification)

Detected targets generate radar plots. Multiple plots are correlated to ensure they belong to a single target. When a potential target is detected over several scans or several looks at a certain area, referred to as *acquisition*, a target track may be initiated.

A *target track* is the continuous determination of specific target state information. A two-dimensional radar system determines and tracks a target in azimuth and range. A three-dimensional radar system determines and tracks targets in azimuth, range, and elevation. Systems can also determine velocity or range rate (therefore, some systems provide a "four-dimensional" track).

Air surveillance systems are typically classified as manual, semi-automated, or automated based on the level of human participation that is required. An example of a manual system is one in which the operator marks the precision position indicator, or PPI, scope each time the radar illuminated the target. In a semi-automated system, the operator marks the display using a pointing mechanism, such as a track ball, to update target information that is then processed by the computer. An automated system performs functions in a similar fashion as semi-automated ones, although in theory, all functions are performed exclusively by the system computer. Track initiation is typically based on mathematical rules, the most common being "M out of N," meaning M detects out of N detection opportunities qualifies for track initiation.

Then that plot information becomes a track. Track initiation is normally performed at a low-level filter center, either a reporting post or at the radar site itself. The reporting post will assign a track number and report that information to the IADS either manually, through an operator who can manually extract the radar data and pass it up, or automatically, by a radar that may have special hardware or software to automatically extract the data.

A number of sensors and systems at various echelons within an IADS are capable of track identification, which is typically performed at the collection and reporting center, or at the echelon just above the reporting post in an IADS. However, individual sensors may also have the ability to determine if a track is hostile, friendly, neutral, or unknown. Upper echelons in the IADS may be able to integrate additional information into the identification process, especially information obtained through intelligence channels that may not be widely disseminated.

Once a target is detected and tracked, it must be identified. Identification is the determination of target track intent: friendly, neutral, or hostile. This is done using identification, friend or foe (IFF) or non-cooperative target recognition systems, as well as more operator-based criteria such as visual identification and track origination (where the track came from). Rules of engagement determine the types of identification methods used and the level of criteria required to engage a target track.

When analyzing this aspect of an enemy IADS, consider the enemy's tactics. Some enemy countries may not require that a track be identified before it is engaged. The ROE may permit any unidentified air contact to be judged hostile and engaged on that basis or may simply permit the engagement of any air contact in a given volume of airspace, without any regard to its identify. Therefore, while this step is part of the normal process, an enemy IADS may, or may not, incorporate it during wartime operations.

(3) Tertiary Processing (Track Correlation and Maintenance)

Tertiary Processing consists of track correlation that obtains multiple tracks to produce fused tracks and eliminate duplicates. Any IADS with more than one sensor requires this level of processing to develop an accurate and common tactical or operational picture. This function normally occurs at a collection and reporting center; however, an IADS that covers large geographic areas may correlate tracks at higher levels (receiving inputs from multiple collection and reporting centers). This process increases the efficiency of weapons assignment against hostile tracks. Track maintenance occurs manually, semi-automatically, or automatically, depending on the IADS's equipment. Track maintenance can occur from the sensor level up to the collection and reporting centers or sector operations center. Plot correlation, although rare, is also a form of tertiary processing.

(4) Plot Correlation

Multi-sensor integration is the fusion of data from multiple sensors across a battlespace or sector of a battlespace. The simplest form of this is achieved by fusing radar sensors together, but the concept is applicable to the fusion of EO, IR, and other sensors with radar systems. This integration builds a shared awareness of the airspace, enabling decision makers to accurately observe the airspace and make crucial air defense decisions.

Multi-sensor integration also aids in the detection of marginal targets, such as when the target is LO, terrain masked from certain sensors, exploiting propagation effects of sensors, or otherwise difficult for a single sensor to detect and track. This can be especially useful when fusing sensors operating in multiple radar bands, allowing systems of various capabilities and limitations to complement each other and reduce the overall shortcomings of an IADS.

Multi-sensor integration is not a silver bullet, however. It is highly dependent on C2 system capabilities such as available bandwidth and processing power, communications systems between sensors across the battlespace, and the training of the system operators.

Track correlation can be done either through multi-sensor track fusion or multi-sensor plot fusion. This occurs when a collection and reporting center has access to unfiltered plot data from subordinate, geographically separated sensors (as well as track data from subordinate RPS), and, is able to process that data to produce system tracks.

Plot fusion takes this data, which has undergone some processing, from multiple sensors, and fuses plots to generate a radar track, including where no one sensor was able to generate a radar track on its own. This can be especially useful in identifying LO targets because LO aircraft are generally engineered to have the smallest RCS in a specific aspect and radar systems from other locations may be able to detect a higher-RCS aspect of the target. Additionally, a LO target may only generate one or two plots at a time for a single system, falling short of meeting the threshold to generate a track. With plot fusion, a few marginal plots across a battlespace can be fused to generate a track with sufficient fidelity to detect, target, and/or intercept the LO aircraft. Essentially, the collection and reporting center can combine individual radar plots from multiple sensors (provided it has the computing power to do so). Plot fusion's two most significant advantages are (1) rapid track initiation and (2) the ability to track targets with low or intermittent RCS. Because plot fusion is more complex and system-intensive than track correlation, there are very few current IADS that use this method; most use the track correlation method mentioned previously.

b. Sensors

The sensors that carry out the detect function include active and passive ASV systems that detect and establish target tracks and, in some cases, identify targets.

(1) Active sensors

Active IADS sensors are the IADS's emitting radars, with varied levels of sophistication spanning multiple frequency ranges. They provide range, azimuth, and/or elevation/height information. There are several types of active sensors:

- Early warning radars
- OTH radars
- Acquisition radars
- GCI radars
- Air-controlled intercept radars
- Bistatic, multistatic, and PCR systems
- Aerostats
- UASs

Early warning or ASV radars are optimized for long-range detection of medium- and high-altitude aircraft. However, an increasing number of systems are capable of low-altitude and LO target detection. These radars are designed to start the IADS kill chain. These radars have limited accuracy but are balanced by good long-range detection capability. Height finder radars provide IADS target elevation data and are often deployed with two-dimensional ASV radars. Dedicated height finder radars are mechanically scanned in azimuth and elevation. Some three- dimensional ASV radars use multiple beams or electronic elevation scans to derive target elevation, eliminating the need for separate height finder radars.

Over-the-horizon radars are a special category of early warning radars. Sky-wave OTH radars are designed for detection and tracking of aircraft and cruise missile flying at any sub-ionospheric altitude from ranges of several hundred nautical miles to a few thousand nautical miles, based on the reflection and refraction of HF signals from and in the ionosphere. Surface-wave OTH systems take advantage of ducting and are often used in costal defense roles. Over-the-horizon waveforms occur as both pulsed and FM continuous waves. These systems use high-speed computers to adjust transmission frequencies according to the atmospheric conditions, process and declutter the returned signals, and display target speed, track, position, and altitude. The range of HF OTH radars can reach well over 500-1,600 nm.

Acquisition radars are designed to provide accurate cueing data for ADA/SAM TTRs that may have a narrow FOV. They must be able to handle fast, maneuvering aircraft at all altitudes.

Ground-controlled intercept and ATC radars provide long-range control for airborne fighters. They can provide early warning and typically have better resolution than ASV radars. Some have three-dimensional capability; however, most are two-dimensional and are paired with height finders. Some countries integrate their civilian ATC radars into their common tactical and operational pictures, while others have stand-alone ATC feeds into their air defense operations centers (ADOC), sector operation centers, or collection and reporting centers. Understanding how ATC data ties into an IADS is key when conducting analysis on how to degrade or deny an enemy’s air picture.

Air-controlled intercept radars are often packaged with airborne early warning (AEW) and control system assets, allowing these systems to provide early warning functions, alongside battle management and/or weapons control (typically to fighters). Airborne platforms with AEW radars extend the horizon of ground-based ASV radars. The detection of low-altitude targets at long ranges is the fundamental advantage of the airborne platform. Therefore, the AEW radar can be used to fill a gap in coverage. When the AEW radar is combined with the necessary computer capability and communication equipment to conduct air-controlled intercepts, it becomes an AEW and control system (similar to US AWACS). These platforms are expensive and not widely proliferated, however this capability may be accomplished through fighters.

Bistatic, multistatic, and PCR systems are technically active as they have active transmitters, which may include the use of cooperative civilian signals (whose transmission they control), or use non-cooperative civilian signals (whose transmission they do not control). However, because they include one or more passive receiver stations they may be considered passive for some purposes. For example, current means of countering active radars may have limited to no effect. Since transmitters and receivers are not collocated, locating receivers may prove difficult since they do not emit a signal. Additionally, when using multiple transmitters or PCR systems, the necessity of locating and disabling all transmitters and receivers further complicates targeting efforts.

Aerostats are lighter-than-air aircraft, filled with gases such as helium or hydrogen that are suspended in the air and tethered to the ground. Aerostats can enhance IADS by serving as a platform to carry persistent surveillance, identifying low-flying aircraft, and acting as communications relays.

Unmanned aircraft systems can be integrated into all three functions of an IADS by hosting sensors to aid detection, control, or engagement. Unmanned aircraft systems can increase or extend the IADS surveillance capabilities by performing broad-area land/sea surveillance and monitoring air activity. Their onboard systems can also increase available decision making time and improve intercept assessments, target identification, and conducting COMINT/ELINT collection. Unmanned aircraft systems assist weapons controllers by providing communications relay and GPS jamming as well as ordnance deployment.

(2) Passive Sensors

Passive IADS sensors are the IADS’s non-emitting sensors, with varied levels of sophistication spanning from an LP/observation post (OP) using the unaided eye to passive RF detection systems. They can provide range, azimuth, and/or elevation/height information. There are several types of passive sensors:

- LP/OPs
- Image intensifiers
- Acoustic sensors
- ELINT/ES systems
- Space-based systems

The simplest form of passive detection is the LP/OP. These observers (sometimes called visual observers, or VISOB) provide near real-time (NRT) reporting of optical and acoustic detection. Though the use of LP/OPs to detect incoming aircraft predates radar and is subject to human error, it is still a viable warning asset for many enemy countries, especially to fill gaps where traditional radar systems cannot provide coverage. Sophisticated strike tactics, and LO technologies that effectively counter radar detection can make LP/OPs the only reliable means of I&W or point defense cueing. Contact data reporting by LP/OPs include location, heading, altitude, airspeed, number, and type. The communications method from LP/OPs to the IADS varies greatly among countries, but can include landline, UHF/VHF radio, cell phones, or satellite phones. Accuracy and timeliness varies depending on the tactical situation. LP/OPs can be either stationary or mobile. Some only use hand-held binoculars (which can permit surveillance up to 6 nm away), while other use more sophisticated equipment. This equipment may include tripod-mounted binoculars with a ruggedized computer, NVDs, thermal imagers, UV sensors, and weapons.

Image intensifiers increase visual detection ranges in low light conditions. While these may be handheld devices used by LP/OPs, technology is trending towards the use of LWIR thermal imaging systems in scanning or staring arrays. They are not limited to low light conditions or nighttime use. Additionally, they can penetrate some battlefield obscurants and have longer range than image intensifiers. Increased sensitivity means increased detection range, possibly in excess of 15 nm. Multiple linked systems may be able to calculate range, and some systems are advertised to track more than 50 targets simultaneously.

Acoustic-based sensors systems passively detect, classify, and provide bearing on target aircraft under non-LOS conditions. Current capabilities are focused on rotary-wing detection, while modifications are required to detect jet and propeller-driven aircraft. Passive acoustic-based rotary-wind detection systems usually feature a cruciform array of microphones, signal-processing software, and a high-resolution display. They must be in a fixed position to operate. Acoustic-based sensors detect acoustic emissions in the 2-150 Hz range. The mechanical-coupling of the rotors gives each rotary-wing aircraft a unique acoustic signature. This enables classification of the aircraft by specialized systems.

Passive ELINT/ES detection systems can provide limited detection, tracking, and/or identification capability against cooperative (i.e., emitting) targets. At frequencies above HF, these systems must have a clear LOS to the emitter. Though beyond LOS detection of higher-frequency signals may occur, it requires specific and exceptional propagation phenomena. Even with these limitations, ELINT/ES systems can provide valuable I&W, radar cueing, and support other surveillance assets.

Finally, space-based detection systems can use the IR or RF emissions of an aircraft to detect it and provide approximate location data.

5003. Weapons Control

The Weapons Control function is a microcosm of the larger air surveillance and battle management. It includes the functions of:

- Acquire Track
- Track
- Engage/Guide Weapon
- Assess

The components that comprise the weapons control function are:

- Weapons control unit
- Weapons employment and integration
- Weapon/fire unit

a. Sub-Functions

(1) Acquire Track

As with ASV, individual weapon systems, whether ADA/SAMs or fighters, must search, detect, and acquire the target. The methods used for this span the spectrum from simple to complex. On the simple end, LP/OPs could scan the sky using binoculars or IR devices in order to provide voice point-outs to an ADA/SAM battery or MANPADS team. Radar ADA/SAMs and fighters tend to use their system’s inherent search radar or radar modes to acquire targets. Electro-optical systems such as TV optics or IR search devices can be used as well.

(2) Track

Unguided ADA units will visually track targets and then use mechanical devices to engage those targets. Radar or IR systems, having acquired the target, will transition to track. Track information for guided engagements must be more precise than the track information for ASV radars, as this information will be used to actually put weapons on target.

(3) Engage/Guide Weapon

Having met a number of critical criteria, including accurate and continuous target track, an intercept range within system parameters, and a valid fire control solution, the missile or projectile can be launched. Surface-to-air missile and AAM systems use a number of mechanisms to guide on targets. Maintaining accurate target track and missile guidance is critical for successful intercept. The final link in the kill chain is warhead detonation.

(4) Assess

Determining whether the target was sufficiently damaged or destroyed must be quickly and accurately completed after time of target intercept. Doing so allows the engagement loop to either be closed or restarted if the target was not successfully intercepted.

b. Components

The weapon system component of an IADS executes the engage function and includes: the weapons control unit and weapon/fire unit segments that complete the kill chain, and the way those weapons are employed and integrated.

The weapons control unit directly controls ADA/SAMs, fighters, or other weapon systems. In addition to subordinate weapon systems, the weapons control units typically communicate with supporting LP/OPs, radars and other sensors, collection and reporting centers, and other IADS elements supplying threat data. Examples of weapons control units include SAM brigade command posts (CP), jammer brigade CPs, GCI elements, etc.

The weapon/fire unit elements are the specific weapon systems. This includes individual SAM sites, ADA batteries, fighters, etc. The effects of the weapon system can be lethal (i.e., ordnance) or non-lethal (including EA, offensive cyberspace operations, or offensive space control effects)

Weapon employment and integration refers to the way in which weapons are arranged and employed across the battlespace. This can be done in three basic ways: area, barrier, and point defense. Each has its own objective and optimal weapons.

Area defenses defend large geographic areas using a classic SAM umbrella with long-range SAMs or fighters.

Barrier defenses defend national borders using SAM belts with medium-range SAMs or fighters. Point defense defends a specific high-priority target using short-range SAMs, fighters, or ADA.

5004. Air Defense Artillery

ADA systems are designed to engage aircraft with gun-launched projectiles.

Commonly, these projectiles are unguided and do not propel themselves, and are most accurate and effective at relatively short ranges. This makes them most suitable to terminal air defense missions.

ADA was the first weapon system specifically designed to defend against air threats and has historically been the deadliest. Some sources credit 60-90% of US combat losses during Vietnam to ADA. Other sources peg the number even higher. Since 2001, in Iraq and Afghanistan US and Coalition combat losses are due almost exclusively to ADA, with MANPADS and SAMs making up only fractions of the total figure.

During Vietnam, US forces mitigated the ADA threat by flying at altitudes where ADA fire was ineffective. This was effective until enemy SAMs were deployed in country and began successfully engaging US aircraft. From that point on, ADA and SAMs began being deployed as combined arms. The SAMs denied medium and high altitudes to aircraft while, at lower altitudes where SAM radars were less effective, ADA denied low altitudes. Today this model of ground based air defense (GBAD) employment continues, with some SAMs responsible for higher altitudes and longer ranges and many ADA systems providing low altitude and point defenses.

The mission of ADA is local air defense. Because many third-world countries employ a mixture of systems, tactics, and doctrine, exact deployment is country-dependent. Compared to other forms of air defense, ADA is relatively inexpensive to acquire and operate, requires less formal training, works well autonomously, and can routinely engage ground targets. For these reasons, ADA is attractive both to countries with limited defense spending and to those who wish to augment existing systems. It is likely that virtually any ground target worth attacking will be defended by some form of ADA. Also, small- and medium-caliber (12.7-40 mm) ADA will routinely be used against ground targets including personnel.

More sophisticated systems are increasingly being used by third-world countries. These systems are characterized by dedicated acquisition radars, dual-band tracking radars (many with millimeter-wave capabilities), and modern EO systems including image intensifiers, thermal imagers, forward-looking IR sensors, laser rangefinders, and low-light level television (LLLTV). Sensor integration has become a significant trend in most recent generation ADA systems, offering advantages in EW environments, degraded weather, at night, and against low-altitude targets. Nonetheless, about half of the existing ADA systems continue to be non-radar directed. The development of new specialty ammunition types has increased the lethality of new ADA designs and upgraded older systems.

The ADA threat should not be underestimated. ADA and small arms continue to be a major concern for US forces. Most violent non-state actors and paramilitary forces operate and are quite proficient with small arms, heavy machine guns (HMG), and light air defense guns (up to 23 mm). These light air defense guns exist in large quantities, are proliferated worldwide, and will continue to be one of the main weapons of choice for violent non-state actors.

As ADA systems have become more widely proliferated, tracking individual systems has become increasingly difficult. In addition, many countries have developed unique variants by adding indigenous accessories such as new sights, incorporating better fire control computers, and, in some cases, combining components of different systems to create new hybrids.

The trend to field gun-missile combination systems is growing in numbers and in capability. Since the fielding of the 2S6 by Russia in 1985, many countries have developed mobile, combination gun-missile systems to minimize manning assets and improve the overall performance of the individual weapons. Russia, along with several other countries, have developed upgraded version of both towed and self-propelled 23 mm ADA which incorporate updated digital components, EO sensors and MANPADS attachments.

Previously called anti-aircraft artillery, or AAA, the role of ADA has expanded beyond simply defending against aircraft in recent years. This now includes systems developed specifically to engage PGMs, rather than the delivery vehicle, hence the name change.

a. Range Terms

Actual threat range depends on many factors including:

- Type of fire
- Shell type
- Fuze type
- Environmental conditions (i.e., air density)
- Target type
- Target flight profile
- Employment doctrine

No single-range value adequately predicts the safe distance or altitude which provides sanctuary for an air target. Environmental conditions such as air density may significantly affect the range of a round. A shell fired form a higher elevation or in warmer temperatures will have an increased range because of the lower air density. Initial analysis at NGIC indicates a shell fired from 10,000 ft MSL will travel 30-40 percent farther than one fired at sea level. Fighting in Afghanistan and Kashmir has indicated this increased range assessment is reasonable.

(1) Tactical Range

Tactical range is the slant range at which a non-maneuvering fighter-type aircraft can expect to receive fire from a particular gun with a high probability of hit. It varies depending on the type of fire control equipment available, weapon caliber, firing doctrine, operator proficiency, and type of target. Because rotary-wing aircraft are generally easier to hit than a fighter-type aircraft, tactical range planning factors should be increased in rotary-wing planning.

(2) Maximum Horizontal Range

Maximum horizontal range is the greatest range a round can travel when the gun is fired at the optimum elevation for horizontal distance, discounting fuze function for self-destruct, this is the maximum horizontal range at sea level. The maximum horizontal range is normally achieved only by armor-piercing rounds.

(3) Maximum Vertical Range

Maximum vertical range, also called maximum ordinate, is the greatest range a round can travelin altitude—assuming the gun is fired at maximum elevation and there is no fuze or self-destruct mechanism—is the maximum vertical range at sea level. The maximum vertical range is normally achieved only by armor-piercing rounds.

(4) Open-Fire Range

Open-fire range is the distance at which a gunner begins firing so that the rounds will impact the target aircraft at the tactical range.

(5) Self-Destruct Range

Self-destruct range is the range at which high explosive projectiles automatically detonates

(6) Tracer Burnout Range

Tracer burnout range is the range at which the tracer elements burn out. This will usually fall between tactical range and self-destruct range.

b. Other Terms

Other terms important to understanding the capabilities and limitations of ADA include the following:

- Basic load: amount of ammunition immediately available for firing and/or reload.
- Caliber: the bore diameter of the gun, normally measured in millimeters.
- Cyclic rate of fire: the maximum theoretical rate of fire of the weapon.
- Elevation limits: minimum and maximum limit the barrel can be raised or lowered.
- Elevation rate: the speed at which the barrel can be raised or lowered.

- **Reaction time:** the time required for the system to acquire and engage a target.
- **Set-up time:** the time required for the system to be made fully operational from normal travel configuration.
- **Traverse rate:** speed at which the gun can be rotated in azimuth.

c. Categories

Air defense artillery is divided into five categories based on the caliber of the weapon:

(1) Small Arms/Automatic Weapons

This category includes small arms and machine guns below 12.7 mm used in an air defense role. These weapons are characterized by:

- High cyclic rates of fire (approximately 600 rpm)
- Thin-tracer paths, although sometimes voluminous and/or multiple
- No projectile self-destruct element
- Capable of damaging an aircraft with a direct hit primarily through kinetic energy. Contrary to past beliefs, one cannot distinguish between threat and friendly fire by tracer-color alone. Both former Soviet Union (FSU) and NATO tracers can include red tracer composition, so this is not a reliable criterion for determining the caliber or nature of the small arms fire.

(2) Heavy Machine Guns and Anti-Materiel Rifles

Heavy machine guns, also known as heavy anti-aircraft machine guns, are 12.7 mm and 14.5 mm air defense guns. Anti-materiel rifles are semi-automatic weapons and are widely fielding in both 12.7 and 14.5mm calibers. Although some larger anti-materiel rifles in 20 mm are in development and have limited fielding. Distinguishing characteristics include:

- High rate of fire (for HMGs)
- Relative precisions (for anti-materiel rifles) against aircraft sized targets when stationary (i.e., landed or in a hover)
- Capable of damaging an aircraft with a direct hit primarily through kinetic energy
- High explosive rounds are available, but projectiles lack a self-destruct feature
- Can be towed, vehicle mounted, or man-portable
- Most are manually operated and optically directed

(3) Light Air Defense Artillery

This category includes automatic guns from 20 mm through 25 mm. These weapons are characterized by:

- High rate of fire
- Most are towed and optically directed
- Self-destruct projectiles

(4) Medium Air Defense Artillery

This category includes guns from 30 mm to 40 mm. Recent advances in ADA have focused on this category. These weapons are characterized by:

- High rate of fire
- Most systems can be radar directed
- Self-destruct projectiles
- Air burst munitions

(5) Heavy Air Defense Artillery

This category includes 57 mm and larger guns. The vast majority of ADA pieces greater than 100 mm are used in a reserve role and are no longer considered first line systems. Heavy ADA systems are characterized by:

- Slow rate of fire
- Most systems can be radar directed
- Self-destruct projectiles
- Air burst munitions

d. Firing Doctrine

(1) Types of Fire

Aimed fire is the most controlled type of fire for ADA. In aimed fire, ADA weapons are aimed specifically at the aircraft. It is the preferred method of fire when the target can be acquired and tracked by the ADA system. The accuracy and effectiveness of aimed fire depends upon the method employed and the type of fire control equipment used. Most modern ADA systems employ aimed fire with air bursting munitions.

Barrage fire is the least-controlled type of ADA fire and is used when the fire control system cannot accurately track the target. Typically, a battery of several ADA units—normally using 37-, 57-, 85-, or 100-mm artillery pieces—lays a cloud of projectiles at various altitudes across the probable path of the target aircraft.

Curtain fire is considered to be the most effective means of employing small arms/automatic weapons. In curtain fire, the gunner aims at a fixed point in front of the target, along the target’s course. Fire is directed at the first point in space until the target passes through the cone of fire.

A new fixed point is then selected and firing continues. Successive fixed points are selected until the aircraft is destroyed or flies out or range.

(2) Firing Duration

All caliber weapons up to and including 57 mm may employ long or short bursts and continuous fire. Generally, calibers above 57 mm employ single rounds.

Burst fire is the firing doctrine considered most effective by most counties. Each burst is followed by a rest period to adjust the gun lay (using tracer observation and subsequent firing adjustments). In systems with optical equipment, the rest period also allows smoke produced by the burst to dissipate. Thus, the duration of the burst is based upon the method of firing, nature of the target, and distance to the target. Overheating of systems also limits the number of bursts during specific periods. The burst length will vary with each caliber weapon. More sophisticated fire control allows shorter burst length with a higher probability of hitting the target.

Short-burst fire for ADA guns normally varies from 2-10 rounds per barrel per burst. Long-burst fire varies from 10-20 rounds per barrel per burst and is normally used at medium and short ranges if the gun crew is well trained and the gunners have high confidence in their firing solution. Continuous fire occurs at short ranges when the burst length exceeds 15-20 rounds per barrel. This type of fire is normally used mostly against diving and ground-attack aircraft at short ranges, typically within 2,200 ft. Suddenly-appearing targets will also be engaged with long bursts or continuous fire. Single-round fire is mainly used with medium- and heavy-caliber weapons.

e. Ammunition

Rounds can have incendiary, tracer, or fragmentary characteristics that enhance their capability. Ammunition is normally loaded with a mix of armor-piercing and high explosive rounds, depending on user doctrine. Many of the defunct Soviet Union’s former client states follow the loading doctrine used years ago by Soviet ADA gunners of one armor-piercing round for every three or four high explosive rounds. However, it must be emphasized that third-world countries, violent non-state actors, and even former Soviet client states can have a variety of ammunition loads.

Most new ADA ammunition development is air bursting munitions. Several manufacturers have developed air bursting munitions in the 30-, 35-, and 40-mm caliber. Sophisticated proximity-fuzed rounds have been developed for 37-, 40-, 57-, and 100-mm ADA systems. Additionally, some manufacturers now produce frangible rounds in 23-, 30-, and 35-mm caliber. Frangible rounds break-up upon impact without fuzing, giving the lethality performance of high explosive projectiles with a fuze. Without the additional weight of a fuze, the frangible rounds will fly farther and travel faster than other comparable size rounds.

f. Fire Control

There are three major types of ADA fire control:

- Optical
- EO
- Radar

Laser rangefinders are used in conjunction with optical and EO systems to provide accurate range data. Most new ADA systems employ a dedicated acquisition radar and an EO sensor suite to provide maximum active and passive targeting capability. Infrared search and track systems have even been developed for ADA; however, such systems have not yet been deployed and will likely continue to remain rare into the future.

(1) Optical

Optical sights are improvements over simple post and notch sights. They include speed rings, direct-view optics, stereo-optic rangefinders, reflex sights, and optical-mechanical computing sights. They are vulnerable to conditions that degrade visibility.

Speed rings are mounted directly to the gun carriage and are the most basic ADA sighting system. Speed rings consist of metal sights with crosshairs and concentric rings that allow the operator to estimate the target speed and compute a rough lead angle. This sight is nearly useless in darkness or when the target is otherwise obscured.

Direct-view optics are normally a telescope mounted directly to the gun carriage with crosshairs overlaid on the optics. This type of sight magnifies the target, making identification easier. Direct-view optics are often used alongside speed rings and provide a reliable fair-weather backup to radar systems in a jamming environment.

Stereo-optic rangefinders use the separation of two telescopes to determine the target’s range and elevation.

Reflex sights use mirrored optics to view the target. This allows for various illuminated sighting aids to be superimposed over the target. These sights allow for flexibility in engagements and are generally more accurate than speed rings or direct-view optics. Reflex sights are often associated with off-carriage optical fire control directors.

Optical-mechanical computing sights combine reflex and/or direct-view optical sighting systems with a system of wheels and gears that are used to transmit target parameters to the ADA piece or battery.

(2) Electro-Optical

Electro-optical sights filter and enhance target information and present it to the operator through a view screen or mounted goggles. They include image intensifiers, IR receivers, and RF receivers and processors. Electro-optical sights enable ADA systems to more effectively engage targets in low light or inclement weather. In addition to providing enhanced optics for a human operator, they can be associated with radar and/or clustered together on fire control sighting systems. When used alone, without radar, they provide passive targeting which decreases detection and increases survivability. These sophisticated systems use modern fire control computers to produced highly accurate targeting information and, in some cases, can automatically direct a battery of ADA.

(3) Radar

On-carriage radar systems are physically located with the gun and are an integral part of the ADA system. On-carriage radar is associated with self-propelled ADA and gun-missile systems. It is often associated with on-carriage optical or EO equipment, which aids in target identification and provides engagement capability in a jamming environment. On-carriage radar can be linked with off-carriage C3 and/or acquisition radar support for enhanced situational awareness. Multiple radar systems, for target acquisition and tracking, are commonly used on modern ADA systems.

Off-carriage radar systems are transported in a separate vehicle and can be used to support ADA pieces or batteries in much the same way as on-carriage radars.

5005. Missiles

A missile is a self-propelled munition with the ability to guide onto target (as opposed to rockets, which are usually unguided). The main categories of missiles of concern to air intelligence include SAMs and AAMs. Certain anti-tank guided missiles can be used for surface-to-air engagements (usually at low target speeds and altitudes or when the target is landed) and other missiles that pose a threat to the MAGTF include cruise missiles, ballistic missiles, anti-ship missiles, and more.

a. Components

Missiles are comprised of four main components:

- Guidance/targeting system
- Flight system
- Engine
- Warhead

A *guidance or targeting system* usually uses some form of radiation (IR, lasers, radar, etc.) to guide the missile to its target (although guidance can take place with an INS that requires no radiation). This can be self-contained (such as in active homing radar missiles or IR-seeking missiles) or facilitated by a separate targeting system (such as a ground-based radar system illuminating a target). It can also be active (such as with radar) or passive (such as with IR).

A f*light system* allows the missile to control its flight path so as to make corrections required by its guidance system, usually through canards.

An engine provides powered flight, usually in the form of a rocket engine or jet engine. These can be fueled with either solid or liquid fuels. Engines can have multiple stages, such as boosters, etc.

Finally, the *warhead* is the portion of the missile intended to cause damage to or destruction of the target. Most often this is some form of explosive (although it can also be a non-explosive effect such as a heavy, high-density material or the body of the missile itself). Warheads may also use the remaining fuel of the engine as additional explosive material or may include sub-munitions.

b. Guidance and Flight

Missile guidance is a key factor in understanding how a missile system operates. The guidance law and guidance scheme will determine how the missile is steered and how the missile system receives information necessary to derive the right steering direction.

A missile *guidance phase* refers to different parts of missile’s flight. These phases of flight are important to understanding how the missile is operating as it has different objectives during each phase.

A missile *guidance* law is a relationship between the missile and the target motion, used to generate missile steering commands. The missile system utilizes one or more of the guidance schemes to communicate the steering commands based on the guidance law of the missile. If the missile implements the guidance law correctly, the missile will intercept the target. In otherwords, a guidance law calculates missile steering commands based on observations of the target.

A missile *guidance scheme* is how the weapon system sends the commands to the missile.

A missile *flight profile* is the trajectory the missiles takes to get to the target. The trajectory will be influenced by many factors, including the guidance law. Each system may have different flight profiles, even when the guidance law is the same. Although there is a distinct correlation between missile guidance law and flight profile, it is important to understand that these are two separate concepts. Generalizations can be made as to how the guidance law will dictate the appearance of the missile as it is guided to its target aircraft; however, it is important to realize hat these are general descriptions. For example, the SA-5 uses the proportional navigation guidance law to calculate the target intercept but, depending on its range to the target, the missile will take an up-and-over (for long-range intercepts) or direct ascent (for short-range engagements) flight profile.

c. Guidance Phases

Missile guidance is generally divided into three distinct phases: boost or launch, midcourse, and terminal.

During *boost* or *launch* phase, the missile leaves the launcher or launch vehicle and accelerates. Its purpose is to gain separation from the launcher and accelerate to high speed. Effective guidance may not be an objective of this phase and some missiles may not be guided at all during their launch. Some missiles may include a separate booster that is ejected from the missile after being used during this phase.

During *midcourse* phase, the missile is flying a trajectory through space towards the target. The purpose of this phase is to get the missile into terminal guidance where it can successfully engage the target. This is often the longest phase by both time and distance. Most missile receive some guidance during this phase.

During the *terminal* phase, the missile is attempting to intercept its target. A high degree of precision and rapid, accurate corrections are required to achieve a successful intercept. All missiles are guided in some fashion during this phase.

Some equipment may discriminate between more discrete stages of missile flight (for example, AAR-47 Missile Warning Set detects UV plume intensity associated with rocket motor operation during six stages of powered flight: ejection, ignition, boost, transition, sustainment, and burnout).

d. Guidance Laws

There are three missile guidance laws: command to line of sight (CLOS), lead angle, and proportional navigation.

In *CLOS* guidance or “three-point guidance,” the missile is fired straight at the target and steered to keep it on a direct LOS between the ground tracker and the target (see fig. 5-1). In a CLOS system, the ground tracker must track both the missile and the target, and from this it generates steering commands directly to the target. Command-to-line-of-sight guidance is also the default mode for launch and intercept against a target that is denying range information (an angle-only rack) or against targets that are being tracked optically. Systems employing this guidance law and engaging from other than a pure nose- or tail-aspect will appear to drift aft of the canopy (of a non-maneuvering aircraft) during its closure on target.

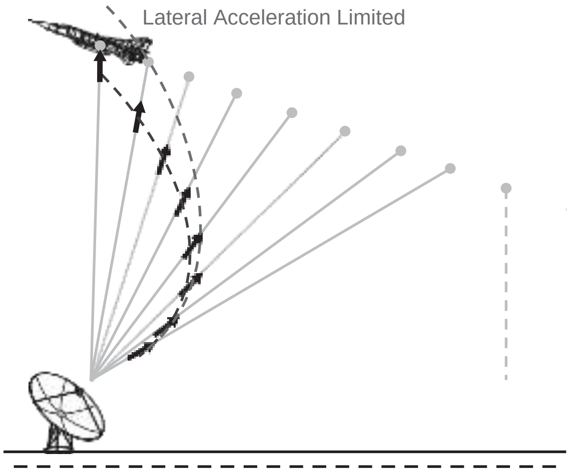

Figure 5-1

Lead-angle or “half rectified” guidance systems attempt to steer the missile on an intercept course with the target along its projected flight path by leading the target. The resulting lead angle profile is more efficient than a LOS profile but not as efficient as a true proportional navigation profile. Lead-angle and half-rectified guidance are often used synonymously and are similar. Lead angle guidance steers the missile to a constant angle ahead of where the target is currently located. Half-rectified guidance law commands the missile to a point halfway between the predicted intercept point and current ground tracker-to-target LOS. Systems employing a lead-angle or half-rectified guidance law and engaging from other than a pure nose- or tail-aspect will appear to drift aft of the canopy (of a non-maneuvering aircraft) during closure on the target.

Proportional navigation, or pro-nav, guidance produces the most efficient trajectory of the guidance laws, allowing lower miss distances and improved missile kinematic range. Pro-nav missiles have a flight path that results from an attempt to steer the missile on an intercept course with the target along the target's projected flight path (see fig. 5-2). Pro-nav is widely used for homing missiles due to the seeker's ability to maintain a zero line of sight rate (LOSR) to the target (i.e., no fore/aft movement of the target relative to the seeker). In a command-guided system, the ground tracker must have some means of knowing the missile-to-target LOSR. Systems employing pro-nav and engaging from other than a pure nose- or tail-aspect will appear steady on the canopy (of a non-maneuvering target aircraft) during its closure on the target. This guidance scheme is so-called because missile acceleration commands are generated *in proportion to the LOSR, causing the LOSR (or change) to be zero (maintaining a constant bearing and decreasing range to the target).*

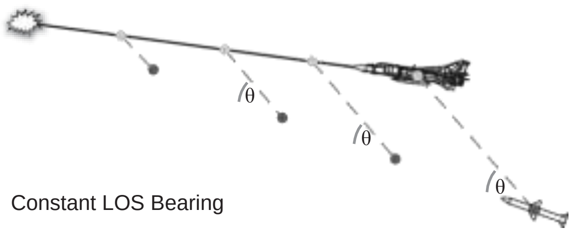

Figure 5-2

Linear quadratic Gaussian is an optimized missile guidance law that employs a linear system, quadratic cost function, and Gaussian noise. Linear quadratic Gaussian is an advanced implementation of pro-nav that makes significant improvements to simple pro-nav guidance and can achieve dramatic results for three-dimensionally maneuvering targets. The basic notion for pro-nav is that if the LOSR is annulled (kept at zero), then (for a non-maneuvering, constant velocity target) the missile is on a collision course. If the target is considered smart or maneuvering, then improvements to pro-nav have been shown to result in better miss distances. These improvements reduce missile target engagement time and required energy.

Linear quadratic Gaussian is, in essence, a guidance law optimized for three-dimensionally maneuvering targets whereby the missile is aware of and able to compute for additional factors in an intercept beyond simple LOSR. One of the most significant factors computed is unequal missile body axis constraints (i.e., ability to perform greater acceleration on one axis than another). Missiles utilizing linear quadratic Gaussian navigation will generate guidance commands to optimize maneuver along the missile's preferred (maximum) acceleration axis. A target maneuvering at 45 degrees (e.g., “down and right”) would lead simple pro-nav guidance to generate equal guidance in the horizontal and vertical axes to chase the target. Unequal body axis constraints (i.e., ability to perform 3 G’s horizontally and 5 G’s vertically), combined with additional factors that simple pro-nav does not compute (e.g., body axis linear acceleration, inertial components, atmospheric turbulence, measurement noise, other external disturbances), will overload the missile’s ability to compute the best intercept path and cause the missile to lag behind the target (i.e., over-maneuvering vertically and under-maneuvering horizontally, in the example above) and follow a sub-optimal intercept path, causing a miss or significantly reducing the missile’s kinematic energy and maneuverability.

Linear quadratic Gaussian reduces these navigation errors in a dynamic environment (i.e., where the target is maneuvering unpredictably) by computing an optimal orientation (i.e., orienting the axis of maximum perpendicular acceleration towards the plane of the intercept) and computing an optimal intercept path to generate axis-aware commands (usually bank-to-turn), banking the missile so as to maneuver on its maximum acceleration axis. This provides a simplified model for computing and generating navigation commands that reduce calculations (to a point where they can be computed real-time on-board the missile), minimizes unnecessary effort from control surfaces, and produces an optimal intercept for an unpredictably maneuvering target.

e. Guidance Schemes

Once a target is acquired and tracked, one of a number of guidance schemes must be used to get the weapon successfully to the target.

Missile guidance is the method a system uses to steer a missile to a target. Two basic guidance concepts are homing guidance, which guides the missile to the target using a seeker and onboard computer, and command guidance, which relies on commands transmitted to the missile from the ground system. Other forms of missile guidance include seeker-aided ground guidance/track-via-missile (SAGG/TVM) and inertial guidance. Some systems may use more than one type of guidance for different phrases of flight. For example, a missile system may use command or inertial guidance in the early-to-middle portion of flight and transition to semi-active homing, SAGG/TVM, or active guidance for terminal homing.

Homing guidance schemes include active homing, semi-active homing, and passive homing.

Active homing radar systems contain both the source for illuminating the target and the receiver, for detecting and homing in on the energy reflected from the target, within the missile. Essentially, the missile carries its own radar transmitting and receiving unit. The advantage of active homing for a system is the weapon system can prosecute a different target once the missile transitions to the active phase. Both SAMs and AAMs can use this guidance scheme. Many missiles utilizing active guidance utilize a different guidance scheme during early phases of flight.

Semi-active homing radar systems home in on energy reflected off of the target provided by an outside source. The outside source must illuminate the target throughout the missile time-of-flight to provide a constant homing signal for the seeker. A loss of illumination will result in a failed intercept during semi-active guidance.

Passive homing systems detect and home in on the natural target emissions such as IR or RF emissions. In other words, the target draws the missile to itself. The advantage of passive homing is that, once the missile is launched, it depends solely on the target emissions for guidance requiring no further input from the operator.

Command guidance systems are typically missiles without seekers and require commands from an outside source, such as a ground tracking radar. Additionally, the tracking system must track the target and/or missile using radar, EO, laser, or IR systems. The ground system calculates proper trajectory for the missile to intercept the target and relays the steering commands to the missile throughout the time-of-flight. Besides steering commands, the command guidance may also include fusing and detonation instructions. Command guided systems tend to be shorter-range systems due to the large tracking errors at long ranges. Many missiles utilize command guidance during the initial phases of flight before switching to another form of guidance. Command guidance can further be divided into manual, semi-automatic, and automatic CLOS, command homing/non-line of sight, and LBR. Manual command line of sight systems require the operator to visually acquire the target and to fly the missile to impact using a joystick-type device. Missile guidance commands are automatically uplinked to the missile via RF signal. *Semi-automatic CLOS* systems require the operator to visually acquire and maintain track on the target using an optical device while a separate automatic tracking device tracks the missile and automatically uplinks guidance commands to the missile via RF signal. *Automatic CLOS* systems differ from semi-automatic CLOS in that both the missile and the target are automatically tracked by the system that then automatically uplinks guidance commands to the missile via RF signal. After lock-on, operator inputs are not required for successful engagement.

Command homing/non-line of sight systems incorporate a seeker (TV or IIR) in the missile nose and a fiber optic cable to receive the seeker's FOV of the target (downlink) and the transmit steering commands (uplink) to the missile. With this type of system, the gunner sits at a control console to monitor a TV screen that shows what the missile seeker sees. The gunner controls the missile with a joystick-type device.

Laser beam rider systems use a form of command guidance, where the ground system tracks a target using a laser beam. The missile then rides the laser beam and makes steering commands to keep the missile centered in the beam. LBR systems tend to be short range due to the large tracking errors at long distances.

Seeker-aided ground guidance/track-via-missile guidance combines both command guidance and semi-active homing guidance. The target and missile are tracked by the ground radar system, as in command guidance. However, in SAGG/TVM the target-tracking beam also serves as a target illuminator, and a receiver on the missile detects the reflected illumination, as in semi-active radar guidance. The ground computer generates commands based on a combination of the radar's target track data and the seeker's target track data, which is sent to the ground via a data link. The ground radar then sends the steering commands to the missile. Simply put, the target is being tracked "via the missile" but steering commands are always formulated on the ground and sent similar to a command guided system. The advantage of a SAGG/TVM system is it provides the tracking accuracy of a homing seeker yet allows the guidance calculations to be performed on the ground where a powerful computer can be fielded. Seeker-aided ground guidance/track-via-missile systems also maintain engagement capability if either the missile or the ground radar is being jammed.

Ground-aided inertial guidance systems include a digital uplink to an INS-equipped missile. In a ground-aided inertial system, the target engagement radar tracks the target, and then uplinks the target's location to the missile. The missile calculates its own location using its INS, compares this location with the target's location provided from the radar, and calculates course corrections to intercept the target. In some systems, the ground radar may also provide missile location updates depending on the accuracy of the missile INS.

f. Missile Warheads

Surface-to-air missiles and AAMs are normally not designed to directly impact their target. Instead, they rely on proximity fuses to detonate in proximity to their target, spreading the lethal area of the missile outwards with blast pressure and shrapnel fragments that, in turn, destroy the target. The intended target for a missile often determines the type of warhead used. There are three general types of missile warheads.

(1) Fragmentation Warheads

The most traditional and least complex, these warheads are composed of an explosive charge surrounded by a dense metal casing (sometimes pre-fragmented) that is designed to expand in all directions upon detonation and puncture the target, destroying it. Theses warheads typically have the smallest lethal radius and are most effective against small targets.

(2) Discrete Rod Warheads

Slightly more complex, discrete rod warheads are composed of an explosive charge surrounded by numerous metal rods that expand upon detonation and continue to fly in the direction of the missile prior to detonation. These warheads are useful against armored targets that may be resistant to the smaller fragments of a fragmentation warhead.

(3) Continuous Rod Warheads

Against larger targets, such as bombers and C2 aircraft, fragmentation and discrete rod warheads may hit the target, but because the airframe is so large, the fragments/rods sometimes pass through the aircraft without damaging any critical components, and thus fail to destroy it. Continuous rod warheads were designed to solve this problem.

Composed of an even number of rods arranged parallel to form a cylinder around the explosive charge and welded together at alternate ends, upon detonation the warhead becomes an expanding circle designed to cut completely through aircraft, destroying it.

g. Performance and Engagement Considerations

Missile performance and engagement is impacted by a number of effects that will dictate its effectiveness in achieving successful intercepts.

Launch altitude impacts performance capabilities. SAM systems located in terrain which places them at higher altitudes or AAMs launched from higher altitudes may have increased capabilities. Increasing altitude produces environmental effects (e.g., reduced air density, reduced relative humidity, and reduced air temperature) that will generally have an effect on missile system performance. When not overridden by system-specific factors, these environmental factors will affect the missile kinematics, IR seeker performance, and motor-burn efficiency.

A missile airframe traveling through lower density air at high altitude will produce less drag than a missile fired at sea level. This will allow the missile to accelerate more rapidly, travel faster, and maintain velocity longer after motor burnout. The most apparent effect of a missile launch from a higher elevation is that the missile will usually fly higher and farther than a missile fired from sea level. A missile fired at higher elevation is also able to gain and maintain higher velocities in all flight regimes.

Altitude also impacts missile motor burn. For solid propellants, the burn characteristics change significantly due to the initial grain (fuel) temperature. Typically, higher altitudes will result in a colder grain and this will cause the propellant to burn longer but at lower thrust levels. The total impulse delivered by the motor usually remains constant. When this is coupled with reduced drag and lower atmospheric pressure at higher altitudes, then it is possible for missile velocity to match sea-level launch velocities and, therefore, significant increases in missile range can result. Liquid propellant burn characteristics typically remain constant and, therefore, an increase in missile performance results. This translates to increases in axial acceleration, velocity, and range for the missile.

Ramjet performance depends upon the altitude environment in which the system was designed to operate. At altitudes above the design criteria, oxygen content of the rammed air is lower and consequently the performance of the motor is reduced. At altitudes below the designed criteria, too much oxygen is introduced and, though the delivered thrust may increase, it may not overcome increased drag. Consequently, it is difficult to draw general conclusions about ramjet motors with regard to impact on their performance at higher altitudes.

5006. Surface-to-Air Missiles

While ADA has historically been the most lethal air defense weapon system, accounting for upwards of 60-90% of all US combat losses in some engagements, the introduction of Surface-to-Air Missiles (SAM) to the battlespace and their proliferation globally has significantly changed the character of a modern IAD’s GBAD capability.

The first SAMs were effective at medium- and high-altitude engagements but performed poorly at low altitudes. When paired with ADA to cover these low altitudes, the two systems proved to be a lethal combination to aircraft.

Surface-to-air missiles span a variety of weapon systems, from lightweight, short-range MANPADS to SAMs that can range hundreds of nautical miles and reach the upper limits of the atmosphere.

a. Engagement Sequence

The engagement sequence for SAMs is similar to the four functions that comprise the engagement function of an IADS (search and acquisition, track, launch/guidance, kill assessment). It is comprised of:

- Search
- Detection
- Tracking
- Fire control and launch
- Missile capture
- Missile fuzing and detonation
- Kill assessment

(1) Search

Air defense systems must inspect a volume of space in order to locate aircraft. Normally, search or acquisition radars scan the volume of space at regular intervals. The time it takes to search the entire volume of the scan once is called the scan period. Many radars have more than one scan mode and therefore can have multiple scan periods. The search function can be performed by a radar located far away from the SAM fire unit, and target information can be passed from the search radar to the fire unit via data link. This is called cueing. In other cases, the search radar is located next to or even on the same vehicle as the track radar. Some multifunction radars perform search and track functions on a time-shared basis with a single radar.

The volume of airspace searched is determined by the maximum range of the radar and by a combination of the antenna beamwidth and the angles over which the beam is scanned. Azimuth search is done by rotating the radar antenna or rotating the direction of the main lobe. This rotation can be accomplished mechanically, electronically, or by using a combination of both.

(2) Detection

Detection occurs when, during search, antenna beams scan across a target location and sufficient energy is reflected from the target to the radar. The amount of reflected energy received by the radar, and thus the detection capability, is dependent on factors such as the radar transmitter power, antenna gain, receiver characteristics, the targets RCS, and the amount of dwell time of the antenna on the target. The reflected energy received will increase as the target gets closer to the radar. Therefore, detection capability is described as the maximum range at which a target of a certain RCS can be detected.

Because radar noise in the environment has a randomly varying strength, detection ranges cannot always be predicted with certainty. Therefore, a detection range is calculated for a given probability of detection. A detection range with a probability of detection of 0.5 means that for every scan past a target at that range, there is a 50 percent chance that detection will be made. Since there is a probability of detection with every scan, most targets will be detected by early warning radars before or at the 50-percent detection range. On-site search and detection can be accomplished by organic early warning and acquisition radars; however, the TTRs themselves will have a limited search and detection capability.

(3) Tracking

Once a target is declared, the target's change in position from scan to scan is measured. These measurements are fed into a track filter to smooth the track estimate and to estimate the target's position at times between scans. This is called non-precision track or track-while-scan because the search radar continues to scan its normal volume.

The track radar receives azimuth and elevation angles from the search radar and is slewed to point at the target. The track radar performs a limited search in angle (usually a few degrees), range, and/or Doppler. The probability of detection depends on the range to the target. For a well-designed system, designation data are sufficient for the track radar to detect and begin track within a few seconds. This phase of the SAM engagement sequence is generally accomplished by on-board acquisition radars.

Precision track is achieved by making accurate and frequent measurements of the target position. Angle measurement accuracy increases as the antenna beamwidth decreases. Because of this, most track radars are designed to have a narrow, nearly circular antenna beam called a pencil beam.

Measurements are fed into an analog or digital track filter which provides an ongoing estimate of the target's position. Therefore, tracks precise enough to support missile guidance are not achieved instantly after track begins but only after about ten or more measurements have been made.

The primary function of the TTR/target engagement radar is to track the target accurately enough to support a missile intercept. These radars usually track in azimuth, elevation, and range. Some radars also track in Doppler. This phase of the SAM engagement sequence is generally accomplished by on-board TTR/target engagement radars.

(4) Fire Control and Launch

Once accurate target information (range, velocity, and azimuth) is known (typically within 5-10 seconds of initial detection, depending on the SAM system,) the final decision to launch is made. Whether a missile is to be launched, and at what range, depends on a number of variables: shot doctrine, system limitations, and target characteristics (i.e., target type, profile, and ECM). Doctrine, training, and operator proficiency all dictate whether intercepts will be attempted at maximum range or shorter ranges.

Most SAM systems can launch a single missile or a salvo. The tactic employed will usually be dictated by the probability of kill of the system in the current engagement and may be a single shot, two sequential shots (shoot-shoot-look), two shots with an intermediate kill assessment (shoot-look-shoot), or some variation. The operator assessment of the probability of kill, system limitations, missile inventory, and target type are key factors that determine the number of missiles to be launched.

Upon launch decision, the missiles must be initialized. For mechanically positioned missiles, the launcher is pointed at the target or the predicted intercept point, depending on the guidance type used. For systems with fixed launchers, parameters such as the initial flight path or target position information are stored in the missile before launch.

(5) Missile Capture

Command-guided missiles must be tracked by the TTR/target engagement radar. The radar must acquire and establish track on the missile much like it does on the target. This process, called missile capture, takes place shortly after launch.

Some missiles are equipped with beacon transponders which allow them to be tracked by the TTR/target engagement radar. The radar transmits interrogation pulses to the missile which the missile, equipped with a receiver, recognizes. The missile sends a signal back to the radar from an on-board transmitter. The radar receives the missile transponder signals and tracks them. Signals transmitted in this fashion are much stronger than reflected EM signals, resulting in a more accurate track.

Some missiles are equipped with flares or EO devices which allow the SAM system to optically capture the missile after launch. The SAM system is generally equipped with an IR sensor which allows the SAM system to see and track the missile as it flies down range.

Although missile capture generally lasts for a couple of seconds or less, it is critical to command-guided SAM system performance. Since missile guidance cannot begin until missile track begins and accurate intercepts cannot occur until sometime after guidance begins, missile capture time directly affects the minimum effective range of the system.

Homing guidance systems generally do not require any sort of missile capture.

(6) Missile Fuzing and Detonation

Most RF SAMs are equipped with RF or optical proximity fuzes. A proximity fuze is designed to detect when the missile is close enough to the target and to detonate the warhead. Proximity fuzes can be active or passive. The entire process of fuzing and detonation takes places in a matter of milliseconds.

(7) Kill Assessment

Most SAM crews make assessments in one of two ways: (1) changes to the target's trajectory after detonation as determined by the TTR/target engagement radar or (2) input from external sources. If the target is not destroyed, the crew may elect to launch again.

b. Range Terms and Definitions

It is not possible to define the range capabilities of a SAM with a single number. Several values are needed to define the capability of the system under the many conditions that it can be employed.

Minimum intercept range is the minimum range a missile can guide and successfully fuze on a target. This may be a function of target conditions.

Maximum recommended intercept range is the maximum range the system was designed to intercept a target. For many SAM systems, the fire control computer or operations manual will recommend a launch solution to the operator to intercept a target at (or inside of) this maximum range. This range is usually specified by the manufacturer and is typically the advertised maximum range. Guided intercepts are possible beyond this range—especially if an intercept was initiated before a target transited outside the maximum recommended intercept range (MRIR), but may have a lower probability of kill. If an aircraft has been engaged inside MRIR, simply flying outside of MRIR may not be enough to defeat the missile.

Maximum intercept range is the maximum range a missile can intercept a target. The intercept range may be limited by such factors as maximum time-of-flight, self-destruct timer, uplink timing, or other factors.

(1) Target Radar Cross Section Considerations

While a radar may be able to track a larger RCS target at a farther distance, there are other factors that preclude a missile launch at those longer ranges. Usually this means a high, fast flyer will reduce a SAM engagement envelope, not the other way around (i.e., a slower, large-RCS target will not enlarge the SAM engagement envelope). The maximum intercept range is used more for the larger, non-maneuverable aircraft and MRIR is generally used for the maneuverable aircraft that can defend themselves.

c. Types of Surface-to-Air Missiles

Surface-to-air missiles can be categorized by their role, mobility, and the seeker/method of guidance used. Because these characteristics are driven by the intended employment and design of the system, these characteristics are interrelated.

The role of a SAM system can be either strategic or tactical. Depending on employment, systems can be used in either role; however, large, long-range SAMs tend to be employed in strategic role, providing area or barrier defenses. Smaller, short-range SAMs tend to be employed in point defenses or as gap fillers for area or barrier defenses. Modern SAMs are increasingly blurring the lines between these roles. For example, a large, long-range SAM may play a strategic role in creating an area or barrier defense while also playing a tactical role in the point defense of a HVT against LO aircraft, cruise-missiles, or other standoff munitions.

A SAM's mobility can be expressed as mobile, movable, or fixed. Mobile SAMs are those designed to shoot within seconds or minutes of stopping and can be torn-down, moved, and set-up again in a matter of minutes or tens of minutes. Mobile SAM systems (missiles, C2 vehicles, radars, and other supporting equipment) are almost always mounted on wheeled or tracked chassis. Movable SAMs are those that are designed to tear-down, move, and set up within an hour to a few hours. And fixed SAMs are those that require a fixed, prepared position from which to fire and cannot be easily move without many hours or days of preparation and work. A SAM's seeker or method of guidance can be IR, RF (including passive antiradiation), EO, laser, or a combination of these. A seeker/method of guidance plays significantly into the SAM's role and mobility. For example, IR SAMs have all the requisite equipment to engage targets in a small package, making them more mobile, and the short-range of IR seekers limits the system to a tactical role.

Finally, MANPADS are a category of SAMs unto themselves. Their method of employment across the battlespace, widespread use and availability, small size, ease of concealment, and rapid engagement ability makes them a unique threat worth discussing separately.

d. Man-Portable Air Defense Systems

As the term suggests, MANPADS refers to any man-portable air defense system. While the majority of these types of weapons primarily use IR seekers, there are also variants that use lasers or EO for targeting and guidance.

Infrared and UV missile guidance units are designed to detect and home in on the IR/UV radiation of an aircraft. The detector element in the seeker is the key component that determines which part of an aircraft's IR signature will be detected by the missile. Cooled detectors are sensitive to longer wavelengths. Advanced IR missiles may use multiple detector elements to support infrared counter-countermeasure (IRCCM) logic.

There are five generations of MANPADS seeker technology.

(1) Generations

First generation seekers employ IR detectors operating in the visible to near-IR region and are uncooled. The most widely used material for these detectors is lead sulfide. Lead sulfide allows these seekers to operate in the near-IR band (1-3 µm), which is usually referred to as the hot metal band. Spin scan or AM is predominantly used in these early systems. Processing electronics consist of analog devices that have a major impact on size and weight. Because lead sulfide detectors can usually only detect the hot metal of engines, first generation systems are usually able to acquire and track a target in the rear aspect only. Lead sulfide detectors can also track on incandescent lights, meaning that first generation systems can achieve lock on an aircraft's landing lights under certain conditions (which could give first generation missiles a limited front aspect capability). First generation seekers do not have IRCCM so they are typically susceptible to flares, jamming and suppression. Second generation seekers employ cooled IR detectors operating in the mid-IR band (3-5 µm). The detector material typically used in this band is indium antimonide. These systems utilize a conical scan technique and exhibit a large FOV. Second generation seekers have all aspect tracking capability and lack an IRCCM capability. Conical scan seekers are susceptible to flares and suppression, but by design are inherently less susceptible to broad band jamming techniques. Third generation seekers employ cooled IR detectors operating in the mid-IR region (3-5 µm). They may use multiple detectors operating in different portions of the IR spectrum (including, in some systems, in the near-IR). Most third generation seekers employ the conical scan technique, although some more advanced seekers produce a pulse-to-pulse modulation using the spin scan technique. Third generation seekers were designed with dedicated IRCCM functions encompassing spectral, spatial, and temporal techniques. Infrared counter-countermeasure capabilities vary between seekers depending on what technique or combination of techniques is employed. Examples of countermeasures used to defeat third generation seekers are: omnidirectional jammers; jammers used with flares; directional flares; combinations of flares with different spectral content; and laser jammers.

Fourth generation seekers are reprogrammable and have either multiple detectors or use pseudo-imaging scanning techniques, all of which contribute to advanced IRCCM techniques. The threat posed by reprogrammable systems is that adversaries can tailor them to IR countermeasures used across different enemies or in different battlespaces, optimizing certain missile systems for the aircraft they will most likely target. Additionally, across the lifetime of the MANPADS, systems can be upgraded with new IRCCMs, allowing for a future where an enemy upgrades aging stocks of fourth generation systems, allowing them to maintain some of their lethality as countermeasure technologies advance.

Fifth generation seekers use imaging sensors and digital signal processing. These seekers will use arrays of detectors with electronics that process the scene in the FOV.

(2) Scan Patterns

There are a number of common scan patterns used by MANPADS. Because the selection of these scan patterns impacts how IR energy is collection and modulated within the seeker, the type of scan used plays a significant role in the capabilities and limitations of the systems.

In a spin scan pattern, the reticle itself spins. The reticle has transparent, semi-transparent, and opaque sections (see fig. 5-3). When these rotate, the IR energy is modulated by amplitude which allows the seeker to determine how to steer the missile. Systems utilizing spin scans have an inherent tracking instability when the IR source is centered or “on boresight.” There is a null return at the center that will bleed over into different reticle sections, causing the missile to drift off-target. Once the target is “off boresight” the seeker can again track the target and bring the missile back onto boresight. This process repeats, causing a corkscrew flight profile.

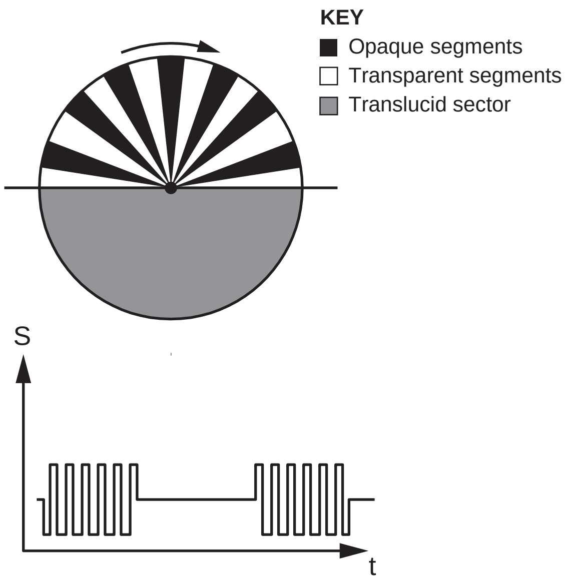

Figure 5-3

In a conical scan pattern, a steady IR signal is radiated from the target and is transmitted through the lens onto a primary mirror. The energy is then reflected off the primary mirror onto a secondary mirror. The secondary mirror is canted off-axis from the centerline of the seeker head and rotates. This rotates the image across the reticle which, in turn, chops the image to frequency modulate the IR energy. The detector element converts the FM IR signal into an electrical signal which is then sent to the signal processing section of the seeker head and derives guidance commands (see fig. 5-4).

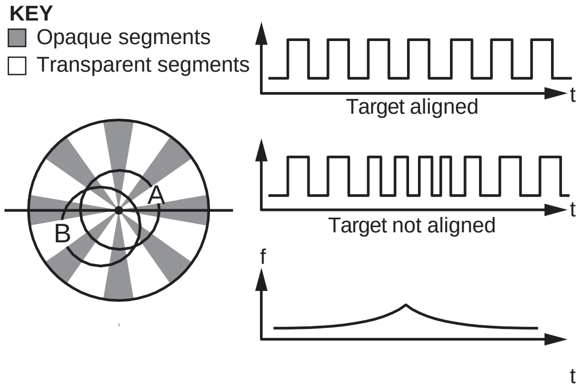

Figure 5-4

In a cruciform array, the sensors are configured in a cross-shape. As the target crosses all four sensors, the seeker head determines azimuth and elevation deviation “off boresight” (based on time difference between sensors) and generates guidance commands to correct the missile’s flight (see fig. 5-5).

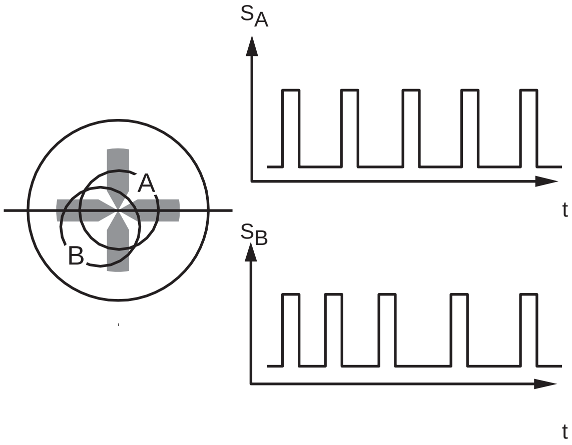

Figure 5-5

In a rosette scan pattern, the optical arrangement of the seeker scans the IFOV in a rosette pattern (see figure 5-6). This enables more advanced IRCCM techniques that exploit a very small IFOV that can be accurately located within the TFOV.

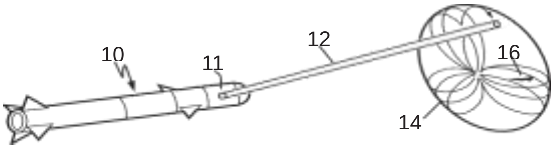

Figure 5-6

(3) Infrared Counter-Countermeasures

The goal of IRCCM is to detect the presence of a flare in the missile seeker's FOV and in response, reject the flare in favor of the target aircraft. Flare rejection is based on two computer functions—trigger and response. The trigger function detects the flare in the seeker FOV. Common trigger techniques include:

- **Rise time (intensity):** A sharp rise in received IR energy within a specified time limit indicates a flare in the seeker FOV. A rapid rise in IR energy triggers the response and the response is switched off when the received IR energy drops to its original level. Infrared thresholds are set to avoid a trigger based on an aircraft selecting afterburner. This trigger is vulnerable to multiple slow rise time flares.
- **Two-color comparison (spectral):** Missiles using this technique sample IR energy levels in two different wavelengths using different detectors composed of different materials. The trigger occurs when the intensity difference measured between the two wavelengths does not match the intensity difference expected from an aircraft's IR signature.
- **Kinematic:** A kinematic trigger assumes a flare will separate very quickly from the dispensing aircraft due to aerodynamic drag. In a beam aspect engagement, an IR seeker that transfers

track from the aircraft to the flare will observe a dramatic change in LOS rate as the flare falls away and initiate a response to the flare. Infrared missiles employing this trigger will have difficulty detecting the flare in high or low aspect engagements. Multiple flares dispensed at very short intervals will probably decoy an IR missile employing a kinematic trigger.

- **Spatial:** The spatial trigger is similar to the kinematic trigger in that it assumes the flare will fall away from the aircraft quickly. As the flare separates, the seeker will see the flare and the target on opposite sides of its FOV. The presence of two IR targets on opposite sides of the FOV triggers the flare response. Multiple flares dispensed at very short intervals may decoy the spatial trigger.

Once the trigger function detects a flare, it activates the response function which enables the seeker to reject or limit the effectiveness of the flare and continue tracking the aircraft. Common response functions include:

- **Simple memory:** When a memory response is initiated, the missile guidance rejects seeker inputs and continues with the guidance solution provided prior to the trigger. This response assumes the flare will fall away from the aircraft and leave the seeker FOV quickly. If the trigger times out before flare leave the seeker FOV, the missile will likely be decoyed by the flare.
- **Seeker-push ahead:** The seeker push-ahead response, otherwise known as track angle bias, or TAB, causes the seeker gimbals to drive the seeker forward in the direction of the target. This causes the flares to leave the FOV more quickly and minimize the amount of time the seeker is not tracking the target. Track angle bias can also be employed by some MANPADS not as IRCCM logic but simply as endgame logic to bias the missile forward of the plume to ensure target impact.
- **Seeker push-pull:** The seeker push-pull response assumes flares will have a higher-intensity IR signature that a target and it is initiated by a spatial trigger. The received energy will rise and fall as the energy of the target and flare is scanned across the detector. When the flare energy is at a peak, the seeker gimbals drive the seeker away from the flare. When the lesser energy for the target is detected, the seeker's gimbals pull the seeker in the direction of the target.
- **Sector attenuation:** The seeker attenuation response is initiated by placing an attenuation filter across part of the seeker FOV. The filter reduces the seeker's sensitivity in that part of the

FOV. If the target is being tracked in the center of the FOV, placing an attenuator in the lower aft quadrant of the seeker should reduce the energy received from a flare.

- **Electronic FOV gating.** This response is used in conjunction with non-circular scan patterns (e.g., rosette scan). At some time after the flare is dispensed, the target and flare will no longer be in the same lobe of the scan. By simply computing the relative motion of the target, the missile is able to determine in which lobe(s) the target should appear. Information from all the other lobes is ignored, allowing the missile to retain track on the target.

(4) Readiness States

The readiness of MANPADS is expressed in states. State 1 is when the missile seeker powered. State 2 is when the MANPADS is in standby mode. State 3 is when the MANPADS is in travel mode.

5007. Aircraft

Aircraft are important component of an adversary’s capability, especially within a functional IADS. Aircraft help to extend an adversary’s area of influence and increase both the offensive and defensive capability of an IADS. The analysis of a country’s airborne capability must include an in depth look at the air order of battle (AOB) and a complete understanding of airborne weapon systems. Once this foundation is met, a country’s capabilities can be further understood by analyzing proficiency, training architecture, platform and system technology, and the doctrine and tactics utilized.

a. Types

(1) Rotary-Wing

During the Vietnam War, Marine aviation began to develop the foundation for the doctrine and tactics that are used today. Prior to the Vietnam War, rotary wing assets were new and not utilized extensively. Increased capabilities including improvements in lift, mobility, fire support have created an environment in which many developing countries rely on rotary-wing assets as their primary airborne capability. In more advanced militaries, rotary-wing assets are used for mission sets such OAS, assault support, and AAW, among others. Rotary-wing aircraft are often used in combination with fixed-wing aircraft to more efficiently achieve these mission sets.

There are three types of rotary-wing aircraft: dedicated attack, armed scout/utility, and assault transport. Dedicated attack helicopters are systems that are designed to fill an attack role, have an array of weapons and usually cannot be used for another role without compromising their combat capability. These aircraft are characterized by having true integration between weapons and fire control systems and great battlefield survivability. Armed scout/utility rotary wing assets are multi-purpose helicopters that have undergone modification including missile and gun capability. These aircraft are relatively low cost and capable of multiple different mission sets making them highly desired by foreign countries. Finally, assault transport assets provide transport of combat troops, supplies, and equipment. They have the capability to deploy large number of combat troops on the battlefield. Typically, assault transport assets carry air-to-ground ordnance but attack is not their primary mission.

Developing technology for rotary-wing aircraft predominately focuses on increasing the survivability of these aircraft. As such, the utilization of aircraft survivability equipment (ASE) is a common component of modern rotary-wing assets with capabilities including suppression, RWR equipment, countermeasures, and jammers. Fire control systems have existed in rudimentary forms for decades. Much of the technology and modernization efforts in the rotary-wing arena are similar to upgrades within the fixed-wing arena, and will be further discussed later in this section.

(2) Fixed-Wing

Fixed-wing aircraft have become more important within militaries throughout the world due to the value that they bring to modern warfare. Fixed-wing aircraft are categorized by the primary mission for which they were designed. The three main categories of fixed-wing aircraft are bombers, special mission aircraft, and fighters.

(3) Bombers

Bombers are typically considered strategic assets. These aircraft are primarily found in countries with large air forces and a large military budget as they are expensive to acquire and maintain. Other than the US and certain allies, only Russia and China produce or utilize these types of aircraft. It is important to note that just because an aircraft has the capability to drop bombs does not make it a bomber. It is only classified as a bomber if long range-bombing is its primary mission.

(4) Special Mission Aircraft

Special mission aircraft are built for roles other than physical attack (dropping bombs and launching missiles). This can include aircraft that have been retrofitted or converted from the original primary mission of physical attack to a new primary mission. These special missions include but are not limited to operations such as aerial refueling, command and control, EA, and transport. Though there are many aircraft capable of these mission sets, an airframe is only classified as a special mission aircraft if it has a primary mission that would not place it in the bomber or fighter categories.

(5) Fighters

The last type of fixed-wing aircraft is the fighter. Fighters are broken down into distinct categories based on their primary mission sets. These subcategories are ground attack, interceptor, and multi-role.

(a) Ground Attack

The primary mission of a ground attack aircraft is air-to-surface weapon employment. They are often capable of carrying air-to-air weapons; however, this is often for self-defense.

(b) Interceptor

The primary mission of the interceptor is to defend against incoming bombers and engaging in air-to-air combat. Although these fighters do not affect ground units directly, they can affect the execution of a ground mission significantly by challenging ground force air superiority. This is an antiquated category. It should be noted most nations with interceptors are moving to multi role aircraft.

(c) Multi-Role

The multi-role fighter achieves the purposes of both the interceptor and the ground attack fighters within one aircraft. These fighter aircraft are designed for both air-to-air and air-to-surface missions. Due to the capability of these aircraft in both aspects, most nations with large militaries rely heavily on them.

(6) Fighter Generations

The numbers of fighter aircraft variations around the world are rapidly expanding as countries are able to purchase them from modern militaries seeking upgrades and building new systems. For this reason, fighter generations have been developed in order to group fighters into categories of similar characteristics. There are five generations of fighters currently in service.

(a) First Generation

First generation fighters are characterized by weak, non-afterburner engines, slow airspeeds, and limited supersonic capability. They have very limited AI radars or no radar at all. These fighters primarily use guns for air engagements and are not very maneuverable in an air-to-air or surface-to-air engagement.

(b) Second Generation

Second generation fighters are generally capable of supersonic speeds in level flight. They have basic pulse-only AI radars and are primarily limited to "look-up" engagement scenarios. These fighters are capable of stern-aspect employment of IR guided missiles, but are not capable of firing semi-active radar or active radar missiles. The onboard systems provide basic targeting and tracking but do not have modern equipment necessary for increased range, accuracy, and tracking capabilities.

(c) Third Generation

Third generation fighters begin integrating the improvements expected in a modern air force. They have supersonic capabilities while maneuvering and limited nighttime capability. Their improved pulse-only radar gives them limited look-down/shoot-down capabilities which are further enhanced through improved "head-up displays." In addition, third generation fighters are capable of employing limited range semi-active radar missiles. Finally, some third generation fighters possess rudimentary EA capabilities.

(d) Fourth Generation

Fourth generation fighters feature superior engine performance over previous generations. This category of fighter introduces enhancements such as turbofan technology and IRSTS. They possess AI radars including mechanically scanned, PESA, and AESA. Fourth generation fighters also have a greatly improved jamming capability and integrated defensives aid suites. The weapons inventory for fourth generation fighters is also enhanced and includes long-range semi-active radar and active radar missiles. For multi-role fighters, fourth generation capabilities have AI radars with both air-to-air and air-to-surface modes allowing the multi-role fighter to accomplish both missions.

Because of numerous advances and wide-spread retrofitting of new technologies onto older airframes, some schemes break out fourth generation fighters into three sub-categories: 4, 4+, and 4++, each sub-category with incremental improvements on the last.

(e) Fifth Generation

Fifth generation fighters incorporate LPI techniques which can be accomplished through LO treatments, shaping, internal weapons carriage, EA systems, or other detection denial techniques. Their engines offer improved thrust or fuel consumption allowing greater range, faster acceleration, and more sustained supercruise (sustained supersonic flight) performance. Integrated thrust vector control allows for slower flight regimes and sustainable high angle-of-attack. Advanced radars and integrated systems allow them to track many more targets than older radar systems are capable of. Fully integrated defensive aid suites give fifth generation fighters targeting advantages and greater ISR capabilities than earlier generations.

b. Size and Operational Capability

The total number of aircraft can be even more important than which type of aircraft a country has. An analyst must consider not only the total number but also the number of operational aircraft, and their maintenance status.

When considering the size of an adversary's AOB, the analyst must be aware of the enemy's surge and sustained rate sortie generation capabilities. The surge rate is the total number of sorties a country can launch for a short period of time. This rate is generally much higher than the sustained rate, which is the total number of aircraft that a country can launch per day for an extended amount of time. Sustained rates will be important when evaluating the adversary in a long-term conflict.

c. Location

Physical aircraft location also plays a role in any intelligence assessment. An aircraft with a limited mission radius (the range that an aircraft can fly with a given ordnance/stores loadout) located well away from the AO will be less of a factor than those aircraft located closer.

d. Regionally-based Aircraft Differentiation Model

Aircraft recognition is an important skill for aviators and aircrew in order to accurately identify threat aircraft and respond with the appropriate tactics and counter-tactics. This skill is especially important for fixed-wing platforms.

The regionally-based aircraft differentiation model (RADM) provides an effective method for aircraft recognition. Under real-world circumstances, RADM provides aviators and aircrew a practical method for easily identifying aircraft in the time-compressed environments they will experience. The RADM concept focuses aircraft recognition on the distinctive features of tan airframe (including their wing/rotors, engine, fuselage, tail) allowing for quick and accurate identification under realistic combat conditions without overloading aviators and aircrew with airframe features that are not distinctive in an AO. This method teaches aviators and aircrew to visually identify the aircraft in the sequence they are most likely to encounter in flight;

beginning with the “nose-on” viewpoint, followed by the “beam” viewpoint” and finally the “tail” viewpoint.

When developing a RADM model for a specific AO, intelligence Marines should ensure there are never two aircraft that are identified by identical features from the same viewpoint. A notional RADM is shown below in figure 5.1.

Using RADM, aviators and aircrew do not need to evaluate every feature of an airframe in order to visually identify an aircraft. The intelligence section should assemble a list of easily identifiable features for all aircraft operating within the AO. This list should include 2-4 features from each of the following viewpoints: nose, beam, and tail. Figure 5-7 provides an example.

Russia			
(Aircraft Name)			
Aspect	Feature #1	Feature #2	Feature #3
Nose	Easily identifiable features within area of responsibility (AOR) (Commonly nose shape, cockpit shape, # of seats, or location/shape of intakes)		
Beam	Easily identifiable features within AOR (Commonly wing shape, wing mount, fuselage shape, or shape of stabilizers)		
Tail	Easily identifiable features within AOR (Commonly shape of stabilizers, # of horizontal and vertical stabilizers, # of engines)		
Su-24 Fencer			
Aspect	Feature #1	Feature #2	Feature #3
Nose	Flank, Dual Seats	Shoulder Mounted Intakes	Blunt, Boxed Nose
Beam	Shoulder Mounted Intakes	Rectangular Fuselage	Single, Central Vertical Stabilizer; Level on Top
Tail	Top Mounted Horizontal Stabilizers	1x Swept Vertical Stabilizer	Dual Mid-Mounted Engines Outside
Su-34 Fullback			
Aspect	Feature #1	Feature #2	Feature #3
Nose	Flank, Dual Seats	Rear Tapered Intakes Under Wings	Thin, Rounded Nose
Beam	Rear Tapered Intakes Under Wings	Lobe Shaped Fuselage	Dual Vertical Stabilizers, Rear Tapered Tips
Tail	Rear Tapered Horizontal Stabilizers	2x Rear Tapered Vertical Stabilizers	Dual Mid-Mounted Engines Outside “Wanker”

5008. Naval Air Defenses

Naval air defenses present several unique considerations. A naval surface combatant brings all of the core elements of an IADS together onto one unit: sensors, weapon systems, C2 capability, and communication networks—all dedicated to providing an integrated defense of the combatant against an air threat. These elements often are as capable as their land- based counterparts. For example, many long-range naval SAM systems and associated radars and missiles are adapted from land-based counterparts.

Surface combatants are both mobile and maneuverable, as well. They can transit the battlespace quickly and directly, presenting a different tactical challenge in locating the threat. Once located, the ships are maneuverable, complicating targeting and weapons employment.

Naval surface combatants, and task-organized groups of combatants, can be broadly employed as an air defense asset in several ways. They can be used to provide an air defense capability in support of a main effort task such as anti-submarine warfare or anti-surface warfare. They can also provide an air defense capability for an aircraft carrier or an amphibious assault force. The can do all of these things at sea, far from a home port, in a power projection scenario. Or they can do it close to home, effectively extending a land-based air defense capability. In any case, to properly measure the threat posed, it is important to assess the capability of the combatant or group of combatants to integrate their air defense capabilities across platforms, both within the group, and with any other air defense groups, at sea as well as on land.

Whether deployed individually or in task-organized groups, a ship at sea must be viewed as a unique IADS threat.

5009. Battle Management

The Battle Management function is the bridge between air surveillance and weapons control. The battle management function includes:

- Threat evaluation
- Decide Response/Weapons
- Assign Weapons to Tracks
- Authorize Engagement

a. Functions

(1) Threat Evaluation

Once a threat has been detected during the air surveillance function, the IADS has to evaluate the threat through the function of Battle Management. During threat evaluation, this is where the IADS decides whether to engage a target, or continue to conduct air surveillance on the threat. Once the decision to engage has been made, the sub-functions of battle management can continue.

(2) Decide Response/Weapons

Based on the type and priority of track, a battle management officer/operator (or automated system) performs weapon allocation. Constraints such as track location, weapon performance parameter, and weapons deconfliction rules determine which weapon a battle managment operator chooses.

(3) Assign Weapons to Tracks

Having made the decision to engage, the target is then allocated to a specific weapon system and the weapon system receives cueing.

(4) Authorize Engagement

Once the weapon has been assigned to the track, and the engagement has been authorized, the battle management officer/operator passes track data and engagement authorization to the weapon's control unit.

(5) Command and Control

Command and control is the manner in which these other functions are executed through the processes and structure of the IADS. This includes its components and how the hierarchy is structured, its method of control, and its methods of integration. The C2 function is expressed in the IADS’s components and hierarchy, method of control, and methods of integration.

b. Methods of Control

All IADS perform the same three functions (air surveillance, battle management, weapons control) and have similar components and echelons. With these similarities in mind, a way to differentiate between various IADS is required. Therefore, IADS are typically categorized based on the type of control used. Command and control is “the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission” (*JP 1, Doctrine for the Armed Forces of the United States*). An IADS is a textbook example of C2 constructs, as command and control is directly related to the control function of an IADS. Broken down further, *command* is the authority of the commander or decision making body to pass instructions to subordinates, while *control* is the ability to do so.

Meanwhile, communications are the means by which these instructions are passed, hence the term C3.

Integrated air defense systems are typically categorized as centralized or decentralized. Decentralized systems can be either semi-autonomous or autonomous. Each type of control has its own inherent strengths and weaknesses (see table 5-2). Because of the complexity of managing an air defense picture of any size, air defense doctrine for most countries demands centralized control.

(1) Centralized Control

Centralized control is top-down control by the highest level of CE in a given air defense structure (e.g., the ADOC or national level). Although centralized control promotes unity of effort across a network and may reduce training requirements at lower echelons, the potential exists to over- task the central echelon, which can result in failure of the overall system. Due to this vulnerability, some countries practice decentralized control.

There are many advantages to centralized control. Decision makers at the ADOC level should theoretically have an understanding of everything that is going on in their airspace. This allows for an efficient use of resources and reduces the chances of mistakes such as fratricide or downing a non-combatant aircraft. In addition, the leadership philosophies of some countries or militaries stress having complete control over their military forces, and centralized systems give them this kind of complete control.

A disadvantage of centralized control is that the decision maker at the ADOC can become overwhelmed by the vast amount of information that needs to be processed. Centralized systems tend to take more time to process information, react, make decisions, and execute responses. No matter how effective the communications of the system are, passing information all the way up and waiting for orders to come all the way back down takes time. In addition, centralized systems may be more susceptible to severe degradation or complete collapse through the manipulation or destruction of a few critical nodes. Susceptibility is dependent on the types of communications the system uses, but in general, centralized systems tend to be more vulnerable to attacks on critical nodes. For these reasons, centralized control is often exercised in peacetime; however, during conflict responsibilities and authorities are often delegated to lower levels of command.

(2) Decentralized Control

Decentralized control is possible the intermediate echelon CPs have defined ROE for their area of responsibility and the essential equipment and capabilities needed to operate with limited or no input from upper echelon CPs. If done correctly, little capability is lost over the centralized mode. Newer C2 systems allow CPs to receive inputs from multiple sources and minimize the stove piping that creates single points of failure in processes; therefore, loss of upper echelon CPs is not as critical.

Decentralized IADS can be further characterized as semiautonomous or autonomous systems. **(3) Semiautonomous Control**

In semiautonomous control, lower echelons operate under direction of the local area commander but may engage some targets autonomously, as permitted by the ROE. The amount of autonomy allowed is based on national operational doctrine, as well as the capabilities of the C3 system involved.

As an example of decentralized, semiautonomous control, the sector operations center sets ROE, which determines the degree of identification required prior to engagement, and provides an ASV picture to lower echelon units. Next, the SAM group CP can engage an ASV track in accordance with the SOC’s ROE (i.e., self-protection, type/class of target). The group CP will designate the track and pass it to one of its battalions to engage the target.

The advantage of semiautonomous control is that there is a shorter time between decision and execution, as the decisions are made at lower levels. Successful semiautonomous operations are dependent on effective ROE and efficient and redundant communications systems. When present, semiautonomous systems tend to be more resilient in the face of attacks on critical nodes, and can allow for graceful degradation as combat decisions are made at lower echelons. For these reasons, semiautonomous operations are often the control method of choice in wartime.

There are disadvantages of semiautonomous control, however. Situational awareness at the highest echelon, and even at the sector operations center-level, may be degraded. Horizontal coordination between sectors, or sub-sectors may also be hampered. The overall IADS may suffer in efficiency and the possibility of fratricide is increased.

(4) Autonomous Control

Autonomous control is normally practiced only when communication links are either disrupted or saturated. In these cases, the individual air defense system operators will operate without direction from higher authority and are forced to rely upon their own systems to execute the kill chain. Autonomous control anticipates that ROE will permit specific weapons units to autonomously engage threats for self-defense during wartime, even with a centralized IADS structure. For autonomous operations to be successful, sound ROE and training are critical.

As an example of decentralized, autonomous control, when communications, including the ASV feed, from the SOC and group CP are disrupted, the SAM battalion can use its collocated early warning or acquisition radar to generate an air picture. The SAM operator can then target and engage one of its self-generated tracks.

The advantage of autonomous operations is that there is little to no time delay as decisions occur at the lowest possible echelon. In addition, autonomous control structures are resistant to degradation from nodal attacks. Each sensor and weapon system is its own entity, its own node, and thus the concept of critical nodes becomes all but irrelevant.

The disadvantage of autonomous operations is that it becomes difficult to have any coordination between autonomous elements. Therefore, it may be difficult for the weapon system to get the cueing information required and there may be a dramatic drop in situational awareness across the board. While decisions are made quickly at the lowest level, they may be the wrong decisions and the chances of fratricide go up exponentially. All of these factors join together to make autonomous operations, generally, the most inefficient type of control.

Table 5-2

Strengths and Weaknesses of Control Types

Control Type	Strengths	Weaknesses
Centralized	- Highest echelon has air picture and situational awareness over all assets - Top-down control promotes most effective use of resources - Coordination between sectors performed at highest echelon - Lease chance of fratricide	- Highest echelon can be overwhelmed by sheer volume of information presented/displayed - Slowest processing and response times as information goes all the way up and then orders are passed all the way back down

		- Very susceptible to degradation or collapse through targeting of critical nodes - Not truly practical/effective in wartime situation - Less flexible, as orders must be received from higher up before actions are taken
Semiautonomous	- Decisions made at lower levels, while highest echelon still theoretically has situational awareness - Faster processing and response time as compared to centralized control - More flexible and resilient to attacks on critical nodes, as decision/engagement authority resides at lower echelons - Use of resources more efficient than autonomous operations, but potentially less efficient than centralized operations - More practical to successfully execute in wartime than centralized operations	- While air picture theoretically exists at highest echelon, overall situational awareness may be reduced - More difficult to coordinate between sectors and sub-sectors (but not impossible) - More dependent on sound ROE and effective communications - Higher opportunity for fratricide as compared to centralized operations
Autonomous	- Fastest response time as every element can carry out actions on its own authority - Most resilient to attack on	- Little to no situational awareness at highest echelons, and possible mid-level echelons

	critical nodes, as every element is its own node	- Difficult to coordinate between sectors, sub-sectors, and even individual elements - Situational awareness reduced across the board - Most inefficient use of resources - Highly dependent on ROE and training, almost to the point of being impractical to execute - Highest chance of fratricide

c. Methods of Integration

An IADS is an air defense system that is integrated. Integration implies deconfliction, but that may not always be the case.

Integration is “the arrangement of military forces and their actions to create a force that operates by engaging as a whole” (JP 1). Deconfliction refers to the process of avoiding interference or hazards (including fratricide) between or among systems being operated by a joint or combined force. A good IADS needs both.

The integrations of an Air defense system (to become an IADS) requires controlling air defense elements through a number of different mechanisms. Deconfliction between aircraft and GBAD is essential to prevent fratricide. While an IADS ideally integrates and deconflicts GBAD, such as ADA and SAMs effectively, the consequences of poor GBAD integration and deconfliction are not severe and usually involves a redundant engagement. The more severe consequences are from failing to properly integrate and deconflict between GBAD and aviation assets or between aviation assets. In that case, the consequences are fratricide.

In principle, integration and deconfliction is easy. In practice, beneath the fog of war, integration and deconfliction is exceptionally challenging. Countries with advanced equipment, sophisticated procedures, and realistic training, are still at risk for fratricide.

In 1994, during Operation Provide Comfort, the operation to maintain a no-fly zone over Northern Iraq, two US Air Force F-15Cs misidentified two US Army UH-60 Black Hawks as

Iraqi Mi-24 Hind helicopters and shot them down, killing 26 aboard. The resulting investigation faulted the F-15C pilots with misidentifying the UH-60s as hostile, an AWACS crew for failing to exercise appropriate control and to intervene, IFF systems aboard the UH-60s or the F-15Cs that failed to function properly, a lack of proper training in the ROE for the no-fly zone, a lack of radios aboard the UH-60s to communicate with the F-15Cs, failure of the US Air Force to adequately integrate US Army helicopters into overall Operation Provide Comfort air operations, and a lack of clear guidance from senior leadership. As seen from this historic example, integration and deconfliction is difficult and requires many moving parts to all work correctly. For most countries operating an IADS, the risk of fratricide outweighs the risk of true integration and therefore risk-adverse integration techniques are usually implemented (e.g., one area is covered by fighters, another by ADA/SAMs). In other countries, fratricide is accepted and an "if it flies, it dies" mentality is adopted.

The three kinds of integration available to an IADS are: physical integration, regional integration, and combined air defense systems. These integration methods are not exclusive of each other and an IADS can exhibit multiple kinds of them at once.

(1) Physical Integration

Physical methods are used in air defense systems to facilitate procedural integration. These include fighter aircraft, SAMs, ADA, and/or EA engagement zones, and safe corridors for ingress/egress of friendly aircraft.

Deconflicting weapon engagement zones sis an important part of physical integration. An IADS will implement ROE to govern which weapons will be used in a given zone. A missile engagement zone (MEZ) is an area where SAMs have the priority to engage airborne threats. Typically, friendly aircraft avoid the MEZ. A fighter engagement zone, or FEZ, is a block of airspace in which the fighter aircraft have primary responsibility for targeting airborne threats. A joint engagement zone, or JEZ, employs both SAMs and fighters in the same airspace and requires continuous, high-fidelity tracking and identification and a significant deconfliction to avoid fratricide. Based on the number and type of assets it has, as well as what a country needs to protect, threat nations have lines of defense. For example, a country may use its SAMs and corresponding MEZ along a border or coast line as their first line of defense. Fighters then cover the gaps in SAM coverage in the central portion of the country as a second line of defense. When a SAM (first line of defense) is destroyed, fighters (second line of defense) may fill that gap based on IADS direction.

(2) Regional Integration

The development of a regional or zonal IADS is another IADS employment option. This approach seeks to combine both strategic and tactical air defense capabilities into a single coordinated IADS, with a given area. In this IADS, integration is achieved primarily through interoperable C3 systems. These systems supply data from the available ASV sensors to senior echelon CPs or operations centers that control all strategic and tactical air defense weapons within the specified area.

(3) Combined Air Defense Systems

Countries may also interconnect their IADSs at the national level, in order to increase capability while minimizing additional investment. Integration between national IADSs may be facilitated by the use of common C3 and weapon systems in neighboring states, and other industrial interdependencies. Such an arrangement exists in the Combined Air Defense Systems, which Russia sponsors, and which integrates the IADS of several Commonwealth of Independent States members.

d. Integrated Air Defense System Components and Hierarchy

Most IADS possess similar components organized in separate echelons. Countries may possess different naming schemes but the following model is representative of many countries' IADS. At the highest echelon, the ADOC is responsible for the air defense of the entire country. For this reason, the ADOC is also sometimes known as the national air defense command center.

The sector operations center, which has control over an individual section of the country, is normally one echelon below the ADOC. For example, a country may have an ADOC in the capital city, and eastern and western sectors controlled by sector operations centers.

Most IADS have a number of collection and reporting centers subordinate to the sector operations center. Collection and reporting centers can be used to control actual intercepts, and are therefore sometimes known as intercept operations centers. While subordinate to them, collection and reporting centers are typically considered part of the same mid-level echelon as sector operations centers.

Finally, the lowest echelon consists of individual sensors and weapon systems. Reporting posts are typically comprised of individual early warning radar sites or LP/OPs associated with the ASV function. Reporting posts take uncorrelated tracks from sensors and output target tracks to the rest of the IADS.

e. Communications

The key to any C2 system is reliable communications among sensors, decision makers, and weapons systems. Communications networks can consist of fixed and/or mobile network nodes. Network nodes will be connected via one or more physical modes of communication, such as landline (such as copper or fiber-optic) or RF links (such as radio relay, HF radio, SATCOM, and cellular-based systems). Telecommunication switches are located at select communication nodes. These switches are responsible for routing information between network users. The communication network can support multiple types of communications. Voice circuits can be established to support passing audible voice and modem- based data communications. And over the past decades, network technologies have evolved allowing information (voice/data) in a digital data format. Computer networks are now set up to support passing data to multiple air defense assets providing a much-enhanced situational awareness at all levels.

The types, sophistication, and redundancy of the communications used in an IADS are critical knowledge for an air intelligence analyst. Communications can be broken into two broad categories with a number of sub-categories:

- Wireless
    - Omnidirectional
    - Directional
- Landline
    - Coaxial cable
    - Fiber-optic

More sophisticated communications systems are available as well, including SATCOM, cellular communications, and even laser communications. Each type of communication mode has its own inherent strengths and weaknesses (see table 5-1).

(1) Wireless

Omnidirectional systems generally work in the HF (3-30 MHz), VHF (30-300 MHz), or UHF (300 MHz- 3 GHz) frequency ranges. These radios are commonly used to connect command elements with mobile ADA/SAMs. These radios are also the primary means through which fighters are controlled by their GCI. They are vulnerable to wireless RF countermeasures such as jamming, intrusion, and exploitation.

Although few, there are disadvantages in using HF for air defense purposes. These are mainly low data rate, noisy communications, and large/bulky equipment. With low data rates during HF transmission, the amount of data being passed is less than that of other communications mediums at higher frequencies. Also, the clarity of communications can be susceptible to various types of interference. Due to the versatility and large coverage area of HF, it makes for a very crowded frequency band, thus it is difficult to find an open channel. Additionally, for two-way communications using HF, it is necessary to have a relatively large antenna. The length of the antenna is relative to the wavelength of the operating frequency (the lower the frequency, the bigger the antenna). This can limit the use of HF on aircraft.

Directional systems include microwave, troposcatter, and cellular. Directional radios are somewhat less vulnerable to jamming, intrusion, and exploitation, as compared to omnidirectional radios.

Directional systems which operate in the 1-100 GHz range are referred to as microwave communications. Microwave communications are limited to LOS and therefore use point-to-point relay stations, usually located at intervals of 5-20 nm.

Troposcatter systems operate in the 100 MHz-8 GHz range and also use relay stations, but at greater distances because troposcatter signals bounce off the troposphere, giving these systems extended rage (link distances can be between 30 -540 nm).

Many countries also purchase cell phones for their IADS elements because using pre-existing commercial capabilities is cheaper than digging trenches and laying cable for regular telephones. Some cell phone communications may also be transmitted over a landline, depending on how the network is configured. Cellular communications are typically not a secure means of communications and, therefore, not a primary communications method among military forces. Cellular communications are vulnerable to exploitation and degradation, but may be used when other means are unavailable (for instance, during primary communications equipment failure). As cellular technology evolves, the convenience of cellular networks may more frequently override security concerns.

In many cases, military commanders and essential personnel are provided government cellular phones for logistics purposes/official use. Possible security measures, such as periodic number changes, GPS scramblers, or encryption technology may be in place to protect information and mobile phone location.

(2) Data Link

One special form of wireless communication is the data link. Data links, such as the US and NATO Link 16, are a communications technology used to securely transmit tactical information. This can include missile guidance or disseminating information processed from radar, IFF information, and EW.

Data links may link fighters to airborne controllers, elements of ISR systems, and ground-based command and control. Data links can provide a range of combat information in near-real time all aircraft, ground vehicles, and ground stations in communications range equipped with the technology. Data links often involve the relay and sharing of information, allowing two nodes outside communication range to share information through intermediate nodes. The displayed information can share an integrated air picture with both friendly and hostile aircraft locations, general situational awareness data, and amplifying data on air and ground targets, including air defense threats. Data links can also be used to transmit targeting quality data between nodes, allowing one node to target for another node to engage. Data links used in this way contribute to the integrated control of fighters by either ground-based or airborne controllers and will greatly increase the fighters' SA and ability either to engage targets designated by controllers or to avoid threats, thereby increasing mission effectiveness and reducing fratricide and attrition.

(3) Landline

Landline is the most secure means of communication. Therefore, it is the preferred communication method among static forces because of its difficulty to counter or exploit. Landline is used to connect fixed communication facilities. Landlines can consist of copper cable (twisted-pair, coaxial cable), multi-conductor, or fiber-optic cable. Older copper cables are still in use, but are being replaced with newer fiber-optic cable technology.

Traditional landline communications consist of twisted-pair wire or coaxial cable, which are metallic conductors surrounded by an insulator material. Landlines can also include telephone cabling, including public switching telephone network and voice over internet protocol, or VOIP. The signal tends to attenuate as it progresses down the wire and therefore repeaters are set up at regular intervals to “clean up” the signal and re-send it on its way. Landline has the advantage of being cheap and relatively easy to lay.

Finally, fiber-optic lines are the most advanced form of landline communications. Fiber-optic cables use light to transmit information. Like traditional landlines, fiber-optics typically have repeater stations at distances of 18-30 nm. The advantages over coaxial cable are the large volumes of information that can be sent, and its small size and light weight.

Though some countries possess their own dedicated military landline networks, many countries choose to lease fiber-optic capacity from the civil communications network. By leasing capacity, the military gains immediate access to modern networks and is not burdened by the high cost of installing and maintaining its own dedicated military network. To alleviate security concerns, data is encrypted and transmitted over separate fiber strands to protect information from flowing over civil communication lines. Another option to secure data is the use of an encrypted virtual private network, which makes use of the public switching telephone network rather than physically-dedicated leased lines in a private network.

Table 5-1
Strengths and Weaknesses of Communications Modes

Communications Mode	Characteristics	Strengths	Weaknesses
Wireless			
Omni directional Radio	- 3 MHz-3 GH (HF, VHF, UHF) - Broadcast to anyone on the frequency	- Highly mobile, as there is no direct link between nodes	- Susceptible to exploitation and jamming/interference
Microwave	- 1-100 GHz (SHF, extremely high frequency - LOS, using point-to-point relay station (5-20 nm apart)	- Useful in rough terrain (as compa to landline) - Relatively inexpensive	- Needs relay stations at regular intervals - Susceptible to exploitation and jamming/interference (although directive nature makes it less so than omnidirectional)
Troposcatter	- 100 MHz-8 G z (VHF, UHF, SHF) - Utilizes relay stations (30-5 nm apart)	- Long range	- High power - Large antennas/footprint - Susceptible to exploitation and jamming/interference
Satellite	- 250-400 MHz (VHF, UHF), 7-8 GHz (SHF) or 20-40 GHz (EHF)	- Long range transmissions - Mobility (can use any receiver within the satellite footprint	- Expensive - Complex - Susceptible to exploitation and jamming/interference

Cellular	- 400 MHz (UHF, 900 MHz-1.8 GHz (UHF, SHF), 2.4 GHz	- Mobility	- Gaps in coverage - Susceptible to exploitation and jamming/interference
Landline			
Coaxial Cable	- Metallic conductors with insulator material - Repeater stations at regular intervals	- Less susceptible to exploitation and jamming/interference - Relatively inexpensive and easy to install	- Poor mobility - Can be degraded by environmental conditions/poor maintenance - Signal degrades as distances between repeaters increases
Fiber-Optic	- Uses light to transmit information - Repeater stations at 18-30 nm intervals	- Most resistant of these communications types to exploitation and jamming/interference	- Expensive - Signal degrades over long distances (as compared to cable)

5010. Integrated Air Defense System Analysis

Understanding the enemy is critical to the success of military campaigns. The history of modern warfare has shown the absolute necessity of achieving air superiority. Joint doctrine reflects and reinforces this necessity.

From the top-down, air superiority is achieved through offensive counterair (OCA) and defensive counterair. *Offensive counterair* includes “offensive operations to destroy, disrupt, or neutralize enemy aircraft, missiles, launch platforms, and their supporting structures and systems both before and after launch, and as close to their source as possible” (JP 3-01). *Defensive counterair* includes “all defensive measures designed to neutralize or destroy enemy forces attempting to penetrate or attack through friendly airspace” (JP 3-01). Suppression of enemy air defenses (SEAD) is a critical part of OCA. *Suppression of enemy air defenses* includes “activity that neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means” (JP 3-01). Effective IADS analysis drives the planning of the SEAD campaign. Looked at another way, from the bottom-up, IADS analysis drives SEAD, SEAD supports the OCA mission, OCA achieves air superiority, air superiority enables the joint and combined force to achieve its military end state.

As a part of this, IADS analysis is absolutely vital for effective targeting at the operational level. The first objective of any air campaign is to suppress the enemy's IADS. While it is not normally the role of Marine air intelligence to design a campaign to roll back an enemy IADS, air intelligence Marines will be called upon to support sorties that may be part of that campaign. During the conduct of any SEAD campaign, the details of IADS operation will change; the enemy will adapt tactics, critical nodes will be destroyed, and firing positions will shift. And in yet other cases, Marine aviation will be exposed to an enemy or potentially hostile IADS in the conduct of a mission whose primary objective is not SEAD.

In all of the above scenarios, air intelligence Marines must understand the principles of how to disrupt the effective operations of an air defense system, integrated or otherwise, to support and enable Marine aviators and aircrew. These principles will enable Marine air intelligence to "roll with the punches" as the battlespace shifts or unanticipated missions arise.

The goal of IADS analysis is not to admire the enemy but to complicate the enemy's targeting abilities sufficiently to enable mission success. As one operator put it, "don't tell me how good the system is; tell me how to present it the hardest problem set."

a. Understanding the Enemy

There are three fundamental components to understanding the enemy:

- **Disposition:** What does the enemy have, where, how many, what type, and how well maintained? These are fundamental OOB questions.
- **System Performance:** Of the systems in the OOB, what are they capable of, what modifications have been made, what associated or supporting equipment is available, and how effective is it? These are fundamental questions about the technical abilities of the systems in the OOB.
- **Training and Tactics Analysis:** What are the enemy's doctrine, training, and skills? What are the abilities of a system's operators? What is the human impact on the system's overall employment and capabilities, and effectiveness (human-in-the-loop factors)? These are questions about the inherent human interactions at every level of air defense system functions and these human dimensions (abilities, training, motivation, etc.) must be understood as they have a significant impact on any system's functioning.

When these three components of the enemy can be brought together and systematically analyzed, it becomes clearer which elements of an IADS is susceptible to targeting to produce the desired effects.

b. Nodal Analysis

Because an IADS is a complex system, the concept of nodal analysis, a systematic approach to support targeting, has natural applications. Nodal analysis offers a way to target the system as a whole, and with synergistic effects, as targeting a system's critical nodes theoretically results in a synergistic degradation of the overall target system.

The concept of nodal analysis is to figure out the most critical links and nodes in the enemy's system and to target them, producing a decisive, negative effect upon the enemy target system. Critical nodes are those components of a target system that have the most system functions linked through them, and consequently, whose destruction or serious damage leads to an overall degradation of the target system itself.

The concept of critical nodes is closely linked to the idea of targeting enemy centers of gravity. It can be applied to any type of targeting system, such as an enemy industrial capability, fielded enemy ground forces, or an enemy IADS. In the step-by-step targeting process, the analyst must first identify and understand the enemy target system, refine the target list to critical nodes and targets, and then confuse, deceive, surprise, or attack the critical nodes. In this way, the effectiveness of the overall system is compromised.

A number of military and intelligence agencies exist to support IADS analysis and any military operations to suppress, roll-back, or destroy an enemy air defense system:

- Joint Warfare Analysis Center's mission is to provide combatant commands, Joint Staff, and other customers with effects-based analysis and precision targeting options for selected networks and nodes in order to carry out the national security and military strategies of the United States during peace, crisis, and war.
- National Air and Space Intelligence Center's mission is to be the primary source for foreign air and space threats; and to create integrated, predictive intelligence in the air, space, and cyberspace domains enabling military operations, force modernization, and policymaking.
- Missile and Space Intelligence Center's mission is to support field commanders, weapon system developers, and policy makers with scientific and technical all source intelligence on SAMs, short range ballistic missiles with ranges less than 1000 km, anti-tank guided missiles, missile defense systems, directed-energy weapons, selected space programs and systems, and relevant command, control, communications, computers, intelligence, surveillance, and

reconnaissance.

- National Ground Intelligence Center's mission is to provide all source and GEOINT on foreign ground force capabilities (including ADA) and related military technologies and integrates with mission partners to ensure the US Army, DOD, Joint, and national level decision makers maintain decision advantage to protect the US and interests abroad.
- Office of Naval Intelligence's Naval Warfare Department mission is to provides detailed analysis of naval warfare threats posed by foreign weapons systems and countries of interest by leveraging the tactical expertise of Fleet experienced submarine, air, surface warfare and information dominance officers and Sailors against the long-term analysis of a career civilian intelligence workforce. Naval Warfare Department supports operational commanders, mission planners, naval warfare development centers, and the national IC with unique and penetrating TTP assessments. The Strike Protection Evaluation and Anti-Air Warfare division serves as the air warfare element of the Naval Warfare Department.
- The mission of US Air Force Tactical Analysis and Reporting Program, or TARP, is to provide analysis and evaluation of operational tactics, training, and employment of air, air defense, space, and cyberspace forces of potential adversaries. Tactics Analysis and Reporting Program information is presented with an operational perspective to support tactics development, operational planning, and threat replication training. Tactics Analysis Team reports are one of the primary products of Tactics Analysis and Reporting Program.

c. Analytical Considerations

The following are considerations for the analyst evaluating the threat posed by an IADS.

(1) Degree of System Integration

This is the ability of the constituent parts of the IADS to effectively coordinate assigned missions, in addition to the effective use of physical deconfliction methods, such as engagement zones, safe corridors, IFF, altitude, and layering.

(2) Command, Control, and Communications Effectiveness

Effectiveness is determined by the ability of the IADS C3 systems to support the mission by ensuring adequate responsiveness, communications paths, network redundancy, sufficient data flow (level of automation versus manual capabilities), and minimization of critical node failures.

(3) Battle Management, Decision making, and Weapons Control Capability

The ability and authority of the IADS commanders at all levels to make effective decisions, target assignments, and assign appropriate weapons to targets. This capability is based on education, training, culture, experience, political motivation, loyalty, and doctrine.

(4) Weapons Capabilities

This is determined by specific weapon systems, their range and performance envelopes, target handling capacities, types of fire control systems (e.g., optical versus radar), and mobility.

(5) Air Surveillance System Capabilities

This is determined by the country's systems, their individual range and performance capabilities, and their ability to be employed in a coordinated fashion to detect and identify the air threats.

(6) Effectiveness of Doctrine

This is measured by the success with which the country's air defense doctrine deals with a variety of potential airspace intrusion adversaries, across a range of foreseeable levels of conflict. Doctrine is determined by government policy, decision making authority, operational concepts, and established local ROE. Doctrine can also be determined by procedures outlined in exported doctrine, adapted to a particular country's needs, or indigenously developed.

(7) Training Effectiveness

This is a function of the level of sophistication, realism, frequency, and ability to incorporate new technology and information present in a country's training processes. Doctrine may force training events to be highly-scripted, while manpower constraints limit the extent and frequency of training, both in terms of the trainers and the training audience. Even with modern hardware, there are many aspects that can limit the tactics developed and performed.

(8) Adaptability to Combat Stress

This is the ability of the IADS to maintain its resilience in the face of high operational tempo, extended alert duty, lack of personnel, and loss of personnel and equipment during combat operations.

(9) Quality of Indications and Warnings

This impacts how prepared an IADS is to handle the peacetime to wartime transition and engage hostile airborne threats. Once warning is received, components of the air defense system resort to a higher state of readiness in preparing to carry out the mission, and reliable I&W may enhance the endurance of the IADS, as it will be able to transition to lower states of readiness when I&W is lacking.

(10) Logistics Preparedness

This includes the availability of combat loads of missiles, ammunition rounds, fuel, food, and other materials, along with the maintenance and repair capabilities needed to sustain combat operations. System reliability depends upon logistics preparedness. At the highest state of technical and personnel readiness, an air defense system can be very successful in conducting its assigned missions. Continuously maintaining this state of readiness, however, is difficult on all aspects of the logistical system.

5011. Jammers

Jamming is the intentional emission of RF signals to interfere with the operation of a RF device (e.g., communications, radar, RWR) by targeting the receiver with clutter or false information. The effectiveness of jamming is normally measured by the jamming-to-signal ratio, which compares the strength of the ECM jamming (often from the target) to the strength of the desired signal (often the desired target's radar return, but this may also include communications or other EM signals). This ratio is expressed in dB. The strength of a jamming signal usually must exceed the targeted signal by a given amount to be effective, therefore successful jamming would be expressed in a positive dB figure.

When strength of the ECM jamming does not sufficiently exceed the desired target's radar return signal (or other targeted signal), the concept of "burn through" comes into play. Burn-through range is the range at which the desired signal can first be detected through the jamming signal. As an aircraft approaches a detecting radar, its return will eventually be larger than the jammer is capable of generating. At this point the approaching aircraft is visible to the radar operator.

Jamming can degrade or entirely deny communications (including voice and data link), navigational information, and collection or detection equipment. Jamming can also be exploited for targeting, such as in systems that can home-in on the jammer.

Airborne jammers include self-protect jammers such as those found on many modern fighters, as well as escort jammers, designed to provide strike formations with supporting electronic fires. Jamming can be done through mechanical or electronic means.

a. Mechanical Jamming

Mechanical jamming consists of jamming techniques in which no RF emissions are made. Three common examples include chaff, corner reflectors, and decoys.

Chaff is made of small metallic strips of different lengths. The lengths are optimized to reflect radar waves of specific sizes and can therefore be tailored to specific threats. When released in the air, chaff reflects radar waves, creating large returns that can cause radar systems to misidentify chaff as a target, mask a target, and confuse radar operators. Chaff can be combined with EM jamming where a jamming signal is emitted through the chaff, amplifying both the effectiveness of the jamming signal as well as the chaff.

Corner reflectors behave in a similar fashion to chaff, designed to reflect RF energy back at its source, creating a strong return that is not the target. These are often employed in defense of ground units, vehicles, or buildings and create a false return that can mask or distract from the true target. Corner reflectors can also be employed on decoys.

Decoys are flying objects that may be small in size, but are designed to have a large RCS to mimic a true target (and complicate engagement), mask the true target, or otherwise confuse the radar operator. These can be towed behind aircraft or launched as missiles.

b. Electromagnetic jamming

Electromagnetic jamming consists of jamming techniques in which RF signals are emitted to cause clutter or false returns.

Because the emitted signals are not reflections from the radar being jammed, those signals must be polarized in the same fashion as the jammed radar, otherwise the receiver will not be affected.

(1) Types of Electromagnetic jamming

Electromagnetic jamming falls into two main categories: noise and repeater jamming.

Noise jamming is a continuous signal radiated with the objective of concealing the target return from the enemy radar. In order for it to be effective, it must have an average amplitude at least as great as the average amplitude of the target return. As a result, *burn through* can occur where the emitted radar (and resultant target return) or communication energy is more powerful than the jamming energy and the jammed device can “see through” the jamming and discriminate the true target or signal. There are three major categories of noise jamming that are grouped by how jamming power is concentrated: spot, barrage, and sweep jamming.

Spot jamming is narrowband jamming concentrated against a specific radar or communications devices at a particular frequency. *Frequency agile* radars or communications equipment that can alter their emitted frequency (and thus look for signals or target returns in that changed frequency), either as a matter of normal operation or in response to jamming, can mitigate the effectiveness of spot jamming.

Barrage jamming is noise jamming spread in frequency to deny the use of multiple radar or communications frequencies to effectively deny information (communications or range). Because the jammer is emitting across multiple frequencies, the power emitted in any one frequency is lower than in comparable spot jamming.

Sweep jamming mixes spot and barrage jamming through narrowband jamming which is swept through the desired frequency band to maximize power output. This technique is essentially sweeping spot noise to create barrage jamming, but at a higher power. This can be highly effective against systems without error correction or countermeasures

Repeater jamming differs from noise jamming in that it manipulates received radar energy and re-transmits it, causing the targeted radar to see a manipulated or false target return.

5012. Unmanned Aircraft Systems

An UAV is a powered aerial vehicle that does not carry a human operator. The vehicle can be expendable or recoverable and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs. A UAV is only a part of a UAS. Unmanned aircraft system capabilities vary widely based on the size and functional design of the UAV it supports. There are multiple UASs but they can be grouped by size and capabilities. Unmanned aircraft systems are attractive for their low cost, versatility, long endurance, and avoidance of risk to aircrew.

Unmanned aircraft systems have also been known by a variety of other names including unmanned aircraft (UA), remotely piloted aircraft (RPA), and remotely piloted vehicles. The term ‘drones’ is frequently applied to these types of aircraft by public media outlets, but a drone is controlled autonomously by computers without human intervention so it is not included.

Unmanned aircraft systems are equipped with a variety of radio transceivers and video downlink equipment to broadcast and receive directly from the aircraft. There are three types of radios on board the UAS: control, full-motion video (FMV) distribution, and coordination.

a. Components

The term UAS is used to describe the entire complex that commands the UAV and receives information from the UAV. Unmanned aircraft systems are comprised of several components, which generally include:

- One or more air vehicles (the UAV)
- The payload on the UAV
- A ground control station (GCS)
- Data link
- Various ground support equipment

The air vehicle is the aircraft part of the UAS. The size and shape of the UAV varies greatly depending on mission requirements. Because of this, UASs are categorized based on the air vehicle. A high-performance air vehicle gives commanders more options in choosing targets for UAV missions. More importantly, larger air vehicles can carry heavier and more capable payloads.

The value and purpose of the UAS is derived from the payload it can carry. Unmanned aircraft systems are primarily employed as ISR assets. A typical ISR payload option for many UAVs combines EO and IR video cameras for day and night operations. UAVs can also be equipped for air-to-ground strike, EA, and SIGINT collections missions. Targeting or ISR payloads may be interchanged to provide mission flexibility with little or no airframe modification or minimal operator training.

The GCS is the human interface with the UAV and payload. Payload and aircraft operators provide inputs to the air vehicle, and payload feed and aircraft telemetry are downloaded. The GCS can vary in size from handheld to truck-mounted.

The data link is the electronic connection between the GCS and the UAV. The data link typically consists of a command uplink, a telemetry downlink, and a payload downlink. Most UAVs also have a backup command uplink. These data links may be restricted to LOS operations; however, more advanced systems are increasingly adding SATCOM capability.

The ground support equipment may include launchers, recovery equipment, and spare parts.

b. Missions

Unmanned aircraft vehicle missions can be preplanned and flown autonomously, or dynamically controlled via man-in-the-loop. These break down into the following categories:

- ISR
- EW
- Attack

(1) Intelligence, Surveillance, and Reconnaissance

Unmanned aircraft systems traditionally are used as ISR platforms. Sensors used for ISR include: EO/IR video cameras, LLTV, SAR, maritime patrol radars, ground mapping radars, light detections and ranging, multispectral imagers, and hyper-spectral imagers.

The quality of the imagery a UAS can collect depends greatly on the sophistication of the user country and the size of the UAV. Despite being less sophisticated than satellite imagery systems, UASs can provide usable imagery due to their relative proximity to their target. In addition to still photos, many UASs provide both daylight and IR video capabilities which, depending on the system, can be exploited post-mission or in NRT via data link.

Both COMINT and ELINT collection suites are available for SIGINT collection. Countries that do not have the capability to develop SIGINT payloads are often able to buy UASs with SIGINT suites from producer countries that do.

(2) Electronic Warfare

Electronic warfare is becoming an increasingly common mission for UASs, encompassing both EA and ES.

Unmanned aircraft systems use two primary techniques to accomplish EA missions—denial jamming and deception. Current UAS-based EA systems mainly target voice communications and PNT systems.

(3) Attack

Attack missions include any mission with the intent to physically disable to destroy a target. Many UAV payloads have a single ball turret that incorporates an EO camera, laser designator, and laser rangefinder to facilitate target identification, designation, and attack.

Strike missions include air-to-ground attack. This may be carried out by dropping ordnance on a target, or a one-way lethal attack on a target.

SEAD missions are carried out via non-lethal and lethal one-way attacks. These missions are separate from strike missions, as UASs performing SEAD missions are typically equipped with an antiradiation seeker or EO control system.

Unmanned aircraft systems are also employed to act as short- and long-range artillery targeting asset. They locate targets and provide immediate feedback to artillery control centers on whether artillery fire is accurate.

Future UASs may be equipped with counterair capabilities.

b. Categories

Unmanned aerial systems are typically categorized based on their size and mission, though other factors are considered.

Reference to a “group” of UASs normally refers to a combination of the physical size of the UAV itself, normal operating altitude, and air vehicle speed. UASs are grouped in one of five categories (groups 1-5) as depicted in the table 5-3. Grouping of UASs does not specifically require system capabilities or sensor configurations, but may hint at inclusion of capabilities. Groups 1 and 2 are generally considered man-portable UASs. Groups 3 and 4 are generally considered tactical UASs. Group 5 systems are generally considered theater UASs. The majority of UASs in use today fall into the group 1 or 2 UAS category, with only larger, more technologically advanced countries developing or operating UASs in other groups

(1) Man-Portable Unmanned Aircraft Systems

These UASs are small, self-contained, and portable. They usually operate below the coordinating altitude. Their use supports the small ground combat teams in the field. Generally, they are controlled by a single individual who also views the sensor images on a small laptop-type computer. Their payloads are often limited to fixed EO/IR sensors and their performance (altitude, range, and speed) are equally limited to local use. The command and control for these systems is simplified by design and generally include only the supported element or UAS personnel team or member. Man-portable UAS characteristics include:

- Self-contained and controlled at the combat team level
- Data is usually direct FMV constrained to LOS to the operator only.
- Data is usually restricted to the operator level but may be disseminated to brigade or battalion tactical operations centers.
- Imagery processing/interpretation is limited to the combat team or operator.
- Communications are independent of the system

(2) Tactical Unmanned Aircraft Systems

Tactical UASs are larger systems that support maneuver commanders at various tactical levels of command and can also support small combat teams. For example, a combat team fitted with a remote video terminal can receive direct downlink imagery from the supporting tactical UAS. These UASs are capable of supporting tactical levels of command, such as battalion- or brigade-level, as well as combat teams. Tactical UAS characteristics include:

- Deployable among the tactical command levels and are operated by specialized UAS units—locally controlled and operated.
- Data products can expand beyond FMV depending on UAS payload configuration.
- Data can be disseminated to combat teams in real-time FMV via remote video terminal and/or distributed among supported tactical command elements.
- Data processing, product assessment, or initial observation reporting may occur within the UAS unit or be forwarded to an intelligence support unit.
- Communication architecture may include some or all of affected command elements, combat teams, UAS units, and supporting intelligence units. Communications may be limited to LOS or via UAS if communication relay capable.

(3) Theater Unmanned Aircraft Systems

Theater UASs are generally deployed to support theater-wide requirements. Theater UAS permit varied support to combat teams and subordinate tactical command levels depending on the type of UAS. Theater UAS characteristics include:

- UAS design and robust C2 architecture permit split-site operations. Specifically, the UAS can be deployed to theater with mission command and control and data collection, processing, and dissemination being conducted locally or outside of the theater of operations under “reach-back” conduits.
- More capable payloads permit more diverse data products that are generally produced in greater volume and scope.
- Data processing is supported by specialized intelligence units via “reach-back” connectivity and/or locally at the theater level.
- Data products are disseminated via direct links or supporting intelligence networks.
- Communication architecture is the most robust and may include some or all of supported command elements, combat teams, UAS units, and intelligence units.

Table 5-3 Unmanned Aircraft Systems Groups

UAS Category	**Maximum Gross Takeoff Weight (lbs)**	**Normal Operating Altitude (ft MSL)**	**Speed (KIAS)**
Group 1	0-20	< 1,200	100
Group 2	21-55	< 3,500	< 250
Group 3	< 1,320	< 18,000	> 250

Group 4	> 1,320		Any
Group 5		> 18,000	

d. Payloads

Payloads carried aboard UAVs can be broken down into:

- Cameras
- Sensors
- Radars
- EA
- SIGINT
- Weapons
- Audio broadcast equipment
- Communications relay equipment
- Spraying equipment

(1) Cameras

The EO video camera is the most often-used payload on modern UAVs. They are easy to obtain and little training is required to interpret the imagery. Power and weight are typically low. It is limited by the need for sufficient illumination to operate and cannot see through haze and clouds. This camera is most adequate for positive identification on specific targets because of its ability to detect colors, structures, and materials. Pairing the EO camera with an IR video camera enables day and night operations.

The IR camera is the second most used payload on modern UAVs. Uncooled imagers are fairly easy to obtain versus their cooled counterparts. Cooled systems are more desirable than uncooled imagers due to better sensitivity and the ability to see targets at longer distances. The IR image may require some training to properly interpret since the observer is seeing transmitted and reflected heat. Resolution is typically less than that of a daylight video camera.

A thermal imager converts an IR scene into a visible image or picture that is then presented to an operator. The scene presented to the operator is limited to the imager's FOV; however, the sensor may be slewed to provide a larger viewing area. Because there is no search capability with an imager, this type of sensor will be more effective when given good cueing information.

(2) Sensors

While IRSTS are not generally found on UAVs today, as UASs expand into the counterair mission, IRSTS are a natural sensor to equip UAVs with. Given the potential for LO UAVs and their ability to achieve maneuverability and endurance that is impossible for manned fighters, IRSTS may be a natural targeting sensor for future counterair UASs.

Systems conducting geospatial ISR missions may be equipped with LIDAR sensors.

Low light television utilizes a camera sensitive to wavelengths above normal visible wavelengths and into the shortwave IR, usually to about 1-1.1 μm. This allows viewing of objects in extremely low light levels (after sunset), where they would not be seen by the naked eye from altitudes that UASs fly. Unlike IR, a light source such as streetlights or automobile headlights is needed to make full use of the LLLTV function. Also unlike IR, LLLTV does not function well in the daytime.

Multispectral imaging sensors are able to produce a color image from a set of images taken at different intervals of continuous wavelengths (bands). Much as the human eye sees visible light in three bands (red, green, and blue), spectral imaging divides the spectrum into many more bands. This technique of dividing images into bands can be extended beyond the range of visible light. The advantage of multispectral imagery is the ability to discern different materials through their spectral signature. This information can be transferred into intelligence and aid in the analysis of targets. Multispectral cameras usually have a near-IR or other band which separates them from standard imagers.

Hyperspectral imaging is similar to multispectral imagery; however, the size of the intervals of continuous wavelengths is much smaller than that of multispectral images, giving the appearance of having a continuous spectrum. This ability allows the users to passively identify materials, including solids, liquids, and some gasses.

Unmanned aircraft systems may also be equipped with spectrometry sensors. A spectrometer is an instrument used to measure the properties of light over a specific portion of the EMS, producing spectral lines and measuring their wavelengths and intensities, typically used to identify materials.

A mine detector payload for a UAV is a standoff detection system using a variety of detection technologies such as thermal imaging and EM inspection techniques. These technologies are limited by a variety of factors such as atmospheric conditions, soil conditions, vegetation, mine size, physical composition of the mine, burial depth, thermal changes, and grazing angle of the sensors.

(3) Radars

As UASs become more common and advanced, especially as they evolve into the counterair role, AI radars and AEW systems are likely to be incorporated into UAV payloads, either to augment manned systems or to eventually replace them.

Maritime patrol radar is an airborne surveillance radar designed to detect the movements of surface ships. Sea clutter is moderate in comparison to ground clutter, allowing maritime patrol radars to see small vessels at long ranges. With the vast areas involved with the sea domain, the long endurance of UAVs make them an ideal platform for maritime patrol radars, especially when augmented with sensors designed to detect a vessel's wake.

Synthetic aperture radar can scan large geographic areas and produce high-resolution reconnaissance imagery. The motion of the sensor platform (airborne or space) and the repeated radar returns from a specific area are combined to generate the imagery.

Moving target indication is a mode of operation of radar to discriminate a target against clutter. The most common approach takes advantage of the Doppler effect on radar when an object is moving toward or away from the sensor array. For a radar pulse, the phase of the radar return from the target will be different from the returns from surrounding clutter. For targets moving across the ground, this mode is usually referred to as ground moving target indicator. Synthetic aperture radar may also be used for maritime detection

(4) Electronic Attack

Unmanned systems may be equipped with satellite navigation jamming, radar jamming, or communication jamming payloads.

(5) Signals Intelligence

Unmanned aircraft systems may be equipped passive SIGINT or ES sensors used to monitor an area for various electronic emitters. These can be used to tip off the pilot or another platform of activity in an area.

(6) Weapons

Unmanned aircraft systems can be equipped with a wide variety of weapons.

Air-to-surface munitions are most common and range from unguided bombs to laser-guided missiles.

Lethal UAVs are equipped with an integrated warhead, usually with high explosive, fragmentation type blast patterns. These warheads typically use a fuze, such as contact or proximity, to trigger the detonation. Lethal UAVs are typically equipped with some type of seeker to guide the UAV to target. These seeker types include antiradiation, EO, radar, and IR. Lethal UAVs equipped with seekers may have an on-board threat library, comparing what they are detecting against known threat systems.

Laser illumination or IR systems aboard UAVs can be used to visually-designate a target, enabling supported forces using compatible optics to visually see what the UAV is designating. Laser designation systems allow UASs to identify and lase targets for manned aircraft or ground forces. In addition, strike-capable UAVs can self-lase targets.

Often in the same package will be a laser rangefinder. These systems are critical in accurately determining distance from the UAV to the target which is essential for using weapons.

(7) Audio Broadcast Equipment

Audio broadcast equipment allows for prerecorded or live announcements to be broadcast to wide coverage areas. Unmanned aerial vehicles equipped with this equipment may be used in information warfare operations.

(8) Communications Relay Equipment

Communications relay equipment is used to relay radio transmissions from selected originating transmitters. Systems equipped with relay equipment allows other UAVs, manned aircraft, or ground forces to increase the range of their data links or voice communications and to overcome LOS limitations or obstacles.

(9) Spraying Equipment

Designed for dispersing agricultural chemicals, UAVs equipped with spraying equipment could be modified for use with chemical or biological weapons.

e. Non-State Actor Threat

Unmanned aircraft systems are no longer the purview only of nation states. In recent years, small commercial UASs are becoming increasingly available. They are small, inexpensive, and not dependent on airfields. Their portability allows them to be deployed from virtually any location. Such systems do not require an extensive amount of mission preparation, ground or maintenance infrastructure. They can be tasked at a moment’s notice and redirected in real-time. Small, commercial UASs are easily modifiable and some are even developed with the intent of carrying payloads (both sensor and external payloads). Some are developed and sold with encrypted and frequency-hopping data links.

These small systems can prove difficult for conventional air defense radars to detect given their small RCS and low, slow flight profiles. Their diminutive size also makes them challenging, if not impossible, for fighters, helicopters, and many conventional GBAD systems to detect and engage. These systems can be easily modified to carry ordnance for two- way attack missions or armed with explosives for one-way attack missions.

Their presence on the future battlespace will only increase. And while they don't pose a significant threat to air superiority in the sense that they deny airspace to US aviation assets, they challenge air superiority in that they expose US forces on the ground (including airfields) to air threats that conventional systems cannot easily counter.

5013. Cyberspace Operations

The MAGTF and Marine aviation is increasingly networked and reliant on cyberspace, integrated circuits, data sharing, and technology in general.

Anything with an integrated circuit and an ability to receive data is potentially vulnerable to attack through cyberspace.

Cyberspace is "a global domain within the information environment consisting of the interdependent networks of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers" (JP 3-12, *Cyberspace Operations*). Cyberspace consists of many different, and often overlapping, networks, as well as the nodes (any device or logical location with an Internet protocol address or other analogous identifier) on those networks, and the system data (such as routing tables) that support them. Cyberspace can be described in terms of three layers: physical network, logical network, and cyber-persona.

The *physical network* layer of cyberspace is comprised of the geographic component and the physical network components. It is the medium where the data travel.

The *logical network* layer consists of those elements of the network that are related to one another in a way that is abstracted from the physical network (i.e., the form or relationships are not tied to an individual, specific path, or node). A simple example is any Web site that is hosted on servers in multiple physical locations where all content can be accessed through a single uniform resource locator.

The *cyber-persona* layer represents yet a higher level of abstraction of the logical network in cyberspace. It uses the rules that apply in the logical network layer to develop a digital representation of an individual or entity identity in cyberspace. The cyber persona layer consists of the people actually on the network.

a. An Enterprise Problem

A cyber attack may be something as simple and overt as the denial of a C2 network. Or it can be something as complex and clandestine as changing battlespace overlays in C2 software to cause confusion, blue-on-blue engagements, and erode the overall trust of friendly forces in their C2 systems.

Cyberspace operations threats are an enterprise problem because ACE commanders rarely control the attack surfaces vulnerable to cyber-attack. Security policies, equipment, and software selection are often established at higher headquarters or at the service/enterprise level.

As a consequence, if an ACE commander were to become aware of a vulnerability within the unit's mission planning software or the ASE aboard the aircraft, the commander would have no ability to devise and implement a solution to the problem, only to put mitigation measures in place. And mitigation in this instance is often reduced to redundancy of systems (or variety of systems), capability for continuity of operations without the use of cyberspace (e.g., pen and paper), and/or avoiding threat environments during the vulnerability.

While media and entertainment often depict or warn about sophisticated and dramatic cyber-attacks, like any other military operation they are often based on a critical factors analysis and follow maneuver doctrine and effects-based planning. Just as it is easier to crater a runway to prevent aircraft from ever taking off than to individually destroy each aircraft, it is easier and preferable to degrade Marine aviation by denying network connectivity to prevent a squadron from receiving an ATO or weather forecasts than it is to crash the aircraft by disrupting critical avionics in flight. Thus, a cyber-attack is more likely to look like disruption of a Web site where a concept of operations (CONOPS) is collaboratively built than to look like a timed and obvious computer hack.

Cyber operations continue to require exquisite intelligence to plan and execute and can sometimes be invalidated with a routine software patch or upgrade that negates months of planning.

Many cyberspace-enabled systems (directly and indirectly) supporting Marine aviation are not operated by the MAGTF (from commercial satellites carrying military communications to the logistics systems operated by the contracted companies providing life support functions like the dining facility), providing the MAGTF limited awareness of vulnerabilities and attacks or the ability to mitigate vulnerabilities and attacks.

Furthermore, tactical actions to defend or mitigate against cyber-attacks are often limited to practicing good information assurance, operations security (OPSEC), information and intelligence sharing, and maintaining non-electronic or off-line backups of critical information (e.g., CONOPS, intelligence estimates, maintenance records, etc.).

b. Attack Surfaces

Cyber-attacks can happen against any critical factors of an aviation unit and not just against the unit's aircraft or in-flight. While these critical factors will vary slightly between TMS, individual units, and deployments and missions, same examples include the following:

- Maintenance and logistics networks (for both the MAGTF and ACE as well as other echelons supporting the ACE) and systems to including systems such as Naval Aviation Logistics Command Management Information System or Automatic Logistics Information System.
- Flight planning and mission briefing systems and software such as Joint Mission Planning System or PowerPoint®.
- Flight control systems including C2 systems within the MACCS and UAS control systems.
- Data link such as Link 16 or Blue Force Tracker.
- Flight line operations support and life support (e.g., berthing and dining facilities) systems or supervisory control and data acquisition systems that may control electricity, generators, fuel pumps, etc.
- Avionics including systems that may be vulnerable to malicious or manipulative RF injection signals or the Web sites and network connections that provide software and firmware updates.
- Any digital communications systems such as voice and data communications.

Cyber-attacks can also happen outside aviation operations. These attacks can range dramatically in technique, scope, and impact.

Attacks can impact the industrial supply chain, crippling the designed capabilities of systems, implanting hidden malicious code that can beacon out or activate on command or after a certain time, or simply degrade the supply chain's ability to supply replacement parts, new systems or airframes, or other prerequisites for operations.

Attacks can also target weapon system development itself, exfiltrating hardware designs and software code during development, exposing to the enemy vulnerabilities of new weapon systems and reducing the relative advantage of US or allied systems as advanced designs are copied.

c. Evaluating Attack Surfaces

Evaluating every attack surface is a challenging task. MSHARPP (mission, symbolism, history, accessibility, recogonizability, population, and proximity) or CARVER (criticality, accessibility, recuperability, vulnerability, effect, and recognizability) analysis can aid in this process, but there exist a few principles in the process.

The more complex a piece of equipment or software is, the more numerous it's components, and the more complex the computer code that operates it, the more likely it is that a flaw exists. The more widely used a piece of equipment or software is, the more likely that the flaw has been discovered and exploited. And the more niche a system, the less likely it is to be robustly defended (e.g., ASE is not protected by network defenses). Enemy access to the system (i.e., commercial software versus software designed and deployed exclusively for US government use) also increases the likelihood of discovered and exploited vulnerabilities. And when equipment and software is considered by the enemy to be a high payoff target (e.g., schematics and software code for an advanced weapon system), the more likely it is to be targeted for exfiltration and exploitation.

Likely cyberspace targets will be—

- Critical to the operational mission (just as in lethal targeting, not all targets are desirable to strike, in cyber warfare, not all systems are desirable to attack).
- Easily accessible through cyberspace (which is not always the same thing as being connected to the internet or having an internet protocol address—targets can be accessed or effects triggered through RF or through other EMS emissions or close-access network operations).
- Vulnerable to attack (i.e., exploitable flaws exist and are known to the enemy).

5014. Adversary Doctrine

The definition of the term doctrine varies from nation to nation and, within any given nation, from branch to branch of a government and, within a military, from the joint force (or equivalent) to the services and components of those services.

In US terms, doctrine "specifies the authorized command relationships and authority that military commanders can use, provides guidance for the exercise of that military authority, provides fundamental principles and guidance for command and control, prescribes guidance for organizing and developing joint forces, and describes policy for selected joint activities." (JP 1). In more general terms, a nation's doctrine dictates how that nation's military will man, train, and equip to fight a conflict.

This makes doctrine important because it can help the intelligence analyst understand how the adversary will array and broadly employ their forces.

Doctrine is informed by many high-level strategic and political concepts, values, and decisions that are difficult to quantify but which trickle down to the lowest levels of warfare.

For example, a nation's political values can be a significant factor in its doctrine. One nation's centralized and authoritarian leadership philosophy may cause its doctrine to be extremely hierarchical and inflexible. Another nation's democratic values and belief in the value of the individual may cause its doctrine to put more decisions in the hands of subordinate units and provide for flexibility and variety.

Or a nation's political alliances over the last half century may have shifted, forcing them to seek compatibility with different military alliances or opening up new weapons acquisition opportunities. Ultimately this may have caused them to adopt the doctrine and weapon systems of a new geo-political power.

Because the impact of national values or strategic decisions are challenging to apply to intelligence support of the MAGTF and the ACE at the tactical level, it is often easier to understand and quantify a nation's doctrine through the lens of its weapon systems.

The weapon systems that a nation fields often relate very closely to the warfighting doctrine of that nation. A nation's doctrine can have an equally significant impact on the weapon systems that nation chooses to acquire and deploy.

Acquisitions decisions can be impacted by a nation's economic capabilities, military budget, technological capabilities, sanctions, foreign relations with other weapons-producing countries, and many other factors. Certain kinds of air and air defense weapon systems are especially expensive both in materiel costs (purchasing the system), network costs (purchasing compatible systems including data links, etc.), and training costs (enabling operators to use complex and sophisticated systems effectively under combat situations).

For these reasons, less wealthy nations may not have the option of a doctrine which emphasizes technologically sophisticated fighters with tactical data links to supporting AWACS. Those nations may be forced to rely on less expensive GBAD. Other nations may have purchased sophisticated fighters but lack the funds to adequately train their pilots or maintain expensive systems, forcing them to revert to a less complex and more centralized doctrine for systems technically capable of more autonomous operations. Yet other nations may have the money to purchase and maintain complex systems that entail great prestige but culturally are not open to the humility required for intense and realistic training in which they would have to admit to faults in order to learn and improve.

All these factors can have a high degree of influence on the doctrine available to or employed by a nation.

Understanding how flexible an adversary’s doctrine can be is also important to effective analysis. There are cases in which a nation’s doctrine is adhered to under peacetime conditions but abandoned in a conflict. There are also cases in which a nation doesn’t follow its own doctrine closely at all, sometimes choosing more expedient options.

Doctrine can also evolve over time as its effectiveness is validated or invalidated, as new technology enables change, or as a nation’s strategic concerns, allies, and enemy’s shift. This process is often slow. But in periods of intense conflict, shifts can take place rapidly as theoretically- or ideologically-sound doctrine is abandoned for what is practical.

a. Characteristics to Evaluate

An adversary’s doctrine can be evaluated by a wide range of characteristics. There is no comprehensive rubric against which to evaluate any adversary’s doctrine and the nuance of any one specific nation’s doctrine can mean two very similarly trained and equipped militaries are employed in significantly different ways. However, the following characteristics and questions can help guide evaluation of doctrine.

(1) Command and Control

How is command and control exercised? Is it hierarchical or flat? Who is empowered to make decisions and at what level? Is independent thinking or risk-acceptance tolerated or are subordinates likely to always defer to a higher headquarters? How resilient is the doctrine to disruptions in communications? Where is risk accepted? Where are ROE decisions made?

What is the acceptance level of fratricide or collateral damage? What are the triggers for different alert statuses? How are ROE, readiness levels, recall status, CAPs, arming of air defense systems different under those alert statuses?

(2) Strategic and Tactical Air Defense

Are there separate weapon systems, forces, and command and control in place for strategic air defense versus tactical? How integrated or subordinated is tactical air defense to ground forces?

(3) Training

Where is the training in an IADS? Is it in the cockpit or GCI (or air-controlled intercept)? How is this manifested in weapon system design? Are aircraft engineered to have high degrees of situational awareness with tactical data-links and user-friendly controls? Or are aircraft designed to be mere engagement platforms with situational awareness and ease-of-control focused in ground platforms? How many hours of training do different types of weapon systems receive? How well are they funded and maintained? Which systems are prestigious? How realistic is the training? Are systems capable of mobility? Is mobility trained to?

(4) Main Effort

Where is the focus of the IADS? Is it in fighters or GBAD? Are high-value airborne assets (HVAA) (e.g., AWACS and aerial refuelers) routinely employed? Does the C2 structure make one element of the IADS subordinate to another (e.g., are the air forces subordinated to/as extensions of the artillery branch). Is quantity emphasized over quality? Is defense valued over offense?

(5) Disposition

Is an IADS deployed to achieve defense in depth with multiple layers, employing strategic and tactical weapon systems in layers and as gap fillers? Are deconflicted engagement zones possible given the system capabilities and training level of forces? How are ground forces integrated? Do they have their own tactical air defense forces? Do they have air liaisons to communicate between ground and air forces to achieve combined arms? Are there air liaisons with air defense units to avoid fratricide? How are different generations of weapon systems integrated (or are they not integrated at all)? Do the different generations of weapon systems employ different doctrine based on their differences in capability? How effective is an IADS in a degraded communications or PNT-denied environment? Is that trained to? Are ECMs employed? Will retired/outdated systems or personnel with outdated training/doctrine be brought back into service during wartime? Are there significant differences in employment between war and peacetime?

(6) Who is the Threat?

Is the IADS designed to defeat or deter (i.e., impose cost on aggressors but not achieve air superiority)? Is its intended adversary a regional neighbor with dated, low-technology weapon systems? Or an advanced adversary with standoff weapons, LO aircraft, and many HVAAs? How does the adversary view distinctions between wartime and peacetime? Is the assumption a perpetual state of elevated tension/threat?

(7) Allied Integration

Are systems compatible with allied technologies and systems? To what degree? Can fuel, ammunition, and air pictures be shared? Is cooperative targeting possible (i.e., systems from one nation targeting for engagement by another)? Is there a physical presence of air defense assets and personnel from foreign allies? Will the nation that manufactured the procured weapon system send advisors or trainers in war or peacetime?

(8) Response to Attrition

How will units be reconstituted? How rapidly is damage to runways or other facilities repaired? What logistics reserves (e.g., petroleum, oil, lubricants, etc.) are available and how are they distributed to forces? What is the redundancy in command and control or systems at the CPs collection and reporting centers, sector operations centers, ADOCs? Will the ROE change when certain systems are degraded or destroyed?

b. General Types of Doctrine

Because there are limited numbers of nations that produce and sell air and air defense weapon systems, because the producing nation’s employment doctrine and training is often exported with the weapon system, and because many of those nations share technology and doctrine between each other, it can be useful to view a nation’s air and air defense doctrine through the broad categories of: FSU, Western, and mixed doctrine.

As technological modifications and upgrades to FSU equipment continue to permeate air and air defense systems throughout the globe, this doctrinal framework will slowly lose its utility. But while many adversaries are modernizing their military equipment and doctrine and are adopting traditionally Western style doctrine, traditional FSU weapon systems and doctrine are still widely deployed throughout the world and still represent the most economical air and air defense option for a nation on a budget.

(1) Former Soviet Union Doctrine

In general terms, FSU doctrine emphasizes highly centralized command and control of weapon systems with engagement decisions being made relatively higher up the chain of command. Former Soviet Union doctrine has a ground force-centric view of air and air defense operations. Generally, all air and air defense operations are controlled by ground force commanders. Often air forces are not organized by functional components within a theater (i.e., a JFACC), but are subordinate to military districts or regions. Within these military districts, an air defense directorate will conduct early warning and detection, tactical air defense operations, and will direct air-to-air engagements through GCI. Overall, FSU air and air defense doctrine is more rigid and centralized, lacking flexibility.

For fighters, employment doctrine is largely GCI-focused and many FSU fighters are specialized either for interception or ground attack with only more modern fighters being designed for multi-role operations. Fighters remain under GCI control until out of radar coverage and then rely on low-level navigation over pre-selected routes. Fighter pilots and weapons officers receive comparatively less training than their controllers on the ground and are in the cockpit to fly the plane in accordance with the ground controller’s direction.

Following observations of the US experience against GBAD in Vietnam and the Israeli experience against GBAD in the Yom Kippur War, FSU doctrine has emphasized the pairing of SAMs and ADA in an especially lethal combination. Some modifications to this doctrine may substitute ADA for short range SAMs like the SA-6 or SA-8. Great importance is placed on ECM training for GBAD forces. When ECM is encountered, units are trained to attempt to reduce the impact of jamming using electronic counter-countermeasure features of their systems or passive acquisition and tracking methods. Former Soviet Union GBAD doctrine also emphasizes mobility, resulting in many vehicle-launched systems. Obsolete or dated GBAD systems are often used in gap filler or auxiliary roles.

Former Soviet Union doctrine also places emphasis on layered defenses characterized by: striking enemy air bases and C3 facilities to degrade enemy offensive and C2 capabilities; use of AWACS and fighters to attack aircraft and cruise missiles at a distance or offshore; barrier defenses using ground-based early warning radars, SAMs, and active jamming; en route defenses using strategic and tactical SAMs and fighters; terminal defenses using SAMs augmented by

ADA; and passive defenses including hardening, mobility, decoys, redundancy and civil defense. IADS training and doctrine can lead to poor reactions in unusual situations as was the case in 1978 and 1983, when off-course Korean Air Liner passenger aircraft were misidentified as US reconnaissance aircraft and fired upon (Korean Air Lines flight 902 in 1978) or shot down (Korean Air Lines flight 007 in 1983).

(2) Western Doctrine

In general terms, Western doctrine emphasizes air superiority as a prerequisite to most ground operations. It also emphasizes centralized command and control but decentralized execution of weapon systems with engagement decisions being made at relatively low levels of the chain of command. A particularly good example of this is the concept of procedural control, where previously agreed to and distributed control procedures and measures are put in place, enabling execution of them at the lowest level. Examples of these procedures and measures include: comprehensive air defense, identification procedures and ROE, airspace coordinating measures, aircraft identification maneuvers, fire support coordination measures, and maneuver control measures.

Western doctrine usually grants authority for air and air defense weapon systems to the senior air force commander in a theater. That air defense commander then normally subdivides the theater into air defense regions or air defense areas of responsibility. Ground force commanders with attached or organic air defense capabilities are delegated engagement authority within certain parameters or ROE and generally have responsibility for surface-to-air engagements. And air force commanders typically retain authority and responsibility over air-to- air engagements. Coordination between all air and air defense forces is achieved through common doctrine, compatible and integrated C3 systems, and standing operating procedure (SOPs).

A great deal of emphasis in Western air defense doctrine is placed on the role of fighters, relying on them to be responsible comparatively more airspace than their FSU counterparts, and backing that emphasis up with HVAAs including AWACS or aerial refuels. This emphasis may also manifest in a greater reliance on airborne patrols as compared to fighters on strip alert.

For fighters, employment doctrine is comparatively focused on the air, providing an immense amount of situational awareness to aviators through tactical data links and shared targeting. Western fighter design tends to be more multi-role as compared to FSU fighters with relatively fewer platforms optimized for one role or another. This enables forces following Western doctrine to assign fighters to counterair roles early in a conflict to establish air superiority and then shift those fighters to ground attack or CAS roles as ground operations begin to predominate. Fighters are often aided or guided in engagements by more powerful airborne or ground (including naval) control assets but retain control over airborne execution of engagements. Fighter pilots and weapons officers receive comparatively more training than their FSU counterparts and fly more complex and realistic training scenarios to enable rapid decision-making in the cockpit.

In Western doctrine, GBAD has a comparatively less significant role as compared to FSU doctrine. Emphasis is placed on fewer, more capable GBAD systems. And integration between GBAD and air forces tends to be more comprehensive, enabled by a heavier reliance on technological identification and deconfliction measures. As a result of this, ECM or degraded communications or PNT-denied environments can pose significant problems for western air defense doctrine and integration.

Western doctrine also places emphasis on layered defenses, however emphasis on air superiority and a higher degree of risk aversion with respect to fratricide makes defense in depth a comparatively more sequential process, attempting to set conditions for air superiority before placing additional assets at risk. Less emphasis is placed on passive defensive measures for ground forces and facilities such as signature management and more emphasis is placed on removing the threat rapidly with high-technology stand-off weapons, PGMs, and LO aircraft and systems. Additionally, US doctrine assumes that conflicts will not take place in or near the homeland. As a consequence, much of Western air defense doctrine emphasizes an effective offense as a primary mode of defense.

In a similarity to FSU doctrine and a common feature of IADS doctrine in general, Western training and doctrine can also lead to poor reactions in unusual situations. One such incident occurred in 1988 when the USS Vincennes, a US guided missile cruiser, misidentified Iranian Air flight 655 as an attacking F-14A Tomcat and shot-down the airliner.

(3) Mixed Doctrine

The most basic form of mixed doctrine is a nation that combines legacy FSU equipment and doctrine with modern Western equipment and doctrine. Integration between the two systems is often limited, with the different systems operating at different times (e.g., night vs. day) or in different operating areas. In some cases, legacy systems can be deployed to attempt to complicate the battlespace and/or to absorb losses so as to increase survivability for the modern Western systems. Alternatively, in conflict or times or increased tension, effectiveness of the modern systems may be traded for simplicity of employment within a broader IADS and the modern Western systems might be employed in the same manner as the legacy FSU equipment.

5015. Adversary Tactics

Doctrine can be understood to set the conditions for employment of effective tactics through command and control, battlefield disposition, weapons and technology acquisition and integration, etc.

However, tactics are "the employment and ordered arrangement of forces in relation to each other" (JP 1). Stated another way, tactics describes *how* forces are employed against one another. Tactics vary widely based on weapon system design and capabilities or limitations. Fixed strategic SAM systems that require hours, if not days, to break down, move, and set up, cannot easily be expected to employ high-mobility tactics. And fighters with no tactical data link will be challenged to employ a cooperative engagement tactic.

Similarly, barrage fire works for many ADA systems because they are designed to fire hundreds or thousands of rounds in a short period of time. But by their nature, SAMs tend to be limited in the size of their engagement salvos.

The specifics of most weapon systems tactics are touched upon in previous sections of this chapter, but there are at least two basic concepts that apply to nearly all air and air defense weapon systems: probability of kill, and practices employment.

a. Probability of Kill

Intelligence analysis of adversary tactics is primarily concerned with a probability of kill or P_k. Tactics is concerned with other factors as well, including survivability, but the most important factor in understanding and assessing adversary tactics is P_k and how it impacts weapons employment.

The mission of an IADS is to engage and destroy targets at the earliest possible time, with the most capable system, while retaining the ability to make other engagements. It is retaining the ability to make other engagements that makes P_k so important.

As an example, an SAM system may have a maximum intercept range (the maximum range a missile can intercept a target) of 100 nm. But at that range, P_k may only be 20% or 0.2. That same system may have a maximum recommended intercept range (the maximum range the system was designed to intercept a target) of only 60 nm. But at 60 nm the P_k may be 0.8.

In this case, most tactics would normally recommend that system only engage targets within 60 nmin order to maximize P_k and thus make the shots count. Engagements outside 60 nm would waste missiles, potentially expose radars and launch sites to attack, and thus reduce the IADS's ability to make additional engagements.

P_k can also apply to engagements that include multiple shots or the simultaneous employment of multiple weapon systems. In these cases, it is important to understand that P_k is multiplicative.

To understand P_k with multiple shots, we must first determine the *probability of not achieving a kill*:

$$1 - P_k$$

With a P_k of 0.9, the probability of not achieving a kill is 0.1. Stated another way, if the same engagement happened 100 times with two missiles, the target would survive the first missile 10 times. The chance of surviving the second missile is still 1 in 10, so in only one of those 10 times would the target survive both missiles, resulting in an overall P_k for a two-missile engagement of 0.99 or 99% probability of kill.

We can determine this by multiplying the probability of not achieving a kill for one shot, probability of not achieving a kill for the second shot (in this case 0.1 x 0.1 = 0.01) and using the resulting number as the probability of not achieving a kill for a two-shot engagement (in this case, 1%) which gives us the overall P_k for the engagement which, in this example, is 99%.

Doctrine may state that a specific P_k (for example, 0.8) is normally the minimum acceptable P_k for an engagement. This can be used to determine either where an engagement will take place (i.e., at the range a system has the specified P_k), or determine how many shots are required to achieve the desired P_k at a given range.

It should be noted that doctrine may specify circumstances where any P_k is acceptable and even highly-unlikely shots will take place. Or in some circumstances, some shots with a P_k of 0 may be acceptable if the intent is the cause the target to attempt to defeat the missile or otherwise deny an engagement zone to the target, as opposed to intending to destroy a target.

Overall, understanding P_k for a system is the most important factor in understanding its tactical employment.

b. Practiced Employment

Tactics documented and instructed in a classroom or practiced in scripted engagements should be studied and understood, but ultimately, the actual tactics employed in combat are most important. It is not always the case that those tactics instructed or practiced in scripted engagements are the same as the tactics that will be employed in a conflict. It is not uncommon for some nations to practice air defense maneuvers against notional targets that fly straight and level, directly into the teeth of an IADS. In some cases, some of the most complex elements of an engagement, including ECM, maneuvering, or hit assessment, are ignored. In these cases, instructed tactics are likely to differ very significantly from tactics employed in real combat. Even advanced nations are likely to have some gap between their ideal tactics and actual employment scenarios. Often the friction and complexity of a conflict cause air and air defense operators to revert to simpler tactics that are easier to employ or that the operator feels most comfortable with. In some cases, this gap may be small, especially if the emphasis in training is on realism. In other cases, this gap may be severe, especially when training is highly scripted and unrealistic.

In general, observed tactics are more reliable indicators for assessments than documented or instructed tactics. For this reason, military exercises are an excellent source for understanding likely combat (versus training) tactics. The higher the degree of complexity, the greater the realism, and the less scripted an exercise, then generally the truer the trained tactics will be to combat tactics.

Even so, such exercises may only feature the best trained air and air defense operators or units, with the most trained and senior people behind the controls, who may already know parameters of the engagement of the exercise.

The best source for understanding likely combat tactics is real conflict. Studying how an adversary has employed their air and air defense forces in recent conflicts can be invaluable. If the adversary has not had recent conflicts, then it is also important to consider what the adversary has learned from recent conflicts involving other nations that operate similar equipment or use similar doctrine. This can be especially true of those nations with recent conflict experience provide advisors or conduct training with the adversary being evaluated. Thus, it is important to temper any assessment of adversary tactics with considerations about likely combat employment of those tactics.

c. Interceptor Tactics

Interceptor tactics can be highly sophisticated and difficult to understand. A multitude of complex factors including physics, aerodynamics, and an intuitive sense of what visual and sensor data is available to a pilot in a given situation play much more heavily into fully understanding interceptor tactics as compared to other classes of adversary air and air defense tactics.

Often US fixed-wing aviators and aircrew themselves best understand the strengths and weaknesses of adversary tactics are they intuitively grasp the complexities of tactically maneuvering and aircraft and employing weapons in combat. These aviators and aircrew can be highly valuable resources in understanding adversary tactics. Some of the best evaluations of adversary tactics rely on close collaboration between operators and intelligence experts. The US Air Force has institutionalized this in the form of the Tactics and Analysis Reporting Program and the Tactics Analysis Team reports that it issues.

National Air and Space Intelligence Center has developed an interceptor threat level matrix that evaluates an adversary air force or individual platforms. The matrix evaluates the following characteristics:

- Typical sorties
- GCI/autonomy
- Formations
- Missile use
- WVR skills
- Countermeasure, EA, and EMCON use
- Day, night, and all-weather capability

And it scores them along a spectrum from:

1. Drone
2. Basic
3. Intermediate
4. Advanced
5. Parity

Because tactics can evolve more quickly than doctrine, only the most current analytic frameworks and intelligence should always be used to evaluate threat tactics.

5016. Asymmetric Threats

Asymmetric threats are those threats that employ weapons or tactics in unconventional ways. Most often, violent extremist organizations are what comes to mind when discussing asymmetric threats. But also included in this category are: state-like militant organizations that may or may not be state-sponsored proxies; former military personnel (and their equipment) operating in an unconventional manner due to the collapse of the government (e.g., in a civil war-like environment); even the forces of another state, conducting irregular or undeclared warfare. Asymmetric threats are, by their nature, difficult to comprehensively evaluate and assess.

For the purposes of air intelligence analysis, we can view asymmetric threats through the three functions of an IADS: detect, control, and engage. Thus, we have asymmetric detection, asymmetric control, and asymmetric engagement.

a. Asymmetric Detection

Asymmetric detection of the MAGTF ACE is especially problematic given the high degree of connectivity and information sharing, extensive proliferation of technology, and an ever-growing pool of resources and tools available, especially online.

Asymmetric detection can be thought of in terms of the unconventional use of public or commercial information and resources, the unconventional use of commercial technology, and the witting or unwitting use of the population.

(1) Public or Commercial Information and Resources

Asymmetric threats may rely on commercially-available satellite imagery to identify airfields and plan indirect fire attacks or direct assaults and infiltrations. Especially in permissive or uncertain operational environments, where the MAGTF ACE may be operating alongside civil aviation, ATC information about flight identification, location, and altitude may be easily available online or with some simple hardware purchases and modifications to commercially-available equipment. Additionally, press reports may include sufficient information to allow asymmetric threats to directly threaten the MAGTF ACE (e.g., identify airfield layout from photos to plan an attack) or to threaten the ACE indirectly (by identifying deployed personnel and threatening or harassing their family members. Malicious cyberspace actors directed by or sympathetic to an asymmetric threat could also use public and commercial information and resources to attack the ACE and its personnel directly or indirectly.

(2) Commercial Technology

Asymmetric threats leveraging commercial technology are only limited by their imagination.

These threats can alter commercial cameras, removing IR filters, to gain limited night-vision capability. Or they may be able to legally or illegally procure actual night vision technology intended for civilian hunting purposes, from military or law enforcement surplus, or on the black market.

Small commercial or hobby UASs pose a unique threat to air superiority, affecting all elements of the MAGTF and the joint and coalition force, providing reconnaissance, surveillance, target acquisition capabilities that can provide intelligence for attack planning, terminal guidance for a vehicle-borne improvised explosive device, or act as a forward observer for indirect fire.

(3) Use of the Population

Asymmetric threats can employ the population for detection purposes.

Social media is a growing concern for its ability to broadcast information widely and rapidly, wittingly or unwittingly. This can be used to detect aircraft at the airfield (exposing direction of flight as well as composition of a sortie), en route, or at the objective.

On 2 May 2011, a resident of Abbottabad, Pakistan reported on social media that helicopters were flying over the city. Unknowingly, the user was reporting the presence of the secret mission and effectively acting in an early warning capacity.

On 24 December 2014, a Jordanian F-16 crashed in Islamic State-held territory while conducting a strike mission. The Islamic State witnessed the crash and used social media to pass word to commence a search for the downed pilot to fighters in the area as well as sympathetic members of the population willing and able to help in the search.

In the first case, the social media activity did not put the operation in jeopardy and in the second case, it’s unclear what role social media played in speeding the pilot’s capture. But both events attest to the asymmetric detection capabilities of the populace.

Asymmetric population support can also come from co-option of legitimate detection capabilities, whether it is bribery of a friendly military radar operator to provide early warning information to the adversary, threatening the family of a civilian ATC operator to provide warning, or an airfield worker sympathetic to the adversary’s cause that is willing to provide details of airfield operations.

b. Asymmetric Control

An adversary conducting irregular warfare may deploy conventional weapon systems with conventionally-trained operators but under an irregular C2 structure. In this case, the weapon may be employed conventionally, but controlled asymmetrically. In such a case, the normal control mechanisms and procedures which allow intelligence analysts the ability to assess the likelihood of an engagement with high confidence are not present, increasing uncertainty about how the weapon system will be employed.

On 17 July 2014, an SA-17, apparently controlled by Russian operators conducting irregular warfare in support of and embedded with Ukrainian separatists, mistakenly engaged and shot down Malaysia Airlines flight 17 over eastern Ukraine, thinking it was a Ukrainian military jet. The normal identification procedures or integration with air forces that might have provided visual identification were not available to the Russian crews. It is also unclear what engagement authority Russian crews were operating under. While the target was civilian, it is not difficult to imagine a similar situation where a MAGTF is operating in an uncertain operational environment (where host nation forces do not have totally effective control of the territory and population) and adversary states are conducting asymmetric warfare with irregular or proxy forces.

The nature of irregular or asymmetric warfare, whether conducted or sponsored by a state actor or whether conducted entirely by violent extremist organizations, makes assessments about the control of air and air defense assets challenging. Additionally, even if clear adversary ROE or control procedures can be discovered, the irregular nature of the conflict puts strict adherence to those rules and procedures in question.

c. Asymmetric Engagement

Asymmetric engagement can include both unconventional employment of conventional weapons as well as the employment of unconventional weapons themselves.

This may take the form of modification of ground-to-ground or air-to-ground weaponry, such as S-5 air-to-ground rockets or anti-tank guided missiles, for use against aircraft. Or it could include AAMs that can be modified to be fired from ground launchers. It may even include surface-to-air systems that are mounted on unconventional platforms such as commercial trucks. These weapons pose a unique threat as they can be difficult to detect, highly mobile, and are difficult to incorporate into threat assessments without detailed reporting of their presence or modified capabilities.

Asymmetric engagement also includes threats or hazards in and around likely LZs, such as mines or IEDs planted in open fields near a high-value target, or intentionally creating flight hazards such as power lines or other cables near likely landing zones. It may also take the form of simply operating in areas that provide natural hazards to rotary-wing aircraft such as mountainous slopes, extremely high altitudes (where lift capacity is reduced), or areas with prohibitively high winds.

Commercial UASs can provide ISR to enable strike or assessments by other assets while modification of these platforms can provide them independent strike capabilities, dropping small munitions. More concerning, industrial agriculture UASs designed to spray pesticides on fields can be re-fitted for chemical or biological attacks. While commercial UAS do not yet pose a significant direct threat to aircraft, they pose a flight hazard and have partially removed the sanctuary from aerial reconnaissance and attack that the MAGTF has enjoyed in the recent past.

Information operations can be used to dissuade civilian or coalition support to the MAGTF and other US forces, attributing unrelated damage or deaths to US strikes and operations, spreading disinformation about the true objectives and intent of US operations, or directly countering US messaging efforts.

CHAPTER 6. Air Considerations for Intelligence Preparation of the Battlespace

Intelligence preparation of the battlespace is "the systematic, continuous process of analyzing the threat and environment in a specific geographic area" (MCRP 2-10B.1, *Intelligence Preparation of the Battlefield/Battlespace*). Intelligence preparation of the battlespace covers all elements and domains within the battlespace: air, land, maritime, space, and cyberspace. Thus, there is no such thing as "air IPB." There do exist, however, air-specific considerations within the IPB process that shape the overall product such that it fully supports the ACE, its mission planning, and its intelligence requirements. This chapter is a supplement to the information contained in MCRP 2-10B.1, that focuses on the points of greatest departure from IPB done to support other elements of the MAGTF. With this information analysts at the squadron, MAG, or MAW can take their knowledge of air intelligence and apply it to IPB in support of the broader MAGTF mission. MCRP 2-10B.1 should be referenced for the full IPB process.

6001. Step 1—Define the Operational Environment

Defining the operational environment allows planners to identify any significant characteristics that can affect friendly and enemy operations. This step also results in the identification of gaps in current intelligence holdings.

Step 1 is important because it assists the commander in defining relative aspects of the operational environment in time and space. During step 1, the intelligence staff must identify those significant characteristics related to the mission variables of enemy, terrain, weather, and civil considerations that are relevant to the mission and justify that analysis to the commander. Failure to identify or misidentify the effect these variables may have on operations can hinder decision-making and result in the development of an ineffective intelligence collection strategy and targeting effort.

a. Aviation Considerations

Special Purpose MAGTF Crisis Response Operations in the Horn of Africa

On December 15, 2013, conflict erupted in South Sudan following an attempted *coup d'état*, trapping a number of American citizens in the country. In the early morning hours of December 21, 2013, US Air Force 8th Special Operations Squadron crews departed in three CV-22 Ospreys to evacuate 30 American citizens from the remote city of Bor, South Sudan.

The mission was proceeding as planned through three countries and 790 nm. After arriving at the United Nations compound in Bor, the CV-22s flew over the compound to gather intelligence on ground activities. Seeing no threat and having been told Bor was a permissive environment, the three crews made their final approach.

The formation quickly came under heavy fire from HMGs, rocket-propelled grenades (RPG), and small arms. The barrage of gunfire and RPGs from the ground hit the formation 119 times, causing multiple system failures on each of the three Ospreys and wounding four personnel.

The flight conducted evasive maneuvers and quickly exited the engagement zone. The crews began life saving treatment on the wounded and the formation commander called for an assessment of aircraft and personnel. The crews said there were flight control failures and hydraulic and fuel leaks on all three aircraft, and four personnel were wounded, three of them severely. Because of the critical condition of both the aircraft and the wounded, the mission commander made the decision to abort. The formation of Ospreys made it to Entebbe, Uganda, nearly 400 nm away, with the wounded still alive.

On that morning, the AO, area of influence, and AOI of Special Purpose MAGTF Crisis Response (based over 3,000 nm away in Moron, Spain) expanded thousands of nautical miles as the unit was tasked by US Africa Command to reposition forces in Entebbe, Uganda.

The movement of approximately 150 Marines, two KC-130Js, and four MV-22Bs from Spain totaled more than 3,400 nm from Spain to Djibouti, and an additional 800 nm from Djibouti to Uganda. This represented approximately one third of the Special Purpose MAGTF’s total force and nearly its entire ACE. The Marines and aircraft continued to operate in the Horn of Africa for nearly two and a half months before redeploying to Spain.

Because Marine aviation assets are normally TACON to the JFACC and because their operational reach extends well beyond MAGTF ground assets, Marine aviation can and often is employed outside of the MAGTF’s primary AO.

Joint doctrine makes this explicit. As stated in JP 1: “The MAGTF commander will make sorties available to the JFC, for tasking through the JFACC, for air defense, long-range interdiction, and long-range reconnaissance. Sorties in excess of MAGTF direct support requirements will be provided to the JFC for tasking through the JFACC for the support of other components of the joint force or the joint force as a whole.”

For example, Marine aviation assets may be employed in support of national objectives, such as ferrying diplomatic personnel into and out of hostile areas, or they may be required to conduct assault support or CAS in adjacent AOs when assets organic to that AO are unavailable.

Additionally, special capabilities within the MAGTF, such as the speed and range of the MV-22 or the LO characteristics of the F-35, may require elements of the ACE to respond to tasking otherwise unrelated to the MAGTF mission, sometimes across GCC boundaries.

The size and scope of aviation operations greatly extends the reach of the MAGTF. As a consequence, the MAGTF's AO, area of influence, and AOI can be subject to rapid, temporary, and significant change, often with little notice and portions of these areas may be non-contiguous. This must be given special consideration during IPB, equally to defining the operational environment with respect to ACE capabilities but also in defining the AOI with respect to enemy aviation capabilities that may have a similarly expansive size and scope.

To account for this, it is useful for air intelligence sections to coordinate through the appropriate channels with higher and adjacent units to maintain awareness of the threat, available intelligence support, and appropriate points of contact across the current and potential future AO. Additionally, air intelligence Marines must understand the factors that might alter or restrict the AO, such as national or theater aviation requirements and diplomatic issues (e.g., airspace clearances and authorizations).

Other special considerations include factoring in combat range, combat radius, how those ranges may be affected by combat/mission loadouts, divert airfields, and even operational shortfalls across other units' battlespaces that may result in additional tasking to the ACE.

6002. Step 2—Describe the Effects on Operations

Once intelligence Marines have identified the significant characteristics related to enemy, terrain, weather, and civil considerations of the operational environment, the full staff describes how these characteristics affect friendly operations. The intelligence staff then describes how terrain, weather, civil considerations, and friendly forces affect enemy forces. Finally, the entire staff determines the impact and effects to the population of friendly and enemy force actions.

If the intelligence staff does not have the information it needs to form conclusions, it uses assumptions to fill information gaps—always careful to ensure the commander understands when assumptions are used in place of fact to form conclusions. These assumptions will the form the basis for PIRs, which will seek to validate or contradict them in time to support the commander's decision cycle.

See Chapter 3 for more information on the science behind how terrain and weather impact aviation and air defense systems.

a. Aviation Terrain Considerations

Terrain impacts IADS sensor performance in three primary ways: limiting LOS, providing a source of clutter, and affecting propagation of EM waves (especially multipath) and acoustic waves. Key terrain, obstacles, cover and concealment, observation and fields of fire, and avenues of approach are used to evaluate the military aspects of terrain. Terrain considerations are traditionally considered more or less symmetric in their effects on friendly and adversary forces, impacting both equally. However, the significant impact that radar terrain masking has on terrain effects can make certain terrain factors asymmetric, significantly impacting either friendly forces or adversary forces but not both.

(1) Key Terrain

Key terrain is “any locality, or area, the seizure or retention of which affords a marked advantage to either combatant” (JP 2-01.3, *Joint Intelligence Preparation of the Operational Environment*). Key terrain is consistent with areas that give full observation over avenues of approach and objectives, permit an obstacle to be covered by fire or are important road junctions or communication centers. Assets can also be considered key terrain when they are known to be likely enemy objectives. Examples include:

- Aircraft/UASs: potential airfields, LZs, drop zones, or terrain or man-made features that can be used as navigational aids or cues to targets.
- ADA/SAMs: transload points or FOBs, terrain that provides coverage for more than one asset, or allows the slewing to one or more secondary target lines.

(2) Obstacles

Obstacles are any natural or manmade terrain feature that stops, impedes, or diverts military movement. For air systems, obstacles are broken down into three primary types: those which prevent the effective employment of air defense systems, those which restrict contour flight, and those which force air assets to employ a particular surveillance or attack profile or route or to gain excessive altitude. Examples include:

- Aircraft/UASs: terrain that denies nap of the earth, or restricts lateral movement.
- ADA/SAMs: surface drainage and slope configuration that impedes cross-country movement and mountains or terrain that prevent or reduce LOS and unhindered reception of UHF/VHF communications.

(3) Cover and Concealment

Cover and concealment have slightly different applications with respect to air systems. The following tactics and techniques fall into the context of cover and concealment: contour flying, pop-up tactics, terrain masking, and ground clutter. Examples include:

- Aircraft/UASs: terrain that permits reverse slope loitering or that denies ADA/SAM target acquisition.
- ADA/SAMs: hide sites and site terrain that provides protection from indirect fire.

(4) Observation and Fields of Fire

These aspects relate to the influence of terrain on reconnaissance and target acquisition. In the IPB context, observation relates to optical and electronic LOS. Many battlefield systems require LOS to effectively operate or acquire and engage targets. These systems include radios, radars, jammers, direct-fire weapons, and airborne or ground sensors as well as friendly ADA/SAMs. Fields of fire relate to the terrain effects on weapon systems. Airspace must be analyzed with regard to routes: which provide the best protection for air threats entering the target area or those that provide the best fields of fire once they reach the target area. Examples include:

- Aircraft/UASs: potential engagement areas.
- ADA/SAMs: launch areas and areas which provide adequate radar LOS and minimize radar clutter.

(5) Avenues of Approach

Avenues of approach are air or ground routes of an attacking force leading to its objective or to key terrain in its path.

Air avenues of approach are evaluated using the same criteria as for ground. A good air avenue of approach will permit maneuver while providing terrain masking from air defense weapon systems (surface-to-air and, when possible, airborne weapon systems). Some common air avenues of approach are valleys, direct lines from the enemy point of origin (e.g., airfields), and river beds. In order to determine an air avenue of approach, both ingress and egress, the following factors should be considered:

- Type of air threat, attack profile, and ordnance
- Air threat point of origin and GCI radar positions
- Probable enemy objective
- Potential to support maneuver forces
- Freedom to maneuver within the air avenue
- Protection afforded to the air system and operator

- Air threat and operator capabilities
- ADA/SAM withdrawal routes from launch points to post-launch hide sites

b. Aviation Weather Considerations

Operation Eagle Claw

In the mid-1970s, Islamic fundamentalists led by the exiled Ayatollah Ruhollah Khomeini began to oppose the pro-American Iranian government under Mohammed Reza Shah Pahlavi. The Shah abdicated on January 16, 1979, and the Ayatollah returned from exile on February 1, 1979. After nearly a year of high tensions, on November 4, 1979, Iranians seized the US embassy and took 66 US personnel hostage (thirteen were later released, leaving 53 in Iranian custody). After considering several options, President Carter decided to authorize a military rescue operation. The mission required five months of intensive planning by personnel from all service branches and the Central Intelligence Agency before receiving the President's approval. Known as Operation Eagle Claw, the mission began on April 24, 1980 with C-130s departing Masirah Island, off the coast of Oman, as planned. At about the same time, eight US Navy RH-53Ds, with Marine aviators and aircrew trained in the low altitude flight required by the mission, lifted off from the deck of the aircraft carrier, USS Nimitz. About two hours into the mission, one of the helicopters experienced a critical warning indicating impending rotor blade failure. The crew landed, abandoned the aircraft, and continued on one of the other RH-53Ds.

Meanwhile, the C-130s, now well into Iran, ran into an area of reduced visibility. This was caused by a phenomenon of suspended dust particles that form a sandstorm, called a haboob, common in the Iranian desert. The possibility that this type of weather phenomenon might occur during the mission was known to the Air Force weather forecasters supporting the mission; however, this information was never passed to the aircrews. For the C-130s, flying at 2,000 ft, it was a minor inconvenience, for the helicopters flying at 200 ft, it was a major obstacle to safe navigation. The C-130s quickly exited the area of the sandstorm and proceeded. The helicopter force entered the haboob and continued, despite the debilitating effects of flying in near zero visibility conditions at night while wearing night-vision goggles.

While in the dust cloud, another helicopter began experiencing problems. More and more of its essential flight and navigation instruments were failing, and without visual flight references, it was becoming increasing dangerous to continue the mission. The helicopter lost sight of the other aircraft and, because the crews were ordered to maintain strict radio silence to avoid detection, the crew was unable to determine the location of the other helicopters or determine the extent or duration of the dust cloud. Because of these uncertainties and the danger they posed, the crew elected to turn back and return to the USS Nimitz. Later, it was determined that the crew were only 25 minutes away from exiting the dust cloud and would have experienced clear conditions the rest of the way to the staging area, codenamed Desert One. The crew would probably have elected to continue had they known that they would exit the dust cloud within a few minutes and had clear conditions for the rest of the flight. The rescue force was now down to six helicopters, the minimum required to continue the mission.

Shortly after landing, one of the helicopters shut down its engines, having suffered a catastrophic failure of its #2 hydraulic system. There was no chance of repairing it at Desert One as the spare parts for the mission were on the aircraft that turned back in the dust cloud. Without six functioning helicopters at Desert One, the mission would have to be aborted.

The plan shifted to getting the assault team back on the C-130s while the helicopters refueled and returned to the USS Nimitz. While repositioning one of the RH-53Ds, severe brownout conditions caused the pilot to lose all reference to the ground and the aircraft drifted into one of the C-130s providing refueling for the mission. When the rotor blades inadvertently collided with a fuel-laden C-130, both aircraft exploded, killing five airmen on the C-130 and three Marines on the RH-53D. The team commanders ordered the remaining helicopters abandoned and everyone to board the C-130s, which soon departed for Masirah Island. With that, Operation Eagle Claw came to an end. President Carter was notified of the mission's failure, and the wreckage at Desert One was broadcast to the world by the Iranian government.

Compartmentalization of the planning staff functions and OPSEC considerations prevented the dissemination of critical weather data from ever reaching the flight crews. The time-tested tradition of direct interaction between weather forecasters and flight crews was broken in an attempt to enhance OPSEC. This denied the flight crews the opportunity to express concerns regarding the environment that they would have to operate in. It also restricted the ability of weather forecasters to provide all available flight weather data to the flight crews. Being forewarned of the possibility of encountering such a weather phenomenon along the mission route would have better prepared the helicopter flight crews to make more informed decisions regarding the continuation or termination of flight operations. This more than likely would have resulted in the seventh helicopter arriving at Desert One, providing spare parts for the helicopter experiencing hydraulic failure, enabling the mission to continue, and not requiring a dangerous nighttime repositioning of helicopters in severe brownout conditions.

While the mission failed due to a long list of reasons, weather turned out to be a critical factor. Poor weather conditions and incomplete forecasting reaching the flight crews contributed to the abort of one of the RH-53Ds, the inability to repair another RH-53D, and the severe brownout conditions at the landing strip that contributed to the fatal crash that served to turn the mission from failure to calamity.

Poor weather significantly increases the risk to aviation. As examples: there are weather-related Naval Air Training and Operating Procedures Standardization limitations for aircraft that ACE commanders do not have the liberty to ignore; flight into adverse weather may cause significant damage to aircraft, making them no longer flightworthy and limiting the ability of the MAGTF commander to provide critical support later, such as CAS or casualty evacuation to ground forces in contact; and finally, extreme weather conditions can easily down an aircraft, changing the mission from the originally intended objective to TRAP, and thus causing mission failure.

Nowhere in the MAGTF are weather effects more significant than in the ACE.

The following are military aspects of weather:

- Visibility
- Wind
- Precipitation
- Cloud cover/ceiling
- Temperature
- Humidity
- Atmospheric pressure
- Sea state

As described in chapter 3, these all have significant impacts on both friendly and enemy systems.

(1) Visibility

Visibility incorporates the effects of all aspects of weather and is not just concerned with illumination. Examples include:

- Aircraft/UASs: fog around airbases may lower sortie generation, make low-altitude routes hazardous, or mask targets; severe visibility restrictions may increase required deconfliction measures or limit flights.

- ADA/SAMs: lack of cloud cover allows better aerial and ground surveillance of ADA/SAM force movement, higher moon illumination allows ADA/SAM security elements to surveil against night ground attacks.

(2) Wind

The effects of wind include blowing sand, smoke, dust, rain, and the force of the wind itself. Severe winds may affect performance and accuracy of missiles or projectiles. Examples include:

- Aircraft/UASs: fuel and payload impacts on aircraft attempting to ingress or egress close to their standard combat radius.
- ADA/SAMs: effect on communications, particularly UHF and VHF antennas and resultant degree of control on the air battle.

(3) Precipitation

Precipitation not only affects the soil conditions, but in heavy amounts, it can significantly affect personnel and equipment. Included with precipitation are storms and lightning. Examples include:

- Aircraft/UASs: degree of icing on airframe prior to or during flight, severe turbulence can make flight impossible, and lightning can case catastrophic electrical failures.
- ADA/SAMs: effect on potential missile storage areas in low ground or enclosed by berms, tenability of potential firing sites, trafficability of avenues of approach.

(4) Cloud Cover/Ceiling

Cloud cover/ceiling influences air operations, while having a negligible or favorable effect on SAM operations. Examples include:

- Aircraft/UASs: low cloud ceilings may force aircraft to use unfavorable attack profiles in relation to munition used.
- ADA/SAMs: heavy cloud cover denies visual surveillance of SAM field activities (transload operations, movement, etc.).

(5) Temperature, Humidity, and Atmospheric Pressure

Temperature and humidity extremes have negative effects on personnel and equipment capabilities, particularly in hot and wet climates. As temperature and humidity increase, the air density (atmospheric pressure) decreases, reducing airframe performance. Examples include:

- Aircraft/UASs: all three factors can reduce airframe payload, ordnance, combat radius;

absolute humidity can negatively affect EO sensor effectiveness.

- ADA/SAMs: unexpected high/low temperatures can decrease crew performance and increase maintenance requirements and absolute humidity can negatively affect EO sensor effectiveness.

(6) Sea State

Finally, sea state can affect the safety of low-level flight over the ocean as well as the ability to take off, land, or conduct other operations (including maintenance, refueling, or rearming) aboard ship.

6003. Step 3—Evaluate the Adversary

The purpose of evaluating the adversary is to understand how an adversary can affect friendly operations. Although adversary forces may conform to some of the fundamental principles of warfare that guide Marine Corps operations, these forces will differ in how they approach situations and solve problems. Understanding these differences is essential to understanding how an adversary force will react in a given situation. Adversary evaluation begins before IPB. The intelligence staff conducts adversary evaluation and develops adversary models as part of the generate intelligence knowledge task of support to force generation. Using this information, the intelligence staff then refines adversary models, as necessary, to support IPB. When analyzing a well-known adversary, the intelligence staff may be able to rely on previously developed threat/adversary models. When analyzing a new or less well-known adversary, the intelligence staff may need to evaluate the threat/adversary and develop models during the problem framing step of MCPP. When this occurs, the intelligence staff relies heavily on the adversary evaluation conducted by higher headquarters and other intelligence agencies.

In situations where there is no adversary force, the intelligence analysis conducted and the products developed relating to terrain, weather, and civil considerations may be sufficient to support planning. An example of this type of situation is a natural disaster.

a. Aviation Considerations

In addition to the OOB and system performance characteristics of the enemy, the complexity of an IADS and many of the systems that comprise it make training and tactics analysis critical to evaluation of the adversary.

The history of modern air combat is filled examples of conflicts in which one side’s systems were technically more capable or much more numerous, but a better-trained enemy was able to maintain or deny air superiority.

In addition to the OOB factors identified in chapter 5 (and the system performance characteristics available in current intelligence products), the air intelligence analyst must pay special attention to the human factors and the system components in an IADS. This includes tactics and training analysis but also recognition that, unlike other aspects of the enemy, an IADS is a system of systems and therefore nodal analysis is significant. See chapter 5, especially the IADS analysis section, for more information on evaluation of IADS.

Relevant human factors include intelligence on:

- Personnel (e.g., quality, education, motivation, loyalty)
- Initial training (i.e., gaining proficiency)
- Continuation training, including hours (i.e., maintaining currency)
- Day versus night training and tactics
- Frequency and realism of exercises (for both C2 personnel and weapon system operators)
- Personnel hierarchy (e.g., promotion based on merit or other factors)
- Career path
- Foreign influences on training/doctrine
- Doctrine versus observed tactics
- Ability to discriminate friendly versus enemy aircraft
- Trust in equipment
- Peacetime versus wartime operation of IADS

6004. Step 4—Evaluate Adversary Courses of Action

During step 4 the intelligence staff identifies and develops possible adversary COAs that can affect accomplishing the friendly mission. The staff uses the products associated with determining adversary COAs to aid in developing friendly COAs during the COA development and selecting a friendly COA during COA steps of the MCPP. The identification and development of all valid adversary COAs minimize the potential of the commander being surprised by an unanticipated enemy action.

Failure to fully identify and develop all valid adversary COAs may lead to the development of an intelligence collection strategy that does not provide the information necessary to confirm what COA the enemy has taken and may result in the commander being surprised. When needed, the staff should identify all significant civil considerations (this refers to those civil considerations identified as significant characteristics of the operational environment) so that the interrelationship of adversary, friendly forces, and population activities is portrayed.

The staff develops adversary COAs in the same manner friendly COAs are developed. Although written specifically as a guide to develop friendly COAs, the COA development discussion in MCWP 5-10, *Marine Corps Planning Process* is an excellent model to use in developing valid adversary COAs that are suitable, feasible, acceptable, unique, and consistent with adversary doctrine. Although the intelligence staff has the primary responsibility for developing adversary COAs, it needs assistance from the rest of the staff to ensure the most accurate and complete analysis is presented to the commander.

a. Aviation Considerations

The MAGTF intelligence section will develop the overall enemy COA with inputs from its major subordinate commands. Air intelligence contributes subject matter expertise and assessments to the development of the overall enemy COA, however, the level of detail within the enemy's air and air defense COAs required by the MAGTF is usually not as high as that required by the ACE commander, subordinate units, and mission planners.

To that end, an air defense system situation templates (SITTEMP) and COA narratives should cover all three functions of an IADS (detect, engage, control), including the following details:

- Placement of sensors and level of emission control
- Radar coverage at varying altitudes
- Vital areas, MEZs, FEZs, and joint engagement zones, along with optimal engagement ranges at varying altitudes
- Anti-radiation missile awareness
- Fixed-wing and rotary-wing employment (roles, element sizes, formations, etc.)
- Aircraft weapons loadouts and combat radii
- Engagement techniques (including shot doctrine)
- CAP location, composition
- Refueling tracks, FARPs, expeditionary airfields
- Primary and secondary target lines
- Level and type of integration and deconfliction (including any safe corridors)
- Engagement authority and ROE
- Modes of communication

- Launch/engagement criteria (including alert aircraft)
- AEW tracks
- GCI reliance, locations
- Day versus night operations
- Gaps in IADS detection of engagement coverage

In addition, an air threat zone overlays (ATZO) can be used to estimate the threat to air operations across the battlespace.

6005. Threat Estimation and Definitions

The estimation of the threat to air operation during IPB and mission planning fundamentally comes down to a definition for the threat and matching available intelligence to that definition. It is important to understand that a threat environment (i.e., “high,” “medium” or “low”) is not synonymous with the enemy and their available weapon systems. While threat is often cast in terms of capability and intent, it is worth recognizing the variables packed into those terms. The enemy’s capability is not merely the weapon system’s capability in the hands of an enemy soldier with a certain amount of training, readiness, and operational posture, but the extent (amount and duration) friendly aircraft are exposed to that weapon system (including countermeasures and tactics that further reduce the threat during that exposure). Only when all elements are considered together can the threat environment be determined.

Beyond calculating the threat accurately, the meaning behind the term (e.g., “high threat”) must be shared among all mission planners and between ACE echelons for it to have utility.

One size does not fit all, however. Between battlespaces, threat terms will not and should not be equal. In a low-intensity conflict with high risk-aversion, a concentration of HMGs and MANPADS in the hands of a proficient enemy might be considered ‘high threat.’ But in a conventional conflict with a near-peer where risk-aversion is comparatively low, the same threat environment may be considered relatively low.

Furthermore, within a single battlespace, across different TMSs, threat terms may differ or, when held the same, have different meanings and implications. A concentration of small arms and RPGs in a hostile town may pose a medium threat to low-flying assault support aircraft that aim to land nearby but may pose a lower threat to more heavily-armed CAS rotary-wing aircraft (and yet a lower threat, still, to high-flying fixed-wing aircraft).

As a result, ideal threat definitions are effects-based and not enemy-based. This will usually compensate for a variance in risk acceptance across TMSs that have different exposure to the same threat or the variety of threats across the spectrum of conflict.

While the specific threat definitions used are ultimately at the commander's discretion, this publication uses the following definitions:

- **Low:** An air threat environment that permits combat operations and support to proceed without prohibitive interference. Associated tactics and techniques do not normally require extraordinary measures for preplanned or immediate support.
- **Medium:** An air threat environment in which the specific aircraft performance and weapons system capability allow acceptable exposure time to enemy air defenses. This air threat environment restricts the flexibility of tactics in the immediate target/objective area. Medium air threat environments normally allow medium altitude missions/attack deliveries with low probability of engagement by enemy air defenses.
- **High:** An air threat environment created by an opposing force possessing air defense combat power that would seriously diminish the ability of friendly forces to provide necessary air support. This air threat environment might preclude some missions, such as immediate CAS, as the requirement for effective radio communications and coordination may not be possible; or the environment might require deliberate SEAD/destruction of enemy air defenses to achieve temporal and local air superiority.

Other threat definitions exist within: NAVMC 3500.14C, *Aviation Training & Readiness Program Manual*; MCRP 3-31.2, *Suppression of Enemy Air Defenses*; MCTP 3-20D *Offensive Air Support*; MCTP 3-20E, *Assault Support*.

6006. Air Threat Zone Overlay

An ATZO is an all-source product that supports a commander's air threat mitigation efforts by graphically identifying a spectrum of air threat zones within an AOI, in an identified operational environment, and utilizing defined metrics. (During the 2000's and 2010's, ATZOs were called air threat zone matrices, or ATZMs)

In a low-intensity conflict, an ATZO may be highly nuanced and balance a large variety of factors. In a high-intensity conflict, an ATZO may be as simple as identifying the IADS coverage (including areas with maneuver forces that have attached, unintegrated GBAD, and areas that have no dedicated anti-aircraft weaponry).

The sophistication and detail of an ATZO is be dictated by the information available, time available, and the people and tools required to build one. With more data and personnel, ATZOs can identify threat zones by altitude block, factor in daytime and nighttime effectiveness of the enemy, and even factor in abort, escape, and beam zones for a missile threat.

ATZOs help with the rapid identification of control points to avoid, TRAP levels, as well as minimum-threat approaches, FARP sites, refueling tracks, holding areas (HA), battle positions, and initial points (IP).

When paired with operational threat-mitigation measures (such as requiring an escort for assault support aircraft operating below a certain altitude during daylight hours in a ‘high threat’ zone), an ATZO becomes an operations/intelligence fusion product that allows the S-2 to easily identify the threat and allows the S-3 to receive the support that they require.

Intelligence personnel must remain cognizant of the measures commanders and air planners implement to mitigate the threats they have described. Certain measures may reduce the risk to flight crews in one area, or from one enemy capability set, only to increase it in another place, or in some other way. As an example, restricted operating zones of significant size may concentrate friendly flight paths along their peripheries, or airspace coordinating measures that seek to route friendly air traffic away from a high threat area may, in fact, end up simplifying the enemy’s targeting efforts by canalizing friendly aircraft elsewhere. Such effects are counterproductive, and must be guarded against through close, continuous coordination with aviation planners.

a. Characteristics

Air threat zone overlays have the following six characteristics:

- **It must define distinct threat zones.** Air threat zone overlays require distinct breaks between one zone and another, where two zones represent appreciably different threats (i.e., the enemy’s capability and intent differ). As a consequence, there must be defined boundaries between the zones.
- **It must use metrics.** The evaluation of the threat must be based on a defined methodology. The evaluation of the threat should be as free from bias and subjectivity as possible. Metrics should be provided with the finished product to ensure clarity between the creator and user of the ATZO.
- **It must predictively support threat-mitigation criteria for different TMSs.** To support mitigation efforts for future sorties, ATZOs necessarily must be both timely and predictive. This requires a methodology for adding new assessments and reporting as

well as removing outdated assessments and reporting. Threat zone metrics must be generated in consultation with operations personnel, be tied to specific mitigation measures (e.g., fly only at night, fly with armed escort, single-wave flights only), and be approved either by the ACE or the MAGTF commander. Threat zone assessments based off of those metrics should be approved by either the ACE or MAGTF commander.

- **It must evaluate the air-specific threat.** Air threat zone overlays must evaluate the threat to air operations and not the threat to the MAGTF as a whole. This must not exclude reporting form ground operations that reveals capability or intent relevant to the air threat (e.g., ground operations discovering caches of HMGs, ground operations encountering heavy resistance from machine guns and RPGs). Air threat zone overlays may recommend threat-mitigation measures (or these may be addressed elsewhere in the unit's SOP), however ATZOs assess the initial threat presented by the enemy. The residual threat will be dependent on the mitigation measures employed.
- **It is a macro threat estimate.** Air threat zone overlays estimate the air threat in an area or along an air route. Air threat zone overlays will not necessarily provide micro assessments of the threat in a specific target/objective area.
- **It evaluates an AO in an operational environment.** Air threat zone overlays cover the unit's area of influence and are tailored to the operational environment (i.e., permissive, uncertain, hostile). Effective threat levels will scale to the threat differently in low-intensity versus high-intensity conflicts.

b. Threat Factors

The following are a list of factors to consider including in an ATZO. Their availability, applicability, and utility will vary across battlespaces.

- Geographic analysis and lines of communication (including roads, trails, rivers, smuggling routes).
- Presence and type of weapons, including aircraft, air defense, and other weapons and factoring in effective ranges or combat radii.
- Population density
- All-source current threat stream reporting of enemy activity, anti-air targeting practices, capabilities and intent to target aircraft (including possible early warning networks), as well as

historic reactions to shifts in friendly tactics, flight routes, and operational tempo.

- Areas of enemy presence and of strategic value to the enemy.
- Forward lines of troops and high-conflict areas.
- Surface-to-air fire (SAFIRE) trend analysis (considering hit percentage).
- Aviation activity levels/airspace density analysis (including friendly, enemy, and other).
- Other significant activity, or SIGACTs, correlating to enemy presence (including MISREP events, overhead persistent IR events, ground events, and other reporting).
- Areas of friendly, enemy, and neutral controlled or influenced territory.
- Terrain and climatology facilitating or restricting air operations.
- Terrain and climatology facilitating or restricting enemy operations.
- Population atmospherics and sentiment (current and historic).
- Presence of enemy night-vision capability.

CHAPTER 7. Aviation Mission Support

This chapter applies the background knowledge and context of the previous chapters to the air intelligence Marine's responsibilities across the full life-cycle of Marine aviation operations. There are five general stages of aviation mission support: pre-deployment, planning, pre-mission, in-flight, and post-mission.

Within each stage, responsibilities span from the Intelligence Officer to the junior analyst, from the MAW G-2 to the detachment S-2 cell. Mission analysis will dictate the details and scope of intelligence support required, as well as how different echelons of intelligence sections will mutually support in each situation.

7001. Pre-Deployment Support

Pre-deployment support includes all intelligence support to aviation training as well as all air intelligence training prior to a planned or likely deployment. This includes scenario development tailored to a specific threat or threat capabilities or intelligence support to aligned operations plan (OPLAN) and other theater contingency requirements.

Pre-deployment support primarily serves to gather, organize, and convey knowledge about the threat and operating environment to an audience for the purpose of training readiness. It also serves to reinforce the role of the intelligence section in mission planning and execution. Through pre-deployment support, both the intelligence and operations sections are trained on intelligence sources, products, and analysis to establish a baseline expectation for real-world operations.

Pre-deployment support is also where intelligence sections gain experience putting threat, weather, and terrain information into an operational context. Such information is rarely important in itself. However, when this information is contextualized by mission planning and execution, it becomes valuable intelligence. Therefore, whenever possible, the intelligence Marine should strive to contextualize information in a way that facilitates mission planning (e.g., stating "the system's limited range of 10 nm allows for relative ease in navigating around its engagement range as well as allowing for employment of standoff munitions" instead of simply stating "the system has a maximum range of 10 nm").

To do this well, intelligence Marines must also be mindful of their audience, the capabilities of the supported aircraft, and the mission of their unit. For example, a minimum engagement altitude of 100 ft might be of value to low-flying helicopters but such a limitation is less relevant to fixed-wing jets that would not reasonably under-fly such a system.

It is critical to recognize that the MAGTF's air intelligence sections are not trained to be the subject matter expert (SME) in specific threat systems, but instead to be the SME in the unit's intelligence support requirements. The air intelligence section must rely on its own analysis of the unit's intelligence support requirements but should not rely on its own analysis of the threat system. This is the role of various agencies within the IC. Oftentimes, it is valuable to establish relationships with these points of contact throughout mission planning and execution and share relevant operational details to better enable them to support the ACE.

Specific pre-deployment support includes IPB, intelligence support to personnel recovery (PR), battlespace assessments, and administrative processes and procedures.

IPB provides estimates that inform standard ASE software loads and expendable load-outs as well as estimates that assist planners in determining standard tactics, countertactics, offensive load-outs, and SOPs.

Battlespace assessments or intelligence estimates update the IPB, including the enemy OOB, and provide threat assessments throughout the AOI.

Administrative processes and procedures include ensuring methods for coordination across echelons are established and efficient. This may include functional procedures such as RFI or collection management processes. It may also include SOPs that facilitate concurrent planning and synchronize and nest intelligence efforts such as standardized products and product requests. For example, the GEOINT and IMINT sections may have a standard LZ study that incorporates items the squadron will request or analysts may have a shared list of mission-specific generic intelligence requirements that allow an analyst to get ahead of RFIs subordinate units will soon submit.

7002. Planning Support

Planning support includes all intelligence support to aviation planning and air intelligence planning from receipt of an order (whether WARNO for a deployment, OPORD for a campaign, or the daily ATO) to mission briefing.

Intelligence inputs drive operational threat mitigation measures such as threat avoidance, detection avoidance, threat suppression, countermeasures, and additional support requests. This makes planning support the most critical phase for intelligence support to aviation operations. These mitigation measures are put into place during mission planning, reducing the residual exposure to the threat and reducing overall risk to the force and mission. As a consequence, the level of intelligence detail required for mission planning often exceeds the level of detail required for mission execution.

At different echelons, this planning support stage can occur at different times. For example, a MAW Future Plans section may begin planning components of an air campaign or sorties beyond the ATO window well before specific units are identified to support the mission. The focus of intelligence support will also change across the planning support timeline. For example, in initial, pre-ATO planning, intelligence requirements are often broad, driving similarly-broad operational decisions, such as the size and makeup of the ACE assets necessary or the general sequencing of the mission. In later planning stages, especially within the ATO cycle, intelligence requirements tend to narrow significantly to enable tactics selection and refine SOMs.

Intelligence support to planning within the ATO cycle can be broken down along four broad phases of flight and the intelligence required for aviation planners to select the appropriate tactics for each phase. These phases are:

- En route
- Ingress
- Objective area
- Egress

The en route phase begins when an aircraft crosses the Forward Edge of the Battle Area (FEBA) to the contact point. Depending on ACE disposition in the AO, the airfield that aircraft take off from may be forward of the FEBA and en route tactics may commence immediately. En route tactics rely primarily on intelligence support that allows aircraft to avoid detection and/or engagement or to avoid major terrain or weather impacts that would compromise or delay the ability to execute the planned mission.

The ingress phase begins at the contact point and ends the initial point. Ingress tactics rely primarily on intelligence support that allows aircrew to set-up successful objective area tactics. These requirements include aiding aircrew in initial identification the objective (whether enemy forces, an LZ, or a drop zone) by visual means or through sensors, mitigating or defeating enemy engagements, or identifying favorable ingress/egress directions as dictated by terrain and weather.

The objective area phase includes from the initial point to the objective. These tactics are often constrained by airframe capabilities, specific flight profiles and countertactics, or weapons release envelopes. Intelligence support to objective area tactics often focuses primarily on mitigating rather than avoiding the threat. Because objective area tactics are often the least flexible and often the

the most exposed to the threat, this phase of flight tends to pose the greatest risk to mission force. The egress phase includes from the objective to an egress point (similar to the contact point that begins the ingress phase). Egress tactics rely primarily on intelligence support that allows aircrew to execute countertactics or otherwise deny or defeat enemy engagement as the aircraft exit the area. Unsuccessful objective area tactics (e.g., a wave-off or required re-attack) may require egress tactics that transition to a second ingress phase. Successful objective area tactics or a mission abort will normally allow the egress phase to transition back into en route tactics.

In all phases of planning, the intelligence section must translate the intelligence picture into a “Cockpit Sight Picture.” This means translating and framing products, assessments, and other intelligence into a form most readily usable by aviators and aircrew. This can take a number of forms but the three most common are the use of airspace control measures or aviation landmarks and reference points as well as the use of platform-specific distance measures or indications. Maps and imagery, with clear center coordinates and neat gridlines, make the spatial placement of significant intelligence-related items of interest (e.g., enemy locations or targets) deceptively easy. In reality, however, the location of these items from the air (often at many thousands of feet in altitude and at hundreds of knots), can be challenging. By orienting aviation planners to significant intelligence-related items of interest by using airspace control measures or landmarks and reference points that are easily identifiable from the air, intelligence Marines can facilitate the location and identification of these areas in-flight. This may include reference with respect to control points (i.e., “1 nm north of control point HAMMERS”), phase lines, or other significant control measures used in the aviation plan. It may also include using major visible terrain features. Intelligence Marines must remember that many terrain features that are clear from imagery may be difficult to identify from an aircraft. For example, a distinctively-shaped house may be challenging to pick out in a village of hundreds of structures, it may be obscured by smoke or dust, it may be oriented such that the distinctive shapes are not clear.

Finally, the systems of various platforms are a significant factor in how aviators and aircrew interact with the world during a mission. Platforms will depict distances or altitudes in various units of measure. Hostile threat indications will also be displayed in a particular manner, based on the ASE and its software load. By using these units of measure or ASE indications in intelligence products, intelligence Marines can most accurately convey intelligence items of interest in the manner that the aviators and aircrew will most directly experience or encounter them.

7003. Pre-Mission Support

Pre-mission support includes all intelligence support to aviation briefs and pre-mission activities after the mission plan has been finalized and approved. This includes briefing support to the flight brief(s), final intelligence updates between mission brief and take-off, and coordination activities for any intelligence actions during mission execution.

Mission briefs distill all previous intelligence efforts into those details required for aviators and aircrew to execute the mission at hand. Of all the intelligence products supporting aviation operations, mission briefs are the most tailored and generally the narrowest in scope. Mission briefs should include only information and context that helps make decisions in the aircraft, such as ASE indications for likely threats or imagery of possible enemy firing points for aerial gunners to orient on.

Under ideal conditions, and when planning support is done well, any last-minute intelligence should not change the plan but, if severe enough, trigger already-established go/no go criteria or mitigation plans.

While some mission planners will already be familiar with the intelligence It is important to understand that not all aviators and rarely any aircrew flying in a given mission are involved in the threat components of mission planning. Therefore, it is important to provide any background context necessary to understand the threat mitigation in place and the residual exposure that remains.

It is important to remember that the overall mission brief contains a vast amount of information critical to successful completion of the mission. Of that information, the S-2 normally briefs first and has one of the shortest portions of the mission brief. Exhaustive intelligence analysis supports the planning phase, while only critical elements required to make decisions in-flight should be presented in the mission brief.

Just as not all aviators and aircrew were involved in the threat component of mission planning, not all intelligence personnel supporting the mission will have been involved in detailed planning for the specific operation. Therefore, it is necessary to conduct pre-mission intelligence coordination to ensure all supporting intelligence personnel understand the mission, plan, threat, and intelligence support required and available.

Ensuring all personnel understand the mission’s purpose and end state, the units involved, the broad SOM, the threat, mission coordination, and post-mission requirements will facilitate efficient and effective intelligence support.

7004. In-Flight Support

In-flight support includes all intelligence support to aviation in-flight (or during the course of the sortie, to include returning to base to refuel/re-arm or await the call for extraction) as well as intelligence activities during the flight vulnerability window. These actions may include mid-mission intelligence updates to the aircrew or collection from the aircrew.

This support may include NRT intelligence, as required, to the aircraft in-flight through the DASC, TAOC, or other designated C2 agencies. In the event of a downed aircraft, emergency, or other contingency, if the squadron is part of the recovery force, the squadron S-2 should be prepared to receive and disseminate the appropriate isolated personnel reports. The squadron S-2 should also be prepared to request available collection asset support and inter-agency support and transmit NRT information and intelligence updates through available communications equipment directly to the aircrew.

If thoroughly coordinated, in-flight intelligence support should require minimal management and oversight. Each individual supporting the flight with intelligence support knows what information to pass to whom, how, and when. And those receiving that information know exactly what to do with it to facilitate mission execution and force protection. These procedures are established in SOPs and during pre-mission coordination. For all individuals supporting a mission, it is important to be familiar with all the modes of coordination arranged for the mission. Generally, this includes designated chat rooms (sometimes multiple chat rooms for the mission, ISR assets, personnel recovery contingencies, etc.), available FMV feeds, radio channels, as well as various watch standers and their contact methods (whether e-mail, phone, chat, etc.).

Additionally, it is important when providing in-flight support to understand both the SOM for the mission and its progress. Often this means having at the ready CONOPS including execution checklist items, timelines, deck cycles, on- and off-station times, etc.

7005. Post-Mission Support

Post-mission support includes all intelligence support to aviation and intelligence activities after a sortie has completed. This includes debriefing, MISREP drafting, review, and approval, PED of weapons video, combat assessment, updating the OOB, and intelligence support to operational assessments.

To this point, the entire air intelligence mission support process has been an inverted pyramid of support focused on a single mission and the individual aviators and aircrew in the conduct of their sortie.

Post-mission, that sortie has an obligation to provide inputs back up through the intelligence enterprise to refine the intelligence estimate and better support future ACE operations. In this way, every sortie is an intelligence collections sortie. When something of intelligence value occurs, capturing it contributes to the intelligence estimate. When nothing of intelligence value occurs, the sortie still contributes a data point to a baseline from which intelligence assessments can be made.

In intelligence terms, this feedback into the system is done through PED, encompassing steps three, four, and five of the Marine Corps intelligence cycle (processing and exploitation; production; dissemination).

This feedback is not only important to the higher headquarters to assemble a clearer intelligence estimate, it also enhances the intelligence support received by the squadron for future operations as well.

Theater requirements and procedures for post-mission intelligence reports are normally established in an intelligence reporting directive published by the GCC JFACC’s ISR directorate.

a. Mission Reports

The most common post-mission product is the MISREP. The MISREP is the initial report of the JFACC’s smallest unit of action and is the historical mission record of what each tactical unit did and observed on a particular mission. MISREPs are derived from flight debriefs and are the basic means of conveying mission results and current intelligence (including BDA, OOB analysis, future targeting, threat development, and battlespace situational awareness) to higher headquarters, adjacent units, and other units in theater in a timely manner.

Just as atmospherics, observations, and contact reports from a squad patrol feed the battalion’s intelligence picture, MISREPs from sorties should provide the same to the MAG, MAW, and JFACC. More than just administrative take-off/land information and SAFIRE narratives, MISREPs should provide historical information of value to intelligence analysts preparing to support a mission to the same or a nearby area in the future.

Debriefers should utilize all the tools available to facilitate the debriefing process. This includes using Naval Aircraft Flight Records to fill in administrative data, in-flight feedback as passed in mission coordination channels, mission CONOP, timelines, execution checklists, and MISREP checklists to ensure all questions are asked and all information is recorded.

Debriefers must also recognize the human impulse for aviators and aircrew to report what they thought they saw, as opposed to what they actually saw. Descriptions are not always consistent within a single debrief, and that is especially the case across multiple debriefs within a single sortie. Therefore, the more significant the reported event, the more members of the sortie the squadron S-2 should debrief. Aids such as imagery or video of the target/objective area, or various threat weapon systems being fired under various conditions (day, night, NVD, side-view, front-view, etc.) can be useful in helping aviators and aircrew recall details as well as to identify where they observed those details.

The JFACC is normally responsible for tracking, collating, analyzing, and disseminating MISREPs for all ATO-tasked flying units. In cases where the ACE may not be under tactical control, or TACON, of the JFACC, requirements and procedures for post-mission intelligence reports will be found in the Annex B of the relevant order, higher headquarters SOPs, or other governing orders, directives, and instructions.

In many cases, storyboards become a primary means of distilling the details of significant MISREP events and briefing them. Whether a SAFIRE or an observation of interest, storyboards should convey the critical elements of an event while making clear that there is additional information available in the original report (or provide that additional information as a reference or in the notes).

b. Weapon System Video

Weapon system video, or WSV, provides combat air forces and other military and political leaders with a visual record of the aircraft’s weapon delivery, targeting, and accuracy. In addition, it enables higher headquarters and operational units the ability to use it for BDA, collateral damage estimation analysis, and may possibly be released publicly as part of an information operations campaign. Furthermore, it can be used by munitions developers to evaluate the effectiveness of current munitions and steer the development of future munitions. Weapon system video uses also include the following:

- Rapid documentation of strike assessment
- Imagery air campaign planners can utilize in forming re-strike decisions.
- Tactical analysis
- Munitions effectiveness assessment
- Imagery for aviator and aircrew training
- A resource to affect international public opinion by demonstrating US aviation combat capability and by providing timely documentary evidence to disprove enemy claims of intentional civilian targeting and/or collateral damage.

c. Joint Combat Assessment Team

Joint Combat Assessment Team's (JCAT) primary mission is to collect data on aircraft combat damage and losses. Information is gathered through photographs of the damage, intelligence reports, and interviews with squadron members. Joint Combat Assessment Teams then prepare reports that provide a comprehensive, quantitative picture of aircraft systems suffering combat damage. The combat damage forensics collected by JCAT and their resulting assessment are to identify vulnerabilities of different aircraft components so that components can be re-engineered or improved to be more survivable in the event of battle damage. Joint Combat Assessment Team assessments also provide valuable real-world information about the effectiveness of enemy weapons and tactics.

Intelligence sections must be familiar with JCAT contacts and procedures in their AO. When JCAT assessors are not available, intelligence sections should seek guidance on what information to collect and how so that it can be forwarded to the appropriate JCAT personnel.

d. Other Requirements

The JFACC's intelligence reporting directive, Annex B of the relevant order, higher headquarters SOPs, or other governing orders, directives, and instructions may include additional reporting requirements, formats, and information flow.

Glossary

Section I. Acronyms

AAM	air-to-air missile
AAW	antiair warfare
ACE	aviation combat element
ACI	air combat intelligence
ADA	air defense artillery
ADOC	air defense operations center
AESA	active electronically scanned array
AEW	airborne early warning
AI	airborne interdiction
AM	amplitude modulation
AO	area of operations
AOB	air order of battle
AOI	area of interest
AOR	area of responsibility
ASE	aircraft survivability equipment
ASV	air surveillance
ATC	air traffic control
ATO	air tasking order
ATZO	air threat zone overlay
AWACS	airborne warning and control system
BDA	battle damage assessment
C	Celsius
C2	command and control
C3	command, control, and communications
CAP	combat air patrol
CAS	close air support
CE	command element

CI	counterintelligence
CLOS	command to line of sight
COA	course of action
COMINT	communications intelligence
CONOPS	concept of operations
CP	command post

DASC	direct air support center
dB	decibel
DOD	Department of Defense

EA	electronic attack
ECM	electronic countermeasures
ELINT	electronic intelligence
EM	electromagnetic
EMS	electromagnetic spectrum
EO	electro-optical
ES	electronic warfare support
ESA	electronically scanned array
EU	European Union
EW	electronic warfare

FARP	forward arming and refueling point
FEBA	forward edge of the battle area
FLIC	flight line intelligence center
FM	frequency modulation
FMV	full-motion video
FOB	forward operating base

FOV	field of view
FSU	former Soviet Union

g	gram
G	Earth gravity
GBAD	ground-based air defense
GCC	geographic combatant command
GCE	ground combat element
GCI	ground-control intercept
GCS	ground control station
GEOINT	geospatial intelligence
GHz	gigahertz
GPS	Global Positioning System
GRG	gridded reference graphic

HF	high frequency
HLL	high light level
HMG	heavy machine gun
HPRF	high pulse repetition frequency
HUMINT	human intelligence
HVAA	high-value airborne asset
Hz	Hertz

IADS	integrated air defense system
IC	intelligence community

IFF	identification, friend or foe
IFOV	instantaneous field of view
IMINT	imagery intelligence
in	inch
INS	inertial navigation system
IP	initial point
IPB	intelligence preparation of the battlespace
IRCCM	infrared counter-countermeasure
IR	infrared
IRSTS	infrared search and track system
ISR	intelligence, surveillance, and reconnaissance
I&W	indications and warning
JCAT	Joint Combat Assessment Team
JFACC	joint force air component commander
JFC	joint force commander
JTF	joint task force
KCAS	knots calibrated airspeed
KIAS	knots indicated airspeed
KTAS	knots true airspeed
km	kilometer
lbs	pounds
LBR	laser beam rider
LCE	logistics combat element
LIDAR	light detection and ranging
LLLTV	low-light level television
LO	low observable
LOS	line of sight

LOSR	line of sight rate
LP	listening post
LPI	low probability of intercept
LWIR	long-wave infrared

m	meter
M	Mach number
MACCS	Marine air command and control system
MAG	Marine aircraft group
MAGTF	Marine air ground task force
MANPADS	man-portable air defense system
MAW	Marine aircraft wing
MCISRE	Marine Corps Intelligence, Surveillance, and Reconnaissance Enterprise
MCPP	Marine Corps Planning Process
MDI	minimum detectable irradiance
MEF	Marine expeditionary force
MET	mission essential task
METAR	meteorological terminal aviation routine weather report
METOC	meteorological and oceanographic
MEU	Marine expeditionary unit
MEZ	missile engagement zone
MHz	megahertz
MISREP	mission report
mm	millimeter
mph	miles per hour
MRIR	maximum recommended intercept range
MSE	major subordinate element
MSIC	Missile and Space Intelligence Center
MSL	mean sea level
MWIR	mid-wave infrared

NAI	named area of interest
NATO	North Atlantic Treaty Organization
NASIC	National Air and Space Intelligence Center
NAVSTAR	Navigation Satellite Timing and Ranging
NEI	noise equivalence irradiance
NGIC	National Ground Intelligence Center
NIP	notice of intelligence potential
nm	nautical mile
NRT	near real-time
NVD	night-vision device
OAS	offensive air support
OCA	offensive counterair
OOB	order of battle
OP	observation post
OPLAN	operation plan
OPORD.	operation order
OPSEC	operations security
OTH	over the horizon
PCR	passive coherent radar
PDE&A	planning, decision, execution, and assessment
PED	processing, exploitation, and dissemination
PESA	passive electronically scanned array
PGM	precision-guided munition
PIR	priority intelligence requirement
PNT	positioning, navigation, and timing
PRF	pulse repetition frequency
PRI	pulse repetition interval
PW	pulsed wave

RADM	regionally-based aircraft differentiation model
RCS	radar cross section
RF	radio frequency
RFI	request for information
ROE	rules of engagement
RPG	rocket-propelled grenade
RWR	radar warning receiver
SAGG/TVM	seeker-aided ground guidance/track-via-missile
SAFIRE	surface-to-air fire
SAM	surface-to-air missile
SAR	synthetic aperture radar
SATCOM	satellite communications
SEAD	suppression of enemy air defenses
SHF	super high frequency
SI/EW	signals intelligence / electronic warfare
SIGINT	signals intelligence
SME	subject matter expert
SOM	scheme of maneuver
SOP	standing operating procedures
SWIR	short-wave infrared
TA	transition altitude
TACC	tactical air command center
TAOC	Tactical air operations center
TFOV	total field of view

TMS	type, model, and/or series
T/R	transmit/receive
TRAP	tactical recovery of aircraft and personnel
TTP	tactics, techniques, and procedures
TTR	target tracking radar
TV	television
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UHF	ultra high frequency
μm	micrometer
UV	ultraviolet
VHF	very high frequency
WARNORD	warning order
WSV	weapon system video
WVR	within visual range

Section II. Terms

air defense—Defensive measures designed to destroy attacking enemy aircraft or aerodynamic missiles, or to nullify or reduce the effectiveness of such attack. Also called **AD**. (JP 3-01)

air defense artillery—Weapons and equipment for actively combating air targets from the ground. Also called **ADA**. (JP 3-01)

air interdiction—Air operations conducted to divert, disrupt, delay, or destroy the enemy's military surface capabilities before it can be brought to bear effectively against friendly forces, or to otherwise achieve objectives that are conducted at such distances from friendly forces that detailed integration of each air mission with the fire and movement of friendly forces is not required. Also called **AI**. (JP 3-03)

air superiority—That degree of control of the air by one force that permits the conduct of its operations at a given time and place without prohibitive interference from air and missile threats. (JP 3-01)

air supremacy—That degree of control of the air wherein the opposing force is incapable of effective interference within the operational area using air and missile threats. (JP 3-01)

air tasking order—A method used to task and disseminate to components, subordinate units, and command and control agencies projected sorties, capabilities and/or forces to targets and specific missions. Also called **ATO**. (JP 3-30)

airborne early warning—The detection of enemy air or surface units by radar or other equipment carried in an airborne vehicle, and the transmitting of a warning to friendly units. Also called **AEW**. (JP 3-52)

airfield—An area prepared for the accommodation (including any buildings, installations, and equipment), landing, and takeoff of aircraft. (JP 3-17)

airspace coordinating measures—Measures employed to facilitate the efficient use of airspace to accomplish missions and simultaneously provide safeguards for friendly forces. Also called **ACMs**. See also **weapons engagement zone**. (JP 3-52)

all-source intelligence—1. Intelligence products and/or organizations and activities that incorporate all sources of information in the production of finished intelligence. 2. In intelligence collection, a phrase that indicates that in the satisfaction of intelligence requirements, all collection, processing, exploitation, and reporting systems and resources are identified for possible use and those most capable are tasked. See also intelligence. (JP 2-0 e)

antiradiation missile—A missile which homes passively on a radiation source. Also called **ARM**. See also **guided missile**. (JP 3-01)

area of influence—A geographical area wherein a commander is directly capable of influencing operations by maneuver or fire support systems normally under the commander's command or control. (JP 3-0)

area of interest—That area of concern to the commander, including the area of influence, areas adjacent thereto, and extending into enemy territory. Also called **AOI**. (JP 3-0)

area of operations—An operational area defined by a commander for land and maritime forces that should be large enough to accomplish their missions and protect their forces. Also called **AO**. See also **area of responsibility**. (JP 3-0)

area of responsibility—The geographical area associated with a combatant command within which a geographic combatant commander has authority to plan and conduct operations. Also called **AOR**. See also **combatant command**. (JP 1)

avenue of approach—An air or ground route of an attacking force of a given size leading to its objective or to key terrain in its path. (JP 2-01.3)

ballistic missile—Any missile that does not rely upon aerodynamic surfaces to produce lift and consequently follows a ballistic trajectory when thrust is terminated. See also **guided missile**. (JP 3-01)

battle damage assessment—The estimate of damage composed of physical and functional damage assessment, as well as target system assessment, resulting from the application of lethal or nonlethal military force. Also called **BDA**. (JP 3-0) Marine Corps amplification: The timely and accurate estimate of the damage resulting from the application of military force. Battle damage assessment estimates physical damage to a particular target, functional damage to that target, and the capability of the entire target system to continue its operations.

begin morning civil twilight—The period of time at which the sun is halfway between beginning morning and nautical twilight and sunrise, when there is enough light to see objects clearly with the unaided eye. (JP 2-01.3)

begin morning nautical twilight—The start of that period where, in good conditions and in the absence of other illumination, the sun is 12 degrees below the eastern horizon and enough light is available to identify the general outlines of ground objects and conduct limited military operations. (JP 3-09.3)

boost phase—That portion of the flight of a ballistic missile or space vehicle during which the booster and sustainer engines operate. See also **midcourse phase; terminal phase**. (JP 3-01)

center of gravity—The source of power that provides moral or physical strength, freedom of action, or will to act. (JP 5-0) Marine Corps amplification: A key source of strength without which an enemy cannot function.

chaff—Radar confusion reflectors, consisting of thin, narrow metallic strips of various lengths and frequency responses, which are used to reflect echoes for confusion purposes. (JP 3-13.1)

clandestine—Any activity or operation sponsored or conducted by governmental departments or agencies with the intent to assure secrecy and concealment. (JP 2-01.2)

close air support—Air action by aircraft against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces. Also called **CAS**. See also **air interdiction**. (JP 3-09.3)

collateral damage—A form of collateral effect that causes unintentional or incidental injury or damage to persons or objects that would not be lawful military targets in the circumstances ruling at the time (JP 3-60)

collection—In intelligence usage, the acquisition of information and the provision of this information to processing elements. (JP 2-01) Marine Corps amplification: The gathering of intelligence data and information to satisfy the identified requirements.

collection management—In intelligence usage, the process of converting intelligence requirements into collection requirements, establishing priorities, tasking or coordinating with appropriate collection sources or agencies, monitoring results, and retasking, as required. See also **collection; collection requirement; intelligence**. (JP 2-0)

collection plan—A systematic scheme to optimize the employment of all available collection capabilities and associated processing, exploitation, and dissemination resources to satisfy specific information requirements. (JP 2-0)

collection requirement—A valid need to close a specific gap in intelligence holdings in direct response to a request for information. (JP 2-0) Marine Corps amplification: An established intelligence need considered in the allocation of intelligence resources to fulfill the priority intelligence requirements and other intelligence needs of a commander.

combat air patrol—An aircraft patrol provided over an objective area, the force protected, the critical area of a combat zone, or in an air defense area, for the purpose of intercepting and destroying hostile aircraft before they reach their targets. Also called CAP. (JP 3-01)

combatant command—A unified or specified command with a broad continuing mission under a single commander established and so designated by the President, through the Secretary of Defense and with the advice and assistance of the Chairman of the Joint Chiefs of Staff. Also called **CCMD**. (JP 1)

command and control—The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Also called **C2**. (JP 1) Marine Corps amplification: The means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken. Command and control is one of the seven warfighting functions.

command relationships—The interrelated responsibilities between commanders, as well asthe operational authority exercised by commanders in the chain of command; defined further as combatant command (command authority), operational control, tactical control, or support. See also **chain of command; tactical control**. (JP 1)

common operational picture—A single identical display of relevant information shared by more than one command that facilitates collaborative planning and assists all echelons to achieve situational awareness. Also called **COP**. (JP 3-0)

common tactical picture—An accurate and complete display of relevant tactical data that integrates tactical information from the multi-tactical data link network, ground network, intelligence network, and sensor networks. (JP 3-01) Marine Corps amplification: 1. Consists of friendly position location information, known and suspected enemy locations, and graphical map overlays depicting information such as fire support coordination and tactical control measures. 2. The current depiction of the battlespace, including current, anticipated, or projected and planned disposition of hostile, neutral, and friendly forces.

communications intelligence—Technical information and intelligence derived from foreign communications by other than the intended recipients. Also called **COMINT**. (JP 2-0)

concept of operations—A verbal or graphic statement that clearly and concisely expresses what the commander intends to accomplish and how it will be done using available resources. Also called **CONOPS**. (JP 5-0)

coordinating altitude—An airspace coordinating measure that uses altitude to separate users and as the transition between different airspace control elements. (JP 3-52)

counterair—A mission at the theater level that integrates offensive and defensive operations to attain and maintain a desired degree of control of the air and protection by neutralizing or destroying enemy aircraft and missiles, both before and after launch. See also **air superiority**; **offensive counterair.** (JP 3-01)

counterintelligence—Information gathered and activities conducted to identify, deceive, exploit, disrupt, or protect against espionage, other intelligence activities, sabotage, or assassinations conducted for or on behalf of foreign powers, organizations or persons or their agents, or international terrorist organizations or activities. Also called **CI**. (JP 2-01.2) Marine Corps amplification: The active and passive measures intended to deny the enemy valuable information about the friendly situation, to detect and neutralize hostile intelligence collection, and to deceive the enemy as to friendly capabilities and intentions.

countermeasures—That form of military science that, by the employment of devices and/or techniques, has as its objective the impairment of the operational effectiveness of enemy activity. See also **electronic warfare**. (JP 3-13.1)

course of action—1. Any sequence of activities that an individual or unit may follow. 2. A scheme developed to accomplish a mission. Also called **COA**. (JP 5-0)

cyberspace—A global domain within the information environment consisting of the interdependent networks of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers. (JP 3-12)

decentralized control—In air defense, the normal mode whereby a higher echelon monitors unit actions, making direct target assignments to units only when necessary to ensure proper fire distribution or to prevent engagement of friendly aircraft. (JP 3-01) Marine Corps amplification: In military operations, a mode of battlespace management in which a command echelon may delegate some or all authority and direction for warfighting functions to subordinates. It requires careful and clear articulation of mission, intent, and main effort to unify efforts of subordinate leaders.

decentralized execution-Delegation of execution authority to subordinate commanders. (JP 3-30)

decision—In an estimate of the situation, a clear and concise statement of the line of action intended to be followed by the commander as the one most favorable to the successful accomplishment of the assigned mission. (JP 5-0)

decision point—A point in space and time when the commander or staff anticipates making a key decision concerning a specific course of action. See also course of action; target area of interest. (JP 5-0) Marine Corps amplification: An event, area, or point in the battlespace where and when the friendly commander will make a critical decision.

decoy—An imitation in any sense of a person, object, or phenomenon that is intended to deceive enemy surveillance devices or mislead enemy evaluation. (JP 3-13.4)

defensive counterair—All defensive measures designed to neutralize or destroy enemy forces attempting to penetrate or attack through friendly airspace. See also counterair: offensive counterair (JP 3-01)

detection—1. In tactical operations, the perception of an object of possible military interest but unconfirmed by recognition. 2. In surveillance, the determination and transmission by a surveillance system that an event has occurred. 3. In arms control, the first step in the process of ascertaining the occurrence of a violation of an arms control agreement. 4. In chemical, biological, radiological, and nuclear environments, the act of locating chemical, biological, radiological, and nuclear hazards by use of chemical, biological, radiological, and nuclear detectors or monitoring and/or survey teams. (JP 3-11)

direct air support center—The principal air control agency of the United States Marine Corps air command and control system responsible for the direction and control of air operations directly supporting the ground combat element. Also called **DASC**. See also **Marine air command and control system; tactical air operations center**. (JP 3-09.3)

direct support—A mission requiring a force to support another specific force and authorizing it to answer directly to the supported force’s request for assistance. Also called **DS**. (JP 3-09.3)

dissemination—In intelligence usage, the delivery of intelligence to users in a suitable form. (JP 2-01) Marine Corps Definition: Conveyance of intelligence to users in a suitable form.

drop zone—A specific area upon which airborne troops, equipment, or supplies are airdropped. JP 3-17)

early warning—Early notification of the launch or approach of unknown weapons or weapons carriers. (JP 3-01)

electromagnetic jamming—The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing an enemy’s effective use of the electromagnetic spectrum, and with the intent of degrading or neutralizing the enemy’s combat capability. See also **electromagnetic spectrum; electronic warfare**. (JP 3-85)

electronic intelligence—Technical and geolocation intelligence derived from foreign non-communications electromagnetic radiations emanating from other than nuclear detonations or radioactive sources. Also called **ELINT**. See also **foreign instrumentation signals intelligence; intelligence; signals intelligence**. (JP 3-13.1)

emission control—The selective and controlled use of electromagnetic, acoustic, or other emitters to optimize command and control capabilities while minimizing, for operations security: a. detection by enemy sensors; b. mutual interference among friendly systems; and/or c. enemy interference with the ability to execute a military deception plan. Also called **EMCON**. (JP 3-13.1)

end evening civil twilight—The point in time when the sun has dropped 6 degrees beneath the western horizon, and is the instant at which there is no longer sufficient light to see objects with the unaided eye. Also called **EECT**. (JP 2-01.3)

end of evening nautical twilight—The point in time when the sun has dropped 12 degrees below the western horizon, and is the instant of last available daylight for the visual control of limited military operations. Also called **EENT**. (JP 2-01.3)

end state—The set of required conditions that defines achievement of the commander's objectives. (JP 3-0)

engage—1. In air and missile defense, a fire control order used to direct or authorize units and/or weapon systems to attack a designated target. See also cease engagement; hold fire. (JP 3-01 2. To bring the enemy under fire. (JP 3-09.3)

engagement—1. An attack against an air or missile threat. (JP 3-01 2). A tactical conflict, usually between opposing lower echelons maneuver forces. (JP 3-0)

engagement authority—An authority vested with a joint force commander that may be delegated to a subordinate commander, that permits an engagement decision. (JP 3-01)

estimate—1. An analysis of a foreign situation, development, or trend that identifies its major elements, interprets the significance, and appraises the future possibilities and the prospective results of the various actions that might be taken. 2. An appraisal of the capabilities, vulnerabilities, and potential courses of action of a foreign nation or combination of nations in consequence of a specific national plan, policy, decision, or contemplated course of action. 3. An analysis of an actual or contemplated clandestine operation in relation to the situation in which it is or would be conducted to identify and appraise such factors as available as well as needed assets and potential obstacles, accomplishments, and consequences. See also **intelligence estimate**. (JP 5-0)

evasion—The process whereby isolated personnel avoid capture with the goal of successfully returning to areas under friendly control. (JP 3-50)

evasion aid — In personnel recovery, any piece of information or equipment designed to assist an individual in avoiding capture. See also **evasion; evasion chart**. (JP 3-50)

evasion chart—A special map or chart designed as an evasion aid. See also **evasion; evasion aid**. (JP 3-50)

evasion plan of action—A course of action, developed prior to executing a combat mission, that is intended to improve a potential isolated person's chances of successful evasion and recovery by providing the recovery forces with an additional source of information that can increase the predictability of the evader's action and movement. See also **course of action; evasion**. (JP 3-50)

fighter engagement zone—In air defense, that airspace of defined dimensions within which the responsibility for engagement of air threats normally rests with fighter aircraft. Also called **FEZ**. (JP 3-01)

fires—The use of weapon systems or other actions to create specific lethal or nonlethal effects on a target. (JP 3-09) Marine Corps amplification: Those means used to delay, disrupt, degrade, or destroy enemy capabilities, forces, or facilities as well as affect the enemy's will to fight. Fires is one of the seven warfighting functions.

force protection—Preventive measures taken to mitigate hostile actions against Department of Defense personnel (to include family members, resources, facilities, and critical information. (JP 3-0) Marine Corps amplification follows. Actions or efforts used to safeguard own centers of gravity while protecting, concealing, reducing, or eliminating friendly critical vulnerabilities. Force protection is one of the seven warfighting functions.

foreign instrumentation signals intelligence—A subcategory of signals intelligence consisting of technical information and intelligence derived from the intercept of foreign electromagnetic emissions associated with the testing and operational deployment of non-United States aerospace, surface, and subsurface systems. Also called FISINT. See also signals intelligence. (JP 2-01)

foreign intelligence—Information relating to capabilities, intentions, and activities of foreign governments or elements thereof, foreign organizations, or foreign persons, or international terrorist activities. See also **intelligence**. (JP 2-0)

forward arming and refueling point—A temporary facility, organized, equipped, and deployed to provide fuel and ammunition necessary for the employment of aviation maneuver units in combat. Also called **FARP**. (JP 3-09.3)

forward-looking infrared—An airborne, electro-optical thermal imaging device that detects far-infrared energy, converts the energy into an electronic signal, and provides a visible image for day or night viewing. Also called **FLIR**. (JP 3-09.3)

forward operating base—An airfield used to support tactical operations without establishing full support facilities. Also called **FOB**. (JP 3-09.3)

geospatial intelligence—The exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. Geospatial intelligence consists of imagery, imagery intelligence, and geospatial information. Also called **GEOINT**. (JP 2-03)

Global Positioning System—A satellite-based radio navigation system operated by the Department of Defense to provide all military, civil, and commercial users with precise positioning, navigation, and timing. Also called **GPS**. (JP 3-14)

guided missile—An unmanned vehicle moving above the surface of the Earth whose trajectory or flight path is capable of being altered by an external or internal mechanism. See also ballistic missile. (JP 3-01)

head-up display—A display of flight, navigation, attack, or other information superimposed upon the pilot's forward field of view. (JP 3-09.3)

high-payoff target—A target whose loss to the enemy will significantly contribute to the success of the friendly course of action. See also **high-value target; target.** (JP 3-60)

high-value target—A target the enemy commander requires for the successful completion of the mission. See also **high-payoff target; target.** (JP 3-60)

homing—The technique whereby a mobile station directs itself, or is directed, towards a source of primary or reflected energy, or to a specified point. (JP 3-50)

human intelligence—A category of intelligence derived from information collected and provided by human sources. Also called **HUMINT**. (JP 2-0)

hyperspectral imagery—Term used to describe the imagery derived from subdividing the electromagnetic spectrum into very narrow bandwidths allowing images useful in precise terrain or target analysis to be formed. (JP 2-03)

identification—1. The process of determining the friendly or hostile character of an unknown detected contact. 2. In arms control, the process of determining which nation is responsible for the detected violations of any arms control measure. 3. In ground combat operations, discrimination between recognizable objects as being friendly or enemy, or the name that belongs to the object as a member of a class. (JP 3-01)

identification, friend or foe—A device that emits a signal positively identifying it as a friendly. Also called **IFF**. See also **air defense**. (JP 3-52)

imagery—A likeness or presentation of any natural or man-made feature or related object or activity, and the positional data acquired at the same time the likeness or representation was acquired, including: products produced by space-based national intelligence reconnaissance systems; and likeness and presentations produced by satellites, airborne platforms, unmanned aerial vehicles, or other similar means (except that such term does not include handheld or clandestine photography taken by or on behalf of human intelligence collection organizations. (JP 2-03)

imagery intelligence—The technical, geographic, and intelligence information derived through the interpretation or analysis of imagery and collateral materials. Also called IMINT. See also intelligence. (JP 2-03)

indications—In intelligence usage, information in various degrees of evaluation, all of which bear on the intention of a potential enemy to adopt or reject a course of action. (JP 2-0

instrument meteorological conditions—Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling; less than minimums specified for visual meteorological conditions. Also called IMC. (JP 3- 04)

integration—1. In force protection, the synchronized transfer of units into an operational commander's force prior to mission execution. (JP 1) 2. The arrangement of military forces and their actions to create a force that operates by engaging as a whole. (JP 1) 3. In photography, a process by which the average radar picture seen on several scans of the time base may be obtained on a print, or the process by which several photographic images are combined into a single image. (JP 1) 4. In intelligence usage, the application of the intelligence to appropriate missions, tasks, and functions. See also force protection. (JP 2-01) Marine Corps amplification: A stage in the intelligence cycle in which a pattern is formed through the selection and combination of evaluated information.

intelligence—1. The product resulting from the collection, processing, integration, evaluation, analysis, and interpretation of available information concerning foreign nations, hostile or potentially hostile forces or elements, or areas of actual or potential operations. 2. The activities that result in the product. 3. The organizations engaged in such activities. See also **all-source intelligence; communications intelligence; electronic intelligence; foreign intelligence; foreign instrumentation signals intelligence; imagery intelligence; measurement and signature intelligence**. (JP 2-0) Marine Corps amplification: Knowledge about the enemy or the surrounding environment needed to support decision-making. Intelligence is one of the seven warfighting functions.

intelligence community—All departments or agencies of a government that are concerned with intelligence activity, either in an oversight, managerial, support, or participatory role. Also called **IC**. (JP 2-0)

intelligence discipline—A well-defined area of intelligence planning, collection, processing, exploitation, analysis, and reporting using a specific category of technical or human resources. See also **counterintelligence; human intelligence; imagery intelligence; intelligence; measurement and signature intelligence; signals intelligence.** (JP 2-0)

intelligence estimate—The appraisal, expressed in writing or orally, of available intelligence relating to a specific situation or condition with a view to determining the courses of action open to the enemy or adversary and the order of probability of their adoption. (JP 2-0)

intelligence preparation of the battlespace—The analytical methodologies employed by the Services or joint force component commands to reduce uncertainties concerning the enemy, environment, time, and terrain. Also called IPB. (JP 2-01.3) Marine Corps amplification: The systematic, continuous process of analyzing the threat and environment in a specific geographic area.

intelligence requirement—1. Any subject, general or specific, upon which there is a need for the collection of information, or the production of intelligence. 2. A requirement for intelligence to fill a gap in the command's knowledge or understanding of the operational environment or threat forces. Also called **IR**. See also **intelligence; priority intelligence requirement**. (JP 2-0) Marine Corps amplification: Questions about the enemy and the environment, the answers to which a commander requires to make sound decisions.

intelligence, surveillance, and reconnaissance—1. An integrated operations and intelligence activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations. 2. The organizations or assets conducting such activities. Also called **ISR**. See also **intelligence**. (JP 2-01)

interdiction—1. An action to divert, disrupt, delay, or destroy the enemy's military surface capability before it can be used effectively against friendly forces, or to achieve enemy objectives. 2. In support of law enforcement, activities conducted to divert, disrupt, delay, intercept, board, detain, or destroy, under lawful authority, vessels, vehicles, aircraft, people, cargo, and money. See also **air interdiction**. (JP 3-03) Marine Corps amplification: To divert, disrupt, delay, or destroy the enemy's surface military potential before it can be used effectively against friendly forces.

isolated personnel report—A Department of Defense form containing information designed to facilitate the identification and authentication of an isolated person by a recovery force. Also called **ISOPREP**. (JP 3-50)

joint engagement zone—In air and missile defense, that airspace of defined dimensions within which multiple air and missile defense systems (surface-to-air missiles and aircraft are simultaneously employed to engage air and missile threats. Also called **JEZ**. (JP 3-01)

joint force air component commander—The commander within a unified command, subordinate unified command, or joint task force responsible to the establishing commander for recommending the proper employment of assigned, attached, and/or made available for tasking air forces; planning and coordinating air operations; or accomplishing such operational missions as may be assigned. Also called JFACC. See also joint force commander. (JP 3-0)

joint force commander—A general term applied to a combatant commander, sub unified commander, or joint task force commander authorized to exercise combatant command (command authority or operational control over a joint force. Also called **JFC**. (JP 1)

key terrain—Any locality, or area, the seizure or retention of which affords a marked advantage to either combatant. (JP 2-01.3)

landing zone—Any specified zone used for the landing of aircraft. Also called **LZ**. See also **airfield**. (JP 3-17) Marine Corps amplification: A specified ground area for landing assault support aircraft to embark or disembark troops and/or cargo and it may contain one or more landing sites.

laser rangefinder—A device that uses laser energy for determining the distance from the device to a place or object. (JP 3-09)

line of communications—A route, either land, water, and/or air, that connects an operating military force with a base of operations and along which supplies and military forces move. (JP 2-01.3)

Marine air command and control system—A system that provides the aviation combat element commander with the means to command, coordinate, and control all air operations within an assigned sector and to coordinate air operations with other Services. Also called **MACCS**. See also **direct air support center; tactical air operations center**. (JP 3-09.3)

maximum ordinate—In artillery and naval gunfire support, the height of the highest point in the trajectory of a projectile above the horizontal plane passing through its origin. (JP 3-09.3)

measurement and signature intelligence—Information produced by quantitative and qualitative analysis of physical attributes of targets and events to characterize, locate, and identify targets and events, and derived from specialized, technically derived measurements of physical phenomenon intrinsic to an object or event. Also called **MASINT**. See also **intelligence**. (JP 2-0) Marine Corps amplification: Intelligence information gathered by technical instruments such as radars, passive electro-optical sensors, radiation detectors, and remote ground sensors.

meteorological and oceanographic—A term used to convey all environmental factors, from the sub-bottom of the Earth’s oceans through maritime, land areas, airspace, ionosphere, and outward into space. Also called **METOC**. (JP 3-59)

midcourse phase—That portion of the flight of a ballistic missile between the boost phase and the terminal phase. See also boost phase; terminal phase. (JP 3-01)

missile engagement zone—In air and missile defense, that airspace of defined dimensions within which the responsibility for engagement of air and missile threats normally rests with surface-to-air missile systems. Also called **MEZ**. (JP 3-01)

munitions effectiveness assessment—The assessment of the military force applied in terms of the weapon system and munitions effectiveness to determine and recommend any required changes to the methodology, tactics, weapon system, munitions, fusing, and/or weapon delivery parameters to increase force effectiveness. Also called **MEA**. See also **battle damage assessment**. (JP 2-01)

named area of interest—The geospatial area or systems node or link against which information that will satisfy a specific information requirement can be collected, usually to capture indications of adversary courses of action. Also called **NAI**. See also **area of interest**. (JP 2-01.3) Marine Corps amplification: A point or area along a particular avenue of approach through which enemy activity is expected to occur. Activity or lack of activity within a named area of interest will help to confirm or deny a particular enemy course of action.

night vision device—Any electro-optical device that is used to detect visible and infrared energy and provide a visible image. Also called **NVD**. See also **forward-looking infrared**. (JP 3-09.3)

node—1. A location in a mobility system where a movement requirement is originated, processed for onward movement, or terminated. (JP 3-17) 2. In communications and computer systems, the physical location that provides terminating, switching, and gateway access services to support information exchange. (JP 6-0 3). An element of a system that represents a person, place, or physical thing. (JP 3-0)

objective area—A geographical area, defined by competent authority, within which is located an objective to be captured or reached by the military forces. (JP 3-06)

observable—In military deception, the detectable result of the combination of an indicator within an adversary’s conduit intended to cause action or inaction by the deception target. (JP 3-13.4)

obstacle—Any natural or man-made obstruction designed or employed to disrupt, fix, turn, or block the movement of an opposing force, and to impose additional losses in personnel, time, and equipment on the opposing force. (JP 3-15)

offensive counterair—Offensive operations to destroy or neutralize enemy aircraft, missiles, launch platforms, and their supporting structures and systems both before and after launch, and as close to their source as possible. Also called **OCA**. See also **counterair**. (JP 3-01)

on-station time—The time an aircraft can remain on station, which may be determined by endurance or orders. (JP 3-50)

order of battle—The identification, strength, command structure, and disposition of the personnel, units, and equipment of any military force. Also called **OOB**. (JP 2-01.3)

ordnance—Explosives, chemicals, pyrotechnics, and similar stores, e.g., bombs, guns and ammunition, flares, smoke, or napalm. (JP 3-15)

overhead persistent infrared—1. Those systems originally developed to detect and track foreign intercontinental ballistic missile systems. (JP 3-14) 2. Within geospatial intelligence, a capability that provides on-demand, persistent, global, and/or localized coverage of high- to low-intensity infrared events to detect energy radiation from various tactical to strategic objects. Also called **OPIR**. (JP 2-03)

passive defense—Measures taken to reduce the probability of and to minimize the effects of damage caused by hostile action without the intention of taking the initiative. (JP 3-60)

personnel recovery—The sum of military, diplomatic, and civil efforts to prepare for and execute the recovery and reintegration of isolated personnel. Also called **PR**. See also **evasion**. (JP 3-50) **point defense**—The defense or protection of special vital elements and installations; e.g., command and control facilities or air bases. (JP 3-52)

pointee-talkee—A language aid containing selected phrases in English opposite a translation in a foreign language used by pointing to appropriate phrases. See also **evasion aid**. (JP 3-50)

positive identification—An identification derived from observation and analysis of target characteristics including visual recognition, electronic support systems, non- cooperative target recognition techniques, identification friend or foe systems, or other physics-based identification techniques. Also called **PID**. (JP 3-01)

precision-guided munition—A guided weapon intended to destroy a point target and minimize collateral damage. Also called **PGM, smart weapon, smart munition**. (JP 3-03)

priority intelligence requirement—An intelligence requirement that the commander and staff need to understand the threat and other aspects of the operational environment. Also called **PIR.** See also **intelligence; intelligence requirement**. (JP 2-01)

radio frequency countermeasures—Any device or technique employing radio frequency materials or technology that is intended to impair the effectiveness of enemy activity, particularly with respect to precision guided weapons and sensor systems. Also called **RF CM**. (JP 3-13.1)

recognition—1. The determination by any means of the individuality of persons, or of objects such as aircraft, ships, or tanks, or of phenomena such as communications- electronics patterns. 2. In ground combat operations, the determination that an object is similar within a category of something already known. (JP 3-01)

request for information—1. Any specific time-sensitive ad hoc requirement for intelligence information or products to support an ongoing crisis or operation not necessarily related to standing requirements or scheduled intelligence production. 2. A term used by the National Security Agency/Central Security Service to state ad hoc signals intelligence requirements. Also called **RFI**. See also **intelligence**. (JP 2-0)

restricted operations zone—Airspace reserved for specific activities in which the operations of one or more airspace users is restricted. Also called **ROZ**. (JP 3-52)

rules of engagement—Directives issued by competent military authority that delineate the circumstances and limitations under which United States forces will initiate and/or continue combat engagement with other forces encountered. Also called **ROE**. (JP 1-04)

scheme of maneuver—The central expression of the commander's concept for operations that governs the development of supporting plans or annexes of how arrayed forces will accomplish the mission. (JP 5-0)

sea state—A scale that categorizes the force of progressively higher seas by wave height. (JP 4-01.6)

shoot-look-shoot—A firing doctrine in which the result of the first intercept attempt is assessed prior to the launch of a subsequent interceptor. Also called **SLS**. (JP 3-01)

short-range ballistic missile—A ballistic missile with a range capability between 300-600 nautical miles. Also called **SRBM**. (JP 3-01)

signals intelligence—1. A category of intelligence comprising either individually or in combination all communications intelligence, electronic intelligence, and foreign instrumentation signals intelligence, however transmitted. 2. Intelligence derived from communications, electronic, and foreign instrumentation signals. Also called **SIGINT.** See also c**ommunications intelligence; electronic intelligence; foreign instrumentation signals intelligence; intelligence**. (JP 2-0)

situation template—A depiction of assumed adversary dispositions, based on that adversary's preferred method of operations and the impact of the operational environment if the adversary should adopt a particular course of action. See also **course of action**. (JP 2-01.3)

special operations forces—Those Active and Reserve Component forces of the Services designated by the Secretary of Defense and specifically organized, trained, and equipped to conduct and support special operations. Also called **SOF**. (JP 3-05)

standard operating procedure—A set of instructions applicable to those features of operations that lend themselves to a definite or standardized procedure without loss of effectiveness. Also called **SOP**; **standing operating procedure**. (JP 3-31)

strike—An attack to damage or destroy an objective or a capability. (JP 3-0)

strike coordination and reconnaissance—A mission flown for the purpose of detecting targets and coordinating or performing attack or reconnaissance on those targets. Also called **SCAR**. (JP 3-03)

suppression of enemy air defenses—Activity that neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means. Also called **SEAD**. See also **electromagnetic spectrum; electronic warfare**. (JP 3-01)

surface combatant—A ship constructed and armed for combat use with the capability to conduct operations in multiple maritime roles against air, surface and subsurface threats, and land targets. (JP 3-32)

survivability—All aspects of protecting personnel, weapons, and supplies while simultaneously deceiving the enemy. (JP 3-34)

tactical air command center—The principal US Marine Corps air command and control agency from which air operations and air defense warning functions are directed. Also called **Marine TACC**. (JP 3-09.3)

tactical air operations center—The principal air control agency of the United States Marine Corps air command and control system responsible for airspace control and management. Also called **TAOC.** (JP 3-09.3)

tactical control—The authority over forces that is limited to the detailed direction and control of movements or maneuvers within the operational area necessary to accomplish missions or tasks assigned. Also called **TACON**. See also **combatant command**. (JP 1)

tactical recovery of aircraft and personnel—A Marine Corps mission performed by an assigned and briefed aircrew for the specific purpose of the recovery of personnel, equipment, and/or aircraft when the tactical situation precludes search and rescue assets from responding and when survivors and their location have been confirmed. Also called **TRAP**. (JP 3-50)

tactics—The employment and ordered arrangement of forces in relation to each other. (CJCSM 5120.01)

target—1. An entity or object that performs a function for the adversary considered for possible engagement or other action. 2. In intelligence usage, a country, area, installation, agency, or person against which intelligence operations are directed. 3. An area designated and numbered for future firing. 4. In gunfire support usage, an impact burst that hits the target. See also **objective area**. (JP 3-60)

target acquisition—The detection, identification, and location of a target in sufficient detail to permit the effective employment of weapons. Also called **TA**. (JP 3-60)

target development—The systematic examination of potential target systems - and their components, individual targets, and even elements of targets - to determine the necessary type and duration of the action that must be exerted on each target to create an effect that is consistent with the commander's specific objectives. (JP 3-60)

targeting—The process of selecting and prioritizing targets and matching the appropriate response to them, considering operational requirements and capabilities. See also **target**. (JP 3-0)

target system—1. All the targets situated in a particular geographic area and functionally related. 2. A group of targets that are so related that their destruction will produce some particular effect desired by the attacker. See also **target**. (JP 3-60)

terminal guidance—1. The guidance applied to a guided missile between midcourse guidance and arrival in the vicinity of the target. 2. Electronic, mechanical, visual, or other assistance given an aircraft pilot to facilitate arrival at, operation within or over, landing upon, or departure from an air landing or airdrop facility. (JP 3-03)

terminal phase—That portion of the flight of a ballistic missile that begins when the warhead or payload reenters the atmosphere and ends when the warhead or payload detonates, releases its sub munitions, or impacts. See also boost phase; midcourse phase. (JP 3-01)

terrain analysis—The collection, analysis, evaluation, and interpretation of geographic information on the natural and man-made features of the terrain, combined with other relevant factors, to predict the effect of the terrain on military operations. (JP 2-03)

thermal crossover—The natural phenomenon that normally occurs twice daily when temperature conditions are such that there is a loss of contrast between two adjacent objects on infrared imagery. (JP 3-09.3)

thermal radiation—1. The heat and light produced by a nuclear explosion. 2. Electromagnetic radiations emitted from a heat or light source as a consequence of its temperature. (JP 3-41)

track—1. A series of related contacts displayed on a data display console or other display device. 2. To display or record the successive positions of a moving object. 3. To lock onto a point of radiation and obtain guidance therefrom. 4. To keep a gun properly aimed, or to point continuously a target-locating instrument at a moving target. 5. The actual path of an aircraft above or a ship on the surface of the Earth. 6. One of the two endless belts on which a full-track or half-track vehicle runs. 7. A metal part forming a path for a moving object such as the track around the inside of a vehicle for moving a mounted machine gun. (JP 3-01)

track correlation—Correlating track information for identification purposes using all available data. (JP 3-01)

tracking—Precise and continuous position-finding of targets by radar, optical, or other means. (JP 3-07.4)

unmanned aircraft—An aircraft that does not carry a human operator and is capable of flight with or without human remote control. Also called **UA**. (JP 3-30)

unmanned aircraft system—That system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft. Also called **UAS**. (JP 3-30)

visual meteorological conditions—Weather conditions in which visual flight rules apply; expressed in terms of visibility, ceiling height, and aircraft clearance from clouds along the path of flight. Also called **VMC**. See also **instrument meteorological conditions**. (JP 3-04)

weapon engagement zone—In air and missile defense, airspace of defined dimensions within which the responsibility for engagement of air threats normally rests with a particular weapon system. Also called **WEZ.** (JP 3-01)

Section III. References and Related Publications

Joint Publications (JPs)

JP 1, Doctrine for the Armed Forces of the United States

JP 2-0, Joint Intelligence

JP 2-01.3, Joint Intelligence Preparation of the Operational Environment

JP 3-0, Operations

JP 3-01, Countering Air and Missile Threats

JP 3-04, Joint Shipboard Helicopter and Tiltrotor Aircraft Operations

JP 3-12, Cyberspace Operations

JP 3-13.1, Electronic Warfare

Navy/Marine Corps Publications (NAVMCs)

NAVMC 3500.14C

Marine Corps Warfighting Publications (MCWPs)

MCWP 3-20, Aviation Operations

MCWP 5-10, Marine Corps Planning Process

Marine Corps Reference Publications (MCRPs)

MCWP 2-10A.2, Counterintelligence/Human Intelligence

MCRP 2-10B.1, Intelligence Preparation of the Battlespace

MCRP 3-31.2, Suppression of Enemy Air Defenses (SEAD)

Marine Corps Tactical Publications (MCTPs)

MCTP 3-20D, Offensive Air Support

MCTP 3-20E, Assault Support

Air Force Tactics, Techniques, and Procedures Publications (AFTTPs)

AFTTP 3-1 Threat Guide

Other Publications and/or References

Brungess, James R., *Setting the Context - Suppression of Enemy Air Defenses and Joint War Fighting in an Uncertain World*, Maxwell Air Force Base, AL: Air University Press, 1994.

Congressional Budget Office, *The Global Positioning System for Military Users: Current Modernization Plans and Alternatives*, Washington, D.C.: Congressional Budget Office, 2011.

Crabtree, James D., *Guerilla Air Defense II: Improvised Antiaircraft Weapons and Techniques*, Charleston, SC: CreateSpace, 2016.

Crabtree, James D., *On Air Defense*, Santa Barbara, CA: CreateSpace, 1994.

Joint Unmanned Aircraft Systems Digital Information Exchange (JUDIE Joint Test (JT, *Joint UAS Information Exchange Handbook*, Washington, D.C.: Department of Defense, 2013

MacFadzean, Robert H., *Surface-Based Air Defense System Analysis*, Boston, MA: Artech House, 1992.

Naval Air Warfare Center Weapons Division (NAWCWD, *NAWCWD Technical Publication (TP) 8347: Electronic Warfare and Radar Systems Engineering Handbook*, Department of the Navy: 2013.

Navy Fighter Weapons School, *TOP GUN Manual*, Department of the Navy: 2018

United States War Department, *Field Manual 100-20 Command and Employment of Air Power*, Washington 25, D.C., 21 July 1943.

Werrell, Kenneth P., *Archie to SAM: A Short Operational History of Ground-Based Air Defense*, Maxwell Air Force Base, AL: Air University Press, 2005.

White, Jack R., *NAWCWD TP 8773: Aircraft Infrared Principles, Signatures, Threats, and Countermeasures*, Washington, D.C.: Department of the Navy, 2012.

Section IV. Nomenclature

AV-8B – single-engine ground-attack aircraft with vertical or short takeoff and landing capability

AH-1Z – twin-engine attack helicopter

B-2 Spirit – heavy penetration strategic stealth bomber

B-52 Stratofortress – long-range, subsonic, jet-powered strategic bomber

C-130 Hercules – four-engine turboprop military transport aircraft

F/A-18 Hornet – twin-engineer, supersonic, all-weather, carrier-capable, multirole combat jet designed as both a fighter and attack aircraft. Single-seat variants are the F/A-18A, F/A-18C, and

F/A-18E. Two-seat variants are the F/A-18B, F/A-18D, and F/A-18F. The F/A-8G is an electronic warfare version of the F/A-18F

F-117A Nighthawk – single-seat, twin-engine stealth attack aircraft

F-22 Raptor – single-seat, twin-engine, all-weather stealth tactical fighter aircraft

F-35 Lightning II – family of single-seat, single-engine, all-weather stealth multirole fighter aircraft

KC-130J – extended-range tanker version of the C-130 Hercules that is modified for aerial refueling

RQ-7B – trailer-mounted pneumatic catapult launched unmanned air system with a Group 3 designation

RQ-21 – twin-boom, single-engine, unmanned air system with a Group 3 designation

UH-1Y – twin-engine, medium-sized utility helicopter

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