MCRP 3-10E.6

Tactics, Techniques, and Procedures for Marine Artillery Sensor Operations

U.S. Marine Corps

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

PCN 144 000260 00

UNITED STATES MARINE CORPS

14 June 2021

FOREWORD

Marine Corps Reference Publication (MCRP) 3-10E.6, Tactics, Techniques, and Procedures for Marine Artillery Sensor Operations, sets forth the doctrinal foundation and technical information that Marines need to provide accurate and timely sensor support. It covers a broad spectrum of issues from general knowledge to Marine-specific equipment. As three of the five requirements for accurate predicted fire, sensor support is critical to the success of artillery (and ultimately maneuver) on the modern battlefield. Marine artillery sensor Marines support firing units and target acquisition assets, enabling indirect fires to mass effectively and deliver surprise observed fires and effective unobserved fires.

This publication applies to Marine air-ground task force artillery commanders, their staffs, and personnel in the 0844/48 military occupational specialty (fire direction control Marine), and field artillery operations chief billets, from battery through regiment, including infantry mortar Marines.

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Publication Control Number: 144 000260 00

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TACTICS, TECHNIQUES, AND PROCEDURES FOR MARINE ARTILLERY SENSOR OPERATIONS

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CHAPTER 1 ARTILLERY SENSOR ORGANIZATION

1-1. Introduction

This publication contains the doctrine, organization, tactics, techniques, and procedures required to manage field artillery target acquisition organizations, systems, personnel, and equipment. It expands on and more clearly defines the roles and responsibilities of sensor section described in Marine Corps Tactical Publication (MCTP) 3-10E, *Artillery Operations.* This publication also incorporates emerging doctrine and information about the Marine Corps planning process (MCPP), automated command and control, and fire support systems as they apply to the functions performed by the regimental and battalion sensor section and its leadership.

This manual closely examines all elements of the sensor section within the target acquisition platoon (TAP). The sensor section provides a myriad of capabilities paramount to the efficient and effective execution of mortar, artillery, and rocket fires. Actively supporting three of the five requirements for accurate fires, the sensor section ensures accurate and common survey control across the battlespace through employment of conventional, inertial, and global positioning systems. Timely and accurate meteorological (MET) support is provided where and when required to ensure accurate fires. The sensor section also employs acoustic target acquisition capabilities to locate hostile acoustic reports from threat indirect fire weapon systems as well as points of origin from explosive events of interest to targeting and intelligence sections. These capabilities are critical to the combat roles of all warfighting functions and specifically in support of artillery operations across the range of military operations.

1-2. Target Acquisition Platoon

a. The TAP (Figure 1-1) provides a comprehensive capability consisting of survey, meteorology, acoustic, counter battery radar, and target processing. This allows the artillery regimental commander flexibility in supporting the maneuver commander with a task organized sensor and target acquisition package.

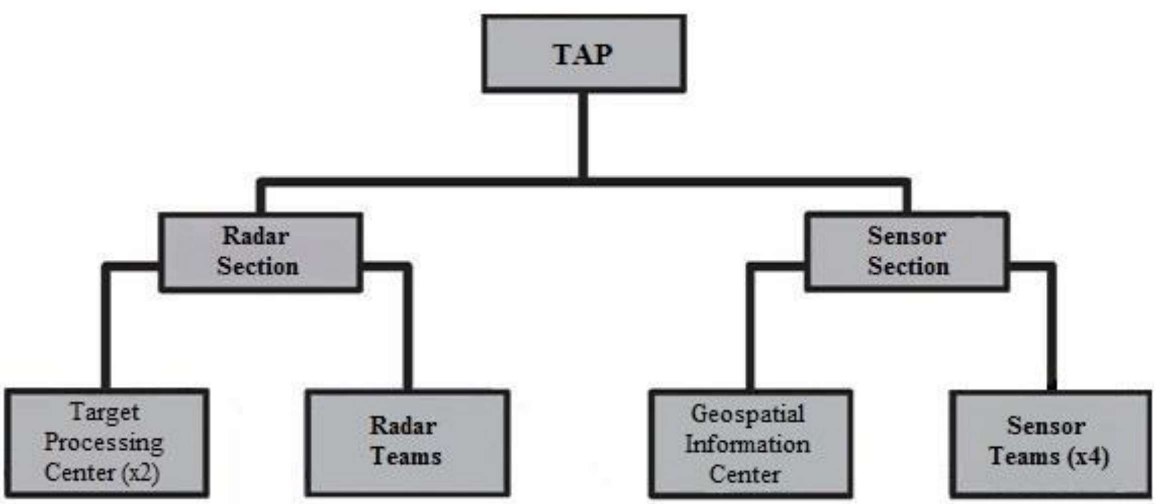


Figure 1-1. TAP Organization

b. The TAP is organic to the headquarters battery of the Marine Corps artillery regiment. The TAP is separate from the operations platoon; however, the TAP commander is responsible to the operations officer (S-3) of the artillery regiment. The TAP is comprised of the radar section and sensor section. The radar section is comprised of the target processing centers (TPCs) and the radar teams. The sensor section is comprised of a geospatial information center (GIC) and the sensor teams. All sections within TAP fall under the command of the TAP commander. This holistic approach to target acquisition fully supports the artillery regiments mission as part of a Marine division serving as the ground combat element (GCE) to a Marine expeditionary force sized Marine air-ground task force (MAGTF).

c. The mission of the TAP is to provide the GCE and other elements of the MAGTF, as may be directed by the artillery regimental commander, with a task-organized unit containing sufficient personnel and radar/sensor coverage to conduct timely and accurate acquisition and processing of counterfire targets, and provide positioning, geographic and meteorological information necessary to meet the five requirements for accurate fires.

d. The TAP can task organize detachments to attach to an artillery battalion in support of a Marine expeditionary brigade (MEB) or a Marine expeditionary unit. In these scenarios, both radar and sensor capabilities can be assigned the mission to support the artillery battalion in a direct support role or general support to the MAGTF.

1-3. Target Acquisition Platoon Sensor Section

The primary mission of the TAP sensor section is to provide continuous all weather survey, meteorological, and acoustic support to the GCE of the MAGTF. The primary survey focus of the section is the maintenance of the division common grid, generally fourth order to adjust the battalions onto the common grid. Additionally, it is responsible for providing meteorological support for artillery and target acquisition assets within the MAGTF as well as any other indirect fire assets (i.e., mortars). The sensor section also has an acoustic detection capability for counterfire, cross queuing of other sensors and intelligence gathering in support of the MAGTF.

1-4. Geospatial Information Center

The GIC is responsible for management of all artillery survey, meteorological, and acoustic assets in the MAGTF and coordinates the logistics and employment of those assets. It maintains the common grid and performs imagery based map reconnaissance and sensor planning. The GIC has the ability to post and manage survey information on the common operating picture via joint tactical common operating picture workstation/command and control personal computer and Advanced Field Artillery Tactical Data System (AFATDS). Meteorological information can be produced at the GIC using modeled meteorological capabilities or the GIC can pass meteorological information from the sensor teams operating additional meteorological assets to supported units. The GIC processes acoustic events and pass targetable data to the TPC for counterfires, cross queuing of radars, or as target indicators for the further processing at the TPC. Acoustic intelligence is passed from the GIC to the regimental combat operations center (COC) intelligence section. The GIC is generally located with the artillery COC and may be co-located with the TPC.

1-5. Sensor Teams

Sensor teams are capable of providing survey, meteorological, and acoustic support as detailed in the sensor plan. Each team can provide meteorological support via modeled meteorological, visual or extrapolated MET procedures. All teams can provide survey support using inertial navigation, Global Positioning System (GPS), and conventional survey methods. Each team can employ and maintain the ground counter fire sensor (GCFS) sensor posts (SP).

1-6. Battalion Sensor Section

a. The primary mission of the artillery battalion sensor section is to provide a common grid over the MEB area of operations (AO). This includes providing survey control to all units, organic or attached, to the battalion. The battalion sensor section may be tasked to provide control to units requiring survey who are not attached to the battalion, but who are operating within the AO. Due to their wide ranging and independent operating nature, the battalion sensor section also acts as the artillery battalion's reconnaissance element.

b. The battalion sensor section will normally perform fifth order surveys. When a battalion is operating independently from the artillery regiment, as with a MEB, they may be required to establish some limited fourth order control and conduct limited regiment TAP functions. Normally, the battalion sensor's mission requires a more timely response than is afforded with fourth order specifications. If a TAP detachment is included in the force, all fourth order work performed by the battalion must be provided to the TAP sensor section for inclusion in their network. The battalion sensor section will not establish permanent survey control unless it is essential to the mission.

c. The artillery battalion operational zone (Figure 1-2 page 1-4) is divided into three areas of concern: the position area, connection area, and the target area. This delineation is necessary to plan operations and to aid in prioritizing work.

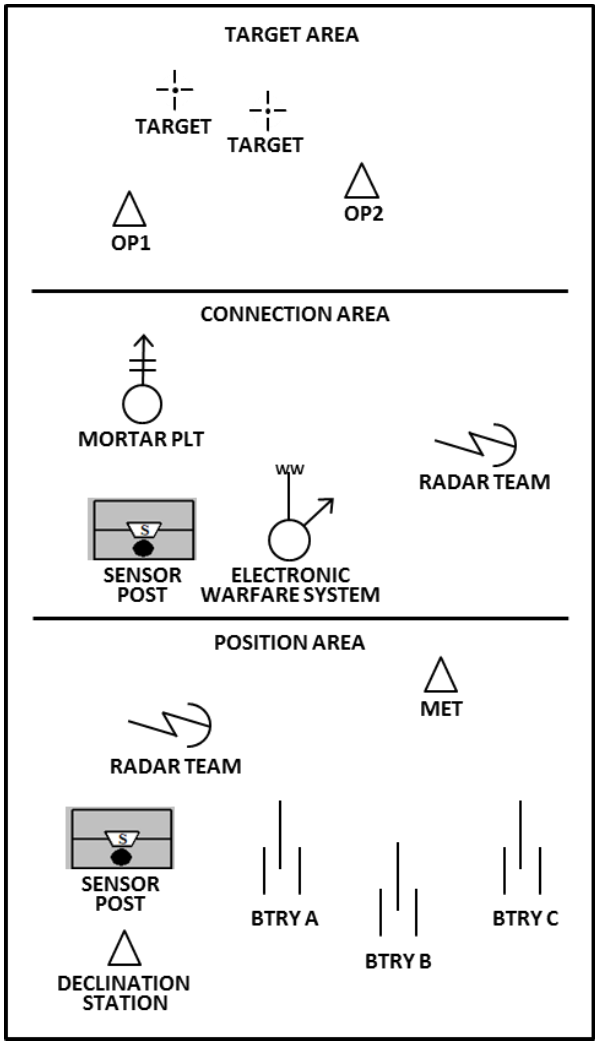


Figure 1-2. Areas of Concern – Artillery Battalion

(1) The position area is the rear most area of the artillery battalion's zone. Positions here are usually afforded the highest priority of work. The position area includes the artillery firing positions (alternate, supplementary, and offset registration positions), declination stations, meteorological, radar, sensor posts, initialization points, and other sites to complete the mission.

(2) The target area is the forward area of the artillery battalion's zone and is generally second area in priority of work. The target area includes target acquisition assets, observation posts (OPs), and targets.

(3) The connection area is the portion of the artillery battalion's zone that lies between the position area and the target area and is generally third in priority of work. It is called the connection area because its main function is to connect the target and position areas into a common network. Positions requiring survey support that lie in this area are included in the connection area surveys. These positions may include radar and meteorological sites, electronic warfare sites, mortar positions, sensor post and other sites to support or complete the mission.

CHAPTER 2 ORGANIZATIONAL OVERVIEW

Section I. ROLES AND RESPONSIBILITIES

2-1. General

This chapter discusses target acquisition platoon key personnel duties and responsibilities, and command and control of sensor assets.

2-2. Target Acquisition Platoon Warfighting Precept

a. Warfare continually evolves, and the commander's challenge is to ensure that the evolution of warfighting tactics and methods stay ahead of the enemy's observe, orient, decide, act loop. To preempt the increasingly rapid and unconventional cycle of the enemy, the Marine Corps has organized and equipped a flexible, task-organized, capabilities-based platoon. The TAP is able to rapidly form and adapt to the myriad of mission sets described in Marine Corps operating concepts in a changing security environment.

b. The sections within TAP have been organized for the purpose of military occupational specialty assignment, billet description, and associated training; however, the TAP organization must be viewed from a holistic standpoint rather than a group of disparate individual capability sets. The TAP is a flexible and viable warfighting capability that weighs the effort of the MAGTF throughout the decide, detect, deliver, and assess targeting methodology. In effect, TAP must be capable of performing its mission in major operations that involve conventional and irregular warfare and transitioning between the two when directed.

c. For details on the Target Acquisition Platoon Warfighting Precept, refer to Marine Corps Reference Publication (MCRP) 3-10E.7, *Tactics, Techniques, and Procedures for Field Artillery Target Acquisition.*

2-3. Target Acquisition Platoon Key Personnel Duties

The following paragraphs describe the duties and responsibilities performed by key TAP personnel and the sensor section (Table 2-1 page 2-2). For duties performed by personnel in the radar section see MCRP 3-10E.7, *Tactics, Techniques, and Procedures for Field Artillery Target Acquisition*.

Table 2-1. Key USMC Target Acquisition Platoon Personnel.

Rank	MOS	Billet	Location
CWO4	**0803**	**TAP Commander**	**Artillery HQ**
CWO3	**0803**	**Radar Officer**	**Artillery HQ**
CWO2	**0803**	**Sensor Officer**	**Artillery HQ**
MGySgt	**0848**	**TAP Chief**	**Artillery HQ**
GySgt	**0848**	**Sensor Chief**	**Artillery HQ**
SSgt	**0848**	**Geospatial Information Chief**	**Artillery HQ**
SSgt/Sgt	**0848/0847**	**Sensor Squad Chief**	**Sensor Section**
Sgt	**0847**	**Sensor Team Chief**	**Sensor Team**

CWO4: chief warrant officer 4
MOS: military occupational specialty
SSgt: staff sergeant
MGySgt: Master gunnery sergeant
Sgt: Sergeant

a. Target Acquisition Platoon Commander. The duties and responsibilities of the target acquisition platoon commander include but not limited to:

(1) Reports to artillery regiment S-3 operations officer.

(2) Advises the division fire support coordinator, assistant division fire support coordinator, force fires officer, maneuver and artillery commanders on the capabilities and limitations of the TAP and detachments.

(3) Ensures the radar and sensor plans are mutually supporting, provides for all support requirements, and supports the friendly scheme of maneuver.

(4) Develops standing operating procedures (SOP) for TAP and counterfire operations ensuring they support combat SOPs of supported units and doctrinal publications.

(5) Responsible for all TAP personnel and equipment to include all training requirements, administration, maintenance, logistical support, communications, and readiness.

(6) Commands and directs the personnel and operations of the platoon.

(7) Participates in operational planning teams (OPTs) as directed by either the artillery regimental commander, S-3, or as required by the assistant division fire support coordinator.

(8) Assists in development of the overall sensor employment in support of the fire support plan and force protection posture.

(9) Recommends task organization of TAP detachments for operations in support of contingencies, Marine expeditionary unit deployments, operations, and training exercises.

b. Radar Officer. The duties and responsibilities of the radar officer include but are not limited to:

(1) Reports to the TAP commander.

(2) Advises the supported commanders on the capabilities and limitations of the radar section to include the technical considerations affecting the employment of radars.

(3) Leads and manages the radar section.

(4) Writes and coordinates the radar plan with the sensor officer and TAP commander.

(5) Ensures radar plan supports the intelligence collection effort and intelligence preparation of the battlespace (IPB).

(6) Recommends and coordinates the employment of radar assets including positioning, coverage, logistics, and survivability.

(7) Develops SOP for radar operations and coordinates that SOP with the sensor officer and TAP commander.

(8) Supervises and coordinates activities of the TPC.

(9) Supervises and coordinates activities of the radar teams.

(10) Coordinates with the sensor officer, fire direction officer, and fire support officer to ensure the GIC, TPC, fire direction center (FDC), and fire support coordination center have up-to-date common operating picture information.

(11) Coordinates with the GIC for map reconnaissance.

(12) Plans, supervises, and inspects training and maintenance of radar assets and personnel.

(13) Performs the duties of TAP commander when directed.

c. Sensor Officer. The duties and responsibilities of the sensor officer include but are not limited to:

(1) Reports to the TAP commander.

(2) Advises the supported commanders on the capabilities and limitations of the sensor section to include the technical considerations affecting the employment of sensor assets.

(3) Manages the sensor section.

(4) Writes the sensor plan and coordinates that plan with the radar officer and TAP commander.

(5) Recommends and coordinates the employment of acoustic sensors and survey/meteorological capabilities including positioning, logistics, movement, and survivability.

(6) Develops SOP for sensor operations and coordinates that SOP with the radar officer and TAP commander.

(7) Coordinates activities of the GIC.

(8) Coordinates activities of the sensor teams.

(9) Coordinates with the radar officer, fire direction officer, and fire support coordination center to ensure the GIC, TPC, FDC, and fire support coordination center have up-to-date common operating picture information.

(10) Recommends task organization and mission priorities of the sensor teams.

(11) Supervises GIC and sensor teams in execution of their duties.

(12) Ensures proper training of GIC and sensor teams and integrates training plan with TAP training plan.

(13) Plans, supervises, and inspects training and maintenance of the sensor section assets and personnel.

(14) Performs the duties of TAP commander when directed.

d. Target Acquisition Platoon Chief. The duties and responsibilities of the TAP chief are as follows:

(1) Reports to TAP commander.

(2) Coordinates with the regimental operations chief for matters pertaining to enlisted personnel.

(3) Recommends SOP for TAP operations to the TAP commander.

(4) Participates in MCPP as directed by TAP commander.

(5) Ensures functionality of target processing communications network, ensuring radar and GCFS SP positions are accounted for in the communications plan.

(6) Performs other duties as directed by TAP commander.

e. Sensor Chief. The duties and responsibilities of the sensor chief include but are not limited to:

(1) Reports to sensor officer.

(2) Advises the sensor officer on all asset and personnel issues that affect the capabilities and limitations of the sensor section.

(3) Assists the sensor officer in preparing the sensor plan.

(4) Advises the sensor officer on all aspects of sensor employment.

(5) Supervises and inspects training and maintenance of sensor assets and personnel.

(6) Recommends SOP for sensor operations to the sensor officer.

(7) Supervises execution of the sensor plan.

(8) Performs the duties of the sensor officer in the sensor officer's absence.

(9) Coordinate with the TAP chief for matters pertaining to enlisted personnel.

f. Geospatial Information Chief. The duties and responsibilities of the geospatial information chief include but are not limited to:

(1) Reports to sensor officer.

(2) Advises the sensor officer on all asset and personnel issues that affect the capabilities and limitations of the geospatial information center.

(3) Supervises and inspects training and maintenance of GIC assets and personnel.

(4) Recommends SOP for GIC operations to the sensor officer and sensor chief.

(5) Supervises the conduct of GIC operations.

(6) Maintains the GCE common grid.

(7) Manages artillery meteorological reporting and assets.

(8) Coordinates with the TPC chief for acoustic acquisition processing.

(9) Coordinates with the intelligence chief for acoustic intelligence processing, provides relevant information gathered by sensor teams, and any collections the intelligence section may request from the sensor section.

(10) Coordinates with the operations chief ensuring proper integration of the GIC into the artillery COC.

(11) Performs imagery-based analysis for positioning of all target acquisition assets and field artillery assets as required.

(12) Performs the duties of the sensor chief in the sensor chief's absence.

g. Sensor Squad Chief. The duties and responsibilities of the sensor squad chief include but are not limited to:

(1) Reports to sensor chief.

(2) Advises the sensor chief on all asset and personnel issues that affect the capabilities and limitations of the sensor teams.

(3) Supervises and inspects training and maintenance of squad assets and personnel.

(4) Executes assigned portion of the sensor plan.

(5) Establishes and supervises security activities and procedures ensuring the safety and survivability of the squad's Marines and equipment.

(6) Supervises sensor squads operations.

h. Sensor Team Chief. The duties and responsibilities of the sensor team chief include but are not limited to:

(1) Reports to sensor squad chief.

(2) Advises the sensor squad chief on all asset and personnel issues that affect the capabilities and limitations of the sensor teams.

(3) Supervises and inspects training and maintenance of team assets and personnel.

(4) Executes assigned portion of the sensor plan.

(5) Conducts route reconnaissance, site selection, and positioning for artillery units as required by the movement plan and for TAP assets as required by the radar and sensor plans.

(6) Supervises sensor team operations.

2-4. Battalion Sensor Section Key Personnel Duties

The following paragraphs describe the duties and responsibilities performed by key battalion personnel and the sensor section (Table 2-2).

Table 2-2. Battalion Sensor Section Key Personnel

Rank	MOS	Billet	Location
CWO2	**0803**	**Target Acquisition Officer**	**Artillery Battalion HQ**
GySgt	**0848**	**Sensor Chief**	**Artillery Battalion HQ**
Sgt	**0847**	**Sensor Team Chief**	**Sensor Team**
CWO2: chief warrant officer 2 MOS: military occupational specialty		GySgt: gunnery sergeant Sgt: Sergeant	

a. Target Acquisition Officer. The duties and responsibilities of the sensor officer include but are not limited to:

(1) Reports to the battalion operations officer.

(2) Advises the supported commanders on the capabilities and limitations of the sensor section and attached assets, to include the technical considerations affecting their employment

(3) Writes the battalion sensor plan and coordinates that plan with the battalion operations officer.

(4) Coordinates the employment of survey, meteorological, and attached assets capabilities, including positioning, logistics, movement, and survivability.

(5) Develops SOP for sensor operations and coordinates that SOP with the battalion operations officer.

(6) Recommends task organization and mission priorities of the sensor teams.

(7) Plans, supervises, and inspects training and maintenance of the sensor section assets and personnel.

b. Sensor Chief. The duties and responsibilities of the sensor chief include but are not limited to:

(1) Reports to target acquisition officer.

(2) Advises the target acquisition officer on all asset and personnel issues that affect the capabilities and limitations of the sensor section.

(3) Assists the target acquisition officer in preparing the sensor plan.

(4) Supervises and inspects training and maintenance of sensor assets and personnel.

(5) Supervises execution of the sensor plan.

(6) Performs the duties of the target acquisition officer in the target acquisition officer's absence.

c. Sensor Team Chief. The duties and responsibilities of the sensor team chief include but are not limited to:

(1) Reports to sensor chief.

(2) Advises the sensor chief on all asset and personnel issues that affect the capabilities and limitations of the sensor teams.

(3) Supervises and inspects training and maintenance of team assets and personnel.

(4) Executes the assigned portion of the sensor plan.

(5) Conducts route reconnaissance, site selection, and positioning for artillery units as required by the movement plan.

(6) Supervises sensor team operations.

Section II. ORGANIZATIONAL GUIDANCE

2-5. Command and Control

a. 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. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. Refer to the *Department of Defense Dictionary of Military and Associated Terms*.

b. Command and control is facilitated by establishing an organization for combat that ultimately assigns a command relationship to every target acquisition asset. Three command and control methodologies exist for employing target acquisition assets.

(1) Centralized control primarily at the division or regimental combat team.

(2) Decentralized control by attaching sensor assets to a subordinate unit.

(3) Combination of centralized and decentralized control.

CHAPTER 3 SENSOR SECTION

Section I. SENSOR SECTION MISSION

3-1. General

This chapter addresses the specific missions of each element of the sensor section (Figure 3-1) in order to better define their role in providing the capabilities of the target acquisition platoon. Chapter three will also cover the capabilities of the sensor section as well as some of the limitations in order to provide an understanding in which to better employ, task organize, and provide the full strength and warfighting functions of the TAP and battalion sensor section.

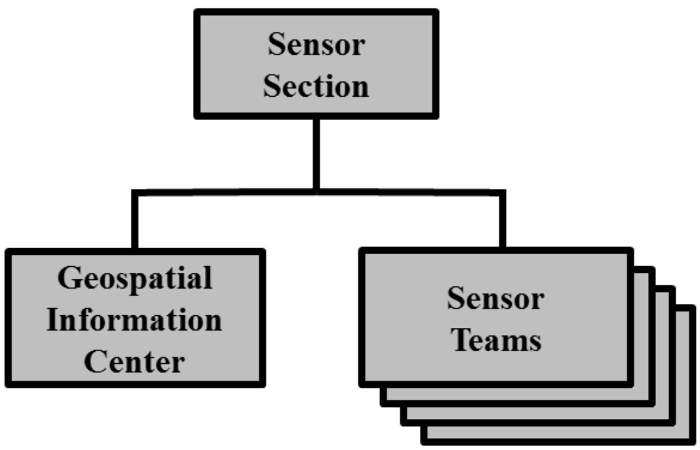


Figure 3-1. Sensor Section Organization

3-2. Five Requirements for Accurate Fires

The mission of the field artillery is to destroy, neutralize, or suppress the enemy by cannon, rocket, and missile fires and to help integrate all fire support assets into combined arms operations. In order to meet this mission there are five requirements for accurate fires. These separate but related requirements must be accounted for in planning and constantly verified during operations. Failure to account for any of the five requirements will result in any number of errors and most importantly, sub-standard artillery support.

a. <u>Accurate Target Location</u>. This is a function of the sensor or observer utilized to locate the target. Short of mensuration, all sensors have a degree of error known as target location error. Target location error is three dimensional and typically exacerbated by distance, direction, and slant angle to the target and must be mitigated as much as possible through a combination of training and accurate positioning and calibration of sensors. Failure to attain accurate target location will result in the inability to achieve the element of surprise and provide first round fires for effect.

b. <u>Accurate Weapon Location</u>. This is a function of positioning accuracy achieved through the employment of survey assets organic to the artillery unit such as inertial, conventional, or global positioning systems. The artillery battalion sensor section is responsible for ensuring survey control for the artillery unit sensors and weapons are on a common grid with each other and with higher artillery headquarters. It should be understood that in the massing of fires, that multiple weapons and target location systems must be on a common survey grid in order to achieve both accuracy and precision. The most important aspect of weapon location is direction as it is a function of range to target while location is a constant regardless of range to target. Failure to achieve accurate weapon orientation will result in increasing error as a factor of range while positional errors will be a constant. Collectively, inaccurate weapons locations will result in the inability to execute accurate fires.

c. Accurate Ammunition and Weapon Information. This is the application of corrections to those measurements of non-standard conditions of the weapon which can be accounted for such as muzzle velocity variation, powder temperature, and difference in projectiles square weight. Failure to account for accurate weapon information will result in inconsistency in fires and inability to achieve precision or accuracy.

d. Accurate Meteorological Data. This is the scheduled and unscheduled measurement of current meteorological conditions (wind speed, wind direction, temperature, and pressure) aloft as close to the vertex (highest point of trajectory) of the round and as close to the time of firing as possible. Failure to continuously update meteorological information could result in excessive target miss distance. Meteorological information is obtained through meteorological assets in the TAP or battalion sensor section organic to the artillery unit.

e. Accurate Computational Procedures. This is the assurance that information used in the computation of the technical gunnery solution is correct and as accurate as possible with respect to the weapon, target, munitions, time, and conditions. Failure to ensure accuracy of computational information may cause errant fires and result in target miss, unwanted collateral damage, or fratricide.

3-3. Common Grid

a. Establishing a common grid is a command responsibility. A common grid does not apply to artillery only. It must be established throughout the battlespace and constantly maintained for use by all fire support and targeting assets. To provide a common grid is to provide data to the required accuracy that permits:

(1) Massing of fires. Bringing more than one firing unit to bear against a common target at the same time without prior adjustment or registration of separate artillery units.

(2) Delivery of surprised observed fires. Accurate and timely fires against enemy positions with no adjustment.

(3) Delivery of effective unobserved fires. Effective and timely fires against enemy positions that are not observed (group and series targets or prep fires). Without

survey, unobserved fires can only be effective if the target had been previously fired upon.

(4) Transmission of target data from one unit to another. The ability of one firing unit to provide locations of adjusted targets to another firing unit for subsequent engagement by that unit or for massing fires.

(5) Transfer of registration data to a new position. This is necessary when moving a battery from one primary position to another and when moving to an alternate or supplementary position. A common grid is also required between a firing position and an offset registration point (RP).

b. All stations surveyed in the same network are relative to specific points regardless of the survey methods used (those points being the known control used to fix and adjust those networks). Stations surveyed from other points that have already been listed as common are relative to those stations at an accuracy determined by the methods and equipment used. For example, if a battalion sensor section establishes a battery initialization point with an inertial navigation system or GPS from fourth order or higher common control, the battery position is common to the higher order control but at a fifth order accuracy. Two points must be referenced to the same datum/ellipsoid and developed from the same map projection. They must be from the same network or have been adjusted or converted to the same network to be considered common points.

c. All stations surveyed from a point whose location was obtained by hasty methods (map spot or hasty resection) or from absolute methods (Global Positioning System-survey [GPS-S]/Defense Advanced Global Positioning System Receiver [DAGR]) are common to that point. However, they are not common to any local control. Stations not already common to another network can be made common by adjustment or by conversion to common control calculations.

d. A battalion sensor section must begin survey operations immediately. The availability of survey control, which depends largely on the tactical situation, terrain, and weather, may be scarce. Although there are several ways of obtaining starting control, the sensor section uses the best available control to begin a survey. Variations in starting control can be grouped into four different categories:

(1) Known coordinates, elevation, and azimuth.

(2) Assumed coordinates and elevation, known azimuth.

(3) Known coordinates and elevation, assumed azimuth.

(4) Assumed coordinates, elevation, and azimuth.

e. Known coordinates and elevation will be obtained from higher echelon sensor sections; i.e., GIC normally from a trigonometric listing (trig list). When known coordinates and elevations are unavailable, they must be assumed through hasty survey methods.

f. Known azimuths can be obtained from several different sources. Normally, a known azimuth will be computed from higher echelon coordinates or published in a trig list. When celestial bodies are visible, an azimuth from astronomic observation is preferred. When known azimuths are unavailable, they must be assumed through hasty survey methods.

g. Temporary positions will be marked with a wooden hub and tag. Hubs will be witnessed by a wooden stake and tagged. Any information pertaining to the establishment of permanent positions will be turned over to the GIC when practical. The orienting station (OS) of any position is marked and witnessed by a painted stake or flagged with tape, colored chemiluminescent (chemlight) at night, and set in the ground at an angle pointing towards the end of orienting line (EOL). The EOL of any position is marked and witnessed by a painted stake or flagged with tape (colored chemlight at night), and set in the ground. Colors are subject to unit SOP.

h. Information written on a tag is subject to SOP. The position number is the only information that must be listed on the tag. SOP must ensure that valuable information is not left on a tag that the enemy may use if discovered; e.g., grid coordinates or unit name.

i. Once surveys are completed, the accumulated data is provided to the battalion S-3 for dissemination to firing units and fire support assets. Data is also forwarded to the regiment's GIC.

3-4. Field Artillery Survey

Accurate target location and weapons location are two of the five requirements for accurate fires. The survey mission of the artillery sensor support Marine is to provide and extend common grid by establishing survey control in the position area, target area, and connection area.

3-5. Field Artillery Meteorology

Accurate meteorological data is one of the five requirements for accurate fires. The MET mission of the artillery sensor support Marine is to provide accurate MET messages to enhance first round accuracy, as well as, effective downwind predictions and intelligence preparation of the battlespace. The most accurate MET data available should be used.

3-6. Field Artillery Acoustic Sensors

The acoustic sensor mission of the artillery sensor support Marine is to determine the location of acoustic events produced by rockets, artillery, mortars, tanks, improvised explosive devices, etc. The primary focus is detection of enemy indirect fire assets; however it can also produce battlespace intelligence through detection of additional acoustic events.

a. The GCFS provides 6400 mil coverage, and it is an all-weather passive acoustic weapons locating system.

b. The GCFS is comprised of a network of individual SP deployed in an array based on tactical considerations and terrain which are best suited to acquire acoustic events. The sensor teams emplace and maintain the SP as a function of their tactical tasks. Ideally, four to eight SP's are deployed, surveyed onto a common grid, and maintained by the sensor teams.

c. The GCFS command post (CP) is located at the GIC which processes acoustic acquisitions and reports counterfire events to the TPC and other events as necessary to the supported artillery intelligence section.

d. The GCFS uses the principles of acoustic signals produced by the firing of rockets, artillery, mortars, IEDs, or other acoustic events to determine their locations. The following paragraphs discuss some basic fundamentals of acoustics necessary for successful employment of the GCFS.

e. When a weapon is fired or an acoustic event has occurred, a region of intense pressure is produced. The surrounding air is displaced outward in all directions against air that is further out; this is known as a compression. The air is pushed away from the origin of the disturbance until the pressure has decreased to a value below normal, known as a rarefaction. The air then flows back into the low-pressure area until the pressure returns to normal again. In acoustics, this series of successive compressions and rarefactions produce what is known as an oscillation or sound wave. Sound is propagated in waves that can be represented if we think of a pebble that is tossed into a pond. As the pebble begins to sink, the water is raised upward and outward. The ripples (waves) we see represent the series of compressions and rarefactions. Sound has a relatively long wavelength. It may propagate (travel) in several ways; along the ground, through the air, refracted from atmospheric inversions, or even scattered by turbulent airflow.

f. The GCFS is a passive acoustic weapon locating system. Acoustic signals produced by the firing of artillery, mortars, rockets, tanks or other acoustic events are detected and measured at each SP. If the SP detects the acoustic event, it will transmit detection data and MET information to the CP. Detections produce lines that extend out from the SP. At the CP the command post computer (CPC) operates in the data fusion processor mode to process intersecting detection lines into locations. Locations are a result of three or more reported detections and will be displayed on the CPC so that appropriate action may be taken. Figure 3-2 (page 3-6) depicts an operational view.

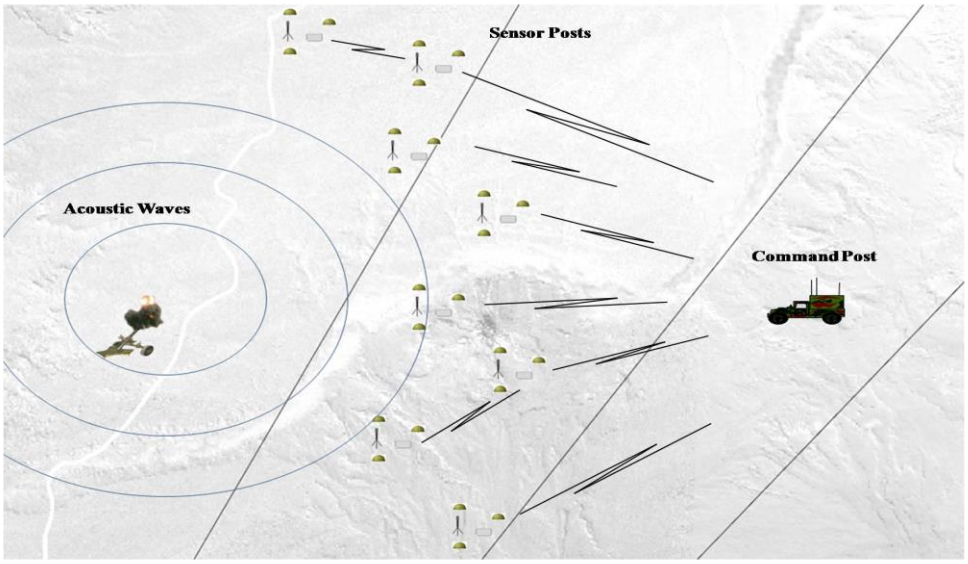


Figure 3-2. GCFS Operational View

3-7. Artillery Route Reconnaissance

The primary purpose of this reconnaissance is to determine the suitability of the route of the unit's movement. Items to be analyzed include possible alternate routes, cover, concealment, location of obstacles, likely ambush sites, contaminated areas, route marking requirements, weight limitations, traffic-ability, and the time and distance required to traverse the route.

Section II. CAPABILITIES AND LIMITATIONS

3-8. Sensor Section Capabilities

The sensor section is comprised of the personnel and equipment required to support the artillery survey, meteorological and acoustic sensors requirements of the MAGTF GCE.

a. The sensor section and equipment can be task organized to support inertial, GPS, and conventional requirements of the artillery firing units as well as OPs and close proximity mortar positions. The sensor section maintains a GIC which is the principal command and control hub for all survey and geospatial activities and is co-located with the senior supported artillery headquarters.

b. Meteorological support will be coordinated by the sensor section and has the capability to support visual observation or numerical weather prediction (NWP) from globally modeled and regionally published weather models. The sensor section's MET assets can support any unit either locally or remotely with all required MET messages as long as there are reliable communications to the supported unit.

c. The sensor section has the responsibility and capability to plan, emplace, and monitor an acoustic sensor network. The GCFS provides 6400 mil coverage of acoustic events. Ideally, between four and eight SPs are deployed, surveyed onto a common grid, and maintained by the sensor teams as a function of their tactical mission.

3-9. Sensor Section Limitations

Each sensor section brings considerable capability, however, it is crucial to know and understand the limitations. The artillery community has mitigated many of the limitations through redundancy, but redundancy must be planned for to be effective. The following are some of the general limitations of the sensor section assets.

a. Global Positioning System survey assets may be exposed to jamming from a number of sources; therefore, it is crucial to establish a survey plan that is prepared for such an event. Equally important, it should be noted that conventional survey operations are time consuming and require considerable planning and coordination. A properly coordinated sensor plan will mitigate almost all limitations short of catastrophic equipment failure or combat loss.

b. The sensor section provides the artillery commander with redundant capability of MET support via visual observations and extrapolated techniques. However, it should be considered during planning that pilot balloon (PiBal) observations must have clear visibility in order to observe and report altitude and azimuth of the ascending balloon. Extrapolated MET assumes a standard atmospheric lapse rate for pressure and temperature and carries surface wind direction and wind speed throughout the zones of the message without change.

c. The GCFS acoustic sensor network is subject to the limitations of the physical and scientific properties of sound propagation. The GCFS provides 6400 mil coverage of acoustic events, however; sounds may be prone to deflection and other such anomalies that may produce erroneous solutions. Additionally, the counterfire fight is typically time critical and GCFS acquisitions are limited to the speed of sound. These limitations are nominal and may be mitigated through the planning process.

CHAPTER 4 BASIC GEODESY

4-1. General

Geodesy is the science of measuring and monitoring the size and shape of the earth, including its gravity field and determining the location of points (through use of a geodetic system) on the earth's surface. A geodetic system serves as a framework for determining coordinates on the earth's surface with respect to a reference ellipsoid and the geoid. It consists of both a horizontal datum and a vertical datum.

4-2. The Geoid

a. The geoid is the equipotential surface in the gravity field of the Earth that coincides with the undisturbed mean sea level (MSL) extended through the continents. It is the zero reference for elevation, a closed surface of equal gravitational force. The direction of gravity is perpendicular to the geoid which approximates MSL over the surface of the earth.

b. Equipotential surface for our use as artillery sensor support means a position that is denoting the direction of greatest increase (pull of gravity) and is perpendicular to a surface (the geoid).

c. The geoid is affected by variances in the density, type, and amount of land mass that push up through the water or lie below it, causing dips and swells over its surface, thus conforming to an equal force of gravity over that surface. The dips and swells are called undulations (Figure 4-1).

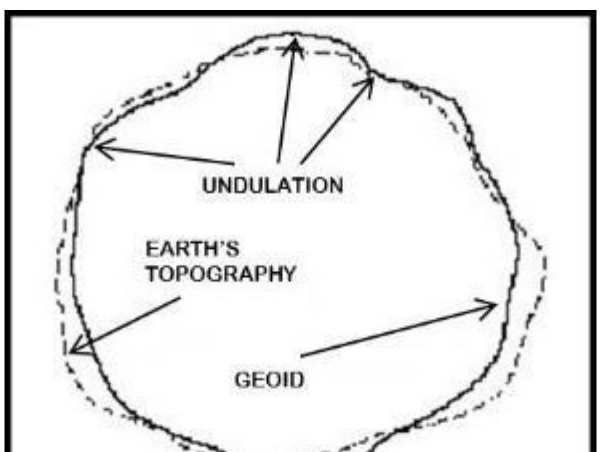


Figure 4-1. Undulation

d. Gravity pulls perpendicular to the geoid. This means that a plumb line lies perpendicular to the geoid and establishes a vertical direction of measurement. An adjusted level vial is centered when it lies parallel with the geoid and establishes a horizontal reference at a specific location. The geoid provides a common reference for elevation wherever the surface of the geoid intersects a land mass is generally referred to as approximate MSL.

e. Elevation is the distance between a point on the Earth's surface and the geoid, measured along a line perpendicular to the geoid (plumb line). Points lying outside (above) the geoid have a positive elevation; points inside (below) the geoid have a negative elevation. Elevation can be referred to as Orthometric height or MSL height. Elevation is labeled "H" (Figure 4-2).

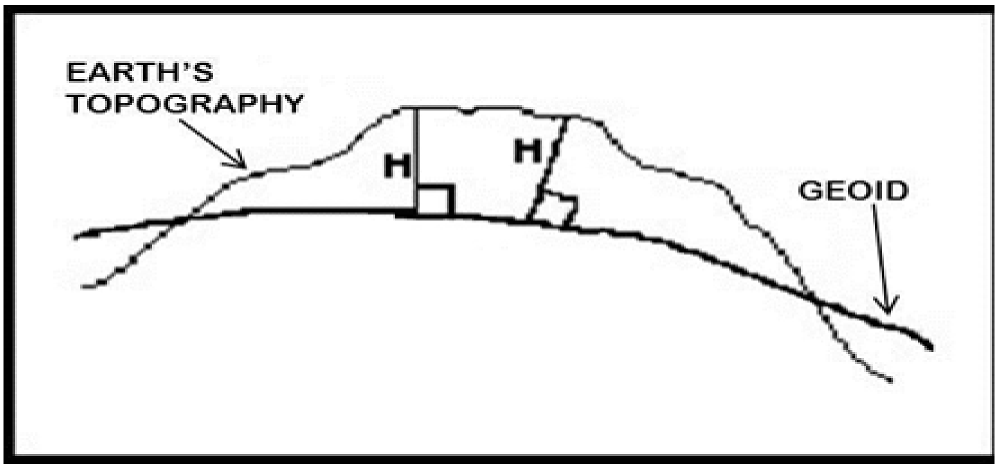


Figure 4-2. Elevation

f. Elevation can be determined in several ways. The most common is to compare the vertical interval between two points using survey equipment and computations which started from vertical control that had already been relative to a MSL station or tidal mark. The elevation then is the accumulated vertical intervals between stations to that point. Sometimes the elevation cannot be determined through survey computations and must be developed in other ways (i.e., GPS). The geoid is not a real surface like the topography which can be touched or measured. It is a shape with a gravity force that is the same over its entire surface. With the collection of topographic surveys already made and the advent of satellite technologies, the geoid surface can be modeled; this modeling allows for the determination of elevation without the need to conduct large surveys.

4-3. Ellipsoid Defining Parameters

a. An ellipsoid is a surface whose plane sections (cross sections) are ellipses or circles, or the solid enclosed by such a surface. It can be more easily identified as a sphere that is flattened or squashed on the sides or the top and bottom. In geodesy, we use an ellipsoid that is flattened on the top and bottom; i.e., an oblate ellipsoid. The terms ellipsoid and spheroid can be considered interchangeable; however, ellipsoid is the correct term (Figure 4-3 page 4-3).

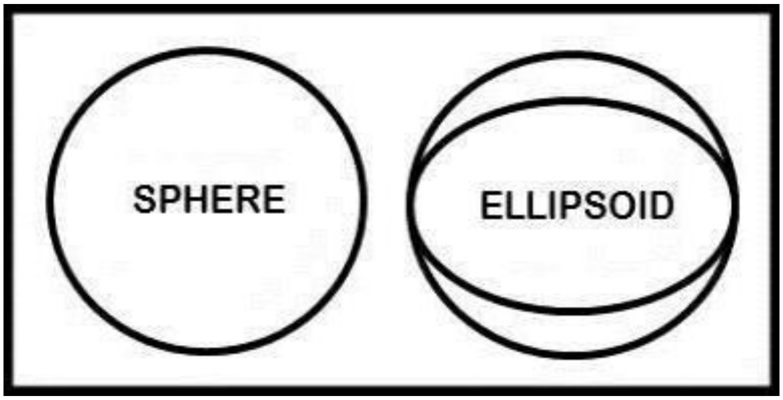


Figure 4-3. Ellipsoid

b. An ellipsoid is defined by many parameters (or dimensions) that provide the size, ellipticity, gravity field, angular velocity, and eccentricity of the ellipsoid. Defining parameters for ellipsoids are discussed in National Imagery And Mapping Agency (NIMA) TR 8350.2, Department of Defense (DOD) World Geodetic System 1984 (WGS 84), and Defense Mapping Agency TM 8358.1, Datums, Ellipsoids, Grids, and Grid Reference Systems. For most applications, only the size and ellipticity of the ellipsoid are necessary (Figure 4-4).

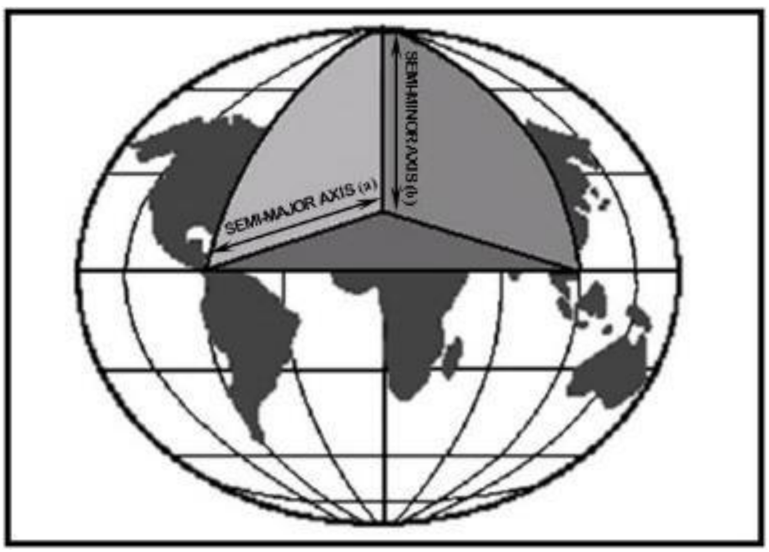


Figure 4-4. Defining Parameters

c. The semi-major axis is the distance along the equatorial plane of an ellipsoid from the center of that plane to its edge or the equatorial radius. It is referred to as the long radius of an ellipsoid or one-half of the largest diameter and is labeled "a."

d. The semi-minor axis is the distance in a meridional plane from the center of the plane to its closest edge, or the polar radius. It can also be referred to as the short radius of the ellipsoid or one-half of the shortest diameter. It is labeled "b."

e. The flattening is the ratio of the difference between the equatorial and polar radii (semi-major and semi-minor axes) to the equatorial radius (semi-major axis). It is labeled “f” but is more commonly expressed as the inverse of flattening (1/f). Flattening is sometimes called ellipticity.

4-4. Reference Ellipsoid

a. The oblate ellipsoid is used in geodesy because it is a regularly shaped mathematical figure. Unlike the geoid, there is no undulation. If the geoid were regularly shaped, there would be no need for an ellipsoid. We would simply compute surveys referenced strictly to the geoid. Since that is not the case, an ellipsoid is defined and then fixed to a specific location and orientation that makes it closely resemble the surface of the geoid. This is accomplished by establishing a horizontal datum. Once an ellipsoid is fixed by a specific datum, it becomes a reference ellipsoid.

b. Reference ellipsoids can be local in extent or global. If the ellipsoid resembles only a small region of the geoid and is fixed to a point on the surface of the Earth, it’s a local reference ellipsoid. If the ellipsoid is fixed to the center of mass of the Earth and is designed to resemble the geoid as a whole, then it is global and is called an Earth-centered Earth-fixed ellipsoid (Figures 4-5 and 4-6).

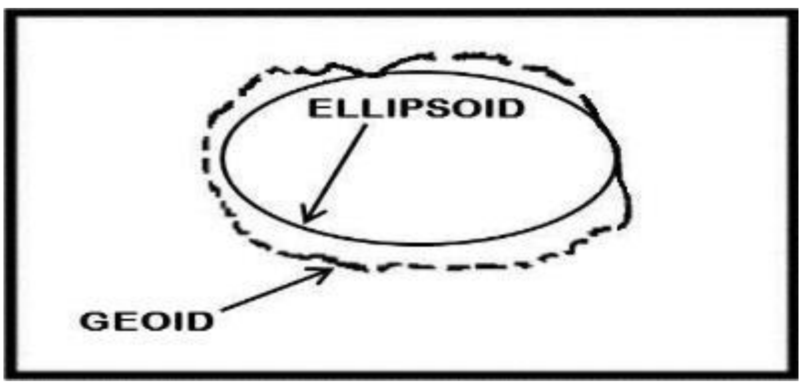


Figure 4-5. Reference Ellipsoid

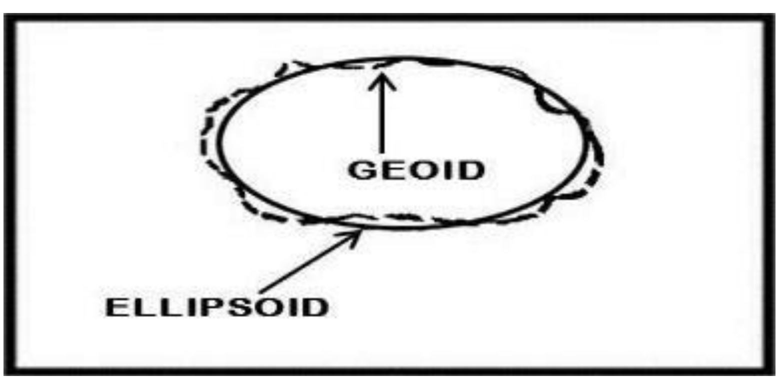


Figure 4-6. Earth-center Earth-fixed Ellipsoid

4-5. Geoid Separation

Geoid separation is the distance from the geoid to the reference ellipsoid, measured along a line that is perpendicular to the ellipsoid. It is positive when the geoid lies outside the ellipsoid; negative when the geoid lies inside the ellipsoid. Geoid separation is labeled “N” and is called geoidal height (Figure 4-7).

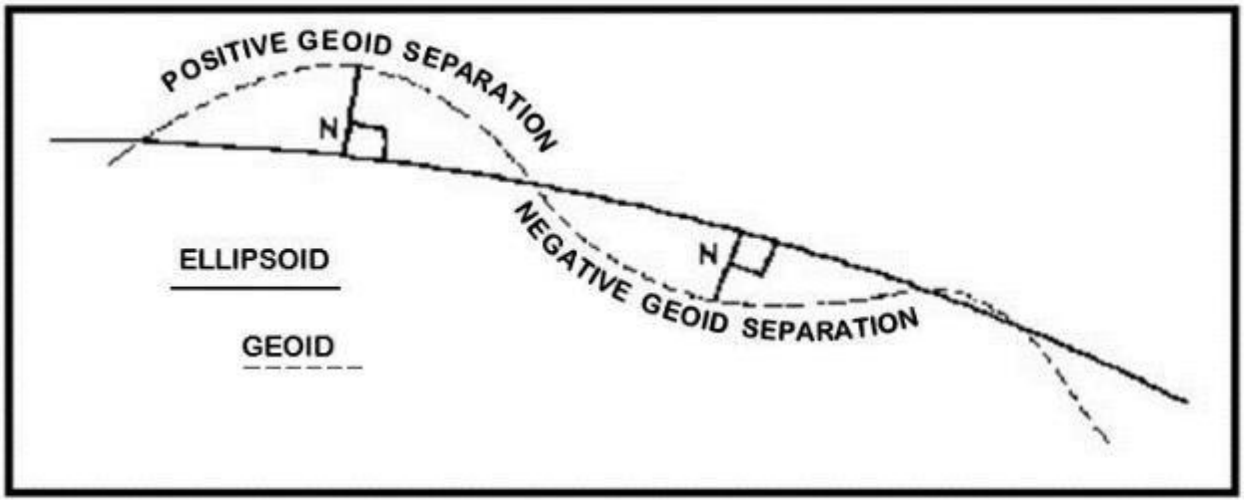


Figure 4-7. Geoid Separation

4-6. Ellipsoid Height

a. Ellipsoid height is the distance from a point on the Earth’s surface to the reference ellipsoid, measured along a line that is perpendicular to the ellipsoid. Ellipsoid height is labeled “h” and can be referred to as geodetic height or height above ellipsoid (HAE) (Figure 4-8).

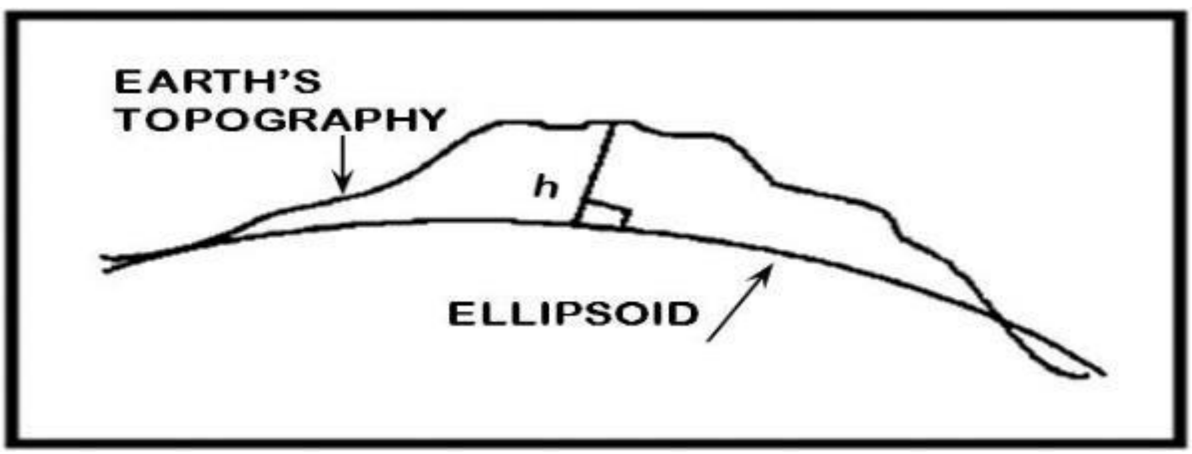


Figure 4-8. Ellipsoid Height

b. The relationship between ellipsoid height (h), elevation (H), and geoid separation (N) is shown in the formula h= H+N (Figure 4-9 page 4-6).

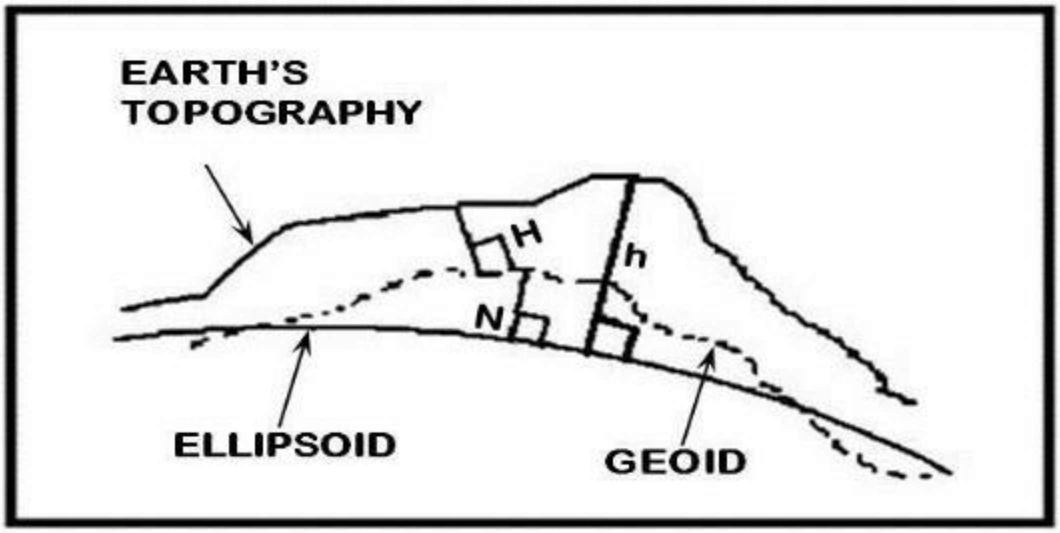


Figure 4-9. Relationship between h, H, and N

4-7. Earth Gravity Models

a. Earth gravity models (EGMs), sometimes called Earth geopotential models, provide a geoid separation value to apply to HAE to generate an elevation.

b. There are several different models available for use at different accuracies:

(1) EGM84- 30 Min grid

(2) EGM96- 15 min grid

(3) EGM08- 5 min grid

c. Positioning systems seek or provide elevation; absolute GPS provides a HAE and uses EGM to determine the elevation for survey systems or the survey system uses the EGM to convert the elevation.

d. Fire support personnel and weapon systems providing elevations will use an EGM to determine the HAE. Different weapon systems use different EGMs.

4-8. Datums

a. A datum is any reference system against which measurements may be made. Horizontal datums measure position on the surface of the Earth, while vertical datums are used to measure elevation. When the term datum is used by itself, it is usually referring to a horizontal datum. Vertical and horizontal datums are generally defined separately from each other. For example, horizontal positions in the Korean peninsula may be defined by the Tokyo Datum referenced to the Bessel ellipsoid; vertical positions are defined by the geoid referenced to the MSL datum.

b. A vertical datum is a level surface or arbitrary level to which elevations are referred. Usually, the geoid (mean low level) is that surface. However, other vertical datums may include MSL, the level at which the atmospheric pressure is 29.92 inches of mercury (1013.2 millibars or an arbitrary starting elevation. Vertical datums are usually defined as a surface of “0” elevation and are also called altitude datums.

c. Since it is impossible to determine exactly where the geoid intersects a land mass, it is impossible to use the geoid as the actual vertical datum. Historically, tide gauge measurements were averaged over 19 years to establish a local MSL. These MSL datums are very close to the geoid but not exactly. For this reason level lines run from tide gauge marks in different regions do not connect exactly at the same elevation. In the United States, the national geodetic vertical datum of 1929 replaced the MSL 1929 and has since been updated to the North American vertical datum 1988. This new vertical datum, based on tide gauge measurements and precise geodetic leveling, has extended a common vertical network to most of the continental United States (CONUS). The North American vertical datum is considered to be within a few meters of the geoid. There is greater uncertainty in the relationship between other local vertical datums and the geoid throughout the world.

d. Because of the uncertainty between local MSL datums and the geoid and unknown exact relationships between those datums, all elevations should be considered to be referenced to the MSL datum to shift between vertical datums.

e. A horizontal datum is a set of quantities that fix an ellipsoid to a specific position and orientation. The point where the ellipsoid is fixed is called the datum point. There are two types of datums: surface-fixed and geocentric.

(1) A surface-fixed horizontal datum is a set of quantities relating to a specific point on the surface of the Earth that fixes an ellipsoid to a specific location and orientation with respect to the geoid in that region. The center of the ellipsoid and the center of mass of the Earth do not coincide. Examples are North American datum (NAD) 27, Tokyo, and ARC 1950 (Figure 4-10).

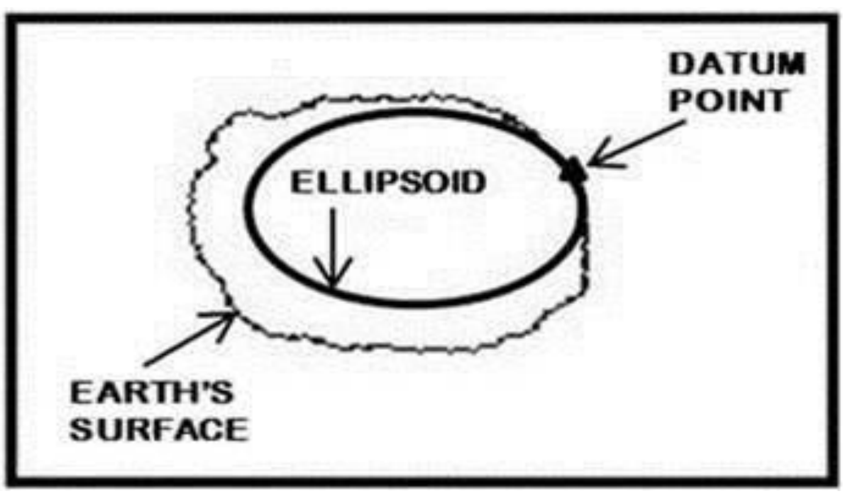


Figure 4-10. Surface-fixed Datum

(2) A surface-fixed datum is generally defined by five quantities: latitude (ϕ), longitude (λ), and geoid height (N) at the datum point; semi-major axis (a), and either semi-minor axis (b) or flattening (f) of the reference ellipsoid. A geodetic azimuth is sometimes listed as a defining parameter for a horizontal datum.

(3) A surface-fixed datum can cover very small areas to very large regions of the Earth. The geoid separation at the datum point is generally zero. However, as you move away from the datum point, the geoid separation increases creating the need for a new datum. Often, the same ellipsoid fixed to a different location and orientation is used.

(4) A geocentric horizontal datum specifies that the center of the reference ellipsoid is placed at the center of mass of the Earth. This point at the center mass of the Earth is also the datum point. Examples are the world geodetic systems, (Figure 4-11).

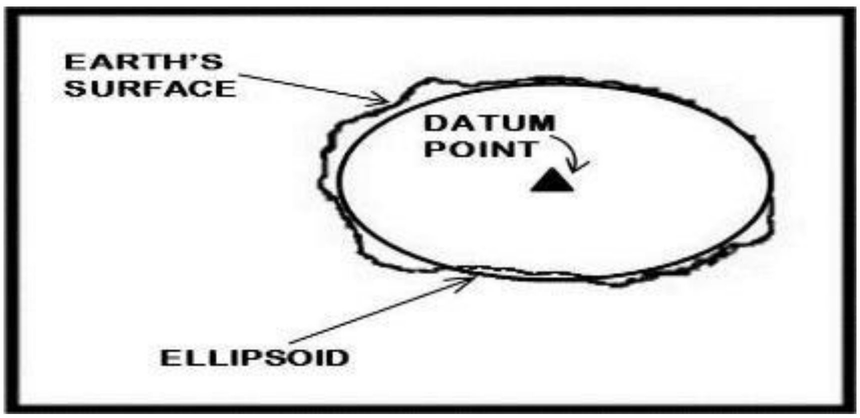


Figure 4-11. Geocentric Datum

(5) At least eight constants are required to define a geocentric datum. Three specify the location of the origin of the coordinate system; three specify the orientation of the coordinate system; and two specify the reference ellipsoid dimensions.

(6) Geocentric datums generally cover a large area of the world and in some cases is global in extent. The geoid separation remains relatively small for the entire region covered by the datum. The world geodetic systems developed by the DMA are global coverage datums; WGS 84 is the newest and most accurate. A world geodetic systems offers the basic geometric figure of the Earth (ellipsoid) as well as an associated gravity model (geoid). This is why the geoid separation remains relatively small over the entire system (generally less than 102 meters within WGS 84).

4-9. Multiple Datum Problems

a. Over 1,000 datums exist. Practically every island or island group in the Pacific Ocean has its own datum. Many areas are covered by multiple datums. This causes the most concern for sensor support Marines who must decide which datum to use and how to convert data between them. Mapping products established from different datums will not match at the neat lines nor will grid lines meet. Target acquisition assets will provide inaccurate data to firing systems if the target acquisition system is not on the same datum as the firing system. Common datum is a part of common grid.

b. The world geodetic systems was developed to create a global system that would alleviate many of these problems. NIMA will eventually revise all mapping and charting products to reference WGS 84 as the datum/ellipsoid for the entire world except for the United States. Mapping and charting products for the United States will reference Geodetic Reference System (GRS) 80 as the ellipsoid and NAD 83 as the datum.

c. All datums are defined relative to WGS 84. For this reason, transformations between datums are performed from and to WGS 84. When converting from surface-fixed datum 1 to surface-fixed datum 2, first transform datum 1 to WGS 84 then transform the WGS 84 datum to datum 2.

d. To develop datum shift parameters, coordinates on both datums at each of one or more physical locations must be known. Typically, for shifts from a local datum to WGS 84, the WGS 84 coordinates were derived from doppler satellite observations over points with already existing surface-fixed datum coordinates. Several methods of datum transformation are available. The rest of this section discusses them.

4-10. Seven Parameter Model

This geometric transformation model assumes that the origins of the two coordinate systems are offset from each other, that the axes are not parallel, and that there is a scale difference between the two datums. Data from at least three well-spaced positions are needed to derive a seven parameter geometric transformation. The seven parameters come from differences in the local and WGS 84 Cartesian coordinate. There are three axis rotation parameters, a scale change, and three origin shift parameters (ΔX, ΔY, ΔZ). The origin shift parameters are the coordinates of the origin of the local reference ellipsoid in the WGS 84 Cartesian coordinate system. Use of the seven parameter method is prescribed by Standardization Agreement (STANAG) 2211, *Geodetic Datums, Ellipsoids, Grids, and Grid References*, for some applications in Europe and England. It is considered more accurate than the five parameter model (Figure 4-12).

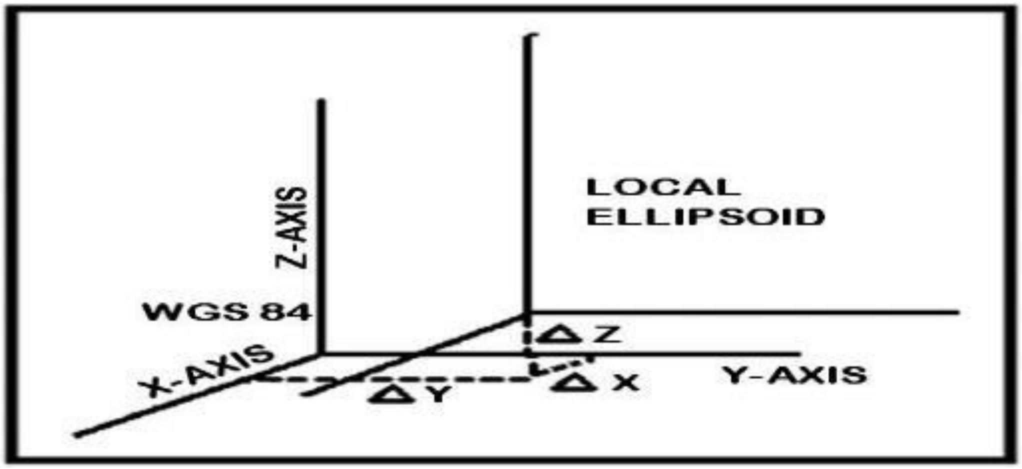


Figure 4-12. Origin Shift Parameters

4-11. Five Parameter Model

This model considers only the relative sizes of the ellipsoids and the offset differences in their origins. The five parameters are the difference in the semi- major axis ($\Delta\alpha$), the difference in flattening (Δfx10^4), and the three origin shift parameters (ΔX, ΔY, ΔZ). Origin shift parameters are the coordinates of the origin of the local reference ellipsoid in the WGS 84 Cartesian coordinate system. This model is used in computing standard Molodensky equations and is considered accurate to 5 to 10 meters.

4-12. WGS 72 to WGS 84

Formulas transforming between these two geocentric datums were created when WGS 84 was developed. These formulas are discussed in detail in NIMA TR 8350.2. Care must be taken when using them to determine the source of the world geodetic systems 72 coordinates. If the world geodetic systems 72 coordinates were transformed from original local datum coordinates, then a direct local datum to WGS 84 transformation is more accurate.

4-13. NAD 83 to WGS 84

These two datums are considered the same. The GRS 80 is the reference ellipsoid for NAD 83. It was developed before WGS 84 and was a factor in upgrading world geodetic systems 72. When developing WGS 84, three of the system's four defining parameters were made identical to the parameters used for GRS 80. The only difference was the gravity model. The two datums are considered identical in all areas covered by NAD 83 except for the Aleutian Islands and Hawaii where a datum transformation is necessary.

4-14. Multiple Regression Equations

Multiple regression equations were developed to deal with distortion on local datums. Datum shifts were created to reflect regional variations within the coverage area. This method is considered more accurate than the seven and five parameter models, usually 1 to 3 meters.

4-15. Lateral Shift Method

When transforming between datums referenced to the same ellipsoid, a constant shift can be determined that is adequate for artillery survey applications over a small area. For example, both NAD 27 and Puerto Rico datums are referenced to the Clarke 1866 ellipsoid. A shift in latitude and longitude can be computed over stations common to both datums, then applied to stations that need to be transformed. The lateral shift method produces accurate data for the entire island of Vieques, Puerto Rico.

CHAPTER 5 MAP PROJECTIONS COORDINATES AND GRID SYSTEMS

Section I. MAP PROJECTIONS

5-1. General

Chapter five will provide a detailed look at the differences between map projections, coordinates, and grid systems. It will explain the purpose of each system and how to locate the necessary information when working with each system. This chapter also provides example figures to help illustrate how and where to locate needed information.

5-2. Map Projections

a. A map projection is a method of representing a portion of the Earth's curved surface on to a flat surface. Because this procedure causes distortions of different types, many different projections have been developed. The type of projection used is dictated by the size of the area being mapped, the map scale, and the intended use of the maps (Table 5-1 pages 5-1 through 5-4).

Table 5-1. Projection Features

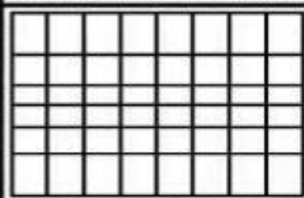
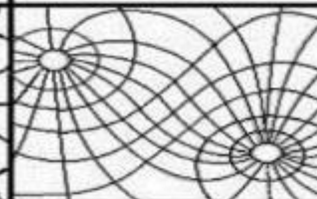
CHARACTERISTICS	MERCATOR	TRANSVERSE MERCATOR	OBLIQUE MERCATOR
PARALLELS	PARALLEL STRAIGHT LINES UNEQUALLY SPACED	CURVES CONCAVE TOWARD NEAREST POLE	SINE LINES
MERIDIANS	PARALLEL STRAIGHT LINES EQUALLY SPACED	COMPLEX CURVES CONCAVE TOWARD CENTRAL MERIDIAN	CURVED LINES
APPEARANCE OF PROJECTION			
ANGLE BETWEEN PARALLELS & MERIDIANS	90°	90°	90°
STRAIGHT LINE CROSSES MERIDIANS	CONSTANT ANGLE (RHUMB LINE)	VARIABLE ANGLE	VARIABLE ANGLE
GREAT CIRCLE	CURVED LINE (EXCEPT) EQUATOR & MERIDIANS	CURVED LINE	
RHUMB LINE	STRAIGHT LINE	CURVED LINE	CURVED LINE
DISTANCE SCALE	MID - LATITUDE		
GRAPHIC ILLUSTRATION	CYLINDER TANGENT AT EQUATOR 	CYLINDER TANGENT AT CENTRAL MERIDIAN FOR GK GRID; SECANT AT CENTRAL MERIDIAN FOR UTM GRID 	CYLINDER CAN BE TANGENT OR SECANT; DEPENDANT ON THE USE 
ORIGIN OF PROJECTORS	CENTER OF SPHERE (FOR ILLUSTRATION ONLY)	CENTER OF SPHERE (FOR ILLUSTRATION ONLY)	CENTER OF SPHERE (FOR ILLUSTRATION ONLY)
DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM EQUATOR	INCREASES AWAY FROM MERIDIAN OF TRUE SCALE	INCREASES AWAY FROM GREAT CIRCLE OF TRUE SCALE
METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL	MATHEMATICAL
NAVIGATIONAL USES	DEAD RECKONING & CELESTIAL (SUITABLE FOR ALL TYPES	GRID NAVIGATION	CHARTS OF GREAT CIRCLE PATHS
CONFORMAL	YES	YES	YES

Table 5-1. Projection Features (Continued)

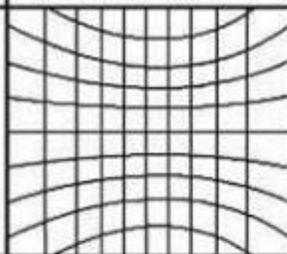
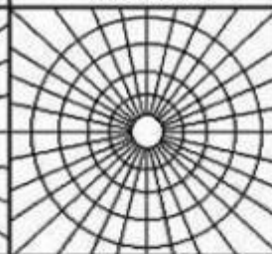
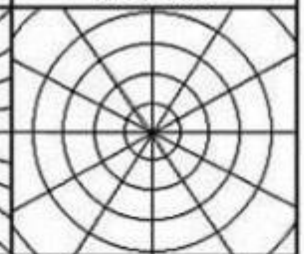
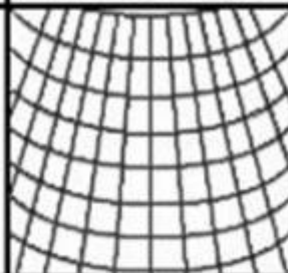
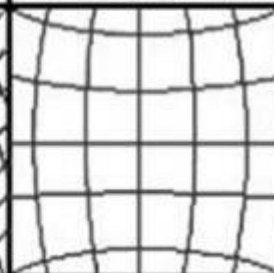
CHARACTERISTICS	GNOMONIC	POLAR GNOMONIC	POLAR STEREOGRAPHIC
PARALLELS	CONIC SECTIONS (CURVED LINES)	CONCENTRIC CIRCLES UNEQUALLY SPACED	CONCENTRIC CIRCLES UNEQUALLY SPACED
MERIDIANS	STRAIGHT LINES	STRAIGHT LINES RADIATING FROM THE POLES	STRAIGHT LINES RADIATING FROM THE POLES
APPEARANCE OF PROJECTION			
ANGLE BETWEEN PARALLELS & MERIDIANS	VARIABLE ANGLE	90°	90°
STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (CREAT CIRCLE)	VARIABLE ANGLE (CREAT CIRCLE)	VARIABLE ANGLE (APPROXIMATES GREAT CIRCLE)
GREAT CIRCLE	STRAIGHT LINE	STRAIGHT LINE	APPROXIMATED BY STRAIGHT LINE
RHUMB LINE	CURVED LINE	CURVED LINE	CURVED LINE
DISTANCE SCALE			NEARLY CONSTANT EXCEPT ON SMALL SCALE CHARTS
GRAPHIC ILLUSTRATION			PLANE CAN BE TANGENT OR DECANT; DEPENDANT ON THE USE 
ORIGIN OF PROJECTORS	CENTER OF SPHERE	CENTER OF SPHERE	OPPOSITE POLE
DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM CENTER OF PROJECTION	INCREASES AWAY FROM POLE	DECREASES AWAY FROM POLE
METHOD OF PRODUCTION	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL
NAVIGATIONAL USES	GREAT CIRCLE NAVIGATION AND PLANNING	GREAT CIRCLE NAVIGATION AND PLANNING	POLAR NAVIGATION OF ALL TYPES
CONFORMAL	NO	NO	YES

Table 5-1. Projection Features (Continued)

CHARACTERISTICS	LAMBERT CONTROL	POLYCONIC	AZIMUTHAL EQUIDISTANT
PARALLELS	ARCS OF CONCENTRIC CIRCLES NEARLY EQUALLY SPACED	METHOD OF PRODUCTION	CURVED LINES
MERIDIANS	STRAIGHT LINES CONVERGING AT THE POLES	MID-MERIDIAN STRAIGHT ALL OTHERS CURVED	CURVED LINES
APPEARANCE OF PROJECTION			
ANGLE BETWEEN PARALLELS & MERIDIANS	90°	VARIABLE	VARIABLE ANGLE
STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (APPROXIMATES GREAT CIRCLE)	VARIABLE ANGLE	VARIABLE ANGLE
GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	APPROXIMATELY STRAIGHT LINE NEAR MID-MERIDIAN	STRAIGHT LINES RADIATING FROM CENTER
RHUMB LINE	CURVED LINE	CURVED LINE	CURVED LINE
DISTANCE SCALE	NEARLY CONSTANT	VARIABLE FOR LARGE AREAS	TRUE AT ALL AZIMUTHS FROM CENTER ONLY
GRAPHIC ILLUSTRATION	SECANT CONE 		NO GEOMETRIC APPLICATION CAN BE SHOWN
ORIGIN OF PROJECTORS	CENTER OF SPHERE (FOR ILLUSTRATION ONLY)	CENTER OF SPHERE (FOR ILLUSTRATION ONLY)	
DISTORTION OF SHAPES & AREAS	VERY LITTLE	INCREASES AWAY FROM MID-MERIDIAN	INCREASES AWAY FROM CENTER
METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL	MATHEMATICAL
NAVIGATIONAL USES	SUITABLE FOR ALL TYPES	NORTH-SOUTH STRIPMAPS	AERONAUTICS, RADIO ENGINEERING, & CELESTIAL MAPS
CONFORMAL	YES	NO	NO

b. Each projection preserves certain properties and distorts others. Most projections are cylindrical, conical, or azimuthal, and project an ellipsoid onto cylinders, cones, or plane surfaces. These surfaces may be tangent to the ellipsoid or they may be secant (Figure 5-1). A projection is tangent to the ellipsoid when only one point or line of the projection surface touches the ellipsoid. It is secant when two points or lines touch the ellipsoid.

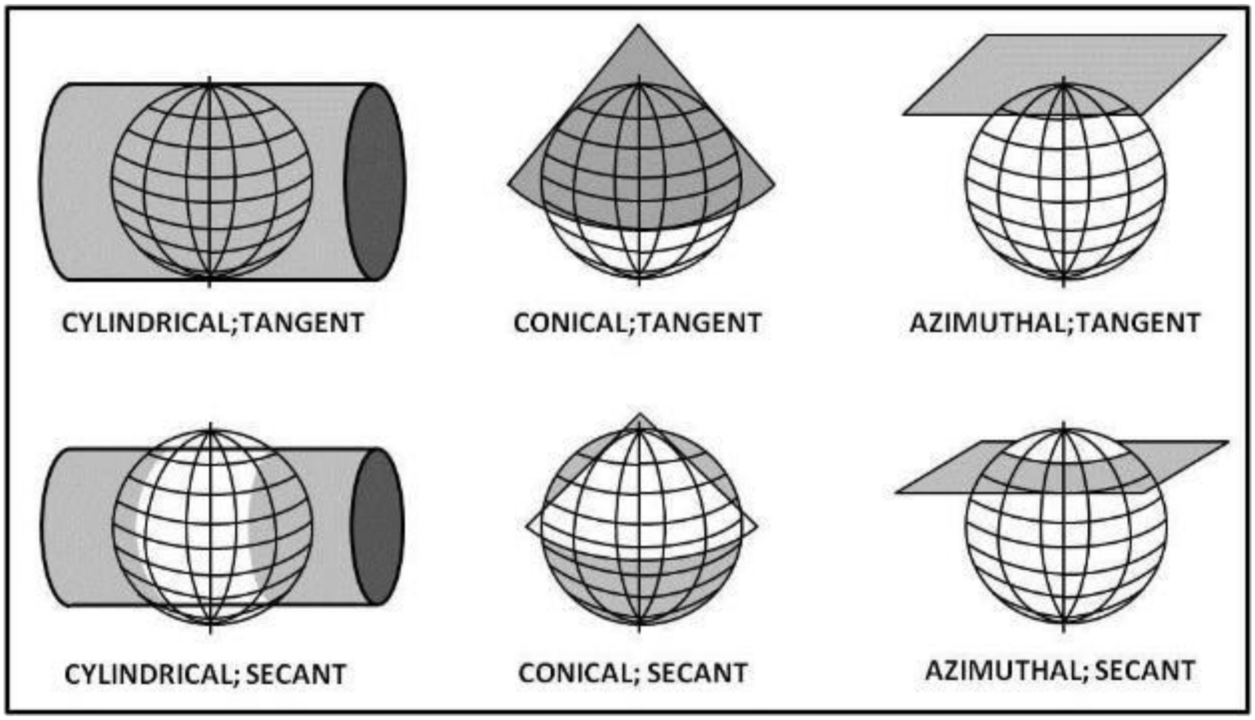


Figure 5-1. Projection Types: Tangent and Secant

c. One common characteristic applies to all United States military maps: they are all based on a conformal projection. A conformal map projection is one that at any point the scale is the same in any direction and the angle between any two lines on the ellipsoid is the same when projected onto a plane.

5-3. Prescribed Projections

a. The transverse mercator (TM) projection is the preferred projection for all military mapping, though it is not necessarily used on all military maps. The following projections are prescribed for US military topographic maps and charts that display a military grid on a standard scale. Military maps of non-US areas produced by other nations may not always conform to the following standards. US maps of foreign areas may be based on other projections due to treaty agreements.

b. Topographic maps at scales of 1: 500,000 or larger that lie between 80°S latitude and 84°N latitude are based on the TM Projection.

c. Topographic maps at scales of 1: 1,000,000 that lie between 80°S latitude and 84°N latitude are based on the Lambert conformal conic projection.

d. Maps at scales of 1: 1,000,000 or larger covering the polar regions (south of 80°S latitude and north of 84°N latitude) are based on the polar stereographic projection.

e. Maps at scales smaller than 1: 1,000,000 are based on the projection best suited for the intended use of the map; mercator being the most used.

5-4. Scale Factor

a. For most military applications, map distance and ground distance are considered the same. However, for some geodetic and artillery operations (especially when long distances or high accuracies are involved), it is necessary to correct between map and ground distances.

b. A scale factor is necessary to compensate for distortions created when projecting an ellipsoidal surface onto a cylinder, cone, or plane depending on the projection type. The scale factor of a projection is the ratio of arc length along a differentially small line in the plane of the projection to the arc length on the ellipsoid. This number depends on both the location of the point and on the direction of the line along which arc length is being measured. For conformal projections, the scale factor is independent of the direction of the line and depends only on the location of the point. The scale factor is labeled “k.”

c. The scale factor is considered exact (unity) when it has a value of 1. Unity occurs at the points of tangency or secancy between the ellipsoid and the projected surface. In a projection where the projected surface is tangent to an ellipsoid, the scale factor increases away from the point of tangency. In a projection where the projected surface is secant to an ellipsoid, the scale factor decreases toward the central meridian or origin and increases away from the points of secancy.

d. True ground distance can be converted to a map distance by multiplying the ground distance by the scale factor.

5-5. Map Scale

a. A map scale is a representative ratio of map distances to ground distances. These ratios vary from map to map. The scale of a map is customarily chosen to correspond to the ratio at a given point or along a given line (if constant along that line) multiplied by a suitable scale factor (usually close to unity). It is usually expressed as a common fraction having one as a numerator and the integer closest to the actual ratio as a denominator.

b. Maps used by the military vary from small-scale planimetric maps showing all of the continents to large-scale topographic maps suitable for tactical operations of small units and fire control. Military maps are classified according to their scale.

Small-scale:	1: 600,000 and smaller
Medium Scale:	Larger than 1: 600,000; smaller than 1: 75,000
Large Scale:	1: 75,000 and larger

c. Map scales can sometimes be confusing in the sense that the scale is smaller as the number increases. This confusion can be cleared by viewing the map scale as a fraction (1/100,000 is a smaller number than 1/ 50,000). The following are standard scales for military maps.

1: 1,000,000	1: 500,000
1: 250,000	1: 100,000
1: 50,000	1: 25,000

5-6. Mercator Projection

a. The mercator projection (Figure 5-2) is a cylindrical projection where the rotational axis of the ellipsoid coincides with the axis of the cylinder so that the equator is tangent to the cylinder. Points on the surface of the ellipsoid are projected onto the cylinder from the origin located on the equatorial plane and vary around three-quarters of the way back from the projected area.

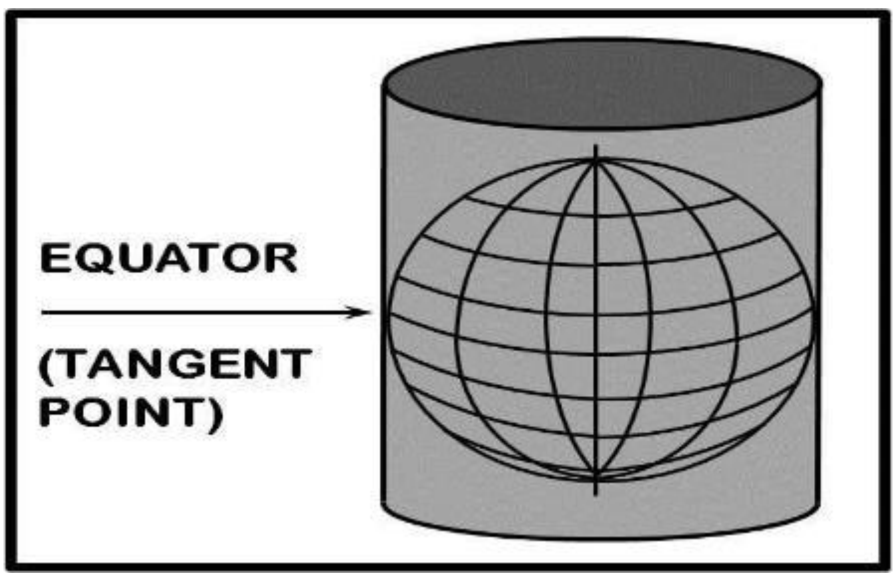


Figure 5-2. Mercator Projection

b. The cylinder is then opened and flattened (Figure 5-3 page 5-8) to produce a plane surface. The parallels of latitude and meridians of longitude both appear as sets of parallel lines that intersect at right angles. The meridians are equally spaced, but the distance between parallels increases as their distance from the equator increases. The poles cannot be shown on this projection (the normal limits are from 80°N latitude to 80°S latitude).

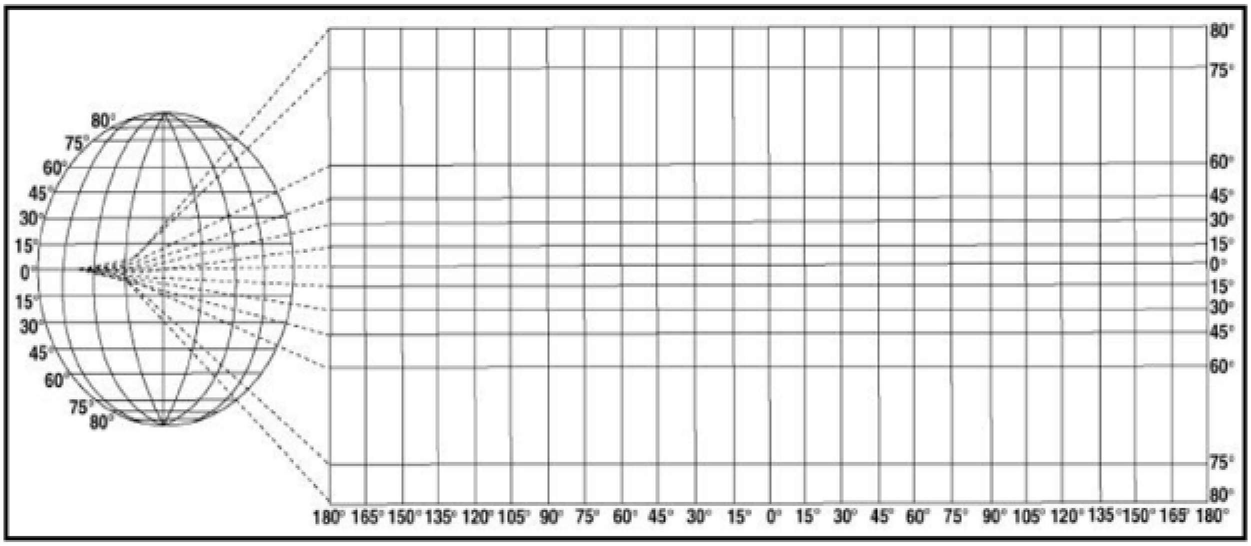


Figure 5-3. Mercator Projection Flattened onto a Cylinder

c. As the distance from the equator increases, so does the amount of distortion; e.g., the map scale at 60°N or S latitudes is nearly twice the map scale at the equator. Maps or charts with this projection will distort the size of an area. This is why Alaska appears to be the same size as the lower 48 states. This projection is not commonly used for military purposes except when the entire Earth must be displayed and relative positions of land masses are more important than size and distance.

5-7. Transverse Mercator Projection

a. The TM projection (Figure 5-4) is a cylindrical conformal projection. It is based on a modified mercator projection in that the cylinder is rotated (transversed) 90° so that the rotational axis of the ellipsoid is perpendicular to the axis of the cylinder. Generally, the TM projection is considered as a cylinder that is secant to an ellipsoid. Only a six-degree wide portion of the ellipsoid is projected onto the cylinder. The centerline of the projected area is called the central meridian. The ellipsoid is then rotated six degrees inside the cylinder and another six degree portion is projected.

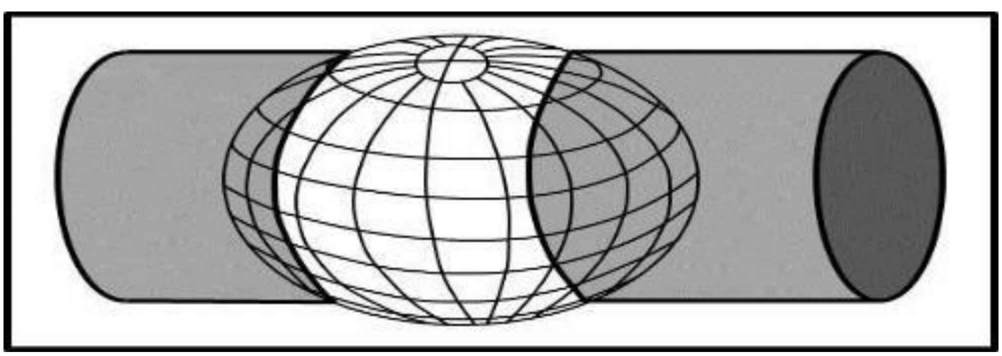


Figure 5-4. TM Projection

b. When the TM projection is used to project a portion of the ellipsoid onto the cylinder, the equator and the central meridian will appear as perpendicular straight lines. A hemisphere will be distorted towards its outer edges. The shaded areas of Figure 5-5 show the varying distortion of two equivalent geographic areas on the same projection. Note that both areas encompass a region 20° by 20° and are both bounded by 20° and 40°N latitude. Therefore, on the ellipsoid they are the same size. But on the projected surface the area bounded by 60° and 80° longitude is much larger than the area bounded by 0° and 20° longitude. To decrease the amount of distortion, the ellipsoid is divided into sixty 6°-wide projection zones, each with a meridian of longitude as its central meridian. Each zone is projected between 84° 30´ N latitude and 80° 30´ S latitude.

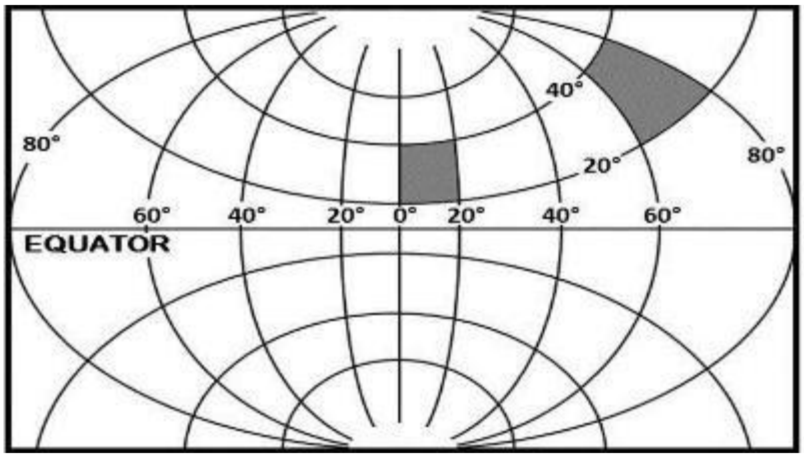


Figure 5-5. Distortion within the TM Projection

c. The cylinder used as the projection surface for the TM projection is generally considered to be secant to the ellipsoid. This means that the cylinder intersects the ellipsoid in two places creating lines of secancy (Figure 5-6 page 5-10) that are parallel to the central meridian of the projection. The lines of secancy are located 180,000 meters east and west of the central meridian of each projected zone.

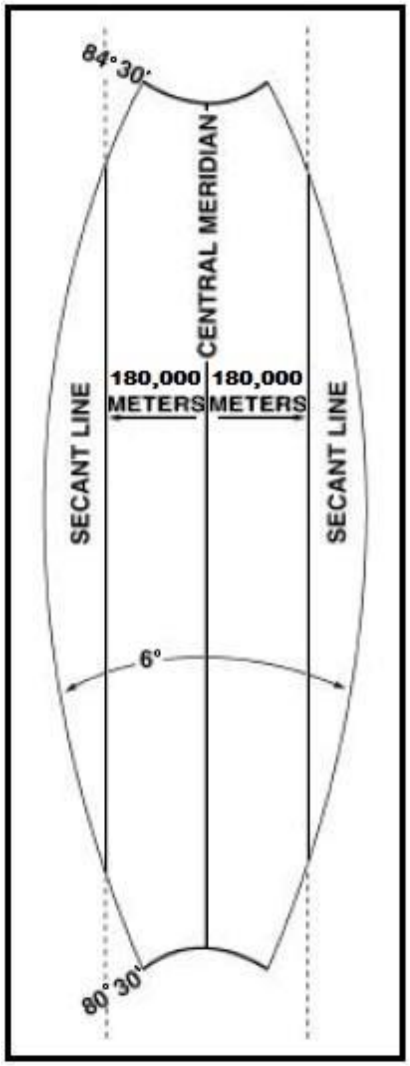


Figure 5-6. Secancy in a 6° Zone

d. Figure 5-7 (page 5-11) shows a cross section of an ellipsoid and a cylinder of projection that is secant to the ellipsoid. The cross section is made by passing a plane through the ellipsoid at the Equator. Line A' M' D' represents the surface of the cylinder. Line AMD represents the projected portion of the ellipsoid surface. M is the central meridian; M' is the projection of the central meridian onto the cylinder. A and D are the meridians located three degrees from the central meridian. A' and D' are the projections of those meridians onto the cylinder. B and C are the points where the cylinder intersects the ellipsoid creating the secant condition.

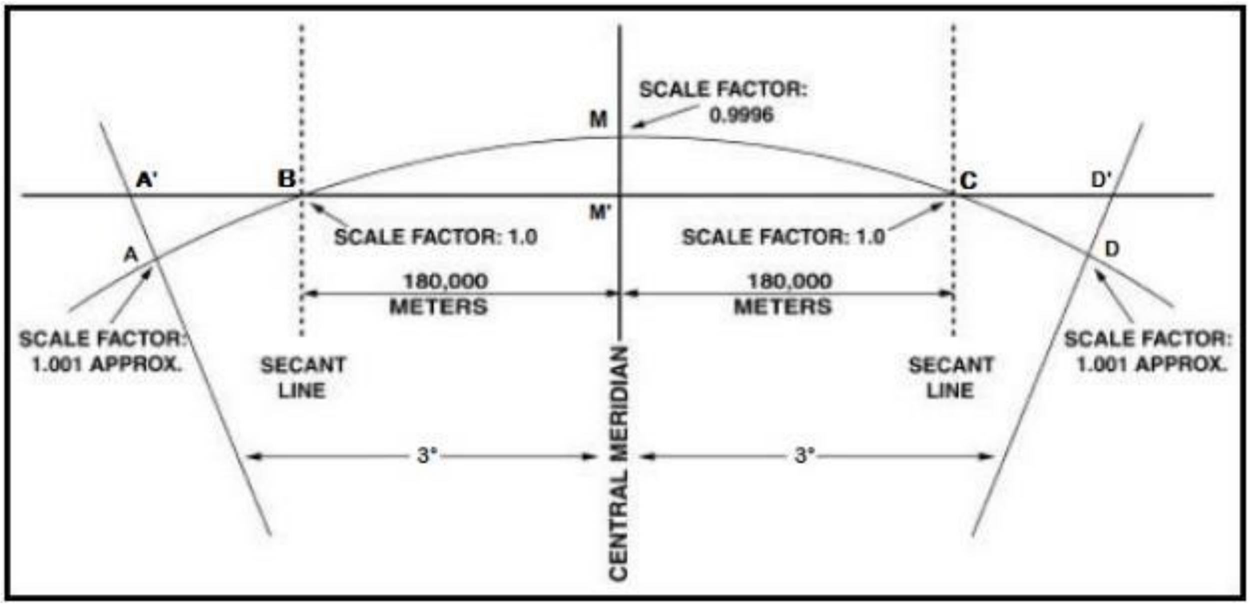


Figure 5-7. Line Distortion and Scale Factor in the TM Projection

e. Note that line BM'C is shorter than line BMC. This shows that any line that lies between the lines of secancy is shorter on its projected plane (map) than it is on the ellipsoid surface. Note also that lines A'B and CD' are longer than lines AB and CD, respectively. This shows that any line that lies between the lines of secancy and the edges of the projection are longer on the projected plane than they are on the ellipsoid surface. For the TM projection, the scale factor at the lines of secancy is unity (1.000 or exact). The scale factor decreases toward the central meridian to 0.9996. The scale factor increases toward the zone limits to approximately 1.001 at the equator (Figure 5-7 and Table 5-2 page 5-12).

Table 5-2. TM Projection Scale Factor by UTM Easting

Easting of Starting Station		Scale Factor (Meters)
500,000	500,000	0.99960
490,000	510,000	0.99961
480,000	520,000	0.99961
470,000	530,000	0.99961
460,000	540,000	0.99961
450,000	550,000	0.99963
440,000	560,000	0.99963
430,000	570,000	0.99966
420,000	580,000	0.99966
410,000	590,000	0.99970
400,000	600,000	0.99972
390,000	610,000	0.99975
380,000	620,000	0.99977
370,000	630,000	0.99982
360,000	640,000	0.99984
350,000	650,000	0.99985
340,000	660,000	0.99991
330,000	670,000	0.99995
320,000	680,000	1.00000
310,000	690,000	1.00005
300,000	700,000	1.00009
290,000	710,000	1.00014
280,000	720,000	1.00021
270,000	730,000	1.00025
260,000	740,000	1.00030
250,000	750,000	1.00037
240,000	760,000	1.00044
230,000	770,000	1.00051
220,000	780,000	1.00058
210,000	790,000	1.00064
200,000	800,000	1.00071
190,000	810,000	1.00078
180,000	820,000	1.00085
170,000	830,000	1.00094

5-8. Gauss-Kruger Projection

a. The Gauss-Kruger (GK) projection (Figure 5-8 page 5-13) can be described as the TM projection derived by mapping directly from an ellipsoid that is tangent to the cylinder. It is a conformal projection with many similarities to the TM projection. The tangent point is the meridian of longitude chosen as the central meridian for the projection. As with TM, the GK projection depicts 60 zones. Many geodesists consider the GK and TM projections to be the same except for scale factor.

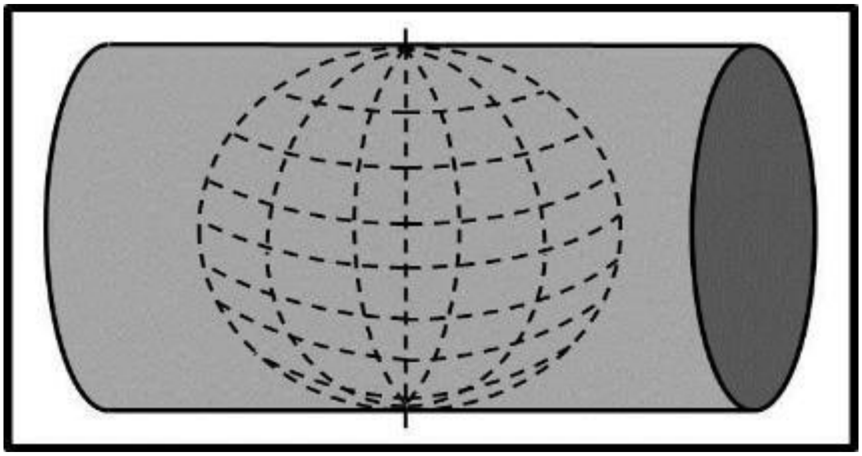


Figure 5-8. GK Projection

b. When a meridian is tangent to a cylinder of projection, there is no distortion along that line. Figure 5-9 shows all lines not located on the central meridian are longer on the projected surface than they are on the ellipsoid. For example, line A’M is longer than line AM when A represents the meridian located three degrees from the central meridian. A’ is the projection of that meridian onto a cylinder. M is the central meridian (tangent point).

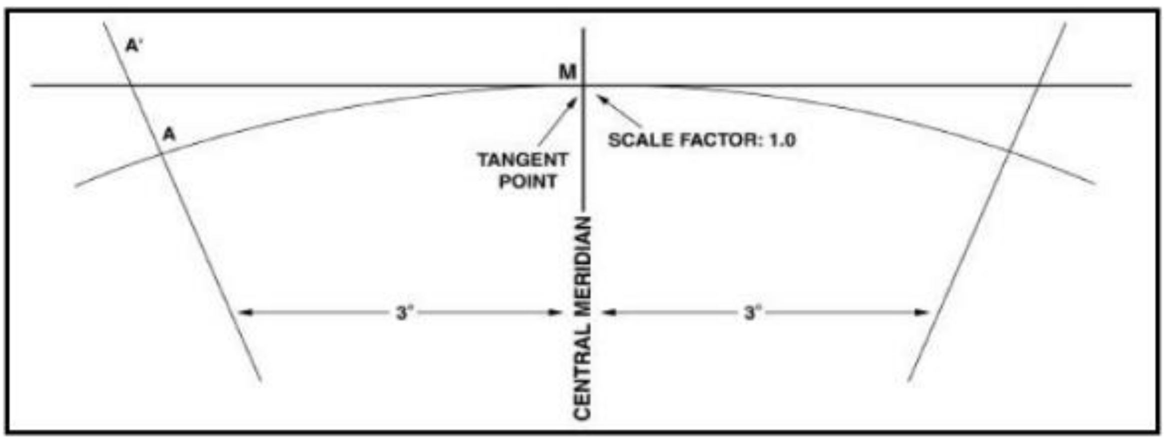


Figure 5-9. Line Distortion and Scale Factor in the GK Projection

c. For the GK projection, the scale factor at the central meridian is unity (1.000 or exact). The factor increases outward toward the zone limits in excess of 1.004 at the Equator.

5-9. Polar Stereographic Projection

a. The polar stereographic projection (Figure 5-10 page 5-14) is used for mapping the Earth’s polar regions and identifies those regions as north and south zones. The north zone extends from the North Pole to 83° 30´ N latitude; the south zone extends from the South Pole to 79° 30´ S latitude. It is a conformal azimuthal projection that is developed by projecting a polar region onto a plane that is tangent to an ellipsoid at the pole or secant to the ellipsoid at a specific latitude (Figure 5-11 page 5-14). The plane is perpendicular to the polar axis of the ellipsoid and the origin of the projection is the opposite pole (Figure 5-12 page 5-15). In this projection, meridians of longitude are straight lines and parallels of latitude are concentric circles.

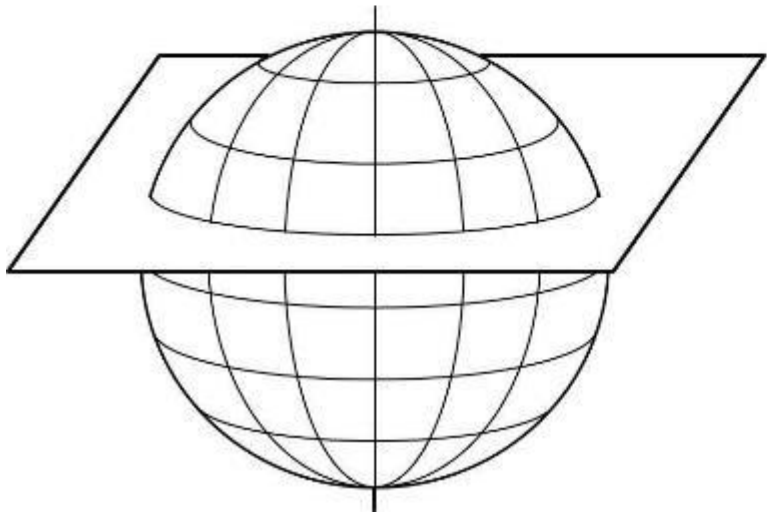


Figure 5-10. Polar Stereographic Projection: Secant

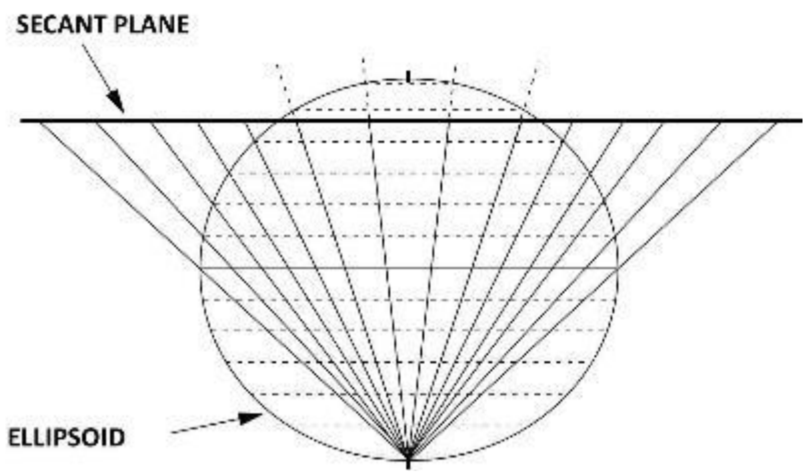


Figure 5-11. Origin of the Projection

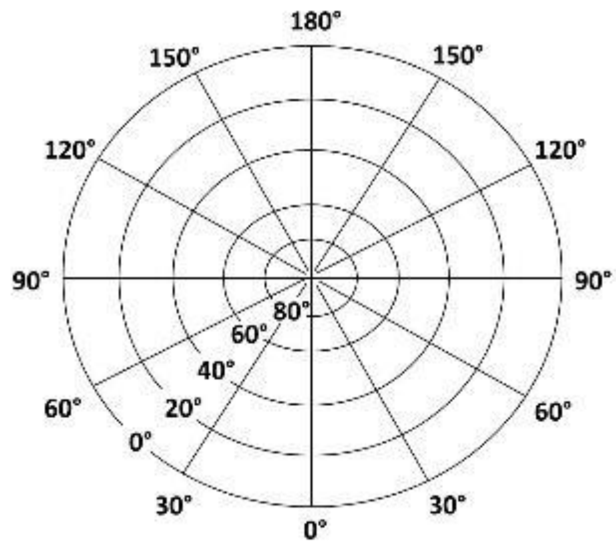


Figure 5-12. View of the Secant Plane

b. The polar stereographic projection is normally considered to be tangent to the ellipsoid. However, distortion is introduced when the curved surface of the ellipsoid in the vicinity of one of the poles is projected on to a plane surface; this is known as secancy of the ellipsoid. This distortion increases as the area is projected further from the pole. For military mapping, in order to reduce that distortion, the plane is placed secant to the ellipsoid at 87° 07´ north and south latitude. This establishes a circle in each zone which is intersects the ellipsoid surface and has no distortion at that circle.

c. Distortion of Lines (Figure 5-13) shows a cross-section of the ellipsoid and the secant plane made by passing a plane through a polar region of an ellipsoid. Line A’P’D’ represents the plane of the projection; arc APD is the surface of the ellipsoid. Note that a line on the ellipsoid which lies within the circle formed by the secant condition (latitude greater than 87° 07´) is longer than the same line projected on a plane (BP is longer than BP’). Note also that a line on the ellipsoid which lies outside the circle (latitude less than 87° 07´) is shorter than the same line projected on to a plane (AB is shorter than A’B).

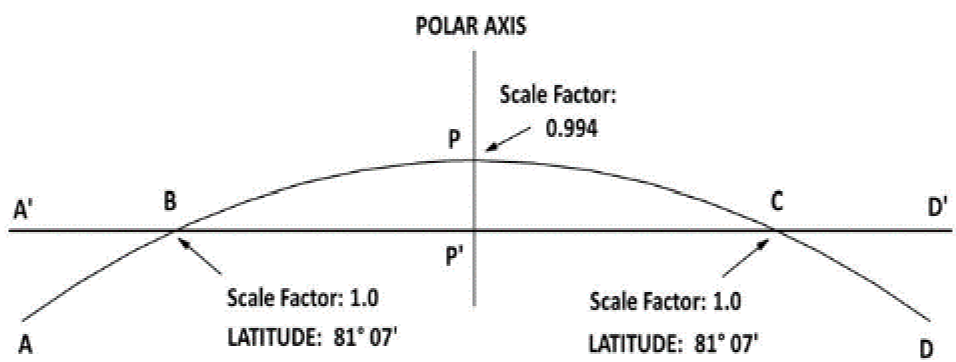


Figure 5-13. Line Distortion and Scale Factor in the Polar Stereographic Projection

d. The scale factor used with the polar stereographic projection is exact (1.000 or Unity) along the line (circle) of secancy (87° 07’ Lat). It decreases to 0.994 at the pole and increases to 1.0016067 at 80° latitude. Scale factor is constant for any given parallel.

5-10. Overlapping Projections

a. For military mapping purposes, the primary projections to be used are the polar stereographic projection in the polar regions and the transverse mercator projection between the polar regions. It is likely that a contingency could cross between these projections in one direction or the other. In order to reduce the amount of confusion caused by leaving a region projected in one fashion and entering another, an overlap was developed.

b. The transverse mercator projection is normally considered to cover areas between 80° south latitude to 84° north latitude. However, a 30 minute extension into the polar stereographic projection area is available providing total map coverage from 80° 30´ south latitude to 84° 30´ north latitude.

c. The polar stereographic projection is normally considered to cover areas south of 80° south latitude to north of 84° north latitude. However, a 30 minute extension into the transverse mercator projection area is available providing a total map coverage from south of 79° 30´ south latitude and north of 83° 30´ north latitude.

d. Maps produced in the overlap of the projections must be inspected to ensure the correct projection is depicted. In most cases, the coordinate and grid systems depicted by grid and neat lines are relative to the projection that is bounded by the latitudes listed above. The overlapping projection will be depicted by tick marks around the neat lines on the map.

5-11. Lambert Conformal Conic Projections

a. Lambert conformal conic projections (Figure 5-14 page 5-17) are the most widely used projections for civilian cartographers and surveyors. Many nations use it for civil and military purposes. This projection can be visualized as the projection of an ellipsoid onto a cone that is either tangent or secant to the ellipsoid. The apex of the cone is centered in the extension of the polar axis of the ellipsoid. A cone that is tangent to an ellipsoid is one that touches the ellipsoid at one parallel of latitude. A secant cone intersects the ellipsoid at two parallels called standard parallels. This text discusses the secant condition.

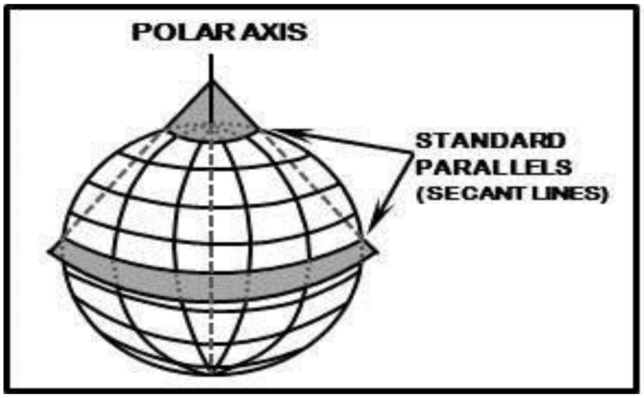


Figure 5-14. Secant Condition of Lambert Conformal Conic Projection

b. When the cone of projection is flattened into a plane, (Figure 5-15) meridians appear as straight lines radiating from a point beyond the mapped areas. Parallels appear as arcs of concentric circles centered at the point from where the meridians radiate. None of the parallels appears in exactly the projected positions. They are mathematically adjusted to produce the property of conformity. This projection is also called the Lambert conformal orthomorphic projection.

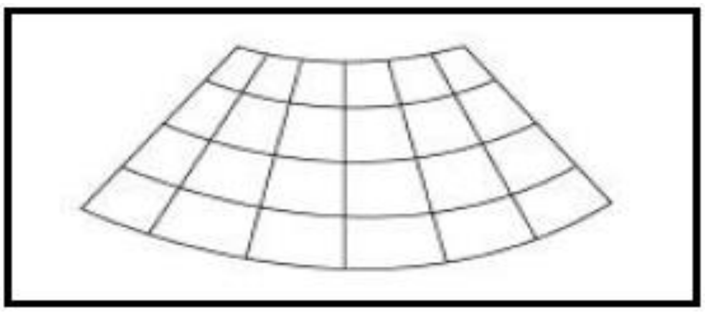


Figure 5-15. Cone Flattened onto a Plane

c. The parallels of latitude on the ellipsoid that are to be secant to the cone are chosen by the cartographer. The distance between the secant lines is based on the purpose and scale of the map. For example, a United States Geological Survey map showing the 48 contiguous states uses standard parallels located at 33°N and 45°N latitudes (12° between secant lines). Aeronautic charts of Alaska use 55°N and 65°N (10° between secant lines). For the national atlas of Canada, secant lines are 49°N and 77°N (28° between secants). The standard parallels for United States Geological Survey maps in the 7.5 and 15-minute series vary from state to state. Several states are separated into two or more zones with two or more sets of standard parallels (Figure 5-16 page 5-18). Since this is a conformal projection, distortion is comparable to that of the TM and polar stereographic projections. Distances are true along the standard parallels and reasonably accurate elsewhere in limited regions. Directions are fairly accurate over the entire projection. Shapes usually remain relative to scale but the distortion increases away from the standard parallels. Shapes on large-scale maps of small areas are essentially true. Scale factor is exact (unity or 1.000) at the standard parallels. It decreases between and increases away from the standard parallels. The exact number depends on the distance between the standard parallels.

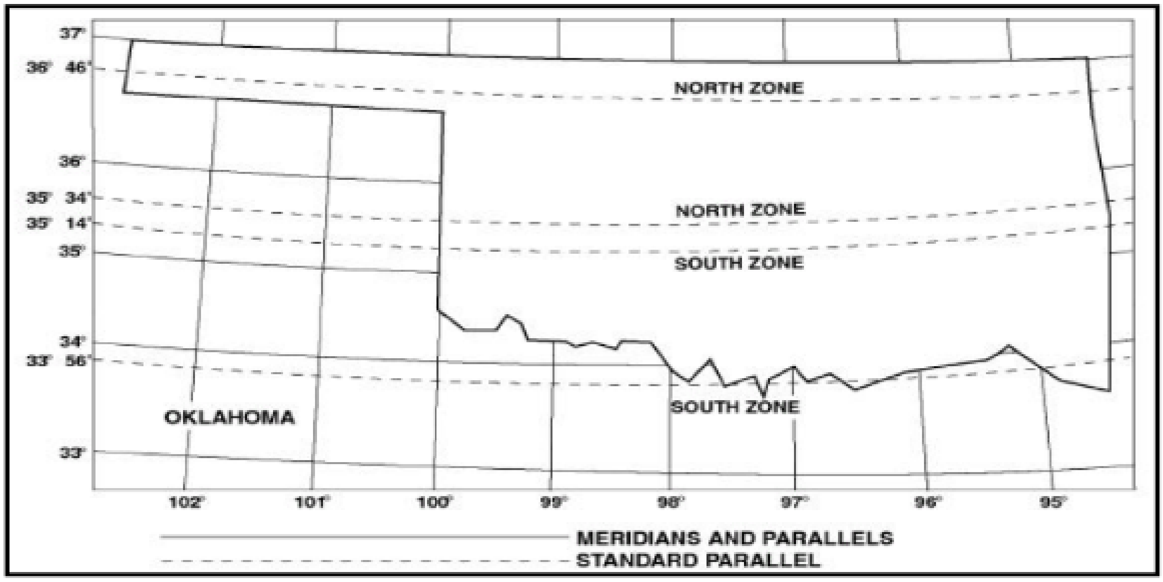


Figure 5-16. Oklahoma Lambert Projection: North and South Zones

5-12. Oblique Mercator Projection

a. The oblique mercator projection is actually many different projections using variations of the TM. All are cylindrical and conformal. But instead of the cylinder being transversed 90° from the mercator projection, it is transversed at an angle that places the long axis of the cylinder 90° from the long axis of the area being mapped. If the general direction of an area that is to be mapped lies in a northeast/southwest attitude, the cylinder of projection would be transverse 45° west of north. The cylinder is usually secant to the ellipsoid to lessen the effects of distortion. The location of the lines of secancy varies between projections. Many oblique mercator projections exist. This publication discusses the Laborde projection and the West Malaysia rectified skew orthomorphic (RSO) projection only.

b. The Laborde projection is used to map the island of Madagascar. It is an oblique mercator type projection with the long axis of the cylinder oriented at 18° 54´ east of north. Scale factor at the origin is 0.9995. This projection is used with the international ellipsoid.

c. The West Malaysia RSO projection is used to map the islands of Malaysia. It is an oblique mercator type projection with the long axis of the cylinder oriented at 36° 58´ 27.1542" east of north. Scale factor at the origin is 0.99984. This projection is used with the modified Everest ellipsoid to map the West Malaysia RSO grid system.

d. Many other oblique mercator projections are used to map areas of the world. Most are designed to work with a specific grid system like the West Malaysia system described above. Examples of these systems include but are not limited to—

(1) Alaska Zone 1 RSO

(2) Borneo RSO

(3) Great Lakes (4 Zones) RSO

(4) Liberia RSO

(5) Malaya (chain) RSO

(6) Malaya (yard) RSO

(7) Switzerland oblique Mercator

5-13. New Zealand Map Grid Projection

The New Zealand map grid projection is used to map New Zealand. It is a sixth-order complex-algebra polynomial modification of the mercator projection. A cylinder cannot necessarily be considered in this projection. It is a mathematical projection set secant to the international ellipsoid. The New Zealand map grid has no defined scale factor at the central meridian. Scale factor ranges from 1.00023 to 0.00078 over the entire projection.

5-14. Cassini Projection

a. The Cassini projection can be viewed outwardly as a GK projection in that the cylinder is transverse 90° from the mercator projection. It is also tangent to the ellipsoid at the central meridian of a zone. The Cassini projection predates the GK and TM projections. It is made by treating all meridians as planes that extend from the ellipsoid out to the cylinder. This projection causes the Equator and central meridian to be perpendicular straight lines. All other meridians appear as lines that intersect the equator at right angles and curve toward the central meridian except for those meridians that are located 90° from the central meridian. Those meridians appear as straight lines that are parallel to the equator. Scale factor at the central meridian is unity (1.00 or exact). This projection is still used in some areas for civil and local grid systems, but is considered obsolete for most purposes. In many areas it has been replaced by the TM projection. This projection is sometimes called the Cassini-Solder projection.

b. Position differences between Cassini grid systems and TM grid systems are slight. For example, northing is the same in the Palestine Cassini civil grid as it is in the Palestine TM civil grid. The easting difference between the two is zero at 20 kilometers (kms) from the central meridian and only 4.1 meters at 100 kilometers from the central meridian.

Section II. COORDINATE SYSTEMS

5-15. Coordinate System

A Coordinate system uses coordinates to uniquely determine the position of a point on the earth's surface. There are several different coordinate systems used, Cartesian coordinates system, geographic coordinates system, and geodetic coordinates system to name a few. this chapter will cover those used with artillery survey.

5-16. Three-Dimensional Positioning

The location of a point on the surface of the Earth is generally represented by coordinates. A coordinate system is a three-dimensional (3-D) positioning system represented by a set of three quantities, each corresponding to angles or distances from a specified origin. The origin is generally either the center or the surface of a reference ellipsoid. Three-dimensional coordinates should not be confused with plane coordinates that are two-dimensional (2-D) and are usually related to a grid system.

5-17. Cartesian Coordinates System

a. Cartesian coordinates identify the location of a unique 3-D (x, y, z) position in space. The system consists of the origin and three coordinate planes (Figure 5-17).

b. The origin is the intersection point of the three coordinate planes and is located at the center of the reference ellipsoid. When the origin is also located at the center mass of the Earth, it is considered geocentric. The three mutually perpendicular coordinate planes intersect in three straight lines called coordinate axes. The axes intersect at right angles at the origin.

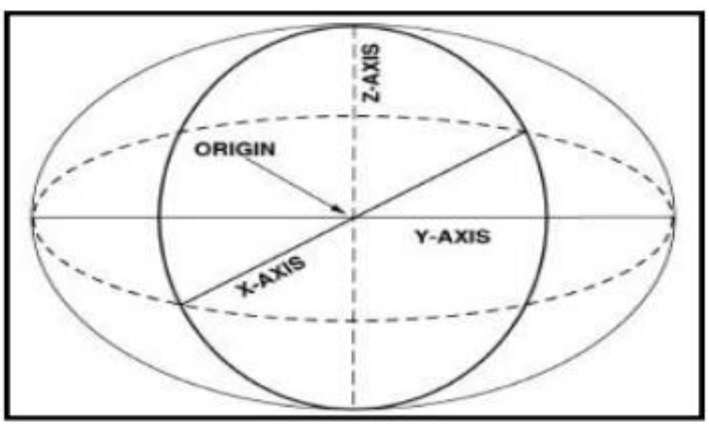


Figure 5-17. Coordinate Planes

c. The x-axis lies on the equatorial plane of the reference ellipsoid at the intersection of the equatorial plane and the plane containing the prime meridian. It is perpendicular to the plane containing the y- and z-axes. The x-axis is positive from the origin to the prime meridian. The y-axis lies on the equatorial plane of the reference ellipsoid, perpendicular to the x-axis. It is perpendicular to the plane containing the x- and z-axes. The y-axis is positive east of the prime meridian.

d. The z-axis corresponds to the rotational axis of the reference ellipsoid (semi-minor axis). It lies perpendicular to the plane containing the x- and y-axes. The z-axis is positive from the origin to the North Pole. The position of a point on the Earth's surface is described in terms of x, y, and z coordinates. These coordinates are distances, usually in meters, from the plane formed by two axes to the point along a line that is perpendicular to the plane and parallel to the third axis (Figure 5-18).

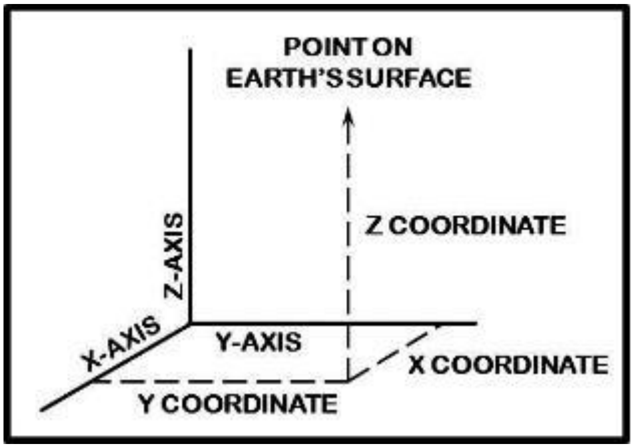


Figure 5-18. Cartesian Coordinates

e. An x coordinate is the length of a line in the x-y plane that is parallel to the x-axis and measured from the y-z plane. A-y coordinate is the length of a line in the x-y plane that is parallel to the y-axis and measured from the x-z plane. A-z coordinate is the length of a line that is parallel to the z-axis and is measured from the intersection of the x coordinate and the y coordinate to a point on the surface of the Earth. The coordinates of the origin are (0, 0. 0).

5-18. Geographic Coordinates

a. Geographic coordinates (Figure 5-19 page 5-22) are any 3-D coordinate system that specifies the position of a point on the surface of the Earth in terms of latitude (ϕ), longitude (λ), and ellipsoid height (h). It is an inclusive term that describes geodetic and astronomic positions.

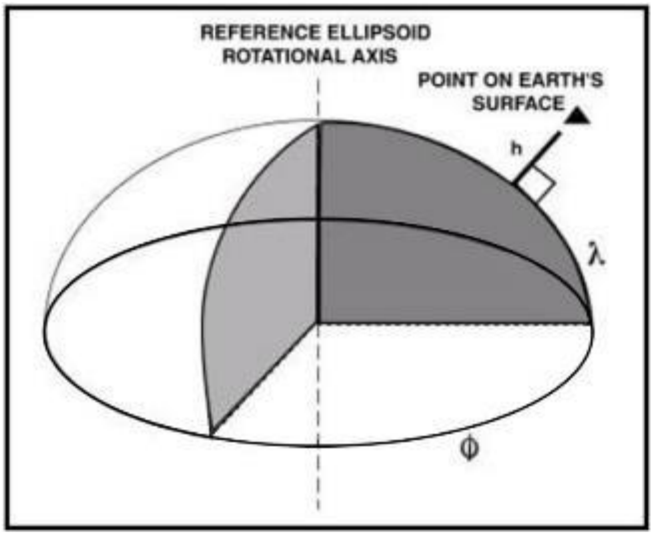


Figure 5-19. Geographic Coordinates

b. Latitude and longitude are generally represented in degrees or degrees, minutes, and seconds along with a cardinal direction corresponding to a hemisphere on the Earth. A position will never have more than 60 minutes in a degree and never more than 60 seconds in a minute.

c. Latitude lines are called parallels of latitude. Latitude originates at the equator at 0°. It increases toward the North and South Poles to 90°. It is labeled N or + for positions in the northern hemisphere; S or - for positions in the southern hemisphere; i.e., 34°N, +34°, 34°S, -34° (Figure 5-20).

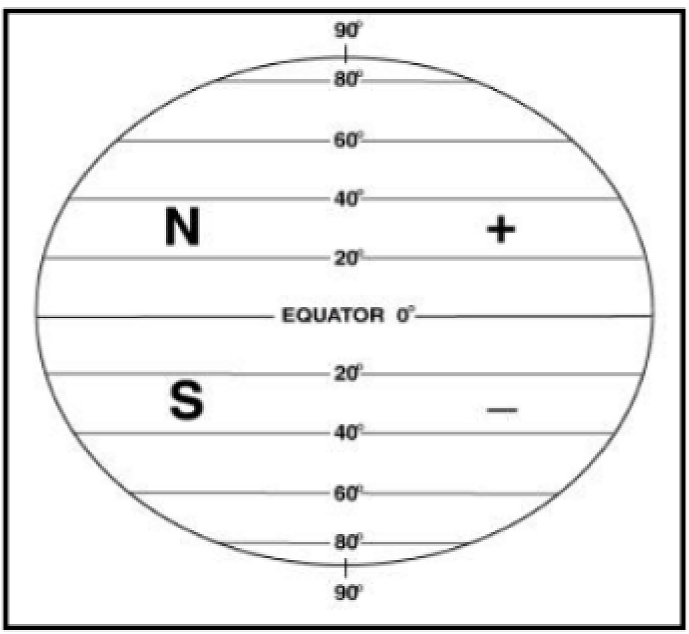


Figure 5-20. Parallels of Latitude

d. Longitude lines are called meridians of longitude. Longitude originates with 0° at the Greenwich Meridian for most geographic systems; however, some systems reference other meridians as the 0° origin or prime meridian. Longitude increases east and west toward the International Dateline at 180°. In the eastern hemisphere, longitude is labeled E or +; in the western hemisphere, it is labeled W or -. For example, 107°E, +107°, 107°W, -107°. In some cases, the position of a point may include a longitude in excess of 180° E. These are converted to the standard format by subtracting the longitude from 360° e.g., 206°E = 154°W. The North and South Poles do not have a longitude (Figure 5-21).

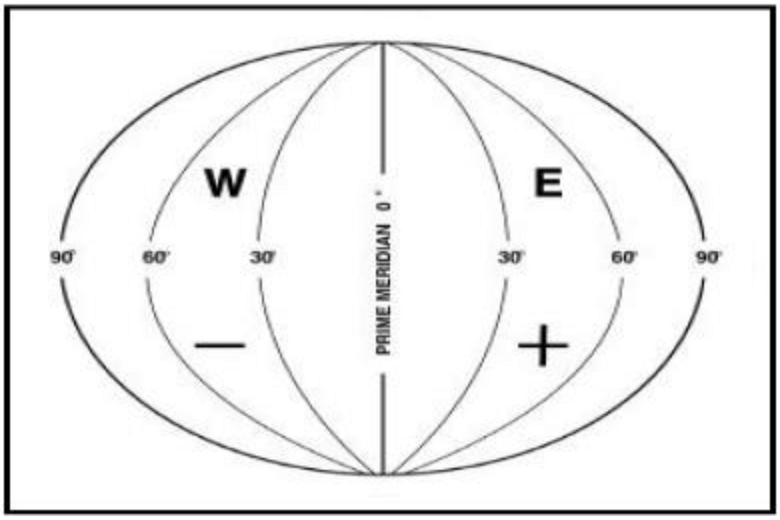


Figure 5-21. Meridians of Longitude

e. A network of lines on a map representing parallels of latitude and meridians of longitude is called a graticule. A graticule can represent the entire globe or a small region of the Earth (Figure 5-22).

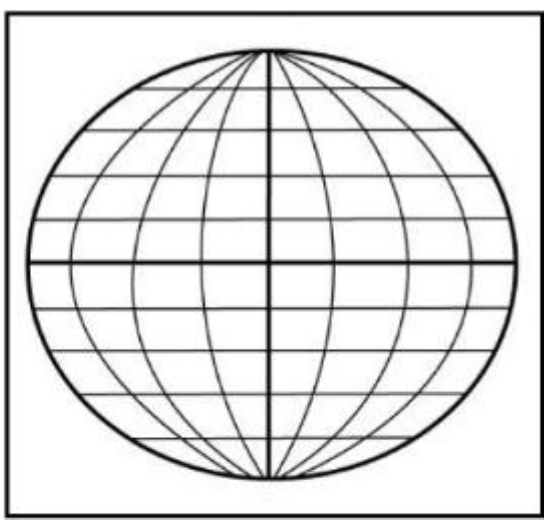


Figure 5-22. Graticule

f. The inclination of two meridians toward each other is called convergence of the meridians, or more commonly convergence. All meridians of longitude are parallel at the equator and intersect at the poles. Convergence of the meridians at the equator is 0°. At the poles, the convergence equals the difference between the longitude values of the meridians. Between the equator and the poles, the convergence varies from 0° to the difference in the longitude values. Because of this, a geodetic azimuth and its back azimuth will differ by the convergence.

5-19. Geodetic Coordinates

a. Geodetic coordinates (Figure 5-23) are the quantities of latitude (ϕ), longitude (λ), and ellipsoid height (H) that define the position of a point on the Earth's surface with respect to the reference ellipsoid. This type of geographic coordinate is the most commonly used by surveyors and cartographers. If the reference ellipsoid is geocentric e.g., WGS 84, coordinates are termed geocentric geodetic coordinates.

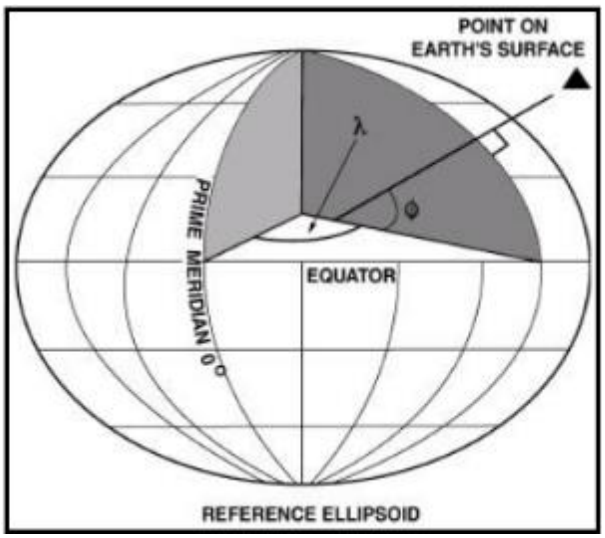


Figure 5-23. Geodetic Coordinates

b. The geodetic longitude of a point on the Earth's surface is the angle formed by the intersection of the plane containing the prime meridian (x-z Cartesian plane) and the meridional plane containing the point. The geodetic latitude of a point is the angle formed by the intersection of the equatorial plane (x-y Cartesian plane) and a line that passes through the point and is perpendicular to the reference ellipsoid.

c. Geodetic coordinates are computed and adjusted as part of a geodetic network. All the points in the network are common to all the other points in that network. They are also common to points extending and adjusted from that network. Geodetic networks can be adjusted together to complete a national network such as the national geodetic reference system in the United States.

5-20. Astronomic Coordinates

a. Astronomic coordinates (Figure 5-24) are those values that define the position of a point on the surface of the Earth or the geoid and reference the local direction of gravity. Astronomic coordinates can also refer to the location of a celestial body. Astronomic positions often establish and define horizontal datums. An ellipsoid is oriented so that a line through a point perpendicular to the geoid (vertical) is also perpendicular to the ellipsoid (normal). The geoid separation is generally zero at that point. At that point, the geodetic and astronomic coordinates are the same.

b. Astronomic latitude is the angle formed by the intersection of the plane of the celestial equator and the plumb line (perpendicular to the geoid). It equals the angle formed by the plane of the observer's horizon and the rotational axis of the Earth. Astronomic latitude results directly from observations of celestial bodies, uncorrected for the deflection of the vertical. The term applies only to the position of points on the Earth. Astronomic longitude is the time that elapses from the moment the celestial body is over the Greenwich meridian until it crosses the observer's meridian. It results directly from observations of celestial bodies, uncorrected for the deflection of the vertical.

c. Astronomic coordinates are computed independent of each other. They can be connected by geodetic methods and adjusted to a geodetic network.

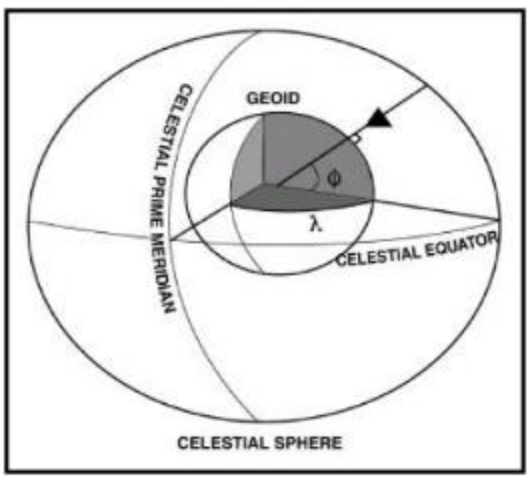


Figure 5-24. Astronomic Coordinates

5-21. The Prime Meridian

The prime meridian is the meridian of longitude referenced as 0° for a particular geographic system. Usually, the term prime meridian is the Greenwich meridian. Several systems use other meridians of longitude as the prime meridian (Figure 5-25 page 5-26). Whenever survey data is provided in a system not referencing the Greenwich meridian as 0° longitude, a simple conversion can be made by applying the longitude offset to the survey data longitude.

Amsterdam, Netherlands Reformed Church, West Tower	4° 53' 01" E
Athens, Greece Observatory, Geodetic Pillar	23° 42' 59" E
Batavia (Djakarta), Indonesia Old Tidal Guage	106° 48' 28" E
Bern, Switzerland Old Observatory	7° 26' 22" E
Brussels, Belgium Observatory	4° 22' 06" E
Copenhagen, Denmark New Observatory	12° 34' 40" E
Ferro, Canary Islands (By definition 20° west of Paris)	17° 39' 46" W
Helsinki, Finland Observatory	24° 57' 17" E
Istanbul, Turkey Hagia Sophia	28° 58' 50" E
Lisbon Portugal Castelo San Jorge, Observatory	9° 07' 55" W
Madrid, Spain Observatory	3° 41' 15" W
Oslo, Norway Observatory	10° 43' 23" E
Paris, France Observatory	2° 20' 14" E
Pulkovo, Russia (USSR) Observatory	30° 19' 39" E
Rome, Italy Monte Mario	12° 27' 08" E
Stockholm, Sweden Observatory	18° 03' 30" E
Tirane, Albania First-Order Trig Point	19° 46' 45" E

Figure 5-25. Longitudes of Prime Meridians

5-22. Angular Measurements

a. Care must be taken to ensure that if survey data is provided covering other nations, including mapping products, that the data is shown or measured in the correct angular system. Two angular systems show coordinate systems on maps and to coordinate survey points: centesimal and sexagesimal.

b. The unit usually associated with a centesimal system is the grad (used extensively in Europe and North Africa). A grad is the hundredth part (1/100th) of a right angle. One grad equals 100 minutes; 1 minute equals 100 seconds. Grads are notated by $^{\mathbf{g}}$; centesimal minutes by $^{\mathbf{c}}$; and centesimal seconds by $^{\mathbf{cc}}$. The entire number is notated together like $12^{\mathbf{g}}8^{\mathbf{c}}27^{\mathbf{cc}}$.

c. The unit usually associated with a sexagesimal system is the degree. A degree is the ninetieth part (1/90th) of a right angle. One degree equals 60 minutes; 1 minute equals 60 seconds. Degrees are notated by the symbol ° e.g., 24°; sexagesimal minutes by a **'**; e.g., 38**'**; and sexagesimal seconds by e.g., 02**"**. The entire number is notated together like 24° 38' 02**"**.

5-23. Deflection of the Vertical

a. Deflection of the vertical (Figure 5-26) at a point is the angular difference between the vertical (plumb line), which is perpendicular to the geoid, and a line through the point that is perpendicular to the reference ellipsoid. This term is more accurately referred to as the astro-geodetic deflection of the vertical.

b. Due to the deflection of the vertical in the plane of the prime vertical (a circle in the east-west direction of the observer's horizon), there is a difference between astronomic and geodetic longitude and astronomic and geodetic azimuths. This is called the laplace condition and is expressed by the laplace equation. The laplace equation yields a correction, which when subtracted from an astronomic azimuth, will produce a geodetic azimuth.

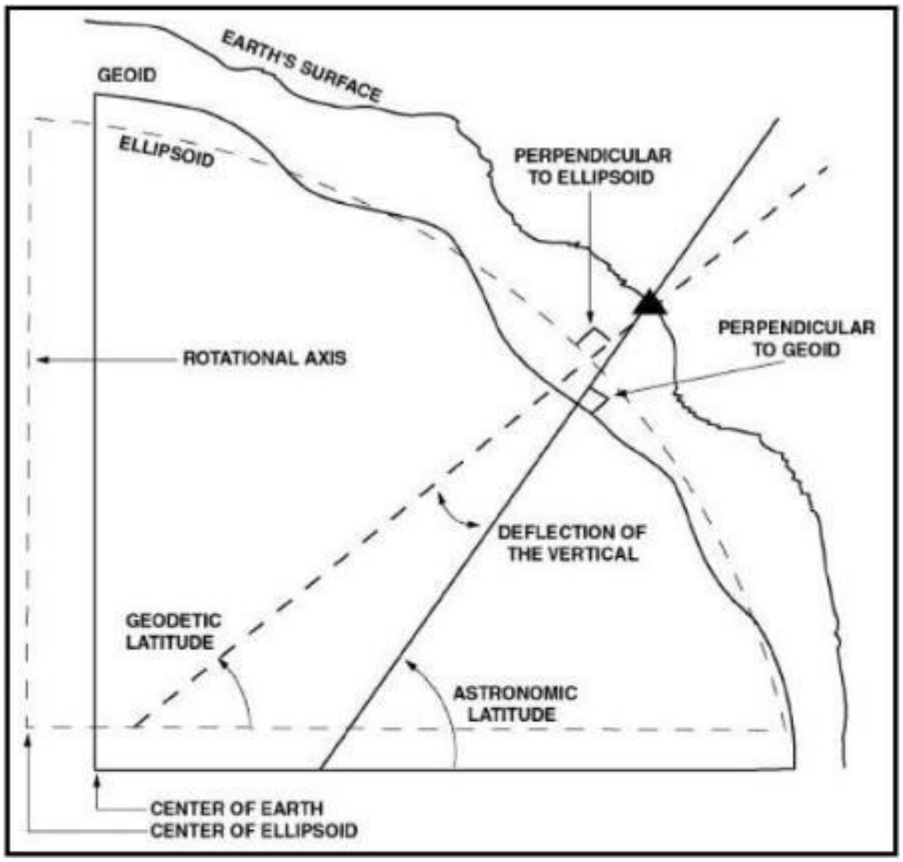


Figure 5-26. Deflection of the Vertical

Section III. GRID SYSTEMS

5-24. Grid Systems

a. A grid system is a 2-D plane-rectangular coordinate system that is usually based on and mathematically adjusted to a map projection. This allows for the transformation from geodetic positions (latitude and longitude) to plane coordinates easting (E) and northing (N) and for the computations relating to those coordinates to be made by ordinary methods of plane surveying.

b. Many grid systems are in use. Most of the local systems will eventually be converted to one of the universal grid systems. Some areas will continue to be mapped in a local system such as the British national grid, the Irish transverse mercator grid, and the Madagascar grid. There are two universal grids used by the United States military and its allies: universal transverse mercator (UTM) and universal polar stereographic (UPS).

c. Grids consist of a system of evenly spaced parallel lines lying perpendicular to another system of evenly spaced parallel lines forming squares. The ground distance between the lines depends on the scale of the map and the type of grid system. Most systems use meters as a basis for grid line spacing, others use yards or feet. Standard scale military maps generally adhere to grid lines on:

- Large-scale maps spaced at 1,000 meters
- Medium-scale maps at 1:250,000 spaced at 10,000 meters.
- For scales smaller than 1:250,000, the grid lines may or may not be depicted, depending on the map's purpose.

d. North-south lines in a grid system are called eastings and increase in value from west to east. East-west lines in a grid system are called northings and increase in values from south to north. (These rules do not apply to grid systems that cover the polar regions such as the UPS). The numerical value of an easting and northing are referenced to a specific origin. A false value is applied to the easting or northing grid line that falls at a particular reference line or point. Usually, that line or point is a meridian of longitude; e.g., central meridian of a zone or a parallel of latitude (like the equator, but it can have other references). The origin for the false easting and false northing are normally different lines or points.

e. Grid convergence is the angular difference between true north and grid north. The direction and the value of the angle are computed differently depending on the grid system. In some systems, grid convergence can be the same as convergence of the meridians.

5-25. Universal Transverse Mercator Grid System

a. The UTM grid system (Figure 5-27 page 5-29) is referenced to the TM projection. The ellipsoid is divided into 60 grid zones, each 6° wide, extending from 84° N latitude to 80° S latitude. Zones are numbered from 1 to 60. Zone 1 starts at 180°-174° west longitude, zone 2 at 174° west - 168° west longitude, continuing east to zone 60 at 174°E - 180° longitude. The prime meridian (0° longitude) separates zones 30 and 31.

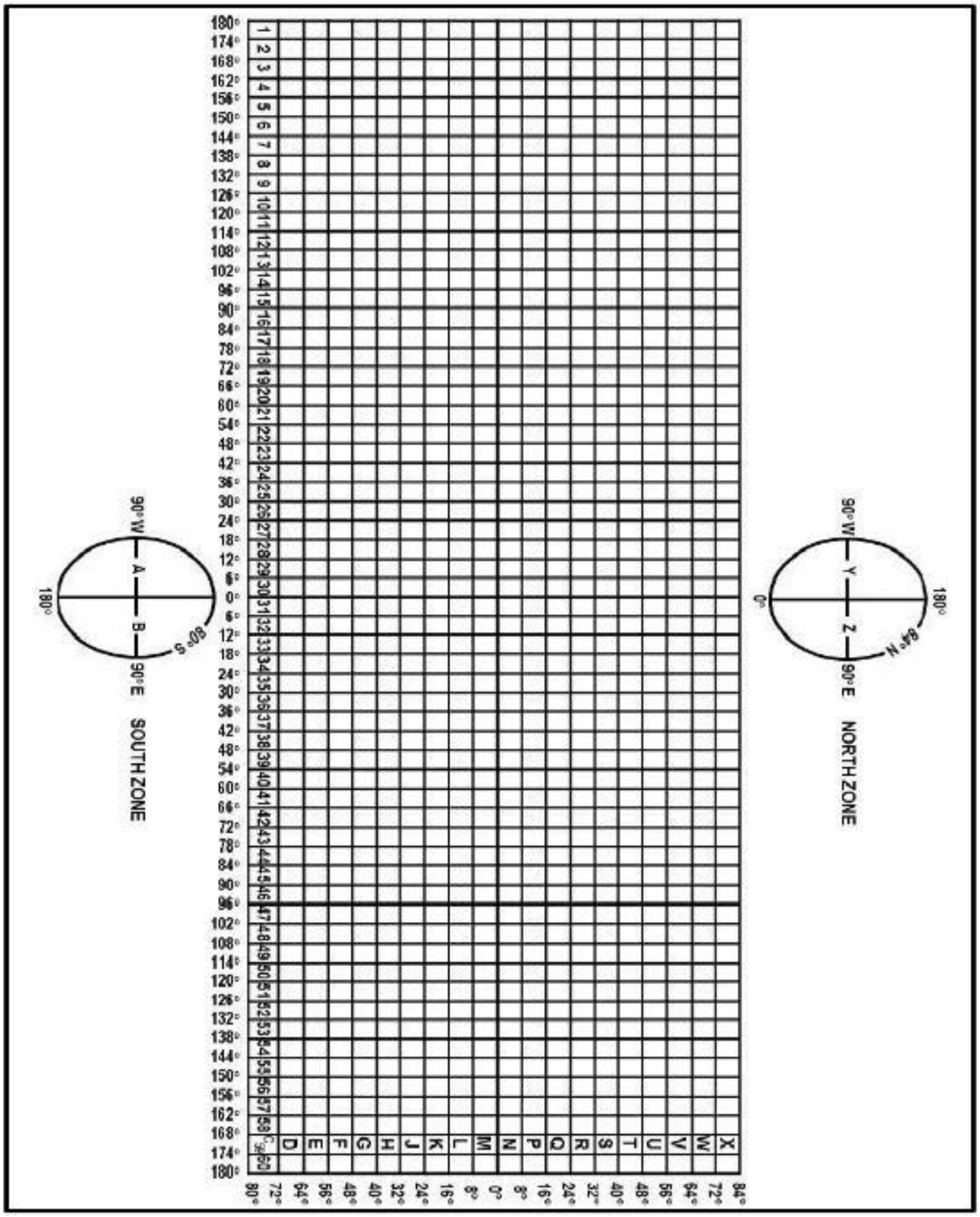


Figure 5-27. UTM/UPS Grid Zones and Grid Zone Designators

b. The location of any point in the UTM grid system can be designated by coordinates by giving its distance east- west (easting) and its distance north-south (northing) from the origin of the grid zone. This origin (for each UTM grid zone) is the intersection of the Equator and the central meridian of the zone. Each UTM zone has a central meridian corresponding to the central meridian of each TM projection zone. The grid is oriented by placing the east-west axis of the grid in coincidence with the equator and the north-south axis of the grid in coincidence with the central meridian of the zone.

c. Once the grid is oriented, the origin for easting and northing are assigned false values. The central meridian (origin for easting) of each zone is assigned an easting value of 500,000 meters. The easting increases east of the central meridian and decreases west. The equator (origin for northing) is assigned two false values. If operating in the northern hemisphere, the northing of the equator is 0 meters and increases north. If operating in the southern hemisphere, the northing of the equator is 10,000,000 meters and decreases south. Grid lines that run north and south are easting lines. They are parallel to the central meridian of the grid zone. Grid lines that run east and west are northing lines. They are parallel to the Equator (Figure 5-28).

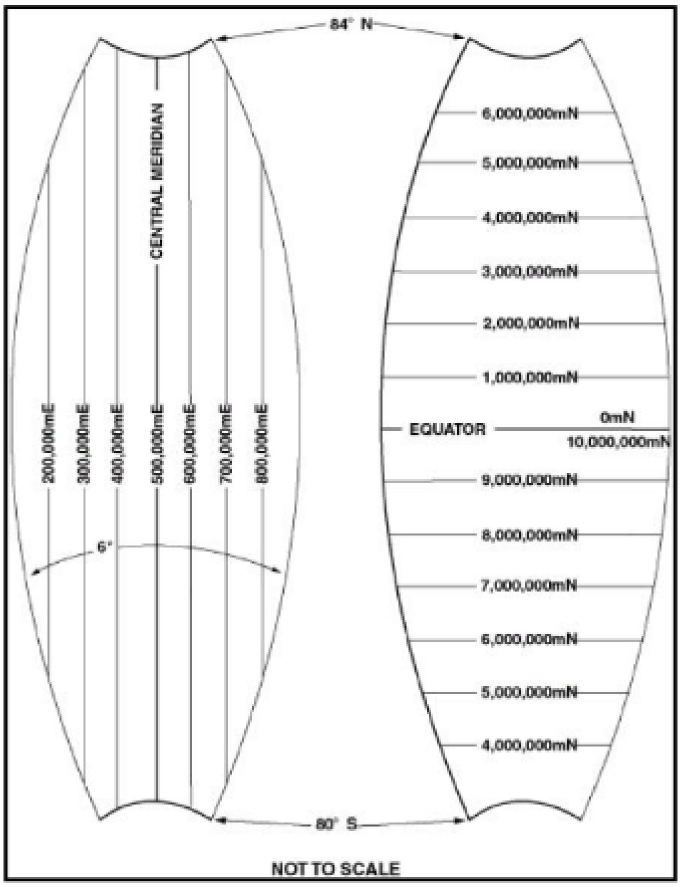


Figure 5-28. UTM Easting and Northing

d. Grid convergence at a point in the UTM system is the angle measured east or west, from true north to grid north. At any point along the central meridian of a UTM grid zone, true north and grid north are the same. At any point not located on the central meridian, grid north departs from true north because of convergence of the meridians. Grid convergence within the UTM system is a function of both latitude and longitude. It will rarely exceed 3° (53.333 mils) and is normally listed in the declination diagram of a map. Grid convergence should be computed for use in fifth order or higher surveys because the information on the map is generally computed for the center of the map sheet. For example, the Lawton map sheet (6353III) lists the grid convergence at 6 mils, the Cache map sheet (6253II) lists it at 4 mils. There are two mils difference between the centers of these two adjoining sheets (Figure 5-29).

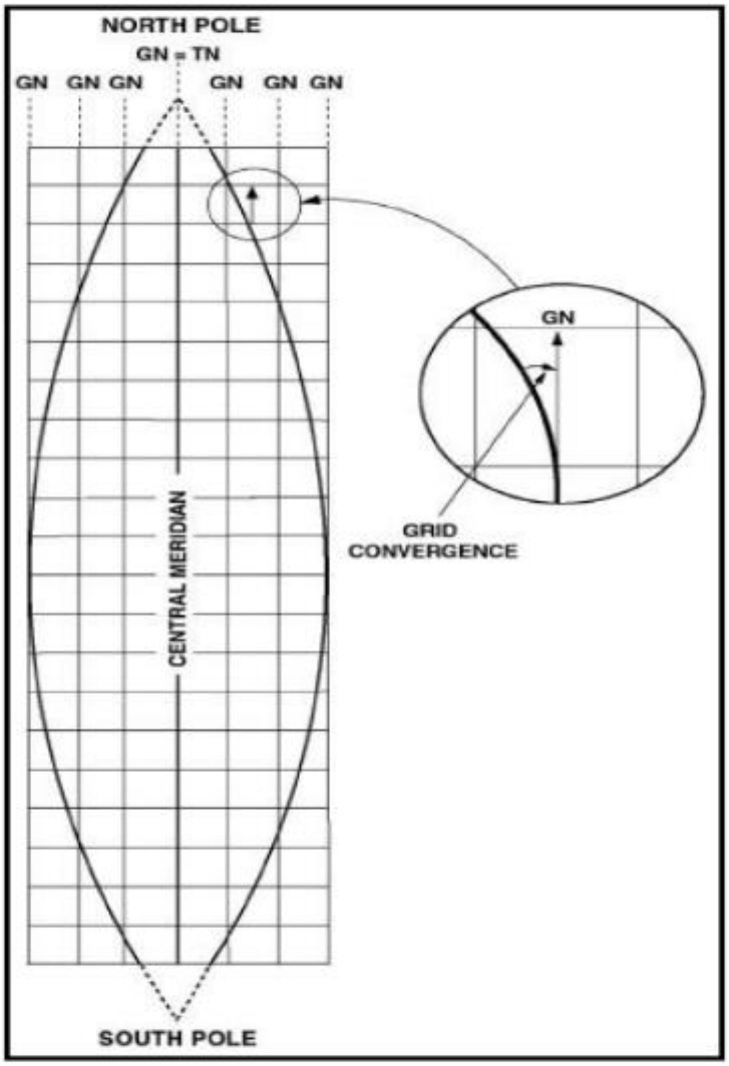


Figure 5-29. UTM Grid Convergence

e. In the Northern Hemisphere, grid convergence is negative east of the central meridian and positive west. In the Southern Hemisphere, grid convergence is positive east of the central meridian and negative west. The direction (+, -) and the value of the grid convergence are applied to a true azimuth to obtain a grid azimuth. If a grid azimuth must be converted to a true azimuth, the value of the grid convergence is the same. However, the opposite sign (direction) must be used (Figure 5-30 page 5-32).

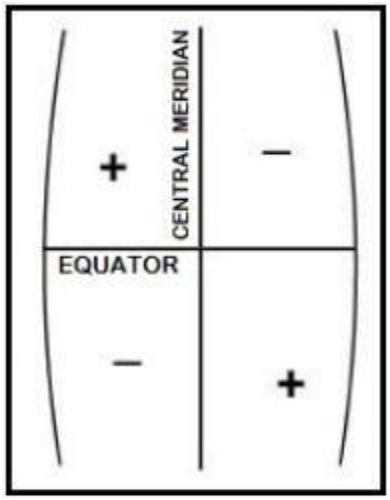


Figure 5-30. Sign of Grid Convergence

f. The standard UTM grid zone is 6° wide. However, portions of several grid zones have been modified to accommodate southwest Norway and the islands of Svalbard. These grid zone modifications are not available in many survey or fire support systems. User-defined options or work-around methods must be used in these areas. Figure 5-31 shows the nonstandard portions of the respective grid zones.

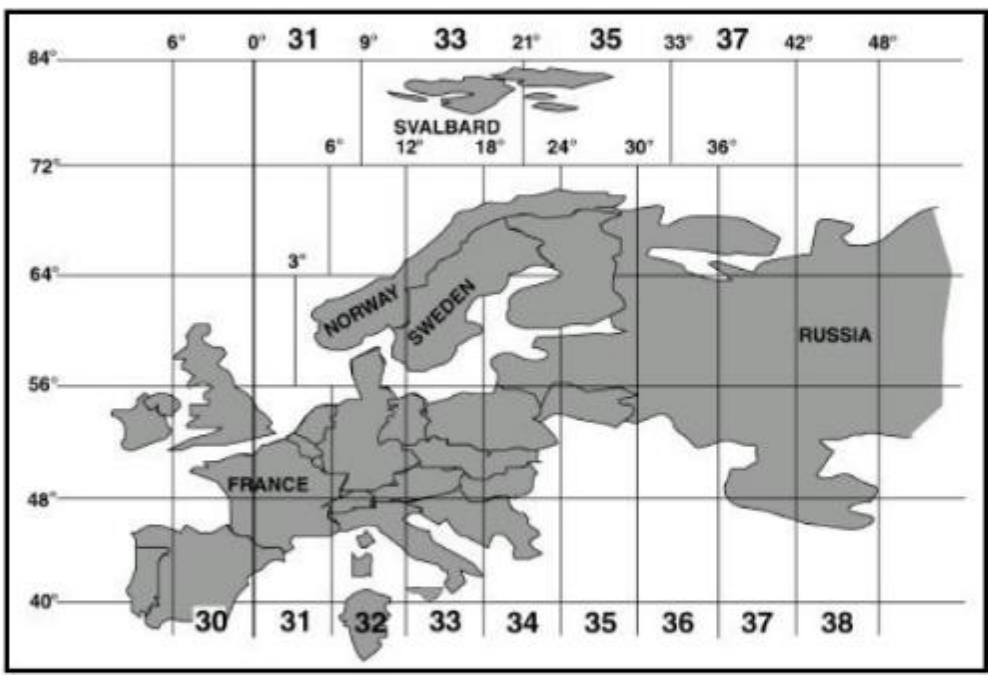


Figure 5-31. Nonstandard UTM Grid Zones

g. Easting and northing values of a point in the UTM grid system are called grid coordinates. Easting consists of six digits before the decimal point. The only exception is positions that are actually located in an adjacent grid zone. An easting can be written with the first digit (100,000 meters) separated from the next five with a space. Northing generally has seven digits before the decimal point. The exception to this is at locations north of the Equator by less than 1,000,000 meters. A northing can be written with the first two digits (1,100,000 meters) separated from the next five digits with a space. The number of digits after the decimal point depends on the order of survey and the accuracy needed. An example of a UTM grid coordinate is 6 39127.84 - 38 25411.24.

h. If at any time you cross the Equator from north to south (at which point you would have a negative northing), you must algebraically add the northing to ten million meters to obtain a northing for the Southern Hemisphere. If you cross the Equator from south to north (which would produce a northing greater than ten million meters), you must subtract ten million meters from your northing to obtain a northing that can be used in the Northern Hemisphere.

5-26. Military Grid Reference System

a. UTM, GK, and UPS grid coordinates are not unique. Any UTM grid coordinates can be plotted in each of the 60 grid zones. Many UTM and GK coordinates will plot in both the Northern and Southern Hemispheres of the same grid zone. All UPS grid coordinates between 84° and 90° north and south latitudes will plot in each of the two UPS grid zones. To make UTM and UPS grid coordinates unique, the grid zone and grid zone designator should accompany them.

b. The military grid reference system (MGRS) is designed for use with the UTM and UPS grid systems. It establishes a unique set of coordinates for each specific location on the Earth. An MGRS grid coordinate consists of a grid zone (UTM only), a grid zone designator, a 100,000-meter square identifier, and the easting/northing coordinate.

c. A grid zone designator is a one-letter code (Figure 5-32 page 5-34) specifying a particular portion of a UTM/UPS grid zone. The grid zone designator is usually listed in the marginal data of a military map.

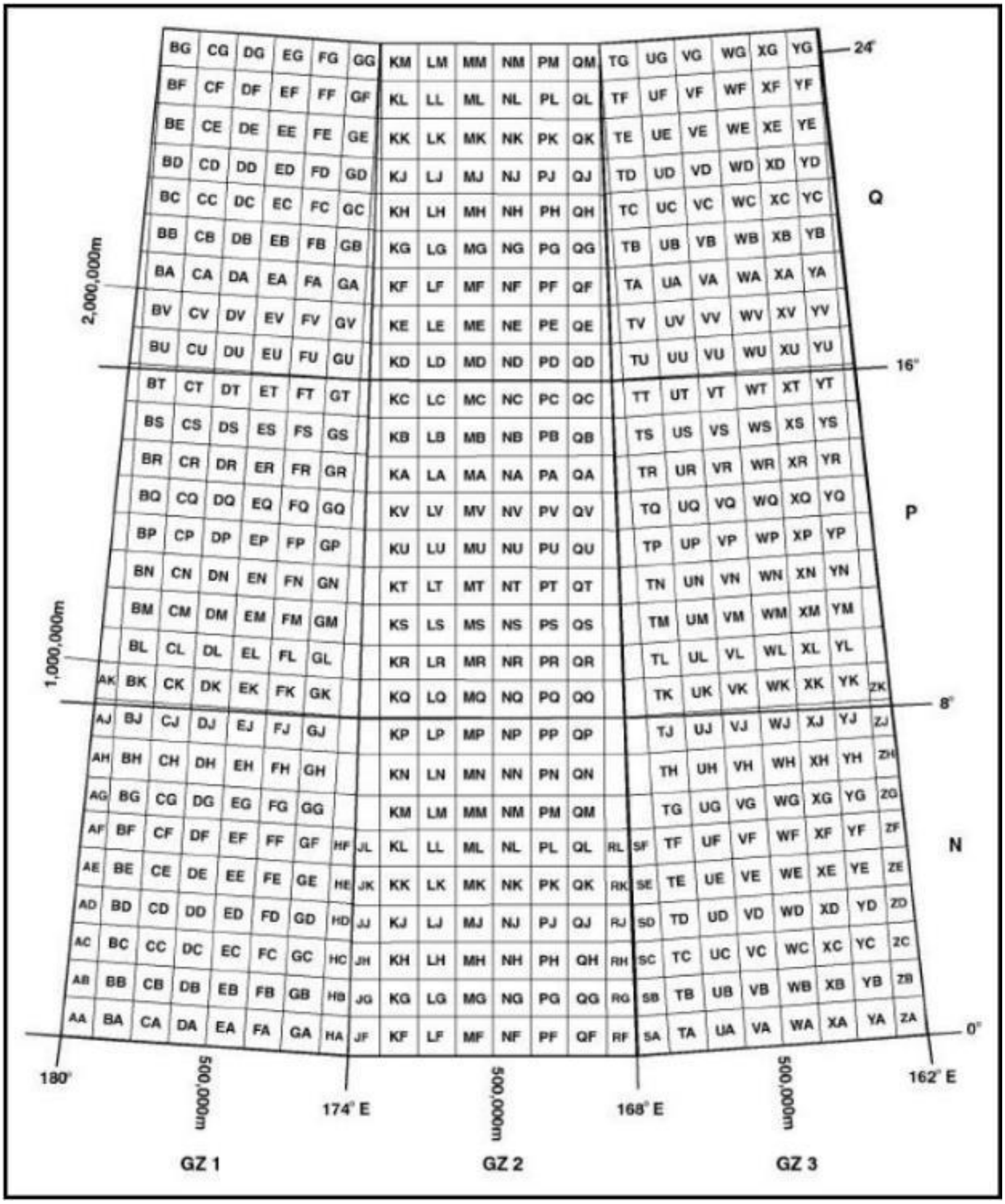


Figure 5-32. MGRS: 100,000-Meter Square Identification Lettering Convention for the UTM Grid, WGS 84/GRS 80 Ellipsoids

d. Each of the 60 UTM grid zones is divided into 20 grid zone designators. Each designator represents an 8° portion of the grid zone except the northernmost (represents 12°). Designators are identified alphabetically by the letters C to X with the letters I and O omitted. C is the southernmost designator, X is the northernmost, and the Equator separates M and N. Thus, a grid zone and grid zone designator together specify a region of the Earth covering a 6° by 8° area except in the northernmost designation X (specifies a 6° by 12° area).

e. Both UPS zones (north and south) are divided into two grid zone designations separated by the 0° and 180° meridians. In the north, the designator Y covers the Western Hemisphere; Z covers the Eastern Hemisphere. In the south, designator A covers the Western Hemisphere; B the Eastern Hemisphere. Since numbers are not used to identify UPS grid zones, a UPS grid MGRS coordinate will begin with the grid zone designator.

f. Each UTM/UPS grid zone is divided into 100,000- meter squares. Squares are identified by two letters called a 100,000-meter square identifier. The first letter is columnar. It is the same for all squares in a north-south column. The second letter is linear. It is the same for all squares in an east-west row in a grid zone. This identifier is usually listed as part of the marginal information on a military map. The lettering convention used depends on the reference ellipsoid. This text discusses the UTM lettering convention used with the WGS 84 and GRS 80 ellipsoids and the UPS lettering convention used with the International ellipsoid. Other ellipsoid lettering conventions are detailed in DMA TM 8358.1, Datums, Ellipsoids, Grids, and Grid Reference Systems.

g. The first (columnar) letter of the 100,000 meter square identification originates at the 180° meridian with the letter A and increases alphabetically eastward along the Equator for three grid zones to cover an area of 18°. The 100,000-meter columns, including partial columns at grid zone junctions, are lettered from A to Z but omit I and O. This alphabet is repeated every 18° eastward around the Earth.

h. The second (linear) letter of the 100,000 meter square identification is lettered from A to V but omits I and O, from south to north covering an area of 2,000,000 meters and is then repeated northward. In odd- numbered grid zones, it originates at the Equator increasing alphabetically north. In even-numbered grid zones, the second letter originates 500,000 meters south of the Equator increasing alphabetically north. Therefore, in odd-numbered grid zones the second letter of the 100,000-meter square identification is A along the Equator. In even-numbered grid zones the second letter is F along the Equator.

i. Each 6° by 8° square is broken up into 100,000-meter squares that occur only once. For example, there is only one square identified by the letters WA inside of the 6° x 8° square of grid zone designation 3N. The only other square in this figure identified by the letters WA is in grid zone designation 3Q. Unique coordinates can be established for every position within the UTM grid using the MGRS (Figure 5-33 page 5-36).

j. The 100,000-meter square identifiers are the same for both UPS grid zones. The difference between two UPS grid MGRS coordinates with the same 100,000-meter square identifiers is the grid zone designator. A/B in the south, Y/Z in the north (Figure 5-33). Designators A and Y (Western Hemisphere) are lettered the same, as are designators B and Z (Eastern Hemisphere). The north zone only includes that portion of the lettering convention that falls inside of 84° latitude.

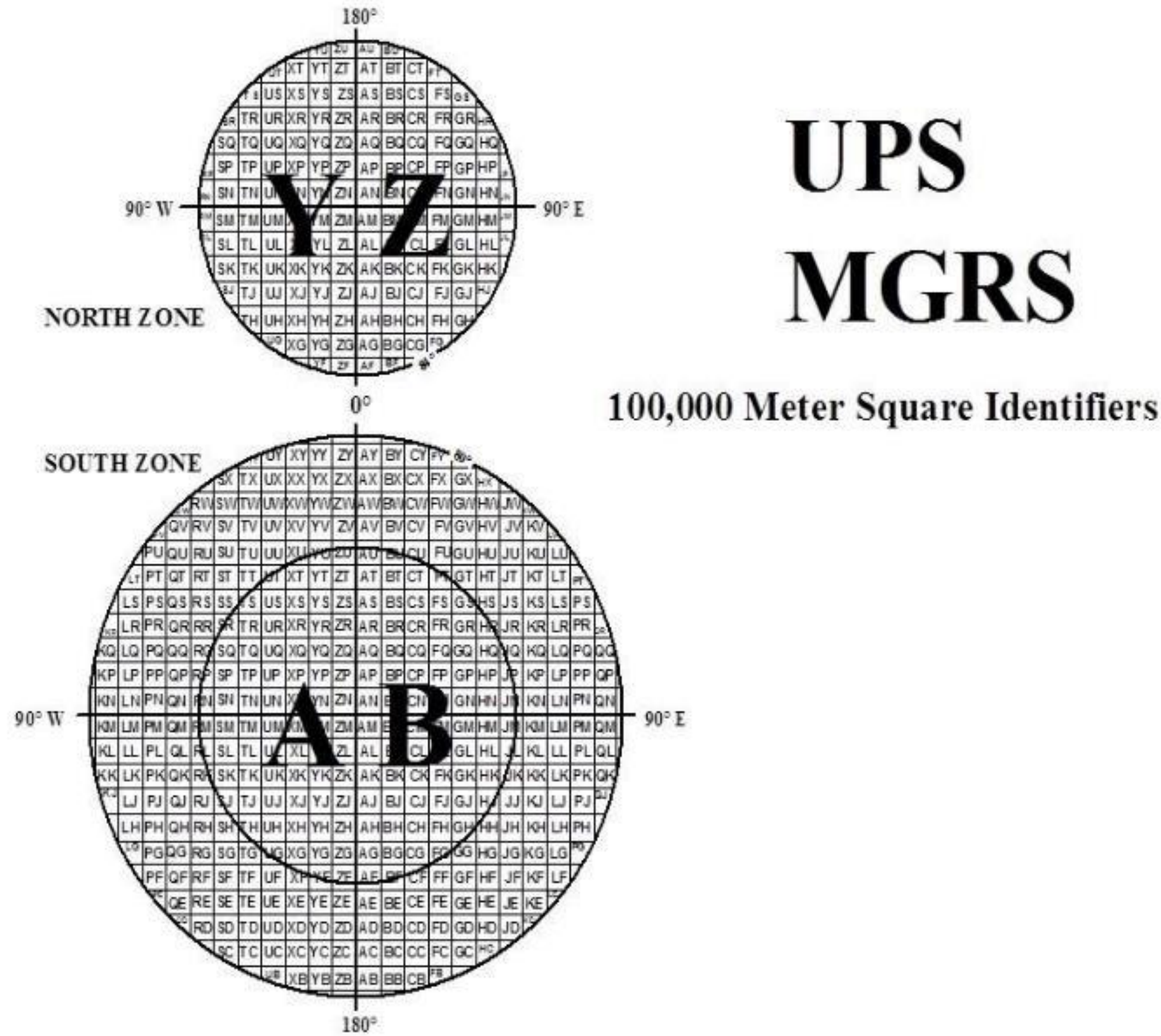


Figure 5-33. UPS/MGRS

k. In the Western Hemisphere the first letter of the 100,000-meter square identifier originates at the intersection of the 80° latitude and 90° W longitude lines. It is lettered alphabetically along the east-west axis from J to Z. M, N, O, V, and W are omitted.

l. In the Eastern Hemisphere, the first letter of the 100,000 meter square identifier originates at the 0° and 180° meridians. It is lettered alphabetically along the east-west axis from A to R but D, E, I, M, N, and O are omitted.

m. The second letter of the 100,000-meter square identifier originates at the intersection of the 80° latitude/180° longitude lines. It is lettered alphabetically from A to Z. I and O are omitted.

n. Easting and northing coordinates used are the same as the grid coordinates used with UTM/UPS with the following modifications.

o. For UTM MGRS grid coordinates, delete the first digit (100,000 meters) from the easting and the first two digits (1,100,000 meters) from the northing of the UTM grid coordinates. Add the grid zone number, the zone designator, and the 100,000-meter square identifier at the front of the coordinates.

p. For UPS MGRS grid coordinates delete the first two digits (1,100,000 meters) from both the easting and northing UPS grid coordinates. Add the zone designator and the 100,000-meter square identifier at the front of the coordinates.

q. The entire MGRS grid coordinate is written as one entity without parentheses, dashes, or decimals (Figure 5-34).

3Q	location within a 6° 8° square
3QXV	location to within 100,000 meter
3QXV41	location to within 10,000 meters
3QXV4312	location to within 1,000 meters
3QXV432123	location to within 100 meters
3QXV43211234	location to within 10 meters
3QXY4321012345	location to within 1 meter

Figure 5-34. MGRS

5-27. Local Grids

Many grid systems have been developed by individual nations that cover only that nation or a region surrounding that nation. Usually, no direct relationship exists between local grid systems (the same as no direct relationship exists between the state plane grid systems of the US). Nonstandard grids are generally named for the nation or region they cover and contain the term grid, zone or belt; i.e., Ceylon Belt, Madagascar grid, and India Zone I. A grid covers a relatively small area. Its limits consist of combinations of meridians, parallels, rhumb lines, or grid lines. A zone is usually wide in longitude and narrow in latitude. Its limits consist of meridians and parallels. A belt is usually wide in latitude and narrow in longitude.

5-28. Global Area Reference System

The Global Area Reference System is an alphanumeric system for reporting positions based on geodetic coordinates. It is the worldwide position reference systems that can be used with any map or chart graduated in latitude and longitude, regardless of the map projection. The primary use of the Global Area Reference System is for inter-service and inter-allied positioning and reporting of aircraft and air targets. This system was previously known as Common Geographic Reference System. It is based on lines of latitude and longitude and provides a common reference to facilitate air to ground coordination. Additionally it provides common language between components and simplifies communications.

5-29. User-Defined Grid Systems

a. When operating in an area that is mapped in a grid system other than UTM and UPS, it may be necessary to define the grid system. Defining the grid system is basically orienting a fire support system or survey system to measure or establish azimuths, distances, and elevations from a different origin than it is programmed for. Most current software versions do not allow this option. If the option is available, the following information is necessary:

(1) Operational ellipsoid.

(2) Ellipsoid parameters (a, b, 1/f).

(3) Scale factor (at the origin) for the projection.

(4) Latitude of the origin.

(5) Longitude of the origin.

(6) Unit (meters, feet, yards, chains or rods).

(7) False easting of the origin.

(8) False northing of the origin.

b. Figure 5-35 (page 5-39) lists the needed information for several common nonstandard grids published in DMA TM 8358.1. Figure 5-36 (page 5-40) lists the needed information for several common nonstandard grids not published in DMA TM 8358.1.

5-30. Gauss-Kruger Grid

The GK Grid System is referenced to the Gauss-Kruger (Transverse Mercator -tangent) projection. Although the GK grid can be considered a universal grid, like UTM and UPS, it is actually a local grid covering Europe, the Middle East, Asia, and parts of Africa. The grid is usually placed on a projection using one of the following reference ellipsoids:

Krassovsky**:** Russia (all former USSR), Albania after 1945, Afghanistan, Bulgaria, China to 1981, Czechoslovakia, Germany, Hungary, Laos, Poland, Romania, and Somalia GRS (China) 1980: China after 1981
Bessel**:** Albania through 1945, Austria, Germany, and North Korea

			ORIGIN		FALSE ORIGIN		
NAME	PROJECTION	ELLIPSOID	LATTITUDE	LONGITUDE	EASTING	NORTHING	SCALE FACTOR
British West Indies	Transverse Mercator	Clarke 1880	00º0'00.000"N	62º0'00.000"W	400,000.000 m	0 m	0.9996
Costa Rica							
Norte	Lambert	Clarke 1866	10º28'00.000"N	84º20'00.000"W	500,000.000 m	271,820.522 m	0.99995696
Sud	Lambert	Clarke 1866	9º0'00.000"N	83º40'00.000"W	500,000.000 m	327,987.436 m	0.99995696
Cuba							
Norte	Lambert	Clarke 1866	21º21'00.000"N	81º0'00.000"W	500,000.000 m	280,296.016 m	0.99993602
Sud	Lambert	Clarke 1866	20º43'00.000"N	76º50'00.000"W	500,000.000 m	229,126.939 m	0.99994848
Dominican Republic	Lambert	Clarke 1866	18º49'00.000"N	71º30'00.000"W	500,000.000 m	277,063.657 m	0.99991102
Egypt	Transverse Mercator	International	00º00'00.000"N	25º20'00.000"E	300,000.000 m	0 m	0.99985
				28º30'00.000"E			
				31º30'00.000"E			
				34º30'00.000"E			
				37º30'00.000"E			
El Salvador	Lambert	Clarke 1866	13º47'00.000"N	89º0'00.000"W	500,000.000 m	295,809.184 m	0.99996704
Guatamala							
Norte	Lambert	Clarke 1866	16º49'00.000"N	90º20'00.000"W	500,000.000 m	292,209.579 m	0.99992226
Sud	Lambert	Clarke 1866	14º54'00.000"N	90º20'00.000"W	500,000.000 m	325,992.681 m	0.99989906
Haiti	Lambert	Clarke 1866	18º49'00.000"N	71º30'00.000"W	500,000.000 m	277,063.657 m	0.99991102
Honduras							
Norte	Lambert	Clarke 1866	15º30'00.000"N	86º10'00.000"W	500,000.000 m	296,917.439 m	0.99993273
Sud	Lambert	Clarke 1866	13º47'00.000"N	87º10'00.000"W	500,000.000 m	296,215.903 m	0.9999514
Levant	Lambert	Clarke 1880	34º39'00.000"N	37º21'00.000"E	500,000.000 m	300,000.000 m	0.9996256
Nicaragua							
Norte	Lambert	Clarke 1866	13º52'00.000"N	85º30'00.000"W	500,000.000 m	359,891.816 m	0.99990314
Sud	Lambert	Clarke 1866	11º44'00.000"N	85º30'00.000"W	500,000.000 m	288,876.327 m	0.999922228
Northwest Africa	Lambert	Clarke 1880	34º0'00.000"N	00º00'00.000"E	1,000,000.000 m	500,000.000 m	0.99908
Palistine	Transverse Mercator	Clarke 1880	31º44'02.749"N	35º12'43.490"E	170,251.555 m	126,867.909 m	1
Panama	Lambert	Clarke 1866	08º25'00.000"N	80º00'00.000"W	500,000.000 m	400,000.000 m	0.99989909

Figure 5-35. Specifications for Secondary Grids Listed in DMA TM 8358.1

			ORIGIN		FALSE ORIGIN		
NAME	PROJECTION	ELLIPSOID	LATTITUDE	LONGITUDE	EASTING	NORTHING	SCALE FACTOR
Camp Fuji, Japan	(Shizuka and Yamanashi Prefectures)						
Zone VIII	Transverse Mercator	Bessel	36°00'00.000"N	138°30'00.000'W	0 m	0 m	0.9999
Marianas Islands							
Guam	Azmithal Equidistant	Clarke 1866	13°28'20.897"N	144°44'55.503"E	500,000.000 m	500,000.000 m	
Rota	Azmithal Equidistant	Clarke 1866	14°07'58.861"N	145°08'03.228"E	5,000.000 m	5,000.000 m	
Saipan	Azmithal Equidistant	Clarke 1866	15°11'05.683"N	145°44'29.972"E	28,657,520 m	67,199,00 m	
Tinain	Azmithal Equidistant	Clarke 1866	14°56'05.775"N	145°38'07.198"E	20,000.000 m	20,000,000 m	
MCAS Iwakuni Japan			36°00'00.000"N	132°10'00.000'E	0 m	0 m	
Okinawa Japan			26°00'00.000"N	127°10'00.000'E	0 m	0 m	
St Barbara Area,	Replublic of Korea						
Central Zone	Transverse Mercator	Bessel	38°00'00.000"N	127°00'10.405"E	0 m	0 m	1.0(Unity)
Subic Bay, Republic	Of the Philippines						
Zone III	Transverse Mercator	Clarke 1866	00°00'00.000"N	121°00'00.000'E	500,000.000 m	0 m	0.99995
Tunisia							
Nord Tunisia Grid	Lambert	Clarke 1880[1]	36°30'00.000"N	09°54'00.000"E	500,000.000 m	300,000.000 m	0.999625544
Clark 1880	(French) Ellipsoid	a=6378,249.2 and	1/f=293,4660208				

Figure 5-36. Specifications for Secondary Grids Listed in DMA TM 8358.1(Cont.)

CHAPTER 6 SURVEY ACCURACY LEVELS AND REQUIREMENTS

6-1. General

The order of accuracy of an established survey can never be higher than the survey control used to establish it, nor can the accuracy ever be greater than the procedure used to establish it. Position accuracies are described by relative value (4th Order) or an absolute value measured using circular error probable (CEP) or standard deviation. Azimuth and elevation accuracies are described by relative value (4th Order) or an absolute value measured using position error or standard deviation.

6-2. Geodetic Control Surveys

a. Geodetic control surveys are high order surveys established for the purposes of mapping, engineering, and other projects requiring extreme accuracy. Classifications and standards for this type of survey are issued by the Federal Geodetic Control Subcommittee (FGCS). FGCS classification and specifications for relative GPS surveys are listed in FGCS manual Geometric Geodetic Accuracy Standards and Specifications for using GPS relative positioning techniques. FGCS classification and specifications for conventional surveys are listed in FGCS manual Standards and Specifications for Geodetic Control Networks.

b. Distance Accuracy and Accuracy Ratio Standards (Table 6-1 page 6-2) shows survey accuracy levels as designated by the National Geodetic Survey and the National Geospatial-Intelligence Agency as well as the three artillery levels.

Table 6-1. Distance Accuracy and Accuracy Ratio Standards

Category	Order	Parts per million	Accuracy Ratio
GPS: National geodetic reference system (terrestrial-based), dependent surveys to mapping, land information, property, and engineering requirements.	(C) Class 1 Class 2-I Class 2-II Class 3	 10 20 50 100	 1:100,000 1:50,000 1:20,000 1:10,000
Conventional	1st	10	1:100,000
Conventional	2nd, Class I	20	1:50,000
Conventional	2nd, Class II	50	1:20,000
Conventional	3rd, Class I	100	1:10,000
Conventional	3rd, Class II	200	1:5,000
Conventional, Artillery	4th	333	1:3,000
Conventional, Artillery	5th	1,000	1:1,000
Conventional, Artillery	HASTY	2,000	1:500

GPS accuracy standards represent at 95% confidence level.

1st, 2nd, and 3rd order conventional standards represent the ratio 1: A, when A (distance accuracy) equals the distance between survey points divided by propagated standard deviation between points.

4th, 5th and Hasty order conventional standards represent the ratio 1: A, when A (accuracy ration) equals the total traverse length divided by the radial error of closure.

6-3. Artillery Survey

a. A relative accuracy value, accuracy ratio (AR), can be determined to show the position accuracy for a survey network. Accuracy ratio is the ratio between the position error and the total length of a survey. It shows the survey length necessary to allow for one meter of position error in a given survey and is expressed as a fraction with one as the numerator, and the survey length producing that error as the denominator. Required ARs for artillery surveys are fourth order, considered accurate to one meter error for every 3,000 meters surveyed (1/3,000) and fifth order, considered accurate to one meter error for every 1,000 meters surveyed (1/1,000). Hasty survey is considered accurate to 1 meter error for every 500 meters surveyed.

b. For some systems or survey methods, e.g., the improved position and azimuth determining system - GPS (IPADS-G) or GPS, probable error (PE) values describe the accuracy. These values generally express absolute accuracy. However, depending on the system and the survey method, they can describe a relative accuracy. These values may be given in terms of CEP, PE, or various standard deviation values; e.g., 2 deviations root mean square (2DRMS) or 3 sigma. These values are expressed in terms of a percentage of probability or confidence that the position given is located within a line, circle, or sphere of a given size.

c. Probable error is a value which is exceeded as often as it is not, i.e., it has a 50% probability of occurrence. With respect to fixation (position), the PE applies to both East/West and North/South axes.

d. Circular error probable is a radius of a circle, centered about the true position such as that any measured or calculated position has a 50% probability of lying within that circle.

e. Probable error and CEP are derived from the positive standard deviation of the measurement as (sigma σ):

(1) PE = 0.6745.

(2) CEP = 1.1774.

(3) CEP = 1.7456 PE.

f. Fourth order astronomic azimuths are established by astronomic observations, the PE of which does not exceed 0.060 mils. The considered accuracy is 0.150 mils.

g. An azimuth of a line in a fourth order survey that, from its point of origin at a fourth order astronomic azimuth or higher order direction, has depreciated in accuracy by a PE value of 0.030 mils per main scheme angle (using a T-2E); or the azimuth of a line computed between two fourth order or higher survey control points (SCPs) is considered accurate to fourth order standards. The computed azimuth is considered accurate to 0.300 mils.

h. Fifth order astronomic azimuths are established by astronomic observations, the PE of which does not exceed 0.120 mils. The considered accuracy is 0.300 mils.

i. The azimuth of a line in a fifth order survey that, from its point of origin at a fifth order astronomic azimuth or higher order direction, has depreciated in accuracy by a PE value of 0.090 mils per main scheme angle (using a T-2E). A fifth order azimuth cannot be obtained by computations between a fifth order point and a point of equal or higher order.

6-4. Required Survey Data

a. The format of the survey data provided depends on the type of position being surveyed.

b. A howitzer with digital fire control system capabilities requires an update point along the route from one gun position to another. When operating in a degraded mode, the High Mobility Artillery Rocket System requires updating along a common survey network to provide the required accuracies for system positioning. The required survey data for an update point is the operational datum and ellipsoid, UTM easting and northing, and elevation (meters).

c. An artillery firing position may require establishing an OS and the EOL. The orienting line must be one of the main scheme legs of the survey when conducting a traverse; both ends of the orienting line must be occupied. The required survey data for an artillery firing position is the operational datum and ellipsoid, UTM easting and northing of the OS, elevation (meters) of the OS, and the UTM grid azimuth (mils) from the OS to the EOL.

d. An artillery radar position requires establishing an OS and the EOL. The required survey data for an artillery radar position is the operational datum and ellipsoid, UTM easting and northing of the OS, elevation (meters) of the OS, UTM grid azimuth (mils) from the OS to the EOL, distance (meters) from OS to EOL, and vertical angle (mils) from OS to EOL.

e. A pilot balloon position for artillery meteorology requires establishing an OS and EOL. The required survey data for a PiBal position is the operational datum and ellipsoid, latitude and longitude (decimal degrees expressed to 0.1°) of the OS, elevation in tens of meters of the OS, true azimuth in decimal degrees expressed to 0.1° from the OS to the EOL.

f. The requirement for a declination station is the operational datum and ellipsoid, UTM easting and northing (map spot) and a UTM grid azimuth (expressed to 0.1 mils) to at least two azimuth marks in different quadrants. The true azimuth in decimal degrees expressed to 0.01° should be provided for declination of the MET theodolite.

(1) A declination station should be established at a location that is convenient to the using units. Declination stations within a battalion area of operations are the responsibility of the battalion sensor section; however, most permanent declination stations on Marine Corps installations are established by the TAP sensor section.

(2) Declination stations should have at least two (four if possible) well-defined azimuth marks with known azimuths in different quadrants, but one mark may suffice. Azimuth marks should be more than 1,000 meters from the declination station if possible. An azimuth mark must never be less than 300 meters from the declination station.

(3) Position and elevation of the declination station do not have to be of any specific accuracy. The position must be adequate to plot the station on a map and to locate the station. The azimuths to the azimuth marks should be at least fifth order. These azimuths can be determined by astronomic observations, Real Time Kinematic

(RTK), the IPADS-G, traverse, or by computations when coordinates of the declination station and azimuth marks are of sufficient accuracy to provide fifth order azimuths.

(4) Establish the declination station in an area free of local magnetic attraction. The following minimum distances from common objects are prescribed:

- Power lines, 150 meters
- Electronic equipment, 150 meters
- Railroad tracks, 75 meters
- Artillery, tanks, etc., 75 meters
- Vehicles, 50 meters
- Wire fences, 30 meters
- Personal weapons, 10 meters

g. The requirement for an OP is the operational datum and ellipsoid, UTM easting and northing, the elevation (meters), and a UTM grid azimuth (mils) to an azimuth mark, preferably an intervisible OP.

h. The requirement for an RP is the operational datum and ellipsoid, UTM easting and northing expressed to the nearest meter, elevation expressed to the nearest meter, and the UTM grid azimuth expressed to the nearest mil. The azimuth should be from the OP designated as O1 for the target survey. Ideally, the RP will be within the 800 mil-fan of the registering battery's azimuth of fire.

i. The survey requirement for targets other than RPs is the operational datum and ellipsoid, UTM easting and northing expressed to 10 meters and elevation expressed to 10 meters.

CHAPTER 7 GLOBAL POSITIONING SYSTEM THEORY AND OPERATIONS

Section I. CONFIGURATION, SIGNALS, AND CODE

7-1. General

Chapter seven will cover the theory, planning, and operation considerations of the GPS. General concepts, applications, and measuring differences and time parameters will be discussed when conducting GPS measurements as well as methods and techniques used for artillery and sensor survey operations.

7-2. Configuration , Signals, and Code

a. The navigation satellite timing and ranging (NAVSTAR) GPS is configured into space, control, and user segments. Each segment depends upon the other (Figure 7-1).

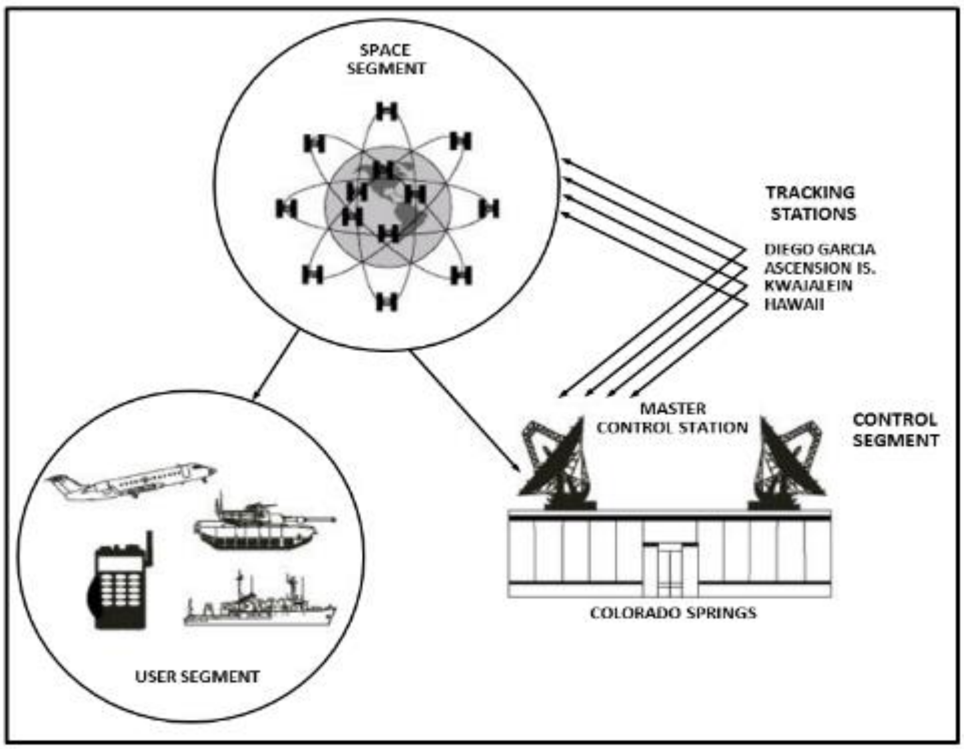


Figure 7-1. NAVSTAR System Configuration: Space, Control, and User Segments

b. Originally, the complete space segment was to consist of 24 Block II satellites. Block I satellites were considered developmental. Block IIR (Replenishment) satellites were developed to provide system operations through the year 2025. Currently the United States Air Force manages the constellation, to ensure availability of at least 24 GPS satellites 95% of the time, with up to 27 operational GPS satellites. They are arranged into six orbital planes, each inclined 55° from the Equator. Each orbital plane contains at least four unevenly spaced satellites orbiting the Earth twice a day at an average 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.

c. The operational control segment, includes a master control station, an alternate master control station, 12 command and control antennas, and 16 monitoring sites. Tracking stations use special receivers to track each satellite individually. The information from tracking the satellites helps control the satellites and predict their orbits. Three of the stations transmit information back to the satellites. All data collected at the tracking stations is transmitted to the master control station, located at Colorado Springs, Colorado where it is processed and analyzed. Ephemerides, clock corrections, and other message data are then transmitted back to the three stations for subsequent transmittal back to the satellites. The master control station is also responsible for the daily management and control of the satellites and the overall control segment.

d. The user segment consists of any one with a GPS receiver. Military and civilian personnel (including the enemy) use these receivers.

7-3. Satellite Signals

a. Each GPS satellite broadcasts signals on two spread- spectrum radio frequencies (RFs). These are termed carrier frequencies (Figures 7-2 through 7-5 pages 7-2 through 7-4) because they are modulated with signal codes "carried" on the radio wave. The satellite's onboard atomic clocks generate a fundamental frequency of 10.23 megahertz (MHz) (10,230,000 cycles per second) multiplied by a factor that produces the actual carrier frequency.

(1) The Link 1 (L1) radio frequency (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). Signal wavelength is 19 centimeters.

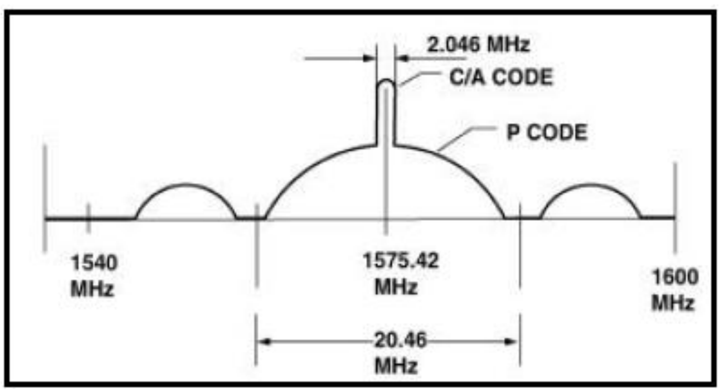


Figure 7-2. L1 Carrier Frequency

(2) The Link 2 (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). Signal wavelength is 24 centimeters.

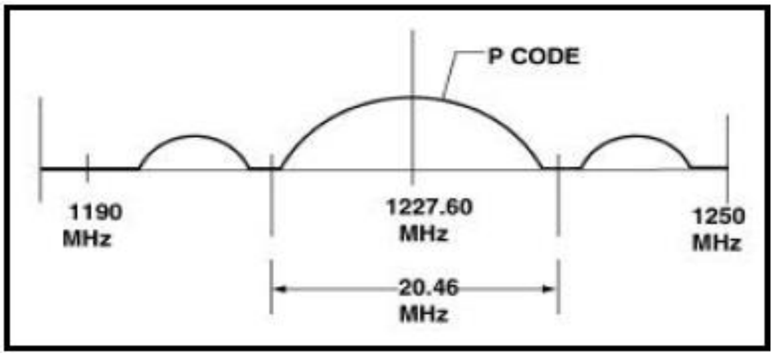


Figure 7-3. L2 Carrier Frequency

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

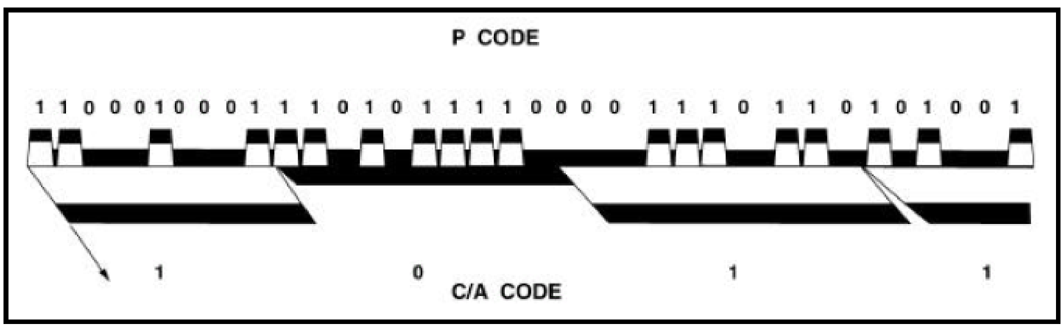


Figure 7-4. P Code and C/A Code Data Sequence

(1) The C/A code is sometimes referred to as the standard (S) code, also called the clear access or civilian access code. It is broadcasted by all GPS satellites on the L1 carrier wave. Transmission of the data sequence is centered at 1575.42 MHz (L1 frequency and modulated at ±1.023 MHz providing a bandwidth of 2.046 MHz. The code contains a sequence of 1,023 pseudo-random binary bi-phase modulations on the GPS carrier at a chipping rate of 1.023 MHz, thus having a repetition period of 1 microsecond. The C/A code is a 300-meter measurement wave.

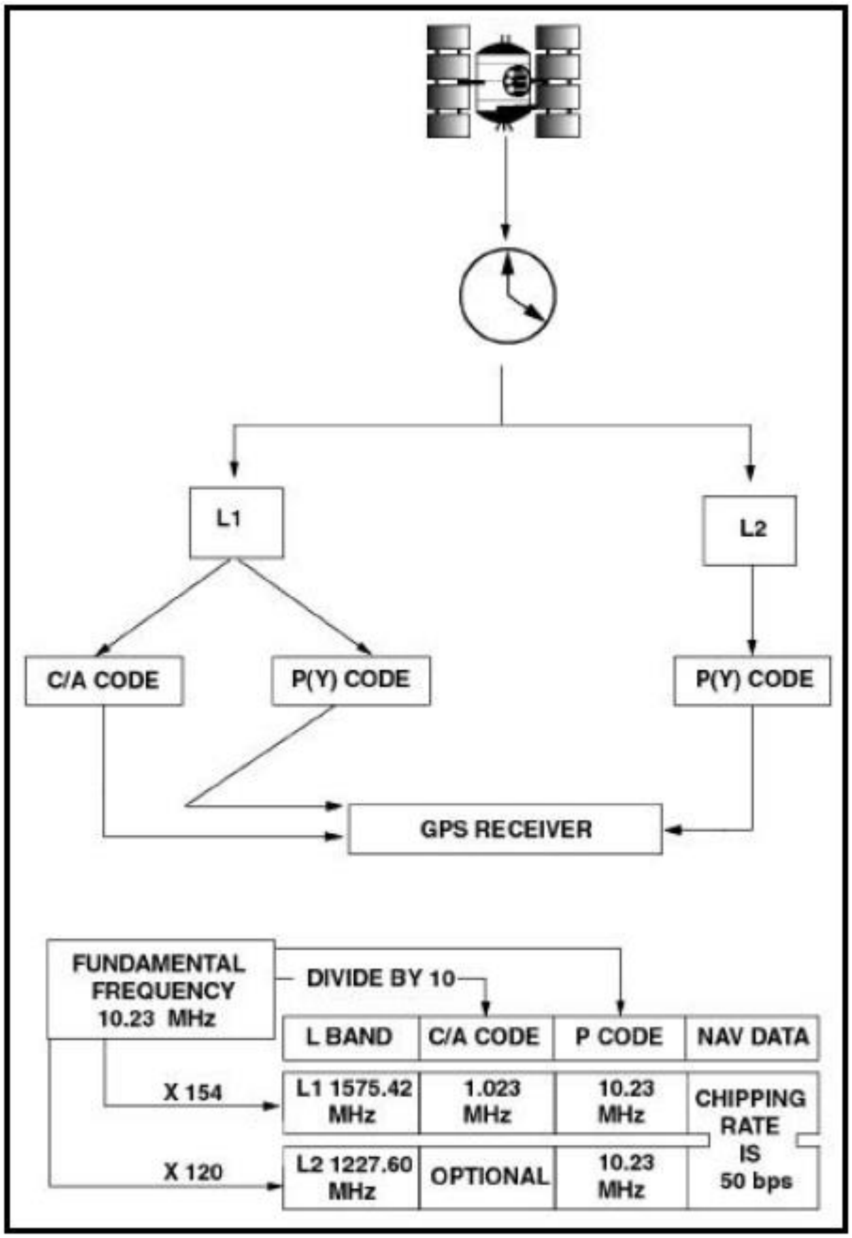


Figure 7-5. GPS Signal Data Flow

(2) 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. Transmission of the data sequence is centered at 1575.42 MHz on the L1 carrier and at 1227.60 MHz on the L2 carrier. It modulates at ±10.23 MHz on carrier frequencies providing a bandwidth of 20.46 MHz. The P code is a 30-meter measurement wave and can be encrypted by the satellite creating a Y code.

(3) The overall P code is a mathematically derived binary sequence that is 267 days (approximately 37 weeks) long. It is broken into 1-week segments for operational use. Five of these 1-week segments are reserved for the GPS control segment. The other 32 segments are available for satellite vehicle. Each satellite vehicle has a

unique 1-week segment code that is a subset of the overall P code sequence. It is generally accepted that the P code repeats every week.

(4) The Nav Data is a 1,500 bit navigation message broadcast on both L1 and L2 carriers at a rate of 50 bits per second or 50 hertz. The Nav Data contains system time, clock correction parameters, ionospheric delay model parameters, and the almanac (ephemeris and health data) on the entire constellation. It is broadcast once each hour by each GPS satellite and referred to as the D code.

(5) The Nav Data is a separate binary data sequence in the satellite, but is modulated over the C/A and P codes for transmission. Each satellite develops the binary code sequence of the C/A code, the P code, and the Nav Data. Since these sequences are all 1's and 0's, the satellite combines the Nav Data with the C/A code and P code to form two data streams: one a combination of the C/A code and the Nav Data, the other a combination of the P code and the Nav Data. These codes are actually transmitted on the carrier frequencies. The ground receiver then extracts the Nav Data from the broadcast C/A or P code, whichever it was receiving.

7-4. Ephemeris and Almanac Data

a. Each GPS satellite transmits almanac data once an hour. The almanac data is the position and health status of all satellites in the constellation. The ephemeris is the position data for each individual satellite. There are two types of ephemeris data to be considered: broadcast and precise.

b. The broadcast ephemerides are actually predicted satellite positions transmitted within the Nav Data. Ephemerides can be acquired in real time by any receiver capable of acquiring the C/A or P codes. Broadcast ephemerides are computed by the master control station using past tracking data provided from the five tracking stations. The new orbital parameters are then transmitted back to the satellites once every 24 hours for subsequent transmission to the user segment.

c. Precise ephemerides are computed from actual tracking data post-processed to obtain more accurate satellite positions. Precise ephemerides are available later and are more accurate than broadcast ephemerides because they are based on actual tracking data and not predicted data.

Section II. SYSTEM SAFEGUARDS, ERROR SOURCES, AND SURVIVABILITY

7-5. Selective Availability

a. When the concept of GPS was initially developed, it was planned that the P code would be reserved for military use, while the less accurate C/A code would be authorized for use by anyone. During initial system testing, it was discovered that while P code measurements provided the expected 10-20 meter accuracy the C/A code provided accuracy as high as 20 meters (much better than the expected 100 meters). The DOD, expecting much lower accuracy, determined that a method of introducing errors into the satellite signals was needed to ensure that enemy forces would not be able to obtain high position and timing accuracy from GPS. Selective availability (SA) was the outcome.

b. The DOD uses SA to deny precise position and timing accuracy to unauthorized users. SA uses two methods to intentionally introduce errors into the signals transmitted to the user segment.

(1) The dither method alters or manipulates the satellite clocks. This method intentionally introduces timing errors, which ultimately produces position errors at the receiver because of the importance of accurate time to the computation of the pseudo-range.

(2) The epsilon method alters the orbital parameters (satellite position) that are broadcast in the Almanac portion of the Nav Data. Position error is then created because the receiver is positioned based on the satellite location.

c. The level of accuracy achieved by a GPS receiver now depends on if the receiver is equipped with an encryption device that allows the receiver to accept and store crypto variables referred to as a key. This key allows the receiver to decrypt SA correction data that is transmitted in the Nav Data message. This key also allows the receiver to use the encrypted P code. The two accuracy levels are the precise positioning service (PPS) and the standard positioning service (SPS).

(1) The PPS is a precise positioning and timing service that is reserved for the US and allied military, as well as, specific authorized civilian users as long as their receiver accepts the crypto key discussed above. The technical specification is listed at 16 meters spherical error probable.

(2) The SPS is the less accurate positioning and timing service offered to all GPS users. The DOD has stated that this service will be accurate to 100 meters in horizontal position and 150 meters vertical, under normal conditions, 95% of the time. The DOD does have the ability to increase the errors created by SA based upon national security needs.

7-6. Anti-Spoofing

Anti-spoofing is a method used by the DOD to prevent possible hostile 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 very 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.

7-7. Crypto Variables

a. As stated before, crypto variables are necessary for a GPS receiver to access the PPS, allowing the receiver to correct for errors caused by SA and spoofing.

b. For current crypto fill refer to unit communications security officer.

c. Two operational cryptographic keys (group unique variable [GUV] key and crypto variable weekly [CVW] key) are available for issue to a GPS user. Both keys can be used by a receiver to obtain a daily crypto variable key (CVd). All operational keys are classified CONFIDENTIAL and are marked CRYPTO.

(1) The GUV key is an annual key. It is a key encryption key that decrypts previously encrypted daily keys. A GPS receiver loaded with a GUV key takes longer to begin processing navigational data than the weekly key because it must first acquire and decrypt the CVd key being broadcast by any GPS satellite. This process could take as long as 12.5 minutes after initial GPS signal acquisition. The GUV key is not a years' worth of daily keys. It is merely the data needed by the receiver to decrypt the broadcast daily key.

(2) The CVW key is sometimes referred to as the crypto key weekly. It is a key production key that automatically generates daily keys within the user equipment. Obtaining the daily key from a satellite downlink is not necessary for receivers loaded with a CVW key. A user with a CVW key starts processing navigational data in less time than those with a GUV key. Because of this special capability, distribution of the CVW key is limited to those users who demonstrate a valid need for initial GPS acquisition in a minimal amount of time.

(3) The GUV key and the CVW key will produce the same CVd key. Once the receiver determines the current working CVd, processing navigational data may commence and the effects of SA and anti-spoofing can be removed from the GPS signal and full navigational accuracy is restored. A CVd cannot be entered directly into the receiver, only a CVW or a GUV key can be entered. The same CVd is used for both SA and anti-spoofing.

d. A maintenance key is available to users for troubleshooting GPS user equipment. It does not allow a user to gain access to the daily encryption key. Maintenance keys are unclassified and may be reused until they are unusable.

e. A simulator key is available to users for testing receivers. The simulator and the equipment must be keyed with the simulator key. The simulator key does not allow a user to gain access to the daily encryption key. Simulator keys are unclassified and may be reused until they are physically unusable.

f. Because of the security classification of the CVW and GUV keys, GPS receivers designed specifically for military uses are equipped with a special certified security module that prevents the extraction of cryptographic information from the receiver. These receivers can then remain unclassified even when loaded with a cryptographic key. If classified information other than crypto is stored in the receiver, the receiver becomes classified at the level of the stored information.

7-8. Global Positioning System Error Sources

There are many sources of measurement error that influence GPS performance. The sum of all systematic errors or biases contributing to the measurement error is referred to as range bias. The observed GPS range (the range from the satellite to the receiver) without the removal of biases is called a pseudo-range. Principal contributors to the final range error that also contribute to overall GPS error are ephemeris error, satellite clock and electronic inaccuracies, tropospheric and ionospheric refraction, atmospheric absorption, receiver noise, and multipath effects. Other errors include those induced by the DOD (SA and spoofing). GPS also contains random observation errors, such as unexplainable and unpredictable time variation. Due to their random nature, these errors cannot be modeled and corrected. The following paragraphs discuss these errors as they associate with GPS positioning and navigation. Most are eliminated or their effects significantly reduced when GPS is used in a differential mode. (The same errors are common to both receivers during simultaneously observed sessions).

a. Satellite ephemeris errors are errors in the prediction of the satellite position that are transmitted to the user in the Nav Data. Ephemeris errors are satellite-dependent and very difficult to predict and compensate. The many forces acting on the predicted orbit of a satellite are difficult to measure directly.

b. GPS relies heavily on accurate time measurements. GPS satellites carry rubidium and cesium time standards that are usually accurate to 1 part in 10^{12} and 1 part in 10^{13}, respectively. Most receiver clocks are actuated by a quartz time standard accurate to 1 part in 10^{8}. The difference between the satellite time and the receiver time is called the time offset. The product of the time offset and the speed of light equal the possible error due to clock bias.

c. GPS signals are electromagnetic signals that are dispersed nonlinearly and refracted when transmitted through a highly charged environment, such as the ionosphere. Dispersion and refraction of the GPS signal is referred to as an ionospheric range effect. The dispersion and refraction of the signal results in an error in the GPS range value. Ionosphere range effects are frequency dependent. L1 and L2 frequencies are affected differently even though they follow the same path through the ionosphere.

(1) The error effect of ionosphere refraction on the GPS range value depends on sunspot activity, time of day, and satellite geometry. Periods of high sunspot activity produce greater range errors than periods of low sunspot activity because of the effects of the Sun's gravity on the ionosphere. Daylight GPS operations will produce greater range errors than night operations. GPS operations with satellites near the horizon will have larger range errors than those with satellites near the zenith because the signal must pass through a larger portion of the ionosphere when the satellite is near the horizon.

(2) Resolution of ionosphere refraction can be accomplished with the use of a dual frequency receiver (L1/L2). During a period of uninterrupted observation of the L1 and L2 signals, the signals can be continuously counted and differenced. The resultant difference reflects the variable effects of the ionosphere delay on the GPS signal.

d. Global Positioning System signals are not dispersed by the troposphere but they are refracted. Tropospheric conditions causing this refraction can be modeled by measuring the dry and wet components.

e. Multipath is a positioning error caused by the signal arriving at the receiver from more than one path. Generally, due to the receiver being located near a reflective surface such as structures, terrain features, or bodies of water. Newer antenna designs have filtering capabilities to reduce the effects of multipath. However, proper mission planning and site reconnaissance is the best way to reduce this type of error. Averaging of GPS signals over a period can also reduce multipath effects. This error source includes a variety of errors associated with the receiver's ability to measure a finite time difference. Errors include signal processing and filtering, clock/signal synchronization and correlation methods, receiver resolution, signal noise, and electronic interference. Most errors cannot be modeled or accounted.

7-9. User Equivalent Range Error

User equivalent range error (UERE) is referred to as the total budgeted error caused by the error sources listed above. Error sources can be reduced through planning. Differential techniques can eliminate some error sources. Figure 7-6 (page 7-10) lists errors and biases by associating them with their source segment. Error values listed do not include the effects of SA.

Segment Source	Error Source	Absolute, C/A code Pseudo-range, m	Absolute, P(Y) code Pseudo-range, m	Differential Positioning, m P(Y) code
Space	Clock Stability	3.0	3.0	Negligible
	Orbit Perturbations	1.0	1.0	Negligible
	Other	0.5	0.5	Negligible
Control	Ephemeris Predictions	4.2	4.2	Negligible
	Other	0.9	0.9	Negligible
User	Ionosphere	3.5	2.3	Negligible
	Troposphere	2.0	2.0	Negligible
	Receiver Noise	1.5	1.5	1.5
	Multipath	1.2	1.2	1.2
	Other	0.5	0.5	0.5
I_0 UERE		±12.1	±6.5	±2.0

Figure 7-6. User Equivalent Range Error

7-10. Absolute Global Positioning System Accuracy

a. Absolute positions are those established with no reference or tie to any other station. They are sometimes referred to as autonomous. For GPS purposes, this is generally accomplished by use of code-phase measurements to determine a pseudo-range. The accuracy of these ranges depends largely on the code (C/A or P(Y)) being used to determine the position. This range accuracy when coupled with the geometrical relationships of the satellites results in a 3-dimensional confidence ellipsoid that depicts uncertainties in all three coordinates. Since satellites are constantly moving, the geometry constantly changes. GPS accuracy is time/position-dependent.

b. The 2-D (horizontal) GPS position accuracy is normally estimated using a root mean square (RMS) radial error statistic called standard deviation or sigma (σ). A 1-RMS (one sigma) error equates to the radius of a circle in which the position has a 63 percent probability of falling. A circle twice this radius represents an approximate probability of 97 percent. This is a 2-σ RMS or 2DRMS (2-deviations RMS) and is the most commonly used accuracy statistic in GPS survey. In some instances, a 3-σ RMS (3DRMS) depicts a circle three times the radius of the 1- σ circle. This circle has a 99.7 percent probability. An RMS error statistic represents the radius of a circle and is not listed with a ±.

c. Figure 7-7 (page 7-11) depicts RMS on an error ellipse at 2-σ. This ellipse represents a normal distribution of GPS position errors and is centered at the indicated position of the receiver. The radii of an error ellipse are expressed in standard deviation (sigma (σ)) of the position distribution and usually provide a direction such as Sigma North, Sigma East, and Sigma Up. Each sigma is a probability estimate of how close the actual position is to the displayed position as discussed.

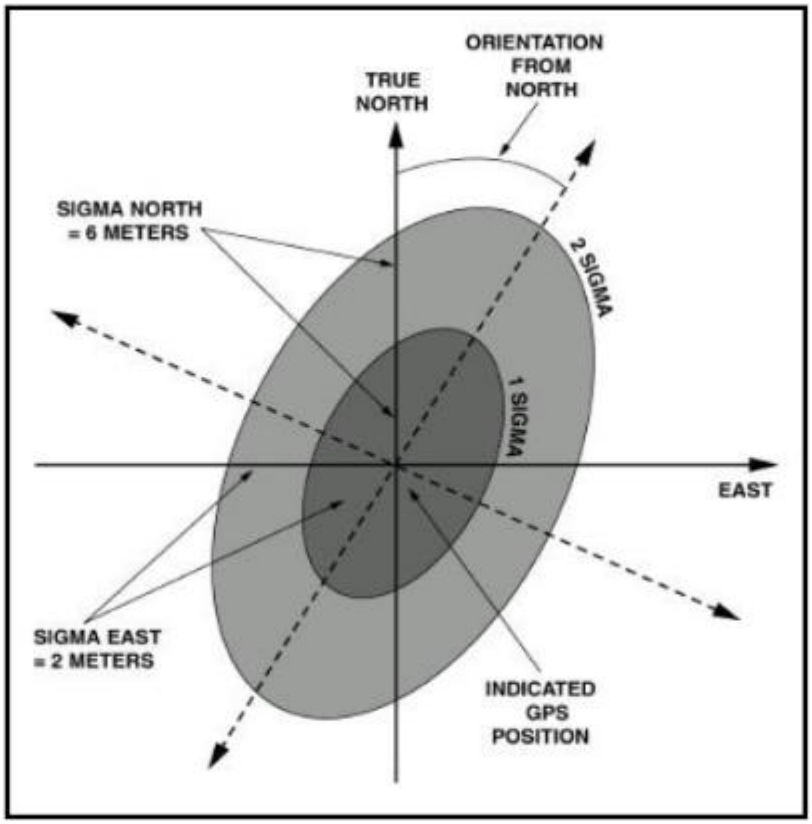


Figure 7-7. Error Ellipse at 2 Sigma RMS

d. In 2-D horizontal positioning, a CEP statistic is most commonly used, especially in military targeting. Circular error probable refers to the radius of a circle with a 50 percent probability of position confidence. A measured or calculated position will fall inside a circle of some radius at least 50 percent of the time.

e. Three-dimensional GPS accuracy is most commonly expressed as a spherical error probable. This value represents the radius of a sphere with a 50 percent confidence level or probability. It is important to understand that this sphere only approximates an actual 3-D-error ellipsoid that represents the uncertainties in the geocentric coordinate system.

f. Dilution of precision (DOP) is a scalar quantity representing the contribution or effect of the satellite geometry to the GPS accuracy. It is the ratio of the standard deviation of one coordinate to the measurement accuracy. It could be said that DOP is the measure of the strength of the satellite geometry. In general, the more satellites which are observed and used in the final solution, the better the solution. Since DOP can be a measure of geometric strength, it can also determine the satellites a receiver uses to determine the most accurate position.

(1) Satellite geometry and DOP can best be visualized by the following analogy. A rubber ball is suspended from five strings. All five strings are attached at the other end to the ceiling within a couple of meters of each other. Because of poor geometry of the strings' attachment to the ceiling, the ball can be moved easily. A large portion of the possible error in the position of the ball is due to poor geometry or high DOP. On the other hand, if the ball was still attached to the same strings but four of the strings were attached to the ceiling at the four corners of the room and the fifth string attached directly above the ball, the ball would not move so easily. This would be due to strong geometry. The DOP would be small.

(2) The main form of DOP used in measuring absolute accuracy is the geometric dilution of precision (GDOP). GDOP is the measure of accuracy of 3-D position and time. GDOP is related to actual range error by stating that the actual range error equals the GDOP multiplied by the UERE.

(3) Position dilution of precision (PDOP) is the measure of the accuracy in 3-D position only. PDOP values are generally developed from satellite ephemerides prior to the conduct of survey operations. The sensor support Marine can more adequately plan sessions and occupations for the equipment.

(4) PDOP represents the position recovery at a particular instance in time and is not representative of the entire session. PDOP error is generally given in units of meters of error per 1-meter error in pseudo-range measurement; i.e., m/m. If the pseudo-range measurement due to clock errors, atmospheric conditions, etc., is in error by 2 meters and the PDOP is 5.5, the possible position error due to satellite geometry is 11 meters. When using pseudo-ranging techniques for absolute positioning (code phase), PDOP values lower than 5 m/m are considered very good; values greater than 10 m/m are very poor. For static-type surveys, it is desirable to make observations during periods of rapidly changing PDOP.

(5) When the values of PDOP and GDOP are observed over time, high values (> 10 m/m) can be associated with poor geometry. The higher the PDOP the poorer the solution for that instant in time. Poor geometry can be the result of satellites being in the same plane, orbiting near each other or at similar elevations.

(6) Horizontal dilution of precision is a measurement of the accuracy in 2-D horizontal position. It is significant in evaluating surveys intended for horizontal control. Horizontal dilution of precision is the RMS position error divided by the standard error in the range measurements. It roughly indicates the effects of satellite range geometry on a resultant position. Horizontal dilution of precision P values lower than 3 indicate the best geometry.

(7) Vertical dilution of precision is a measurement of accuracy in standard deviation (σ) in vertical height. Mathematically, it is the σ_u (Sigma Up) divided by UERE (around 6 meters with P(Y) code and 12 meters with C/A code). Vertical dilution of

precision values lower than 3 indicate a strong vertical component in geometry.

(8) Time dilution of precision is the measurement of the accuracy of the time determined by the GPS receiver. Global Positioning System vulnerabilities are generally grouped by the segment they threaten.

7-11. Space Segment

a. The height of the GPS satellites (10,898 miles) is outside the range of current antisatellite weapons. Such space weapons would be deployed at lower altitudes where they could possibly be used against more attractive space-based systems. The constellation generally keeps the satellites approximately 44,000 kilometers apart in each orbital plane. The control segment manages the system so that no two satellites will orbit within 8,100 kilometers of each other. This spatial separation ensures that a single nuclear burst in space at half the closest distance will have little effect, forcing a more direct assault against individual satellites. A ground-launched attack by antisatellite would be detected early enough in the 3-hour flight time to allow for maneuvering of satellites.

b. It is unlikely that current or projected technology would allow a nation to launch a direct attack or even detonate a nuclear device in the GPS orbit. A nuclear detonation in space would equally affect other space- based systems with a blackout or scintillation effect lasting 10 minutes or longer in the L-band. Detonation would disturb the atmosphere and the ionosphere with subsequent effects on propagation. Radiation effects could incapacitate the functioning of the erasable read only memories and random access memories of these systems if the blast is close enough. GPS satellites have built-in protection against the electromagnetic pulse caused by nuclear detonations and can restore their erased memories through the control segment.

c. Two other factors exist that add an unplanned edge of survivability against antisatellites. The Russian Global Navigation Satellite System orbits at an altitude close to the GPS orbit. A nuclear assault against GPS would have the same effect on the Global Navigation Satellite System. The increased use of GPS by former Eastern Bloc nations including the former Soviet Union is also an unplanned edge.

d. Since the introduction of the Strategic Defense Initiative, lasers have become a planned vulnerability to orbiting satellites. Survivability of GPS against laser technology is enhanced by limited laser hardening of the satellites. A space-based laser at low altitudes would be an extremely heavy device to launch. Tracking and targeting of a GPS satellite is extremely difficult due to its relatively small size and its orbital rate (14,500 kilometers per hour). Technology is available for a high-power ground-based laser-to-target and has a limited effect on GPS satellites.

e. Should there be a loss of any GPS satellite, replenishment from the ground can be accomplished within 2 months. The system can operate fully even with the loss of 9 or more satellites, still providing 3-D coverage for 12 hours and 2-D coverage for more than 20 hours.

7-12. Control Segment

This segment is considered by many to be the most vulnerable GPS segment. The master control station (Colorado Springs) is very well protected by being co-located with several military bases. The tracking stations do not have this protection. All stations are susceptible to espionage and natural disasters, but tracking stations are much more vulnerable to nuclear and conventional assaults. These factors have been considered, and although the ability exists to exert complete control over the satellites from the master control station, the uplink to each satellite will be less frequent than the current eight hours. Next-generation satellites are planned to provide a cross-link ranging capability that will allow satellites to communicate with each other, making offshore tracking stations redundant. Jamming the control segment between the tracking stations and the master control station is a real possibility.

7-13. User Segment

a. Only two major vulnerabilities exist with the user segment: cryptographic key security and jamming. Several types of jamming can be used against GPS receivers.

b. Should the enemy capture a GPS receiver with a valid crypto fill, the PPS-security module prevents reverse engineering so that the enemy cannot gain access to the cryptographic data stored inside the receiver. Also, the regular change of crypto keys adds to the security and survivability of the system.

c. Spoofing is classified as the enemy’s attempts to duplicate or imitate GPS signals. Spoofing requires that the enemy have 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 spoofers can disrupt the duplicated navigation signals to cause navigation errors.

d. When GPS anti-spoofing protection is enabled, spoofers cannot autonomously generate the signals needed to deceive the receiver that is looking for the encrypted P code. This technique transforms the P code by cryptographic means. The resultant bit stream is a cypher text called the Y code that replaces the P code in its entirety. Receivers with a valid crypto key will encrypt their own generated P code to produce a Y code inside the receiver needed for correlation with the satellites transmitted Y code. The C/A code is totally unaffected by the P code encryption. This is why the C/ A code are very susceptible to deception jamming.

7-14. Continuous Wave Jamming

A continuous wave (CW) jammer (spot jammer) concentrates its jamming power in a very narrow band around the L1 or L2 carrier. In the GPS receiver the jamming power spreads out according to the receiver processing gain using the modulated C/A or P code. After spreading, only a small portion of the jamming power enters the tracking loops of the receiver. Consequently, a CW jammer needs to be very powerful to effectively jam a GPS receiver.

7-15. Wide Band Jamming

A wide band jammer needs a sufficiently wide spectrum to cover the frequency band of the GPS signals. Usually, wide band jamming is performed in either a sweeping mode or a quasi-random noise (barrage) mode. In a sweeping mode the jammer carrier moves rapidly and possibly randomly through the band to be jammed. In barrage jamming the spectral power density is low compared to spot jamming.

7-16. Pulse and Amplitude Modulated Jamming

A pulse jammer switches its power on and off during an operation cycle. The modulation rate can be chosen as needed (pulse repetition frequency and pulse duration). An amplitude modulated jammer varies its power linearly; modulation depth and frequency can be chosen as needed. Besides jamming effects already described, this type of jamming could have a negative impact on the GPS receiver by disturbing the internal operating cycles of the receiver processor unit or the electronics of the antenna.

7-17. Jamming Effects on Code Acquisition

a. The GPS user is at a severe disadvantage when having to use C/A code acquisition in a hostile region. Current technology receivers have a limited tolerance to jamming during C/A code acquisition (usually around 25 decibels). Although only 1,023 chips must be searched in the C/A code, a large frequency window must be searched to account for satellite and receiver Doppler shift. The receiver must maintain a large pre-detection bandwidth to acquire the C/A code at the expense of reduced jamming signal tolerance. The C/A code is widely disseminated. A smart jammer can broadcast a false signal and lock up the receiver with very low power. Tests indicate that a very modest 1- watt noise jammer prevents a receiver from acquiring the GPS signal using the C/A code out to 85 kilometers. If the jammer were to transmit a spoofing signal, the receiver would not be able to discriminate between the desired GPS signal and the spoofing signal. The receiver’s jamming tolerance would be on the order of zero decibels, a 1-watt spoofer could deny C/A code acquisition past 1,000 kilometers or to the jammer’s horizon.

b. The P(Y) code is virtually impossible for an adversary to spoof because of its long length and the encryption of the P code into the Y code. Also, the P(Y) code has 10 decibel more anti-jam protection than the C/A code because of its 10 times larger bandwidth. Some current technology receivers using direct P(Y) code acquisition (hot start) can tolerate a jamming signa level in excess of 35 decibels. However, because the P(Y) code is so long, (6×10^{12} chips) much time or more correlations operating in parallel are needed for the 2-D search over code timing and Doppler frequency. Thus, up to date satellite ephemerides and accurate code timing must be available to effectively perform a hot start.

c. Reacquisition typically has very accurate initial code timing. If this accuracy is available during direct P(Y) code acquisition, the reacquisition problem is the same as the acquisition problem with increased jamming signa tolerance (in excess of 50 decibels depending on the receiver).

7-18. Anti-Jam Capabilities of Global Positioning System

a. Global Positioning System vulnerability to jamming can never be completely eliminated. With constantly improving techniques and technology, higher power outputs by the enemy jammers is required to deny access to GPS signals.

b. The GPS satellites broadcast in the ultrahigh frequency domain. Ultrahigh frequency signals cannot "go around" obstacles such as buildings, hilltops, large rocks, etc. the way low domain frequencies can. For this reason, ground based jammers are restricted by severe line-of-sight limitations. Air or space-borne jammers, are not so restricted. A smart user will position the GPS receiver to limit the effects of a line-of-sight jammer. Defilade areas that still allow open skies for satellite signals can be used. Handheld receivers can be placed in a "cat hole" or the user can simply turn their back to the suspected direction of the jammer. Once the receiver has a lock on the P(Y) code, the user should be able to operate normally in most jamming environments.

c. The satellite signal is a CW type signal. This signal is spread by modulation and enters the receiver with the jamming signal. The original signal is recovered as the jammer energy is spread over the modulation and most of the jammer power is filtered out.

d. To locate, track, and demodulate a satellite signal, the receiver requires a certain minimum ratio between received signal power and the noise power. This value (or threshold) is referred to as the signal-to-noise ratio. The noise power is dissipated over a wide bandwidth, while the satellite signal power is concentrated in a very narrow frequency band. Using filters, the GPS receiver narrows its bandwidth to the absolute minimum in order to receive the maximum signal power and minimum noise. A receiver can usually recognize the jammer power as noise; therefore, much of its effects are filtered out. Depending on the power output of the jammer, the signal-to-noise ratio may be too high for the receiver to filter out enough noise to determine data.

e. Many other anti-jam capabilities exist for GPS. Among them is the inertial navigation system integration with GPS and high cost antennas. Both are used in military applications but generally with missile, rocket, and aircraft navigation technologies. For the most part, anti-jam capabilities for Marine ground units will be enhanced by proper planning and positioning of GPS assets.

f. The sensor support Marine must be aware of the ambient conditions of the GPS satellites and their surrounding environment. Solar flares, occurring in 11-year cycles, send great fountains of electromagnetic energy and radiation deep into space, causing interferences in GPS signals. Meteor showers occur close to the Earth, and could potentially damage satellites in the GPS constellation. Global Positioning System satellites are hardened against such possibilities, but are not invulnerable.

7-19. Military (M Code)

a. A major component of the modernization process, a new military signal called M-code was designed to further improve the anti-jamming and secure access of the military GPS signals. The M-code is transmitted in the same L1 and L2 frequencies already in use by the previous military code, the P(Y) code. The new signal is shaped to place its energy at the edges (away from the existing P(Y) and C/A carriers).

b. Unlike the P(Y) code, the M-code is designed to be autonomous, meaning that users can calculate their positions using only the M-code signal. P(Y) code receivers must typically first lock onto the C/A code and then transfer to lock onto the P(y)-code.

c. In a major departure from previous GPS designs, the M-code is intended to be broadcast from a high-gain directional antenna in addition to a wide angle (full Earth) antenna. The directional antenna's signal, termed a *spot beam*, is intended to be aimed at a specific region (i.e., several hundred kilometers in diameter) and increase the local signal strength by 20 decibel (10x voltage field strength, 100x power). A side effect of having two antennas is that the GPS satellite will appear to be two GPS satellites occupying the same position to those inside the spot beam.

d. While the full-Earth M-code signal is available on the Block IIR-M satellites, the spot beam antennas will not be available until the Block III satellites are deployed, tentatively in 2017.

Section III. GLOBAL POSITIONING SYSTEM MEASUREMENTS

7-20. Global Positioning System Reference System

The GPS satellites reference their own position to the WGS 84 coordinate system. This system is based on the WGS 84 ellipsoid. To fix the Earth in time and space for the development of the WGS 84 ellipsoid, the Conventional Terrestrial Pole of 1984 was chosen. The position of the Earth's polar axis at 1984.0 as defined by the Bureau International De l'Heure is used to define the z-axis of the WGS 84 Cartesian coordinate system. The x- and y-axes are then referenced to that z-axis. All positions determined by GPS are originally in this format, WGS 84 Cartesian. Receivers and software applications for GPS have the capability to provide positions in other coordinate systems and other datum/ellipsoid references.

7-21. Code Phase Measurements

a. The primary purpose of code phase measurements is to determine approximate ranges from satellites to the GPS receiver that allow the receiver to determine its position. Since this position is not referenced or relative to any other position or receiver, it is referred to as an absolute position. Clock biases, atmospheric absorption and refraction, and other inherent errors make determination of a true range virtually impossible. The actual range determined by the GPS receiver is referred to as a pseudo-range (Figure 7-8).

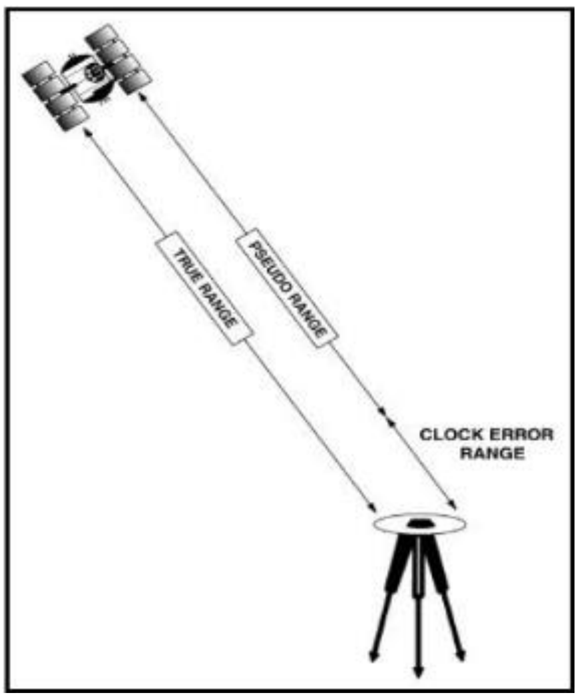


Figure 7-8. Pseudo-Range

b. The pseudo-random noise (PRN) code (Figure 7-9 page 7-19) is a binary data string of digital ones and zeros that is unique to the satellite broadcasting it. This code is used by the receiver to identify the satellite it is tracking. This code is repeated every millisecond (C/A) and every week (P/Y).

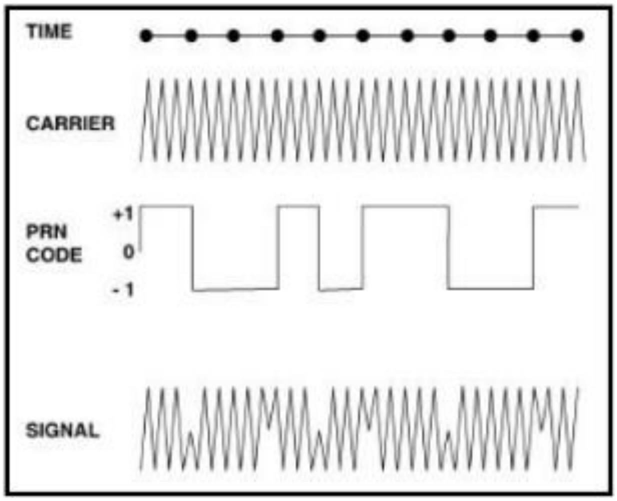


Figure 7-9. Carrier Modulated by PRN

c. Before the receiver can compute the pseudo-range to the satellite, it must determine the time required for the signal to travel from the satellite to the antenna. The receiver stores a replica of each satellite's PRN code. When the receiver detects a satellite signal, it identifies the satellite by its PRN that has been replicated from memory. The code received from the satellite is then compared to the replicated code. The receiver slides the replicated code in time until it lines up with the satellite's transmitted code. The amount of time that was needed to slide the code is the time delay of the transmission or travel time (Figure 7-10).

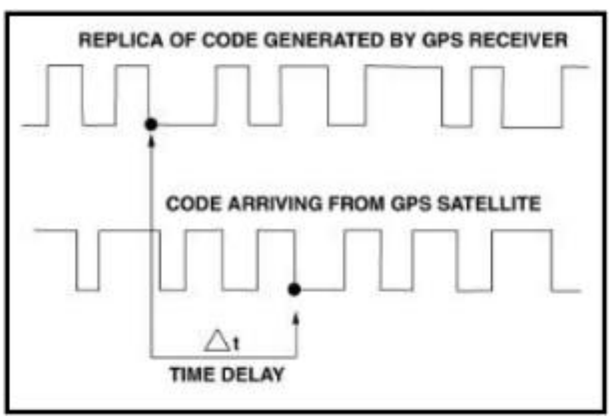


Figure 7-10. Time Delay of a GPS Signal

d. The only measurement made by a code-phase receiver is the time delay or transmission time. Radio waves travel at the speed of light. This constant value is stored in the memory of the GPS receivers. A receiver capable of making code-phase measurements will compute the pseudo-range using the formula pseudo-range = $\Delta t \times$ speed of light.

(1) This procedure can be simultaneously performed on many satellites. The number of

satellites depends on the receiver used, or more specifically, how many channels are available in the receiver.

(2) Once a satellite is tracked and the receiver determines a pseudo-range, the receiver basically knows it is located on a sphere whose radius equals the pseudo-range with the satellite at the center of the sphere (Figure 7-11).

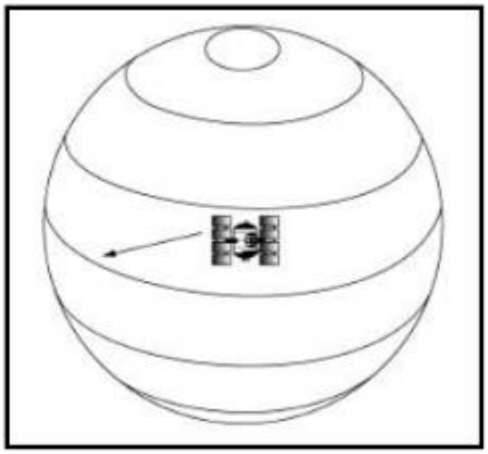


Figure 7-11. Ranging One Satellite

(3) When the second satellite is acquired, the same ranging technique is used creating a second sphere (Figure 7-12). The intersection of the two spheres is a circle. The receiver is located somewhere along the edge of that circle.

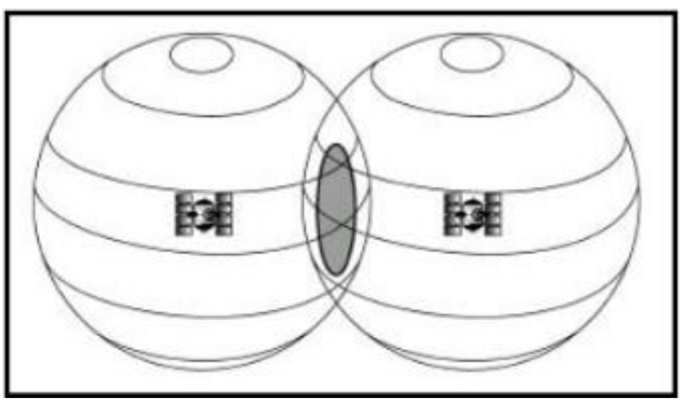


Figure 7-12. Ranging Two Satellites

(4) The third sphere determined by ranging a third satellite would intersect the circle created above at two points. The receiver knows that its position is referenced to the WGS 84 ellipsoid/datum. Only one of the two points of intersection will be located on this geodetic system. The other point will be out in space, deep inside of the ellipsoid or moving at an extreme velocity. With three satellites, a receiver can provide a 2-D position. To achieve a 3-D position, at least four satellites must be ranged. The fourth satellite provides the timing data for the receiver to resolve timing errors in the system (Figure 7-13 page 7-21).

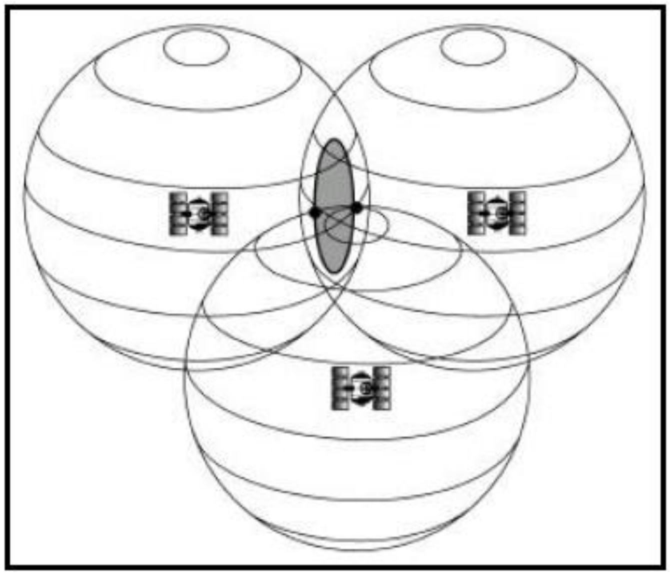


Figure 7-13. Ranging Three Satellites

7-22. Carrier Phase Measurements

a. The primary purpose of carrier phase measurements is to determine ranges from satellites to receivers that will allow the receiver to position it. Usually these positions are processed relative to another receiver position and are referred to as differential positions. Ranges to the satellites are pseudo-ranges, as in code phase. However, this method of ranging requires the solution of the integer ambiguity of the signal. The determination of this distance requires that the number of whole carrier wavelengths be known.

b. The whole number of wavelengths between the satellite and the receiver is known as integer ambiguity or cycle ambiguity. Knowing the L1 carrier wavelength is 19 centimeters long and L2 is 24 centimeters long, and since most carrier phase receivers can determine the partial wavelength to an accuracy around 2 millimeter; the pseudo-range can be accurately measured as long as we can determine the number of complete wavelengths between the satellite and receiver. This is done by comparing changes in the received frequency, caused by the Doppler Effect, to the broadcast frequency over time.

c. Carrier phase GPS receivers contain an internal oscillator that generates a carrier signal. This generated carrier signal is compared to the received signal from the satellite. The carrier phase observations, also called carrier beat phase, are determined from these measurements.

d. When the receiver first locks on to a satellite signal, it can only measure the fractional part of the wavelength. It has no knowledge of the number of full wavelengths at that specific point in time between it and the satellite. After that first measurement, the receiver will count the number of whole wavelengths it observes. This is the continuous carrier phase. If the satellite signal is interrupted the continuous carrier phase is reset and set to the next fractional wave measurement, carrier phase observable immediately following the break.

e. A cycle slip is the interruption or break in the continuous carrier wave. The wave fronts that are counted by the receiver during continuous phase tracking are called cycles. When the signal is interrupted, the continuous count of those wave fronts or cycles is broken, or the count slips. This cycle slip causes the continuous carrier phase to be reset. The baseline processor in most GPS-S systems can reestablish this count whether in a static or a kinematic mode.

f. Cycle slips can be caused by any number of barriers between the satellite and the receiver. These barriers can include terrain masks, trees, or even an operator standing between the satellite and the antenna. Cycle slips could cause burst jamming signals. Usually reconnaissance, line of sight (LOS) clearing, and planning can eliminate many sources of cycle slips.

7-23. Differencing

a. Differencing is a method used by the processors to solve for the first estimation of a baseline solution and remove measurement errors.

b. A single difference can be formed by differencing the measurements acquired by two receivers observing the same satellite at a particular point in time or epoch. Therefore, integer ambiguities associated with each receiver are combined. Single differences between receivers virtually remove all satellite- dependent errors such as satellite clock error, and to a large extent, orbit errors, and atmospheric delays (Figure 7-14).

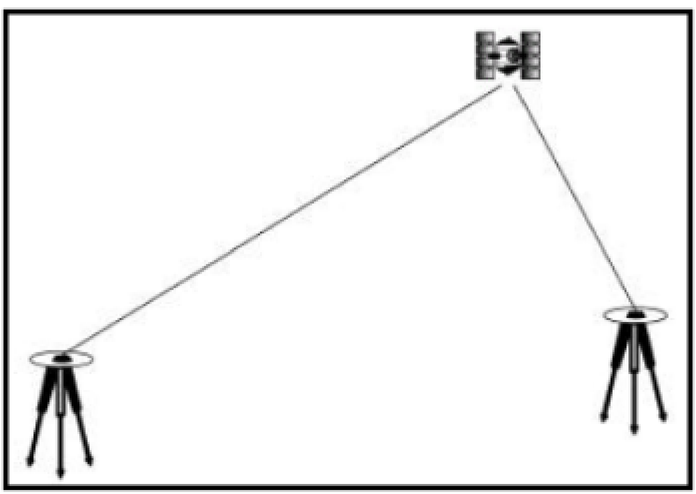


Figure 7-14. Single Differences between Receivers

c. A single difference can be formed by differencing the measurements acquired by one receiver observing two satellites at a particular point in time or epoch. Single differences between satellites (Figure 7-15 page 7-23) reduce most receiver dependent errors.

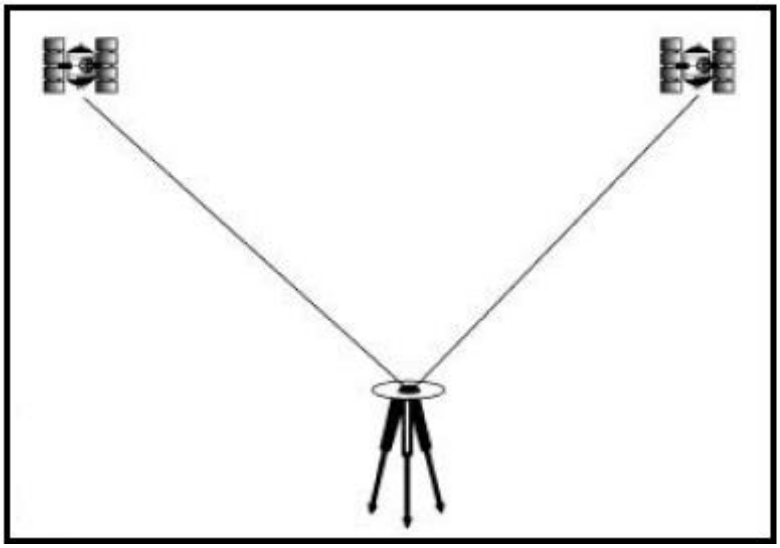


Figure 7-15. Single Differences between Satellites

d. A double difference (Figure 7-16) is formed by differencing two single differences. This involves two receivers observing the same two satellites at the same epoch. Four separate measurements and four separate integer ambiguities are combined to create a difference. The double differencing mode removes most of the effects of satellite and receiver clock drift.

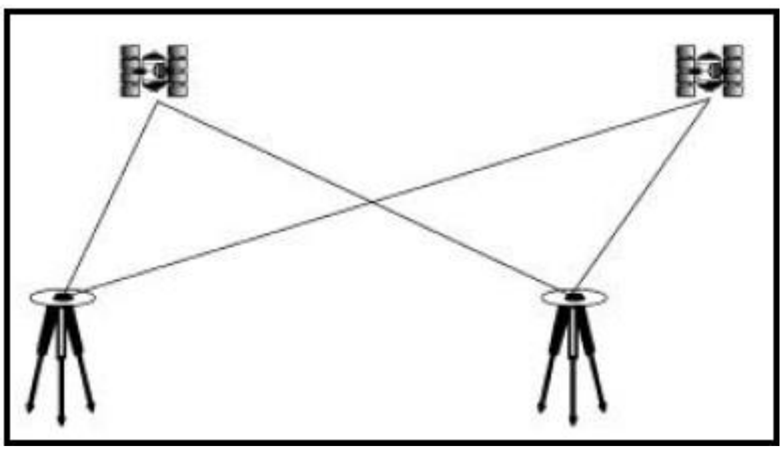


Figure 7-16. Double Differencing

e. A triple difference is determined by combining two double differences over time. The double difference determined by a set of satellites and receivers at a particular epoch is combined with the double difference form the same satellites and receivers at a different epoch. In this mode, integer ambiguities cancel out of the computations because it does not change over time.

f. Triple differences (Figure 7-17 page 7-24) are often used to find cycle slips. A cycle slip, in the single differencing mode, causes the receiver to re-compute the combined integer; therefore after a cycle slip, the integer ambiguity does change. A large change in the triple difference is a good indicator of a cycle slip at that epoch.

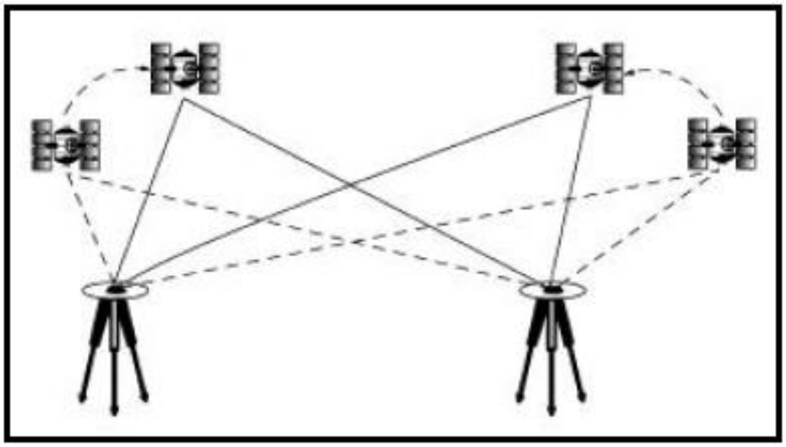


Figure 7-17. Triple Differencing

7-24. Baseline Solutions (Vectors)

a. A baseline solution (vector) is a straight line defined by its 3-D (ΔX, ΔY, ΔZ) values when one end of the vector is the origin and the other end is the point containing those relative values. The processor uses the differencing methods described above along with code solutions to determine an initial estimate of the baseline vector. This initial estimate is called the triple difference solution.

b. If the integer ambiguity is known, multiply that value by the wavelength (19 centimeters - L1, 24 centimeters - L2) and add the partial wavelength to obtain the pseudo-range. At this point in the processing, the integer ambiguity is still an unknown value.

c. Once an initial estimate of the baseline vector has been determined, place that value in the formula:

$$\Delta X, \Delta Y, \Delta Z = (N \times \lambda) + \Delta\phi$$

Whereas:
ΔX, ΔY, ΔZ is the baseline vector,
N is the integer ambiguity,
λ is the integer wavelength,
$\Delta\phi$ is the phase change observed in a small portion of the data.

(1) Often in processing, the value for N as determined in the above formula is not an integer. The ambiguity computes to a value such as 500.52. This value is not close enough to an integer for the processor to determine if the ambiguity is 500 or 501. The processor cannot set the value to an integer.

(2) The value determined is compared against the remaining observations to see how well the value fits. If the residuals are within a certain tolerance, the processor generates a new baseline vector; i.e., the float solution.

d. A fixed solution is obtained when the processor determines a set of integer values for the ambiguity that is significantly better than the other values.

(1) The processor rounds the ambiguity value determined above to whole numbers for each satellite, each time testing different combinations of whole wavelength values to compute a baseline.

(2) Each time a new set of integers is used, an associated variance, square of the standard deviation, is generated. After all possible combinations of whole wavelengths have been tried, the processor selects the solution with the lowest variance, least error. This is the fixed solution or fixed-integer solution.

(3) The ratio of the errors between the integers used for the last computation of integer values can be determined as:

$$\text{Ratio} = \frac{\text{(integers giving next least) Errors}}{\text{(integers giving least) Errors}}$$

(4) With a dual-frequency receiver, it is possible to combine carrier phase observables to create other fixed solutions. A wide lane carrier phase is generated when the processor differences the carrier phase observables (L1-L2). The effective wavelength is 86.2 centimeters. This combination allows for easier resolution of the integer ambiguities so it is often used to solve long baselines. The narrow lane carrier phase is generated when the processor combines the carrier phase observables (L1 + L2). The effective wavelength of the narrow lane carrier phase is 10.7 centimeters. This combination is very effective for canceling out ionospheric errors. This baseline solution uses a combination of the L1 and L2 carrier phases to model and remove the effects of ionospheric interference on the signals. This is the optimal solution, used for high-order control networks and for observing long baselines.

Section V. GLOBAL POSITIONING SYSTEM SURVEY METHODS AND TECHNIQUES

7-25. Absolute Positioning

a. Absolute positioning is a GPS survey method that involves using a single passive receiver; e.g., AN/PSN 13 DAGR, AN/GSN 14 GPS-S .The term absolute does not refer to a specific accuracy. It means this method does not rely on any source of information other than what is collected by the receiver at that station. This position is not on common survey with any other station. The accuracy of this position depends on many different error sources as well as the user's level of authorization.

b. The receiver collects data from multiple satellites and uses this data to determine position, velocity, and timing information. The position is generally determined from code phase measurements. Some receivers can use carrier phase measurements to determine absolute positions.

7-26. Differential (Relative) Positioning

a. Differential positioning requires at least two receivers collect data from at least four common satellites simultaneously to compute a vector between them. The vector is then fixed at one end to a point and the other end is the relative position.

b. Usually, one receiver is located at a known point. Depending on the differential technique used, more than four common satellites may be necessary. Processing the collected data can be performed in the office or by the receiver in the field, also depending on the differential technique used.

c. Much of the accuracy achieved from this method is due to the use of common satellites and common epochs. Figure 5-16 shows that differential techniques negate most sources of error. This is because the same error exists at each station collecting data from a specific satellite at a specific epoch. The errors broadcast by satellite PRN23 and collected by receiver A, at epoch 1, are the same errors collected by receiver B, at epoch 1. The errors broadcast from the satellites have no effect on the dimensions of the vector because the errors are equal at each end.

d. This is actually only true for error sources in the Space and Control segments. User segment error sources are not always equal at each end of the vector. For distances under 30 kilometers, the tropospheric and ionospheric errors are basically the same. Signals from satellite PRN23 to receiver A travel through the same sampling of the atmosphere as the signals from PRN23 to receiver B. Larger distances may add some small errors into these measurements. An L1/L2 antenna will decrease this error.

e. Determining differential positions from code phase measurements is performed by applying a correction to the pseudo-range determined from an individual satellite to the receiver.

(1) This process begins with the pseudo-ranges from code phase measurements used to determine the absolute positions of the receivers. Since the errors collected at each receiver are the same for each epoch, a pseudo-range correction (PRC) can be computed. In other words, assume we know the exact position of a satellite at a specific epoch and the surveyed position of a GPS receiver, we can determine a true range. If the measured pseudo-range is 79 meters and the true range is 81 meters, the PRC is two meters. A PRC can be generated for each satellite being observed. Any receiver that is simultaneously collecting data from at least four common satellites can apply the PRC to its pseudo-range measurements to obtain a relative position; thus the distance between the two points will be relatively accurate (0.5-10 meters) even when the absolute positions are not.

(2) Code phase differential positioning has its primary applications in real-time navigation where relative accuracy is as low as ten meters are acceptable. Also, some engineering survey applications can tolerate this accuracy. This would not be acceptable for geodetic applications, and does not meet artillery specifications.

f. Determining differential positions from carrier measurement is as simple as fixing an end of a measured vector to determine the position of the other end. Through processing, other vectors can then be fixed to the end of the first vector to create a network. Kinematic and static surveys are both usually performed using carrier phase differential positioning.

7-27. Static and Kinematic Techniques

a. When GPS receivers are used for surveying purposes, it is generally accepted that the survey will be performed using carrier phase differential survey methods. Differential survey is usually divided into two techniques: static and kinematic.

b. Static surveys provide the most accurate results. Receivers must remain stationary for a period of time depending on the type of static survey performed. There are two types of static survey: static and fast static. Both require extensive planning and post-processing. Static survey allows for extremely accurate networking of survey control. Due to planning, field work, and post-processing requirements, this technique should only be used by sensor support Marines whose mission is to provide fourth order control.

c. A kinematic survey provide accuracy results sufficient for most artillery survey missions, fourth and fifth order, but does not provide the same networking capabilities as static techniques. There are two types of kinematic surveys: stop-and-go and continuous. Stop-and-go surveys can be post-processed on office computers or in the field by the receivers using RTK procedures. Kinematic survey techniques require that one receiver remains static while another acts as a rover, moving along a route or from station to station collecting data.

CHAPTER 8 CONVENTIONAL SURVEY

Section I. FIELD RECORDER'S NOTES

8-1. General

The mission of the Marine artillery surveyor is to provide a common grid. This ensures all fire support and targeting assets are oriented the same with respect to azimuth, position, and elevation to a prescribed accuracy. A common grid is based on the sum of the components of relative survey (the geodetic system, the coordinate system, and the map projection/ grid system) of the operational area. Chapter ten will cover several areas of conventional survey to include, recording, fundamentals, closing a traverse and how to adjust a traverse. As one of the five requirements for accurate fire, survey is critical to the success of artillery (and maneuver) on the modern battlefield. Marine artillery surveyors support firing units *and* target acquisition assets, enabling indirect fires to mass effectively and deliver surprise observed fires and effective unobserved fires.

8-2. Survey Recorder Duties

a. The recorder's notebook is a legal document to document field notes during the course of field survey work. The recorder maintains the only original record of field measurements and any occurrences that may affect those measurements. The recorder must also be thoroughly trained in the requirements for all survey methods. Data recorded includes but is not limited to measurements, sketches, descriptions, and remarks.

b. Duties include:

- Records survey data neatly and legibly
- Checks and means angular data
- Records and means distances
- Provides required data to the survey computers

c. Horizontal angles, vertical angles, and distances from the instrument operator must be recorded. Sketches must be oriented with a north arrow and should be as close to scale as possible. In a long survey, the sketch may be separated over several pages.

d. Descriptions of stations to supplement the sketch should be written in the remarks section. Include distances from objects used to locate a station, type of marker, etc. Any changes to descriptions in a trig list should also be noted for submission to controlling agencies.

e. The remarks section should include any remarks that clarify survey data. Include descriptions of extreme weather phenomena and explanations of voided angles and pages. Some survey methods have required entries for the remarks section. These required entries are listed in the sections describing that method of survey. Temperature and pressure entries used as corrections for the S7 Total Station, instrument heights, and target heights should be included.

8-3. General Rules

a. Recording field notes is regulated by certain rules that apply to all methods. For the most part, these rules are designed for consistency between different recorders and to aid in the legibility and neatness.

b. Record all information with 0.5 millimeter mechanical pencil. Never erase in the notebook. Use only upper case letters. Do not slant letters and numbers or strike over them. Use approved abbreviations and symbols. Use a straight edge and protractor for the sketch. Record directly into the notebook. Never record into an extract or on paper and then transcribe recorded data to the recorder's notebook. All math must be done using the Artillery expression rules (Refer to MCRP 3-10E.4, *Tactics, Techniques, and Procedures for the Field Artillery Manual Cannon Gunnery*).

c. Abbreviations that can be used are:

AZMK	Azimuth mark
COP	Chief of party
D	Direct
DIST	Distance
FWD	Forward
GN	Grid north
HI	Height of instrument
HORZ	Horizontal
HT	Height of target
IO	Instrument operator
MN	Mean
OCC	Occupied
R	Reverse
RCDR	Recorder
READ	Reading
SCP	Survey control point
STA	Station
VERT	Vertical

d. When drawing a sketch, symbols may be used. The symbols in the legend of a map sheet from the area of operations should be used.

e. The first numbered page of the recorder's book is the index (Figure 8-1 page 8-3). Page 1 includes the left and right sides. Heading and column blocks are set up as follows.

DESIGNATION: INDEX DATE: 31 AUG 2000

PAGE	DATE	TITLE			
1	--------	INDEX			
2	10 SEP 00	TRAVERSE			
3	10 SEP 00	TRAVERSE CONT			
4	5 OCT 00	TRIANGULATION			
5	5 OCT 00	TRIANGULATION CONT			
6	21 OCT 00	ARTY ASTRO			
7	6 NOV 00	3 POINT RESECTION			

PAGE	DATE	TITLE			

Figure 8-1. Index Page

(1) Fill in the designation block with the word "INDEX"

(2) Fill in the date block with the date the book was officially opened, usually the day the first survey in that book was performed

(3) Do not list any information in the heading blocks on the right side

(4) Label the column titles under the heading from left to right as:

(a) 1, PAGE. Identify the page number that includes a particular set of survey data

(b) 2, DATE. List the date written in the date block of that page

(c) 3, TITLE. List the designation written in the designation block of that page

(d) 7, 8, and 9: Same as columns 1, 2, and 3

f. Recording procedures for

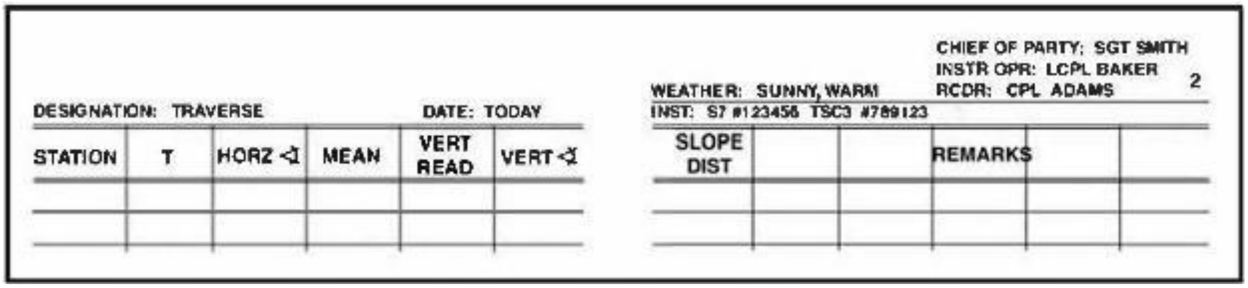
(1) GPS-S survey recorder sheets are located in Appendix A

(2) Astronomic observations are discussed in chapter 11

(3) IPADS-G recording sheets are located in Appendix A. Either the recorder's notebook or recoding sheets are acceptable for recording IPADS-G survey

8-4. Recording a One-Position Angle

a. This type of angle is used for fourth and fifth order traverse and most fifth order conventional methods and IPADS-G auto-reflection (Figure 8-2 page 8-4).



CHIEF OF PARTY: SGT SMITH
INSTR OPR: LCPL BAKER
RCDR: CPL ADAMS 2

DESIGNATION: TRAVERSE DATE: TODAY

WEATHER: SUNNY, WARM
INST: S7 #123456 TSC3 #789123

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	SLOPE DIST			REMARKS		

Figure 8-2. Heading and Column Titles (One-Position Angle)

b. Fill in the designation block with the survey method being conducted; e.g., traverse. Fill in the date block with the date the field work was done.

c. Fill in column titles as:

(1) STATION, Identify occupied, rear, and forward stations

(2) T. (Telescope), identify the telescope position, direct, or reverse (R)

(3) HORZ ∢, Record horizontal readings measured at the occupied station and the mean horizontal angle used for computations

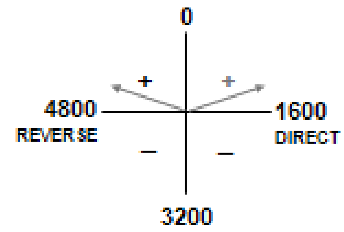
(4) MEAN, Record the mean of the direct and reverse horizontal readings at the forward and rear stations. The MEAN is determined by first making the reverse reading look like the direct reading by applying 3200 mils. Next add the direct reading to the reverse reading. And last divide by 2. The answer is the MEAN of the direct and reverse readings.

Rear Station Reverse Reading	3200.286
Apply 3200.0	- 3200.000
	0000.286
Add Rear Station Direct Reading	+ 0000.172
	0000.458
Divide by 2	÷ 2
Equals the Mean	0000.229

(5) VERT READ, Record vertical readings measured by the instrument operator.

(6) VERT ∢, Record direct and reverse vertical angles calculated by the RCDR from the vertical readings and record the mean vertical angle used for computations. The vertical angle is determined by comparing the vertical reading to the cardinal direction. The sign is determined by its relationship to the horizon. The MEAN is determined by adding the Direct and Reverse vertical angles and dividing by 2.

Use with Direct Vertical Readings	1600.000
Direct Vertical Reading	- 1544.260
Direct Vertical Angle	+ 55.740



Reverse Vertical Reading	4855.752
Use with Reverse Vertical Reading	- 4800.0
Reverse Vertical Angle	+ 55.752
Direct Vertical Angle	+ 55.740
Plus Reverse Vertical Angle	+ 55.752
	111.492
Divide by 2	÷ 2
Occupied Station Mean Vert. ∢	+ 55.746

(7) SLOPE DIST, Record slope distances from the TSC3. The MEAN is determined by adding all three distances and dividing by 3.

(8) REMARKS, Record any information about measurements and subsequent computations. The MEAN horizontal angle is determined by subtracting the MEAN horizontal reading to the rear station from the MEAN horizontal reading to the forward station.

Forward Station Mean	0441.563
Minus Rear Station Mean	- 0000.229
Occupied Station Mean Horiz. ∢	0441.334

d. On the right side of figure 8-4, list weather conditions (left side of the top line). Use two words. The first word describes visibility; e.g., clear, sunny, cloudy; the second describes temperature; e.g., cool, warm, hot.

(1) List instrument types and serial numbers under weather conditions. This helps identify the instruments that may need adjustments due to errors.

(2) List names of the COP, instrument operator, and RCDR on the right side above the top line.

e. STA and T Columns (Figure 10-3) fill out the T (telescope) column as shown.

(1) Record the rear station (AzMk) name in the direct mode row directly below the STA column.

(2) Skip one line and record the occupied station name.

(3) Skip one line and record the forward station name.

DESIGNATION: TRAVERSE DATE: 21 DEC 2000

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢
MCAS WT	D				
	R				
USMC 21	MN ∢				
TS-1	D				
	R				

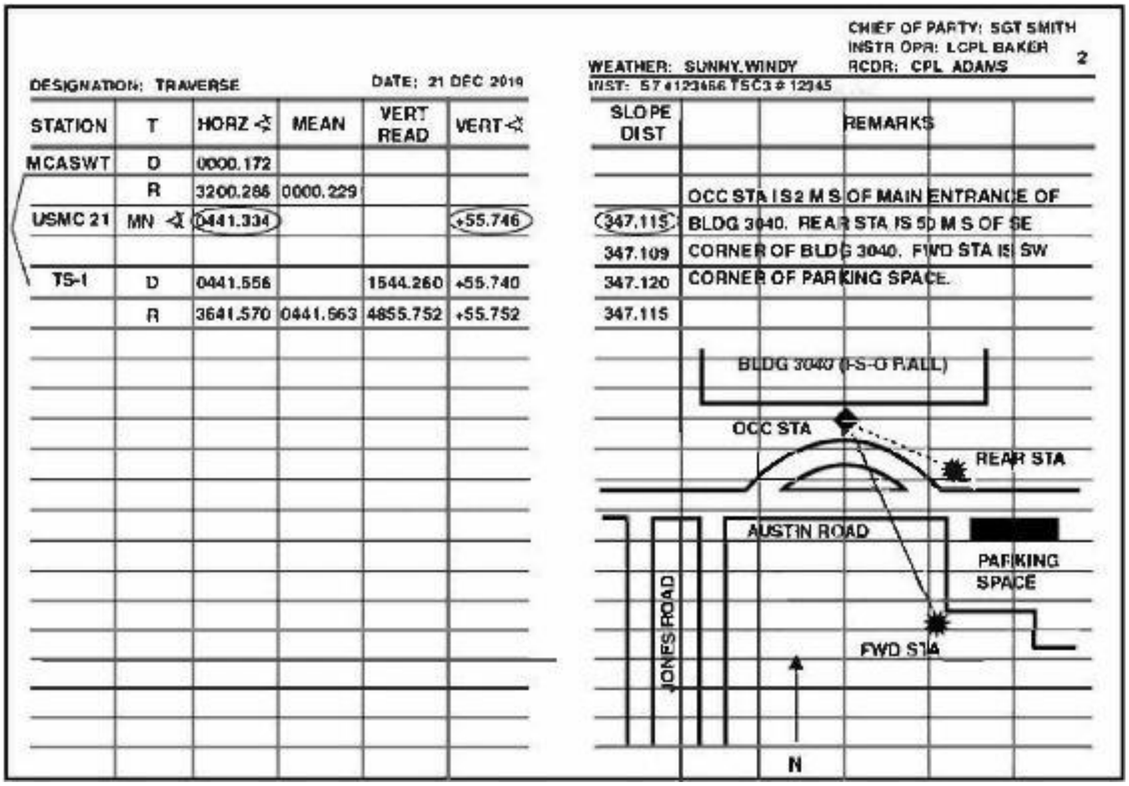
Figure 8-3. Station and T Columns

f. Record field data in the columns and rows that correspond to the pointings. For example, when the instrument operator sets the initial circle, the S7 Total Station is in the direct mode, pointed at the rear station. Determine the measurement from the horizontal circle. Record the initial circle setting in the horizontal angle column in the direct mode row for the rear station. Figure 8-4 shows the standard order for measuring and recording a one-position angle. Figure 8-5 (page 8-7) shows data recorded with means computed. Note that only data used by the computer is circled.

CHIEF OF PARTY: SGT SMITH
INSTR OPR: LCPL BAKER
WEATHER: SUNNY, WINDY RCDR: CPL ADAMS 2
DESIGNATION: TRAVERSE DATE: 21 DEC 2019 INST: S7 #123456

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	SLOPE DIST			REMARKS		
MCAS WT	D	1									
	R	9									
USMC 21	MN ∢										
						4					
TS-1	D	2		3		5					
	R	7		8		6					

Figure 8-4. Standard Order for Recording a One-Position Angle



CHIEF OF PARTY: SGT SMITH
INSTR OPR: LCPL BAKER
RCDR: CPL ADAMS
2

DESIGNATION: TRAVERSE   DATE: 21 DEC 2019
WEATHER: SUNNY, WINDY
INST: 57 #123456 TSC3 # 12345

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	SLOPE DIST	REMARKS
MCASWT	D	0000.172					
	R	3200.286	0000.229				OCC STA IS 2 M S OF MAIN ENTRANCE OF
USMC 21	MN ∢	0441.334			+55.746	347.115	BLDG 3040. REAR STA IS 50 M S OF SE
						347.109	CORNER OF BLDG 3040. FWD STA IS SW
TS-1	D	0441.556		1544.260	+55.740	347.120	CORNER OF PARKING SPACE.
	R	3641.570	0441.563	4855.752	+55.752	347.115	

Figure 8-5. Example of a Completed One-Position Angle

8-5. Recording A Two-Position Angle

a. This angle is required for certain fourth order methods such as triangulation and trig traverse. Use of this method for other survey methods is a matter of local SOP.

b. Heading and column titles. These are the same as for a one-position angle (Figure 8-6 page 8-8).

c. STA and T columns. These are the same as for a one-position angle. The second angle starts two spaces below the first angle.

d. Recording field data. The first of the two measured angles is determined the same as a one-position angle. The second of the two measured angles is the same as it is for a one-position angle except that the initial circle setting for the second angle will be 3200.000 mils (± 0.100 mils).

(1) Vertical angles and distances are determined during the first-position angle.

(2) When a two-position angle is observed, the two measured angles must agree within +0.050 mils. If they differ by more than 0.050 mils, reject and measure both angles again. Determine the mean of the two- position angles by adding the two position angles together; then divide that total by two.

(3) Figure 8-6 shows data recorded with the means computed. The mean horizontal angle of each position angle is recorded in parentheses. The mean of the two position angles is circled.

CHIEF OF PARTY: SGT SMITH
INSTR OPR: LCPL BAKER
RCDR: CPL ADAMS
2

DESIGNATION: TRAVERSE DATE: 21 DEC 2009
WEATHER: SUNNY, WINDY
INST: 57 #123456 TSC3 # 12354

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	SLOPE DIST
MCAS WT	D	0000.172				
	R	3200.266	0000.229			
USMC 21	MN ∢	(0441.334)			+55.746	347.115
						347.109
TS-1	D	0441.556		1544.260	+55.740	347.120
	R	3641.570	0441.563	4855.752	+55.752	347.115
MCAS WT	D	4800.158				
	R	1600.268	4800.213			
USMC 21	MN ∢	(0441.351)				
TS-1	D	5241.555				
	R	2041.572	5241.564			
		1st POS	0441.334			
		2nd POS	0441.351			
		MN POS	0441.342			

REMARKS

OCC STA IS 2 M S OF MAIN ENTRANCE OF BLDG 3040. REAR STA IS 50 M S OF SE CORNER OF BLDG 3040. FWD STA IS SW CORNER OF PARKING SPACE.

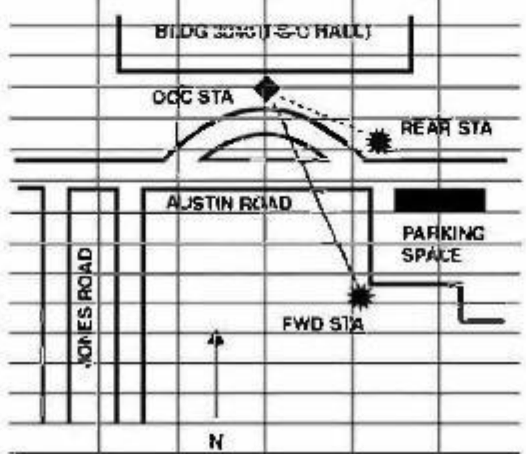


Figure 8-6. Example of a Completed Two-Position Angle

8-6. Closing an Angle on the Horizon

a. Use this angle when a two-position angle is required or as local SOP directs. Closing on the horizon means that the second angle measured closes a horizontal circle at 6400 mils. The first angle is the station angle; the second the explement angle (Figure 8-7 page 8-9)).

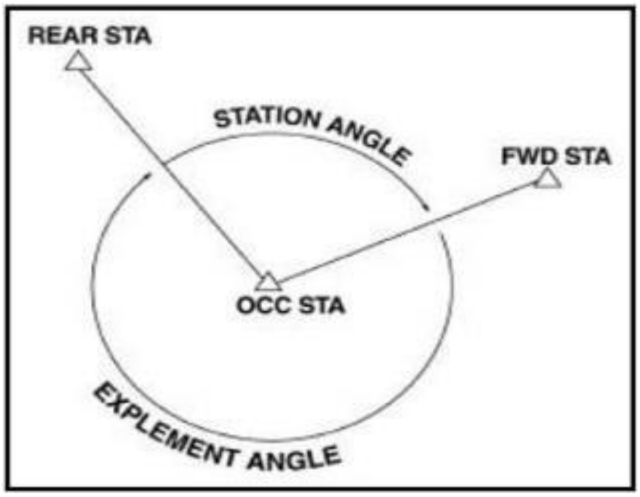
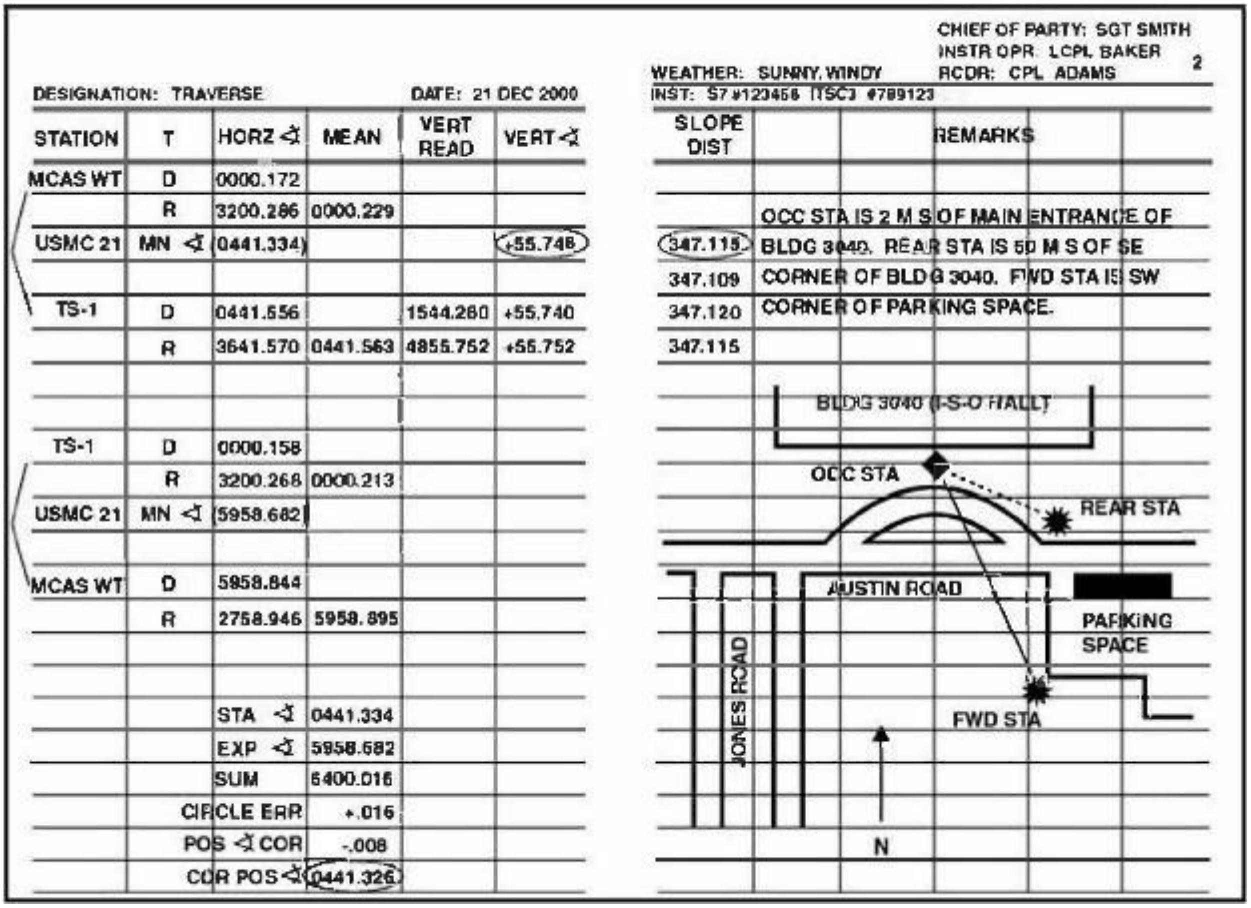


Figure 8-7. Angle Closed on the Horizon

b. Heading and column titles. These are the same as for a one-position angle.

c. STA and T columns. These are the same as for a one-position angle. The explement angle starts two spaces below the position angle.

d. Figure 8-8 (page 9-10) shows an example of data recorded with the means computed. Note that the mean horizontal angle of each measured angle is recorded in parentheses. The corrected station angle is circled. The station angle is determined the same as a one-position angle. The explement angle is the same as for a position angle except the rear and forward stations are reversed to measure the rest of the horizontal circle.



STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	SLOPE DIST	REMARKS
MCAS WT	D	0000.172					
	R	3200.286	0000.229				
USMC 21	MN ∢	0441.334			+55.746	347.115	
						347.109	
TS-1	D	0441.556		1544.260	+55.740	347.120	
	R	3641.570	0441.563	4855.752	+55.752	347.115	
TS-1	D	0000.158					
	R	3200.268	0000.213				
USMC 21	MN ∢	5958.682					
MCAS WT	D	5958.844					
	R	2758.946	5958.895				
		STA ∢	0441.334				
		EXP ∢	5958.682				
		SUM	6400.016				
		CIRCLE ERR	+.016				
		POS ∢ COR	-.008				
		COR POS ∢	0441.326				

Figure 8-8. Example of an Angle Closed on the Horizon

e. Determine vertical angles and distances with the station angle. Determine the mean horizontal angle by applying half of the error (from 6400 mils) to the station angle. When an angle closed on the horizon is observed, the sum of the two measured angles must be within ±0.050 mils of 6400 mils. If the sum differs from 6400 by more than 0.050 mils, both angles must be rejected and re-measured.

8-7. Recording Reciprocal Vertical Angles

When conducting a fourth order traverse or surveying a traverse leg of more than 1,000 meters, measuring reciprocal vertical angles is required. Heading and column titles (columns 1-6) are the same as for a one- position angle. Columns 7-12 are discussed below (Figure 8-9 page 8-11).

a. Column 7, MN RECIP VERT. Record the mean of the reciprocal vertical.

b. Column 8, SLOPE DIST. Record slope distances from the S7 TOTAL STATION. If only horizontal distances are measured, this column will be titled DIST.

c. Columns 9-12, REMARKS. Record any information pertinent to the measurement and subsequent computations.

d. STA and T Columns are labeled the same as for a one- position angle. However, if the top angle on the page includes a vertical angle to the rear station, the first row below the column titles will be skipped.

e. Vertical angles are measured to the rear station the same as they are to the forward station. Vertical readings are measured and recorded when the horizontal readings are made (the vertical reading to the rear station in the direct mode is made directly after the initial circle setting is recorded).

f. Vertical angles determined by the recorder that will be included in the mean of reciprocal vertical angles will be recorded in parentheses. The mean of the reciprocal vertical angles will be circled and recorded in column 7 in the row corresponding to the mean angle at the occupied station.

CHIEF OF PARTY: SGT SMITH
INSTR OPR: LCPL BAKER
RCDR: CPL ADAMS
2

DESIGNATION: TRAVERSE DATE: 21 DEC 2000
WEATHER: SUNNY, WINDY
INST: S7 #123456 TSC3 #789123

STATION	T	HORZ ∢	MEAN	VERT READ	VERT ∢	MN RECIP VERT ∢	SLOPE DIST	REMARKS
					(+5.657)			
USMC 21	D	0000.172		1594.365	+5.635			
	R	3200.286	0000.229	4855.752	+5.679			
TS-1	MN ∢	0441.334			+55.746	+55.724	1347.115	
						(+55.746)	1347.109	
TS-2	D	0441.556		1544.260	+55.740	(-55.699)	1347.120	
	R	3641.570	0441.563	4855.752	+55.752		1347.115	
					(-55.699)			
TS-1	D	0000.158		1655.711	-55.711			
	R	3200.268	0000.213	4744.313	-55.687			
TS-2	MN ∢	4456.351			(-12.058)	-12.072	1329.564	
						(-12.058)	1329.565	
NOAH	D	4456.555		1612.090	-12.090	(+12.087)	1329.564	
	R	1256.572	4456.564	4787.974	-12.026		1329.563	
					(+12.087)			
TS-2	D	0000.135		1587.901	+12.099			
	R	3200.179	0000.157	4812.075	+12.075			
NOAH	MN ∢	3438.118			(-68.257)	-68.276	1587.364	
						(-68.257)	1587.363	
MOSES	D	3438.293		1668.300	-68.300	(+68.295)	1587.364	
	R	0238.257	3438.275	4731.786	-68.214		1587.365	

Figure 8-9. Example of Recording with Reciprocal Vertical Angles

8-8. Recording Angles from an M2A2 Aiming Circle

a. These angles are generally used for hasty survey purposes. Hasty survey is discussed in chapter 10. As with all field notes, the first page of the notebook is the index.

b. Heading and column titles. Fill out as described below (Figure 8-10).

(1) Fill out the designation block with the survey method being conducted; i.e., hasty traverse. Other entries may be included after the method of survey.

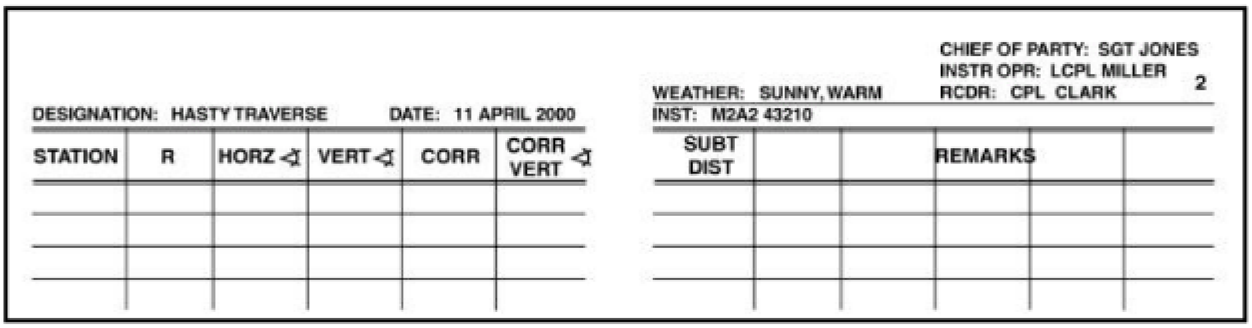
(2) Fill out the date block with the date the field work was performed.

(3) Fill out the heading of the right side of the page as follows:

(4) List weather conditions at the left side of the top line. Use two words; e.g., clear, warm.

(5) List instrument types and serial numbers on the left side of the second line of the header.

(6) List the COP, instrument operator, and RCDR at the right side of the right page, above the top line.



DESIGNATION: HASTY TRAVERSE DATE: 11 APRIL 2000

STATION	R	HORZ ∢	VERT ∢	CORR	CORR VERT ∢

CHIEF OF PARTY: SGT JONES
INSTR OPR: LCPL MILLER
WEATHER: SUNNY, WARM RCDR: CPL CLARK 2
INST: M2A2 43210

SUBT DIST			REMARKS		

Figure 8-10. Heading and Column Titles (M2A2 Angles)

c. Fill in column titles as follows:

(1) 1, STA. Identify the occupied, rear, and forward stations.

(2) 2, R. Identify the reading.

(3) 3, HORZ. Record the horizontal readings and the mean horizontal angle.

(4) 4, VERT. Record the uncorrected vertical angle to the forward station.

(5) 5, CORR. Record the vertical angle correction determined during operator tests.

(6) 6, CORR VERT. Record the corrected vertical angles and the mean corrected vertical angle.

(7) 7, SUBT DIST. Record the subtended distance as extracted from the subtense tables in MCRP 3-10E.3, *Tactics, Techniques, and Procedures for Field Artillery Manual*

Cannon Gunnery, and the Executive Officer's handbook. This column may also be labeled for the subtended angle or horizontal distance if taped or paced.

(8) 8-12: REMARKS. Record any information pertinent to the measurements and subsequent computations.

d. STA and R columns. Fill out these columns as shown in figure 8-11. Record the rear station name directly below the STA column title. Record the occupied station name directly below the rear station. Record the forward station name directly below the occupied station. Record a "1" in the row directly below the "R", a "2" below the "1", and "MN" directly below the "2".

CHIEF OF PARTY: SGT JONES
INSTR OPR: LCPL MILLER
RCDR: CPL CLARK
2

DESIGNATION: HASTY TRAVERSE DATE: 11 APRIL 2000
WEATHER: SUNNY, WARM
INST: M2A2 43210

STATION	R	HORZ ∢	VERT ∢	CORR	CORR VERT	SUBT DIST	REMARKS
EOL1	1	1469.5	-25.5	+0.6	-24.9		
OS1	2	2939.5	-25.0	+0.6	-24.4		SUBTENDED DISTANCES DETERMINED
TS1	MN	1469.8			-24.6	154	FROM FM6-50 USING M-16A2.
OS1	1	3864.0	+3.0	+0.6	+3.6		
TS1	2	1328.5	+3.0	+0.6	+3.6		
OS2	MN	3864.2			+3.6	102	

Figure 8-11. Example of Recording Data for a Hasty Traverse

e. Recording field data. Record the horizontal, vertical, and subtended angles to the nearest 0.5 mils.

(1) Record a subtended distance directly from MCRP 3-10E.3 or the Executive Officer's handbook.

(2) Record the mean horizontal angle to the nearest 0.1 mil.

(3) If the second reading is greater than the first reading, compute the mean horizontal angle by dividing the second reading by 2. The mean horizontal angle is circled.

(4) If the second reading is less than the first reading, compute the mean horizontal angle by adding 6400 mils to the second reading, then divide by 2. The mean horizontal angle is circled.

(5) The mean horizontal angle must match the first reading within +0.5 mils. If not, void the angle and re-measure.

8-9. Recording Intersection Method

a. The intersection method is the preferred way to determine target location when the target cannot be occupied. Follow the procedures below when computation of the target location is performed with azimuths measured to the target vice horizontal angles.

b. Fill out the heading and column titles as described below (Figure 8-12).

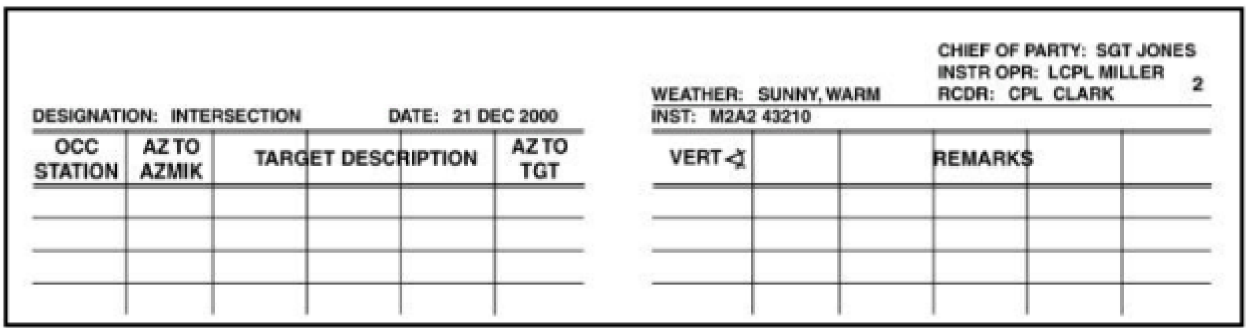
(1) Fill out the designation block with the survey method.

(2) Fill out the date block with the date the field work was performed. Fill out the heading of the right side of the page.

(3) List weather conditions at the left side of the top line. Use two words. The first word describes visibility; e.g., clear, sunny or cloudy. The second is a description of temperature.

(4) List the instrument types and serial numbers on the left side of the second line of the header.

(5) List the COP, instrument operator, and RCDR at the right side of the right page, above the top line.


DESIGNATION: INTERSECTION DATE: 21 DEC 2000

OCC STATION	AZ TO AZMK	TARGET DESCRIPTION			AZ TO TGT

CHIEF OF PARTY: SGT JONES
INSTR OPR: LCPL MILLER
RCDR: CPL CLARK
2
WEATHER: SUNNY, WARM
INST: M2A2 43210

VERT ∢			REMARKS		

Figure 8-12. Heading and Column Titles (Intersection)

c. Fill in column titles as follows: (Figure 8-13 page 8-15).

(1) 1, OCC STA. Identify the occupied stations.

(2) 2, AZ TO AZMK. Record the computed azimuth to the rear station. This is the azimuth set on the horizontal scale of the aiming circle.

(3) 3-5, TARGET DESCRIPTION. Identify the target and fwd station.

(4) 6, AZ TO TGT. Record the measured azimuth to the target.

(5) 7, VERT. Record the vertical angle to the target.

(6) 8-12, REMARKS. Record any information pertinent to the measurements and subsequent computations

DESIGNATION: INTERSECTION DATE: 21 DEC 2000

WEATHER: SUNNY, WARM
INST: M2A2 43210

CHIEF OF PARTY: SGT JONES
INSTR OPR: LCPL MILLER
RCDR: CPL CLARK
2

OCC STATION	AZ TO AZMIK	TARGET DESCRIPTION	AZ TO TGT	VERT ◁	REMARKS
OP 15	1825.5	TANK W/ TURRET FACING SO	4676.0	-12.5	
		APC ON E-W RIDGE FACING NO	4785.5	-5.0	
		POL SITE	4521.0	+3.0	
		RUNWAY W/ ATTITUDE 2800 MILS	3987.0	-9.5	CENTER OF RUNWAY

Figure 8-13. Example of Completed Intersection Method (M2A2)

d. Record the azimuth to the azimuth mark to the nearest 0.5 mils. Record the azimuths and vertical angles to the targets to the nearest 0.5 mils. The target description should be adequate for another observer to identify that particular target.

8-10. Recording Artillery Astronomic Method (Fifth Order)

Paragraphs 8-10 and 8-11 will outline proper recording of field data associated with astronomic observations.

a. Heading and column titles (Figure 8-14). Fill in the designation block with ARTILLERY ASTRO (Sun) or (Star).

DESIGNATION: ARTILLERY ASTRO (SUN) DATE: 4 DEC 2000

WEATHER: CLEAR, WARM
INST: T-2E #123456

CHIEF OF PARTY: LCPL SMITH
INSTR OPR: LCPL BAKER
RCDR: LCPL ADAMS
2

STATION	T	TIME h	TIME m	TIME s	HORZ ◁	REMARKS

Figure 8-14. Heading and Column Titles (Fifth Order Artillery Astro)

b. Fill in the date block with the date the field work was performed. This will be the date used in the computations.

c. Fill out the heading of the right side of the page the same as with traverse. Include the weather description, instrument number, COP name, instrument operator name, and RCDR name.

d. Label column titles under the heading (from left to right) as follows:

(1) STA. Identify the occupied, rear, and forward stations. The forward station star name will be listed.

(2) T. Identify the telescope position (direct or reverse ({R}).

(3) TIME (h m s). This column designates the exact time the instrument operator announced target in position (TIP) during the observations. “TIME” is split between the columns in the top half of the blocks. Hours (h) are listed in the lower left corner of column 3, minutes (m) centered between the columns, and seconds (s) in the lower right corner of column 4.

(4) HORZ. Record horizontal readings to the azimuth mark and to the celestial body.

(5) REMARKS. Use this side of the page to record information pertinent to these observations. Include required entries and some optional information that may be needed by the computer or for future reference (Figure 8-15 page 8-17).

(6) Required entries are:

(a) Easting and northing of the occupied station.

(b) UTM grid zone.

(c) Horizontal datum/ellipsoid.

(d) Source of the position information.

(e) Center, leading or trailing edge if using the Sun.

(f) Time zone letter. If using local time, indicate daylight saving or standard times.

(g) Sketch (as close to scale as possible).

(7) Optional entries are:

(a) Location of occupied and rear stations.

(b) Route to these locations from a known point.

(c) Changes to data in trig list on the stations.

(d) Weather phenomena not covered in header information.

(e) RCDR, instrument operator, COP initial blocks.

(f) Approximate azimuth to AzMk.

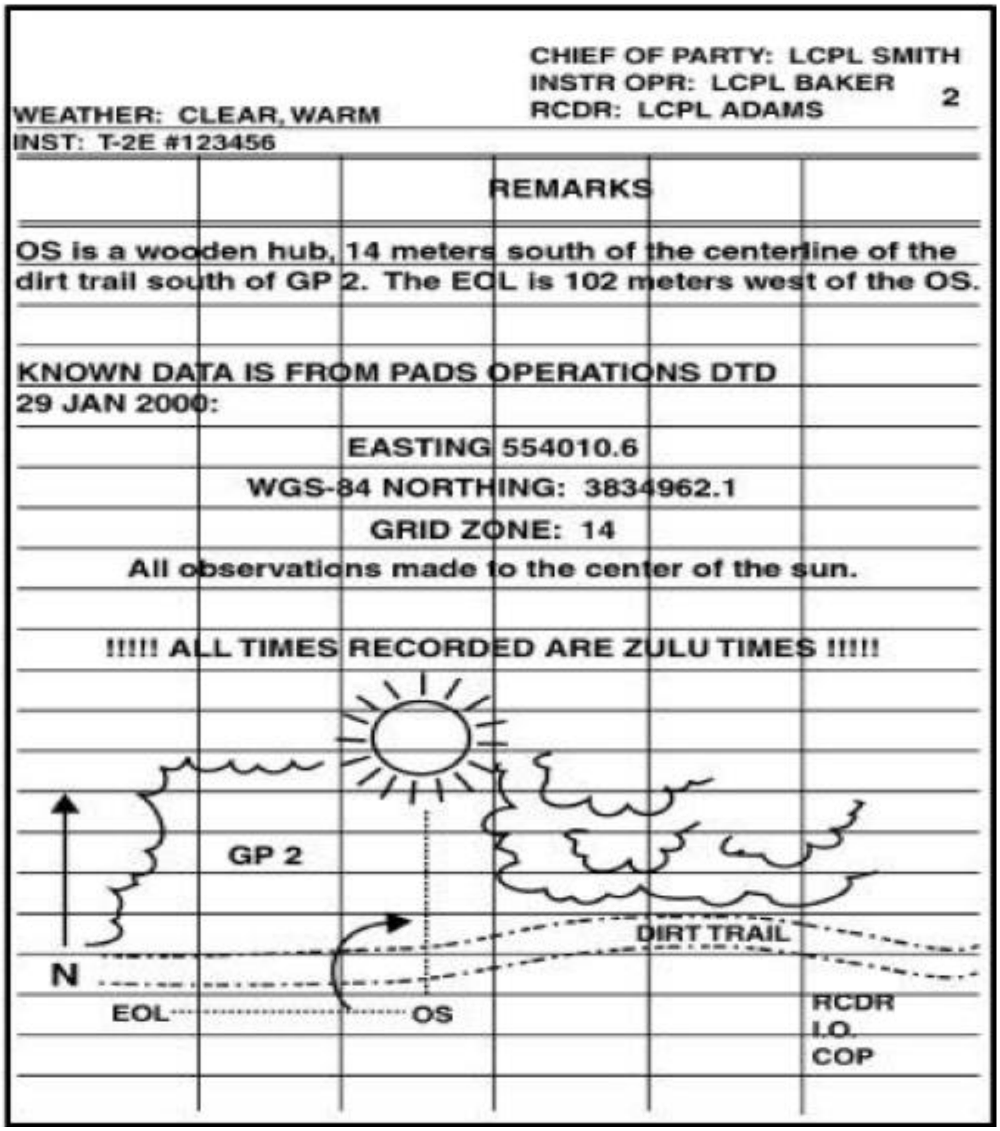


Figure 8-15. Remarks for Artillery Astronomic Observation

e. Record field data in the columns and rows corresponding to the pointing. Record the initial circle setting in the horizontal angle column in the rear station/direct reading row (Figure 8-16 page 8-18).

DESIGNATION: ARTILLERY ASTRO DATE: 4 DEC

STATION	T	TIME h	m	s	HORZ ∢	
OCS WT	D				0000.191	
	R				3200.124	
ABLE 2						4282.014
SUN	D	20	50	48	5970.202	
	D	20	51	49	5974.008	
	D	20	52	39	5977.221	

Figure 8-16. Field Data (Fifth Order Artillery Astronomic Observation)

(1) Fill out the "T" (telescope) column as shown in Figure 8-16. The rear station (AzMk) name will be recorded in the direct mode row directly below the STA column title. Skip one line to record the occupied station name. Skip one line to record the forward station (celestial body) name to the left of the first direct pointing on the body. If the celestial body is a star, record its name.

(2) Record time (seconds, minutes, and then hours {24-hour format}).

(3) To record angles, record the entire number then read the value back to the instrument operator.

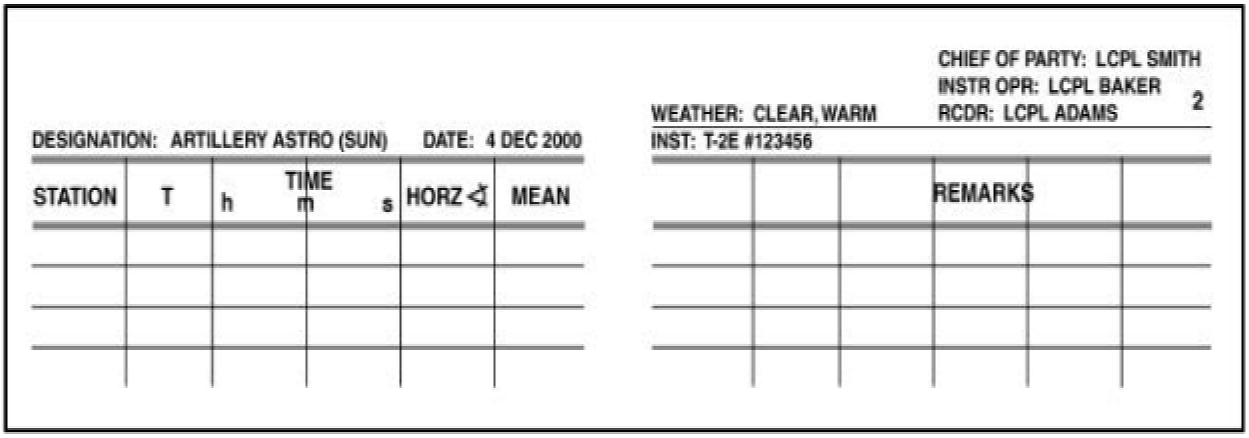
(4) Record the closing angle and verify that the horizontal collimation error is within specifications (±0.150 mils).

(5) If the azimuth is being computed in the field using the computer's internal clock, the solution is part of the field work. It must be included in the field notes. Record the solution in column 6 in the row listing the occupied station and circle it.

8-11. Recording Artillery Astronomic Method (Fourth Order)

a. Two sets of observations are made: one with the telescope in the direct position, the second in the reverse. This method minimizes the effects of small pointing errors on the observed stations.

b. Titles will remain the same as fifth order recording except for the addition of column 6, MEAN (Figure 8-17 page 8-19).


CHIEF OF PARTY: LCPL SMITH
INSTR OPR: LCPL BAKER
RCDR: LCPL ADAMS
2
WEATHER: CLEAR, WARM
INST: T-2E #123456
DESIGNATION: ARTILLERY ASTRO (SUN) DATE: 4 DEC 2000

STATION	T	TIME h	m	s	HORZ ∢	MEAN

REMARKS

Figure 8-17. Heading and Column Titles (Fourth Order Artillery Astronomic Observation)

c. Fill in the designation block with ARTILLERY ASTRO (Sun) or (Star).

d. Fill in the date block with the date the field work was performed. This will be the date used in the computations.

e. Fill out the heading of the right side of the page the same as with traverse. Include the weather description, instrument serial number, COP name, instrument operator name, and RCDR name.

f. Label column titles under the heading from left to right as follows:

(1) STA. Identify the occupied, rear, and forward stations. If the forward station is a star, list its name.

(2) T. Identify the telescope position, direct (D) or reverse (R).

(3) TIME (h m s). This column designates the exact time the instrument operator announced TIP during the observations. “TIME” is split between the columns in the top half of the blocks. Hours (h) are listed in the lower left corner of column 3, minutes (m) centered between the columns, and seconds (s) in the lower right corner of column 4.

(4) HORZ. Record horizontal readings to the azimuth mark and to the celestial body.

(5) MEAN. Record the solutions for the direct and reverse sets and the mean solution of the sets.

(6) REMARKS. Use this side of the page to record information pertinent to the observations. Include required entries and some optional information that may be needed by the computer or for future reference as with fifth order observations.

g. Record the first set as the procedures listed for fifth order except that the solution is not circled (Figure 8-18 page 8-20).

DESIGNATION: ARTILLERY ASTRO (SUN) DATE: 4 DEC 2000

STATION	T	TIME h	TIME m	TIME s	HORZ ∢	MEAN
OCS WT	D				0000.191	
	R				3200.124	
ABLE 2						
SUN	D	20	50	48	5970.202	
	D	20	51	49	5974.008	
	D	20	52	39	5977.221	
OCS WT	R				3200.124	
	D					
ABLE 2						
SUN	R					
	R					
	R					

Figure 8-18. Field Data (Fourth Order Artillery Astronomic First Set)

(1) Fill out the “T” (telescope) column (Figure 8-19). Allow three spaces between the last direct reading in the first set and the initial circle setting (“R” reverse reading) in the second set.

DESIGNATION: ARTILLERY ASTRO (SUN) DATE: 4 DEC 2000

STATION	T	TIME h	TIME m	TIME s	HORZ ∢	MEAN
OCS WT	D				0000.191	
	R				3200.124	
ABLE 2						(4282.014)
SUN	D	20	50	48	5970.202	
	D	20	51	49	5974.008	
	D	20	52	39	5977.221	
						4282.002
OCS WT	R				3200.124	
	D				0000.196	
ABLE 2						(4281.990)
SUN	R	20	55	32	2787.911	
	R	20	56	16	2970.707	
	R	20	57	01	2793.403	

Figure 8-19. Field Data (Fourth Order Artillery Astronomic Second Set)

(2) When recording the second set, record the rear station (AzMk) name in the reverse (R) mode row. Skip one line to record the occupied station name. Skip one line to record the forward station (celestial body) name to the left of the first reverse pointing on the body. If the celestial body is a star, record its name.

(3) When the field work is completed for the first set, the instrument operator has a pointing on the rear station in the reverse position. This is the closing angle for the first set. The recorder will enter that closing angle as the initial circle setting for the second set. The instrument operator needs only to observe the celestial body in the reverse position and close the angle in the direct mode to complete the second set.

(4) Record seconds, minutes, and then hours (24-hour format).

(5) When recording angles, record the entire number then read the value back to the instrument operator.

(6) Record the closing angle and verify that the horizontal collimation error is within specifications (±0.150 mils).

If the azimuth is being computed in the field using the computer's internal clock, the solution is part of the field work. Include it in the field notes. Record the solution in column 6 (MEAN) in the row listing the occupied station and place in parentheses. The azimuth determined from the direct readings must equal the azimuth from the reverse readings, ±0.150 mils. After the second set is computed, the solutions for the two sets are meaned. The mean azimuth is recorded in column 6 (MEAN) in the center row of the three spaces between the two sets.

8-12. Correcting Errors and Voiding

a. The recorder must make entries small enough that if an error is made in the data, there is enough room left in the block to write the correct data. When a value is recorded incorrectly, the value is lined out with a single straight line and the correct value written above. Do not erase errors in the notebook.

b. A partial void voids an area of a recorder's page. This is usually done over a single angle. Include the reason for the partial void in the remarks section. A partial void is performed by sketching an "X" over the area to be voided, using a straight edge, and writing "VOID" over the "X" (Figure 8-20 page 8-22).

c. A full-page void voids every entry made on a recorder's page. This is usually done when voiding two-position angles, angles closed on the horizon, and astronomic observations. These methods all require the use of the entire page. Include the reason for the void in the remarks section. A full-page void is performed by sketching an "X" over each page, using a straight edge, and writing "VOID" over the "X" on each page (Figure 8-21 page 8-22).

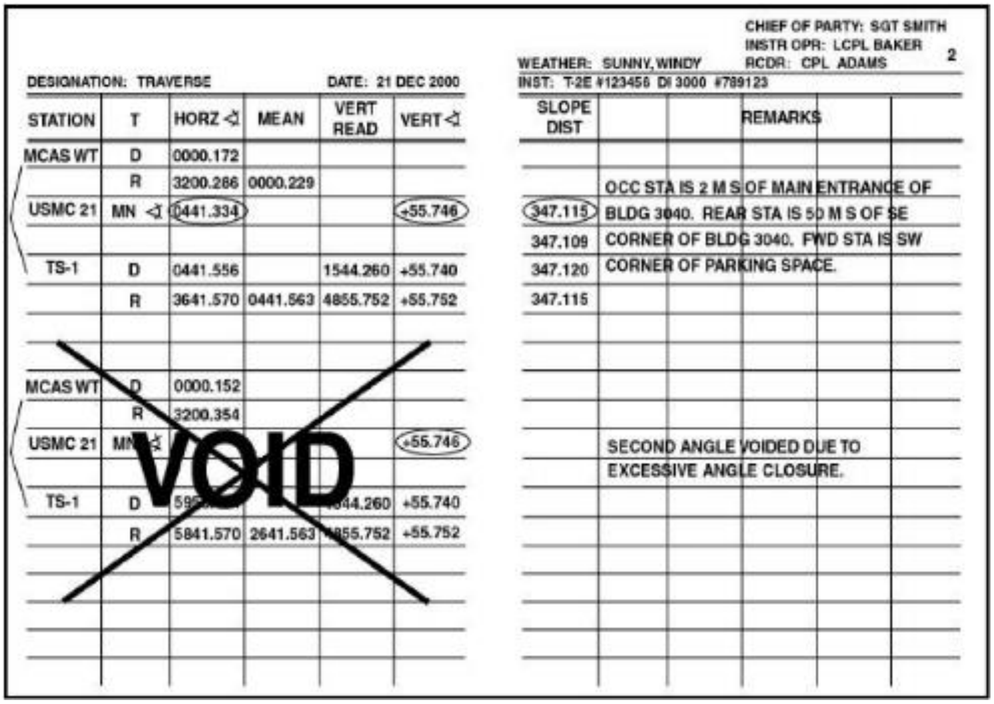


Figure 8-20. Example of a Partial Void

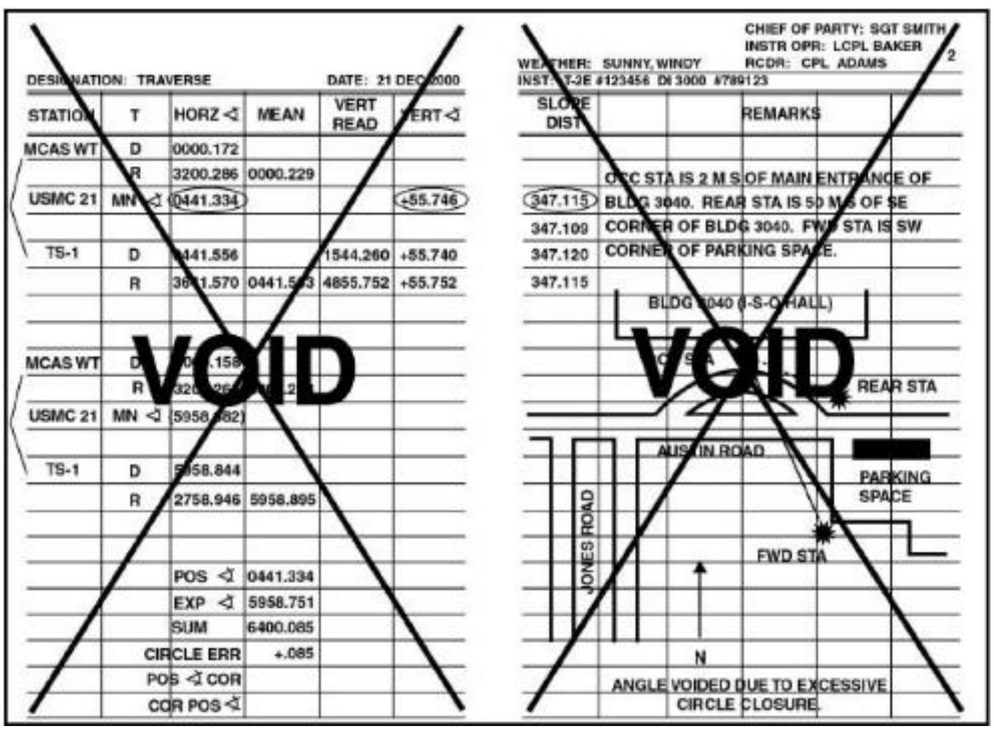


Figure 8-21. Example of a Full-Page Void

8-13. Security

a. The notebook could provide the enemy with a large amount of valuable information should it fall into their hands (firing positions, radar sites, MET sites, OPs, etc.). It could also provide names of personnel, equipment types, locations of SCPs, and other information that can be used for intelligence purposes.

b. In a contingency situation, the notebook must be safeguarded from the enemy. Some information could be classified; e.g., OS or SCP coordinates. Therefore, the book becomes classified. When the threat of capture becomes imminent, a decision must be made as to the disposition of the notebook. If the capture cannot be avoided, destroy the notebook.

8-14. Storing the Recorder's Notebook

a. Use the notebook until filled. Then properly store it to eliminate damage. The storage area must be dry and safe from accidental damage such as spills. Maintain the notebook for at least the minimum times as discussed below.

b. Notebooks with information used in establishing permanent control must be maintained for at least as long as those control points are intact or until they are resurveyed.

c. Notebooks with information used in establishing nonpermanent control must be maintained for at least the same amount of time as position safety, per local SOP.

d. Notebooks may be maintained for archive purposes. If a unit establishes survey control in an area that is not used very often or not used before, the notebook could include information for planning future operations in that area.

Section II. CONVENTIONAL SURVEY METHODS

8-15. Survey Methods

Conventional methods of survey may be used to extend or establish survey control if the IPADS-G is not available. Conventional methods can also be used to supplement IPADS-G operations, such as providing update points for the IPADS-G reducing the need for the IPADS-G to backtrack to update the survey. The conventional survey team gives the target acquisition officer flexibility while developing the sensor plan. This allows the plan to be tailored to fit the factors of METT-T and allows for sustained survey operations by rotation of sensor support personnel. Conventional survey methods are traverse and intersection.

8-16. Traverse

a. Traverse is a conventional survey method that determines the position and elevation of the stations occupied by a sensor support team as well as the azimuth between those stations. Traverse can be used for all accuracy levels of artillery survey (fourth, fifth, and hasty). But in the chaotic and rapidly changing environment of the battlefield it may be too time consuming to perform at battalion and battery levels where accurate direction is the most critical data needed to begin firing. Establishing fourth order horizontal control by traverse operations will usually be conducted by the TAP sensor section. Hasty survey is discussed in chapter 10.

b. Traverse has several advantages over other conventional survey methods. It is well-suited for any terrain. Whether surveying in a forested area with 100-meter legs or a desert region with 12-kilometer legs, traverse is the preferred method.

c. Traverse allows a great deal of flexibility. If necessary, a survey plan can be modified while traversing. Often, a traverse can be laid out ahead of the instrument operator during the survey.

d. Traverse requires less planning and reconnaissance than other conventional survey methods. A traverse works similar to determining a polar plot grid from a map sheet. But instead of plotting the azimuth and distance, coordinates are plotted with plane trigonometry (Figure 8-22).

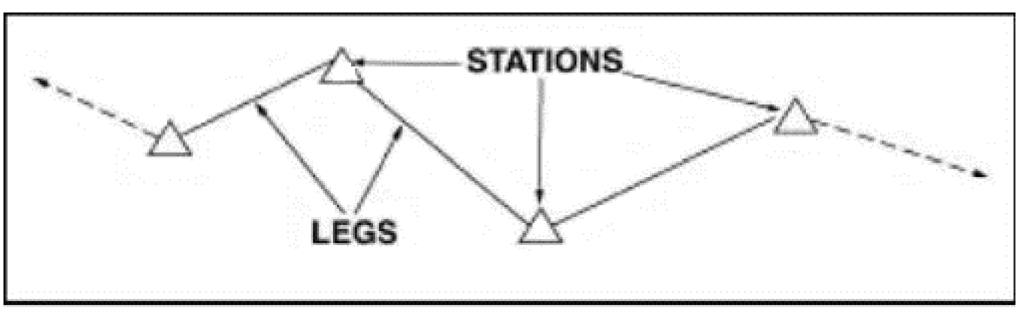


Figure 8-22. Traverse

8-17. Intersection

Intersection (Figure 8-23) is a method of survey used to locate an unknown point by determining azimuths from two or more known points. This method of survey is used as a means of establishing control to desired positions and of checking the locations of points established by other survey methods. A point established by the intersection method should be observed from at least two known stations of equal or higher order of survey than the survey being conducted. One of the points is designated as 01. The height of 01 must also be known. The location and height of the unknown are computed from 01.

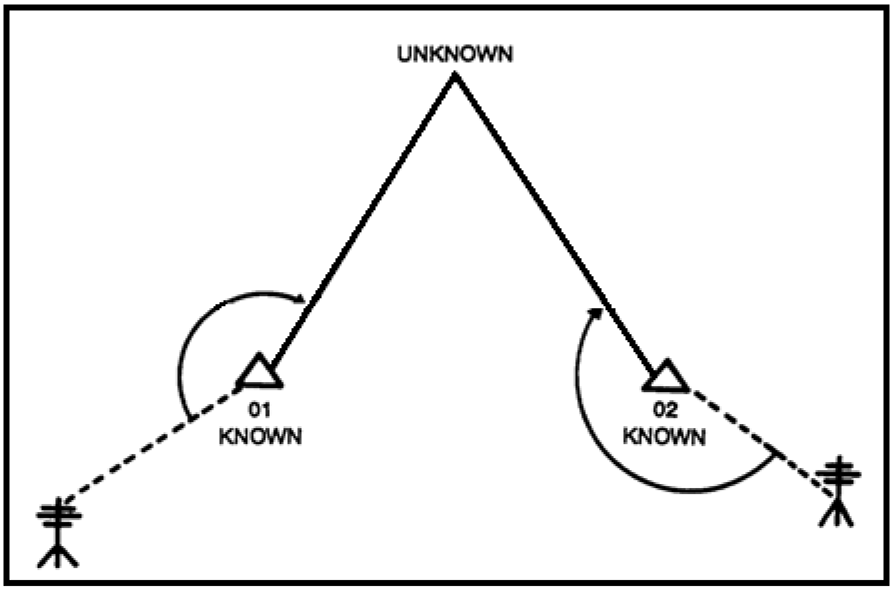


Figure 8-23. Intersection

Section III. TRAVERSE FUNDAMENTALS

8-18. Open Traverse

This traverse begins at a point of known control and ends at a station whose relative position is known only by computations. It is the least desirable type of traverse because it does not check the accuracy of the control, field work or computations. Use open traverse only when time or the enemy situation does not permit closure on a known point (Figure 8-24).

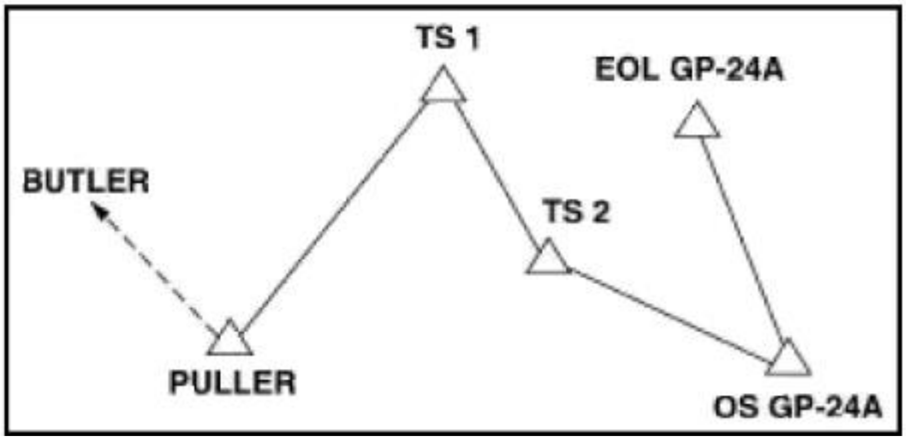


Figure 8-24. Open Traverse

8-19. Closed Traverse

a. This traverse starts and ends at stations of known control. Because it provides a basis for comparison of computed data against known data, a closing accuracy can be determined.

b. Closed traverse on a second known point begins from a point of known control, moves through the various required unknown points, and then ends (closes) at a second point of known control, fourth order or higher. This preferred type of traverse checks on field work, computations, and control (Figure 8-25).

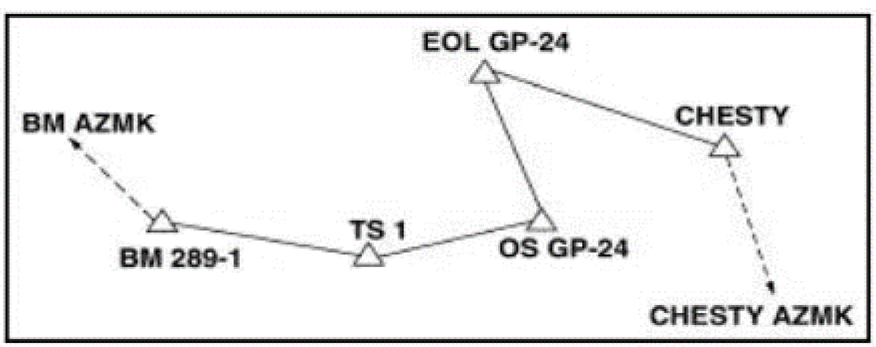


Figure 8-25. Closed Traverse on a Second Known Point

c. Closed traverse on the starting point begins at a point of known control, moves through the various required unknown points, and ends (closes) at the same starting point. This type of traverse is more desirable than an open traverse but less than closing on a second known point. It checks field work and computations but does not check starting data accuracy or detect any systematic errors (Figure 8-26).

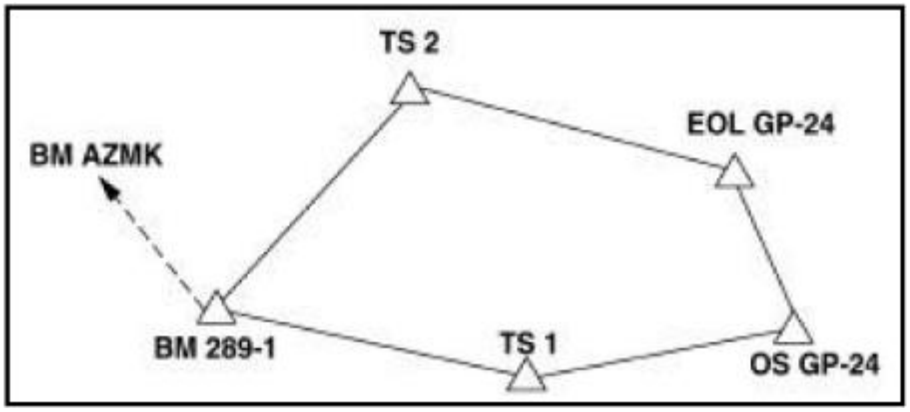


Figure 8-26. Closed Traverse on the Starting Point

8-20. Directional Traverse

This traverse extends directional (azimuth) control only. It can be open or closed. If open, close the traverse at the earliest opportunity. Close on the starting azimuth or another known azimuth. Since direction is the most critical element of artillery survey and time is an important consideration, sometimes lower echelons must assume battery location and extend direction only.

8-21. Sources of Control Data

a. Three elements of survey control must be known to start and close a traverse: the UTM grid coordinates and the elevation of a point and an azimuth from that point to a visible azimuth mark. (Figure 8-27).

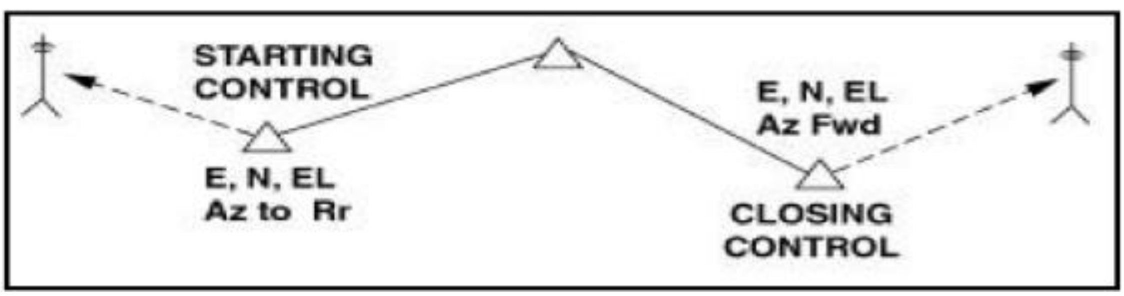


Figure 8-27. Starting and Closing Control

b. Starting and closing data may be obtained from many different sources, but the two basic types of control are known and assumed.

c. Position and elevation may be acquired from trig lists of local or national survey agencies; e.g., NGS or NIMA or from supporting survey elements of a higher headquarters. An azimuth-to-an-azimuth mark may be determined from astronomic observation, computation from known coordinates or by reference to an existing trig list. Use an azimuth determined by an IPADS-G two-position mark or IPADS-G auto-reflection as a starting and closing azimuth for a fifth order traverse. An azimuth cannot be determined from computations between IPADS-G points. IPADS-G positions can be used for extending fifth order traverse, but the survey must be closed on the starting station.

d. If no known control is available, survey data may be obtained by assuming control (map spotting control through the best available resources). If any portion of starting control (coordinates, elevation, and azimuth) has to be assumed, the traverse must open and close on the same station.

8-22. Field Work

a. Traverse field notes are recorded in the current version of the field recorder’s notebook.

b. In a traverse, three stations are of immediate significance: the rear, occupied, and forward (Figure 8-28).

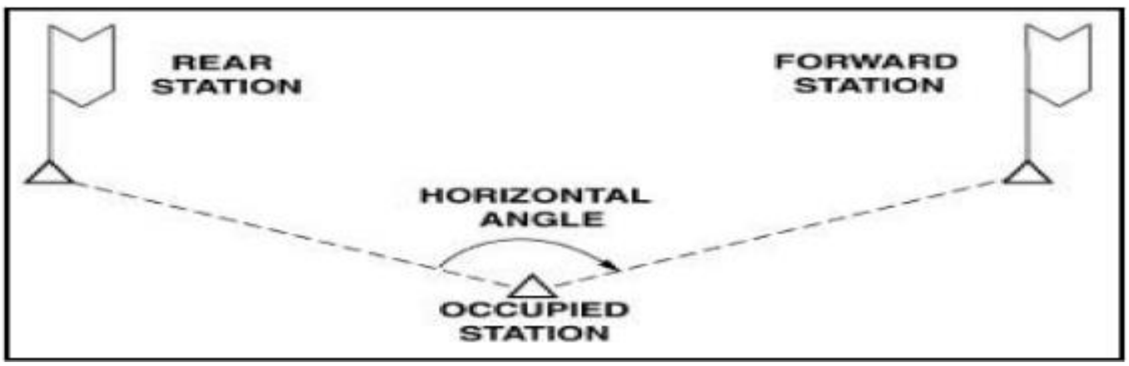


Figure 8-28. Rear, Occupied, and Forward Stations and Horizontal Angles

(1) The occupied station is where the theodolite is set up.

(2) The rear station is where an azimuth from the occupied station is known or has been computed. It is the initial azimuth mark in a traverse or the occupied station during the previous angle.

(3) The forward station is where the azimuth from the occupied station needs to be determined; it will be the next occupied station.

c. At each occupied station (except the closing station) horizontal angles, vertical angles, and distance are measured. Only a horizontal angle is required at the closing station unless a reciprocal vertical angle is required.

(1) Horizontal angles are measured at the occupied station with a theodolite by sighting on the rear station and measuring the angle to the forward station. Horizontal angles determine the azimuth to the forward station (Figure 8-29 page 8-29).

(2) Vertical angles are measured at the occupied station with a theodolite to the height of instrument at the forward station, usually a target set with a prism. Vertical angles are used primarily to determine the difference in height between the occupied and forward station (Figure 8-29).

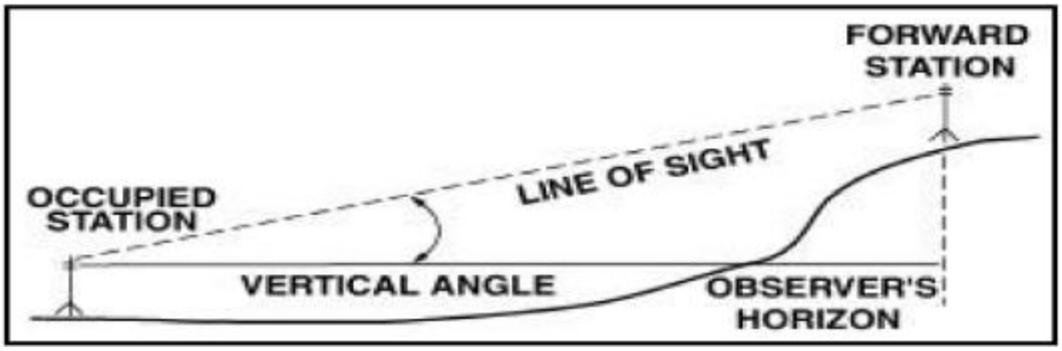


Figure 8-29. Vertical Angles

(3) When the distance between two successive stations in a traverse exceeds 1,000 meters, reciprocal vertical angles must be measured from each end of that particular traverse leg. This reciprocal measurement procedure negates errors caused by the Earth's curvature and refraction (Figure 8-30).

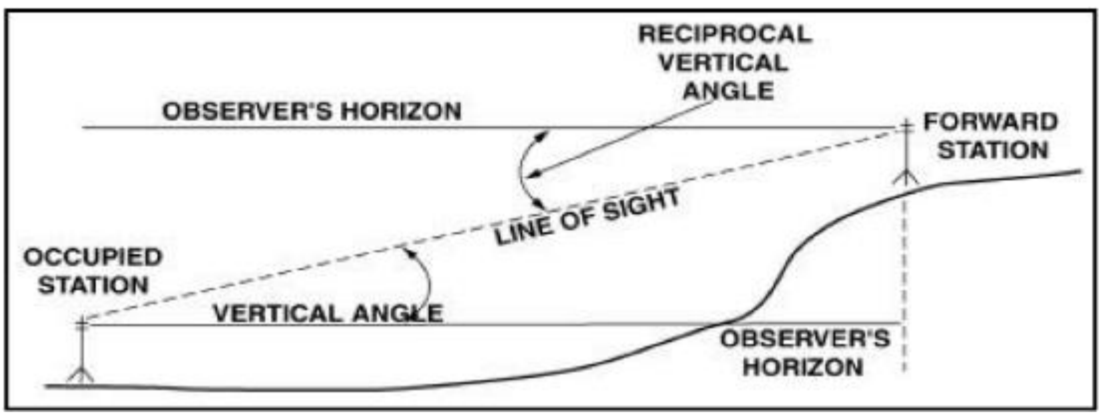


Figure 8-30. Reciprocal Vertical Angles

(4) The Earth's curvature correction increases with distance. For example, at 1,200 meters, the correction is 0.1 meters; at 2,700 meters, 0.5 meters; and at 9,800 meters, 6.5 meters. It is easy to see that these corrections are substantial. If reciprocal vertical angles are not measured, these corrections will accumulate into very large errors.

(5) Refraction varies depending on the Sun's altitude, temperature, and distance. It cannot be modeled like Earth curvature.

(6) Some survey computer systems correct the vertical angle for Earth curvature if nonreciprocal vertical angles are measured, but not for refraction. A computer cannot determine its value with the data provided. Since this is only a partial

correction, reciprocal vertical angles should be measured over all lines when time is available to negate the effects of refraction and Earth curvature. This is especially important during measurements in high heat shimmer conditions.

(7) The distance between the occupied station and the forward station is measured by using electronic distance measuring equipment, horizontal taping or trig-traverse.

8-23. Distances

a. The distance that determines the coordinates of the forward station is not necessarily the distance measured. Slope, horizontal, and grid distances must be considered (Figure 8-31).

b. A slope distance is a straight-line distance between two stations that includes the effects of terrain. The straight-line distance between two stations of different elevations is longer than the distance between those same stations at equal elevations. Any distance determined by using electronic distance measuring equipment is a slope distance.

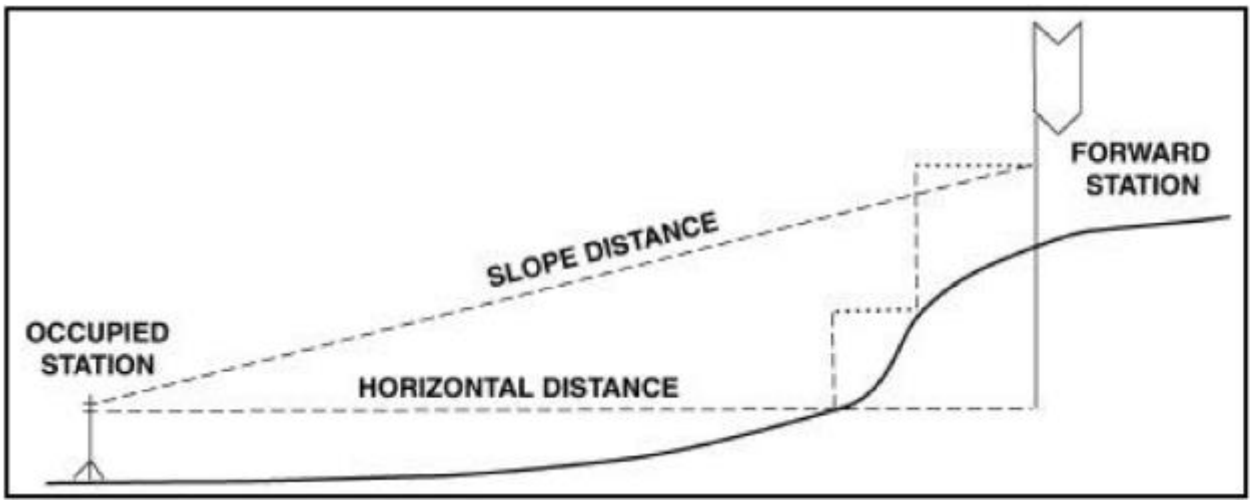


Figure 8-31. Slope and Horizontal Distances

c. A horizontal distance is a straight-line distance between two stations, determined without the effects of terrain (the distance between the stations if they were both at the same elevation).

d. Any distance measured with a steel tape or determined through trigonometric computations is a horizontal distance.

e. A slope distance can be converted to a horizontal distance using the formula horizontal distance = cosine (cos) (vertical angle) × slope distance.

f. The vertical angle should be the mean of the reciprocal vertical angles if the slope distance exceeds 1,000 meters. With most calculators, an angle must be in degrees to determine the trigonometric function of that angle.

g. A grid distance is the distance needed to compute the traverse leg. This distance is the same as a map distance. Determine a grid distance by reducing the horizontal distance to sea level. Then correct the sea level distance to grid by applying a scale factor correction.

h. The reduction to sea level correction is negative when elevation is positive (Figure 8-32). The scale factor correction can be positive or negative depending on where the traverse line is with respect to the secant lines of the projection.

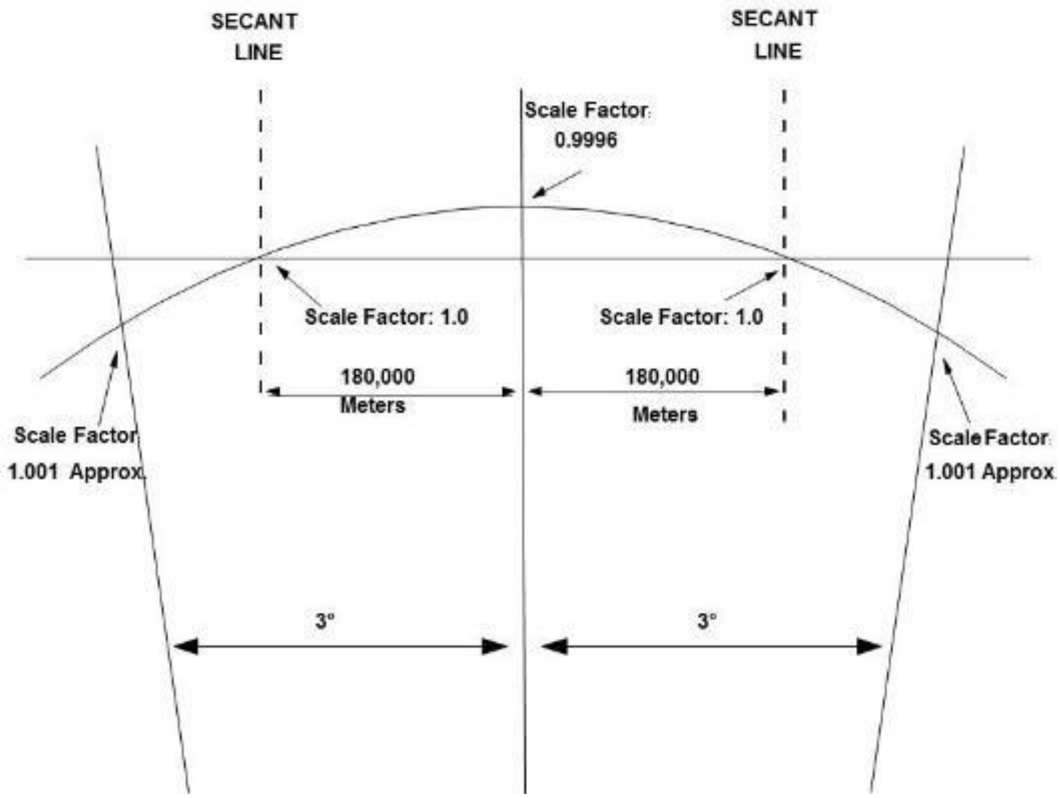


Figure 8-32. Reduction to Sea Level

i. Since most survey computer systems apply the reduction to sea level correction to the horizontal distance automatically, the scale corrections (parts per million) for the S7 Total Station must not include this correction.

8-24. Traverse Legs

a. A traverse leg is the line between two traverse stations. One end of the line is a point of known position (easting, northing, and elevation). The other end is a point requiring control. There are two types of traverse legs in artillery survey: main scheme legs and offset legs (Figure 8-33 page 8-32).

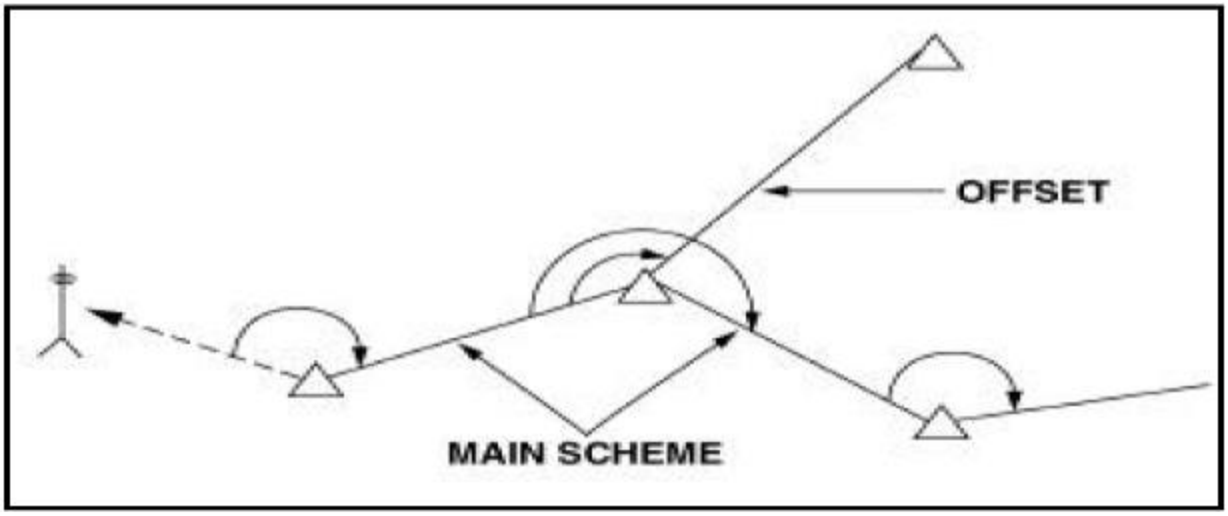


Figure 8-33. Traverse Legs

b. A main scheme leg is one where both ends of the leg are an occupied station in the traverse. An offset leg is one where only the first station of the leg is occupied. The important difference is that an offset leg is left open (the coordinates and elevation determined for the offset station is not used in computations of other stations). Offset leg computations are performed before main scheme leg computations that originates from the same station.

c. The field data for the offset leg is measured and recorded during the same occupation as the main scheme data. The horizontal angle measured is called a multiple angle because it includes determining two horizontal angles from one set of observations. The vertical angle is determined the same way as with a main scheme leg including determining reciprocal vertical angles if the offset leg is longer than 1,000 meters.

Section IV. SURVEY MATH AND TRIGONOMETRY

8-25. Extending Azimuth

a. An azimuth is the clockwise angle from a known reference line to a second line. For artillery survey purposes, the reference line is grid north and the second line is the traverse line to the forward station. Every line has a forward azimuth and a back azimuth. In artillery survey, we consider the Earth to be a flat surface. A forward azimuth and back azimuth differ exactly 3200 mils (Figure 8-34).

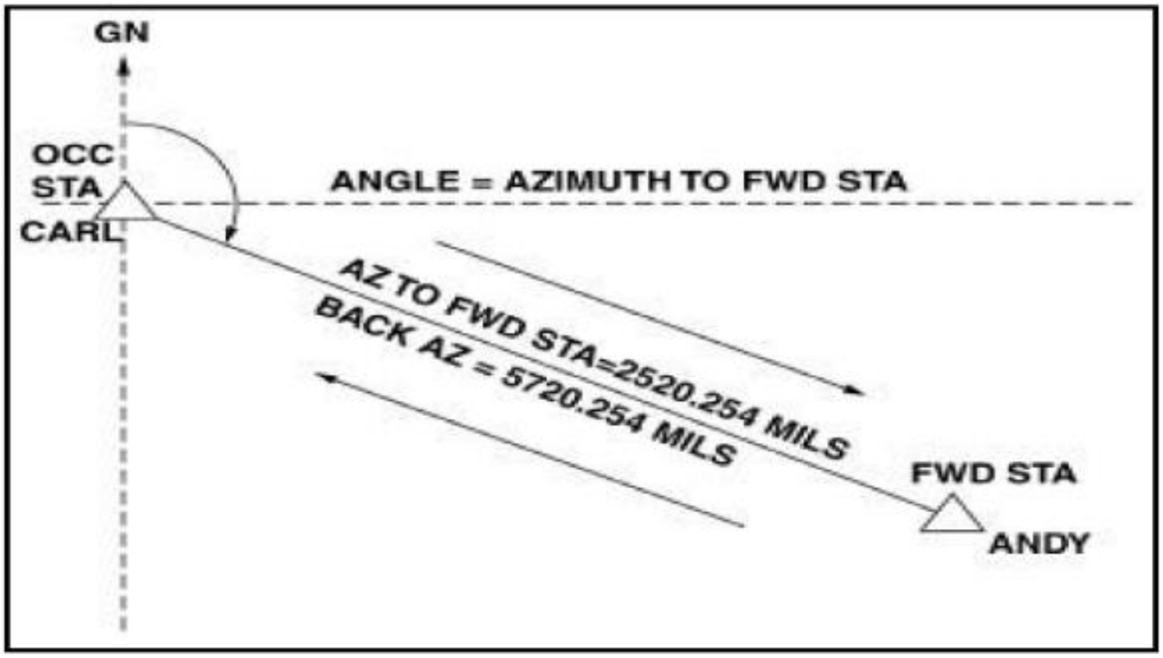


Figure 8-34. Azimuth

b. When traverse computations begin, the only known azimuth is the azimuth from the occupied station to the rear station. To determine the azimuth to the forward station, add the horizontal angle measured at the occupied station to the azimuth to the rear station (Figure 8-35 page 8-34).

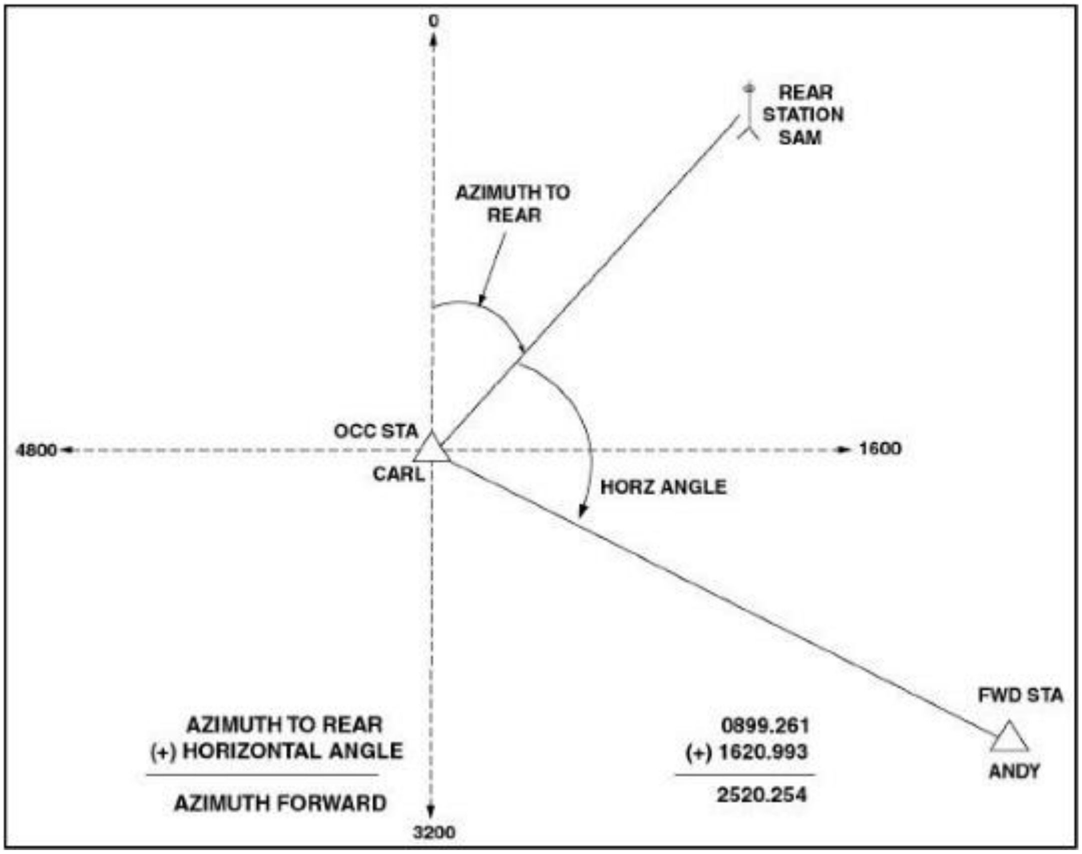


Figure 8-35. Azimuth-Angle Relationship

c. Sometimes the sum of the azimuth to rear and the horizontal angle produces an azimuth larger than 6400 mils. Subtract 6400 mils from that sum to determine the azimuth necessary for computations.

d. Once the azimuth to the forward station is determined, the computations necessary to determine the coordinates of the forward station can be made. The extension of the survey beyond that point requires that the azimuth to the rear be determined from the azimuth to the forward station, as determined above. To do this, apply 3200 mils to the forward azimuth as shown in the following example:

Az to Fwd Sta (Carl to Andy):	2520.254 mils
±3200 mils	3200.000 mils
Az to Rear (Andy to Carl)	5720.254 mils

e. The azimuth to the forward station (Andy) from Carl is 2520.254 mils. This azimuth is used to compute the coordinates of Andy. To determine the coordinates of the forward station when Andy is occupied, the azimuth from Andy to the rear station (Carl) must be known. In the example it is 5720.254 mils.

8-26. Solutions of Right Triangles

a. Simple plane trigonometry can be used to compute a survey. The solution of two right triangles is necessary to determine differences in coordinates and elevation.

b. The distance and azimuth between two points can be used to form a right triangle. The grid distance between the traverse stations is the hypotenuse of the right triangle. The other two sides of the triangle are the easting and northing coordinate differences between the stations. The difference easting (dE) and difference northing (dN) are the unknowns that are determined by solving the right triangle (Figure 8-36).

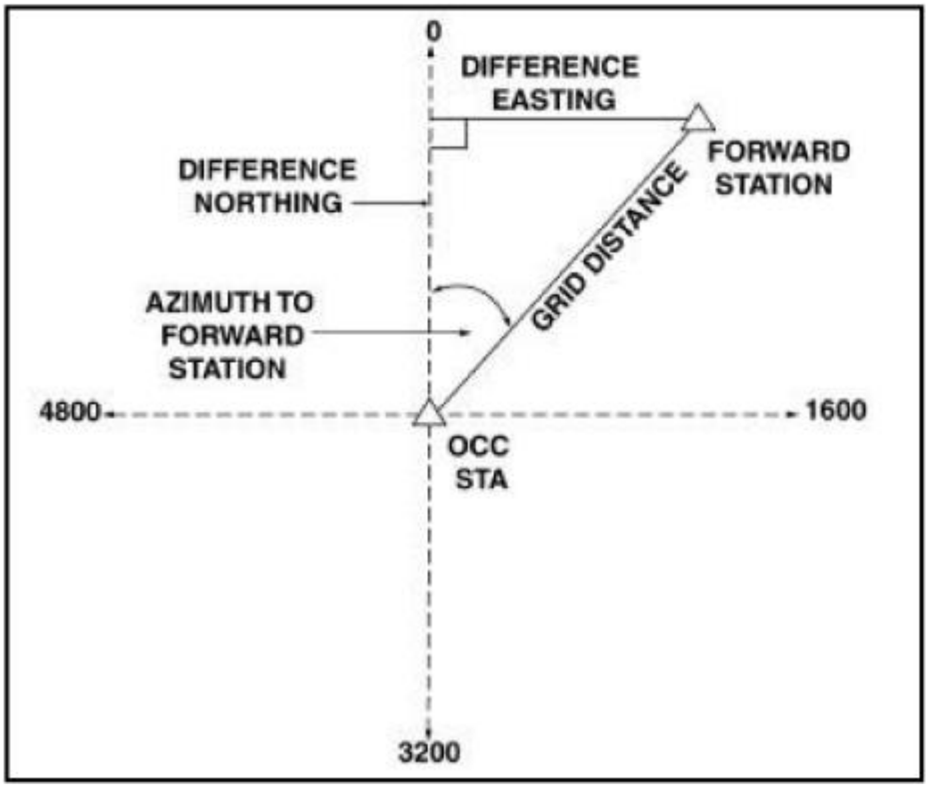


Figure 8-36. Coordinate Triangle

c. Forming the elevation triangle. The distance and vertical angle between two points can be used to form a right triangle. The sides of the triangle forming the right angle are the grid distance and the elevation difference between the stations (dH). The vertical angle is the angle formed by the grid distance and the line of sight (the hypotenuse). It is opposite the vertical interval (Figure 8-37 page 8-36).

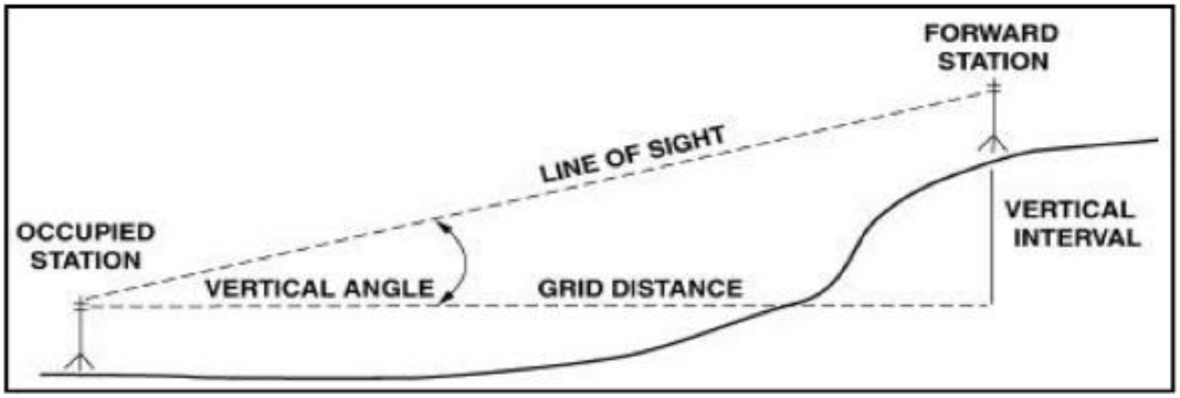


Figure 8-37. Elevation Triangle

d. Sine (sin) and cos compute the differences in easting and northing coordinates. Tangent (tan) computes the difference in height.

(1) The values of sin and cos are the distances corresponding to an angle formed at the center of a circle whose radius is one. Figure 8-38 shows that in a circle of radius 1, the length of side dE is the sin of 849 mils (47.75625°) and the length of side dN is the cos of 849 mils. If you were to use a scientific calculator to determine the sin of 47.75625°, the answer would be 0.74029 and the cos would be 0.67229.

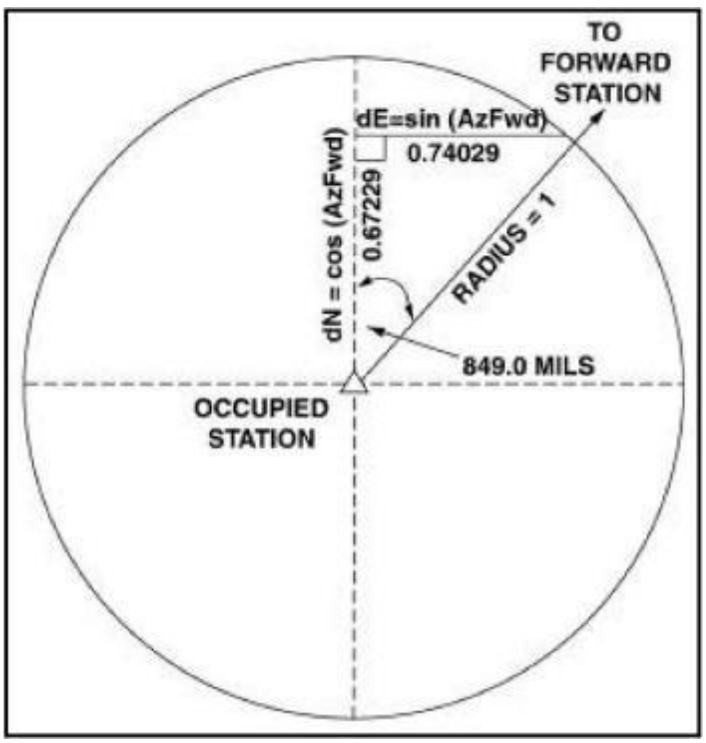


Figure 8-38. Value of Trigonometric Functions of Angles

(1) The value of tan equals the value of sin divided by the value of cos.

e. Determining coordinate and elevation differences (Figure 8-39). The formulas for solving a right triangle are generally written as:

$\sin(\text{angle}) = \frac{O}{H}$ whereas: O is the side opposite the angle

$\cos(\text{angle}) = \frac{A}{H}$ A is the side adjacent the angle

$\tan(\text{angle}) = \frac{O}{A}$ H is the hypotenuse

and: Angles are converted to degrees from mils using the formula degrees = milsx 0.05625

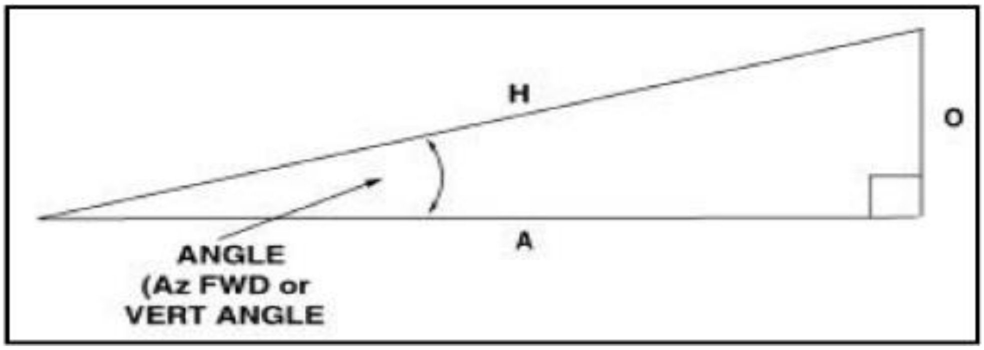


Figure 8-39. Right Triangle

f. For computations of the coordinate and elevation triangles, it is easier to understand if we substitute the O, A, and H with the actual values used:

$$\sin(AzFwd \times 0.05625) = \frac{dE}{Grid\ Dist}$$

$$\cos(AzFwd \times 0.05625) = \frac{dN}{Grid\ Dist}$$

$$\tan(AzFwd \times 0.05625) = \frac{dH}{Grid\ Dist}$$

(1) The formulas listed immediately above can also be written as:

$$\text{dE} = \sin(Az\ Fwd \times 0.05625) \times \text{Grid Dist}$$

$$\text{dN} = \cos(Az\ Fwd \times 0.05625) \times \text{Grid Dist}$$

$$\text{dH} = \tan(\text{Vert Angle} \times \text{Grid Dist}$$

(2) The previous example produced an azimuth forward (Carl to Andy) of 2520.254 mils. If the grid distance from Carl to Andy is 524.876 meters and the vertical angle is 27.821 mils, the dE, dN, and dH can be determined by substituting those values into the formulas immediately above.

$$dE = \sin(2520.254 \times 0.05625) \times 524.876$$
$$dE = 324.84 \text{ meters}$$

$$dN = \cos(2520.254 \text{ x } 0.05625) \times 524.876$$
$$dN = 412.28 \text{ meters}$$

$$dH = \tan(27.821 \text{ x } 0.05625) \times 524.876$$
$$dH = 14.34 \text{ meters}$$

8-27. Determining the Coordinates and Elevation of the Forward Station

a. Determine the coordinates by algebraically adding the dE and dN to the coordinates of the occupied station. To algebraically add means to add or subtract depending on the sign + or- of the subject value.

b. Determine the sign of the dE and dN by plotting the azimuth to the forward station (Figure 8-40).

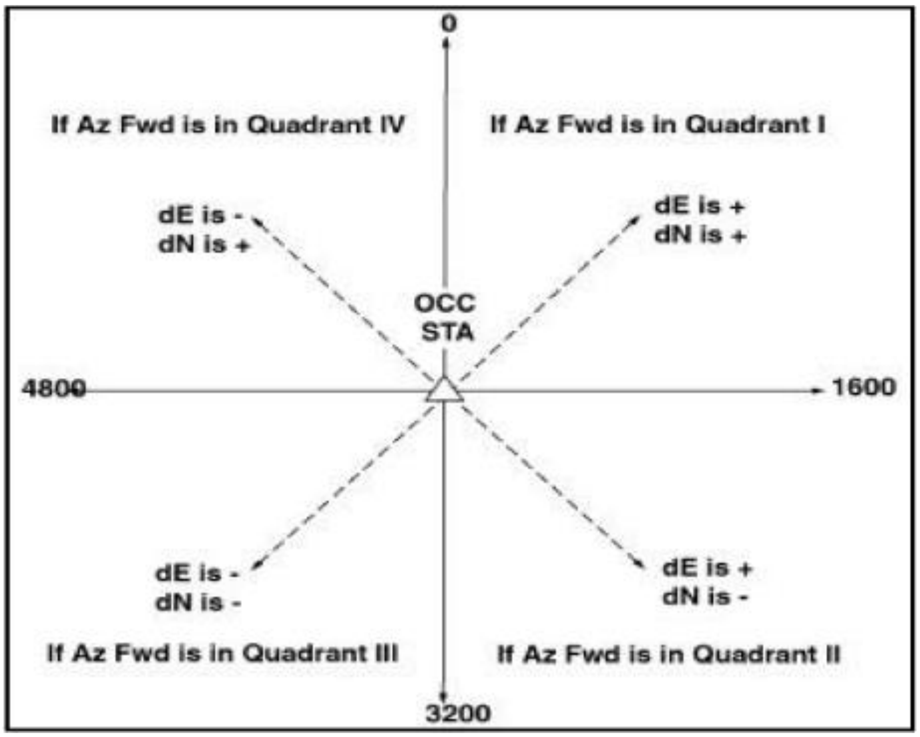


Figure 8-40. Determining the Sign of dE and dN

c. The dE and dN with the proper sign are then algebraically added to the coordinates of the occupied station.

d. Determine the elevation by algebraically adding the dH to the elevation of the occupied station. The sign of the dH is the same as the sign of the vertical angle.

e. The examples shown produced an azimuth forward (Carl to Andy) of 2520.254 mils and produced a dE of 324.84 meters, a dN of 412.28 meters, and a dH of 14.34 meters.

f. The coordinates of Carl are E: 5 40666.21, N: 34 13666.78, El (m): 666.34

g. The azimuth from Carl to Andy is 2520.254 mils which plots in quadrant II in figure 8-40. So, the dE is positive, the dN is negative. The coordinates of Andy are determined as:

Carl	5 40666.21	34 13666.78	666.34
dE, N, H	+324.84	–412.28	+14.34
Andy	5 40991.05	34 13254.50	680.68

8-28. Computing the Traverse

a. After computation of a main scheme leg, the station that was the forward station now becomes the occupied station. The data determined for that station determines the coordinates and elevation of the next forward station.

b. Figure 8-41 shows a traverse with only main scheme legs. It can be seen that the coordinates and elevation of Andy are used to compute the coordinates of John.

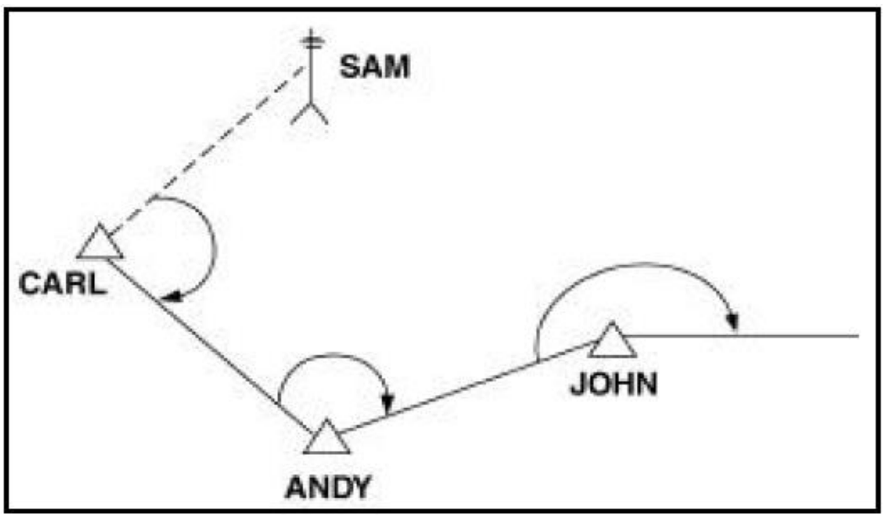


Figure 8-41. Main Scheme Legs

c. A traverse cannot continue from an offset station because the offset station is not occupied. Its coordinates and elevation are not used to compute another forward station. The next forward station is computed from the same station as the offset.

d. Figure 8-42 (page 8-40) shows a traverse with an offset leg from Carl to Andy. The main scheme portion of the traverse runs from Carl to John, then to Jim. The coordinates and elevation of Andy will not be used to compute the coordinates and elevation of John. The coordinates and elevation of John must be computed using the data from Carl.

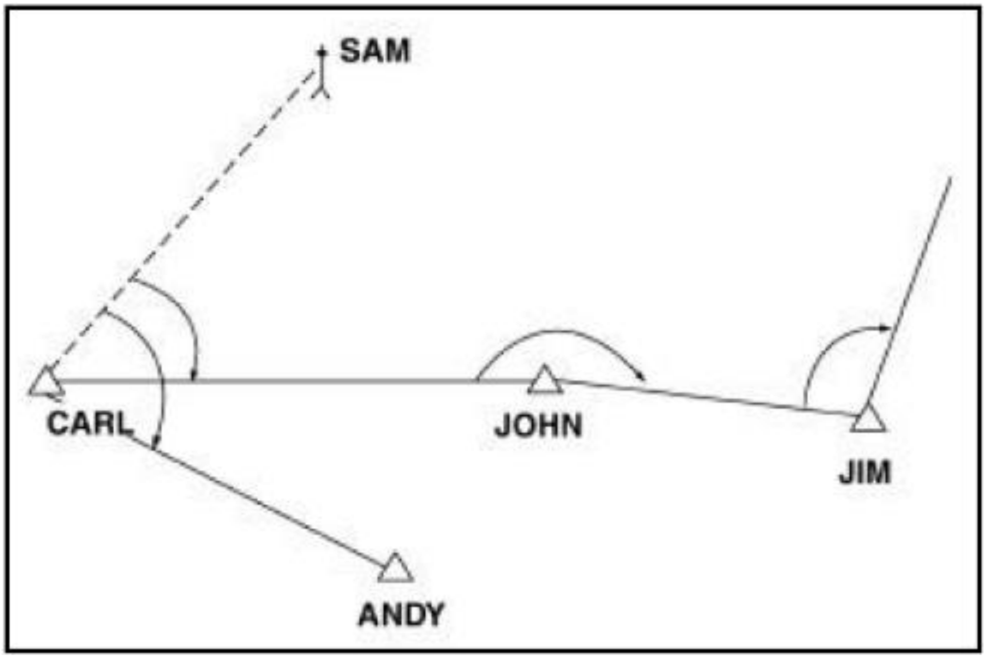


Figure 8-42. Offset Legs

Section V. TRAVERSE CLOSURE

8-29. Traverse Closure

Traverse closure is performed by comparing the computed data for the closing station to the known data for the closing station. These comparisons produce errors that must meet certain specifications for the order of traverse being performed.

8-30. Comparisons

Three comparisons must be made to determine if a traverse meets closure specifications: coordinate comparison, elevation comparison, and an azimuth comparison. Closing data for a traverse consists of radial error (RE) of closure, elevation error, azimuth error, and accuracy ratio (Figure 8-43).

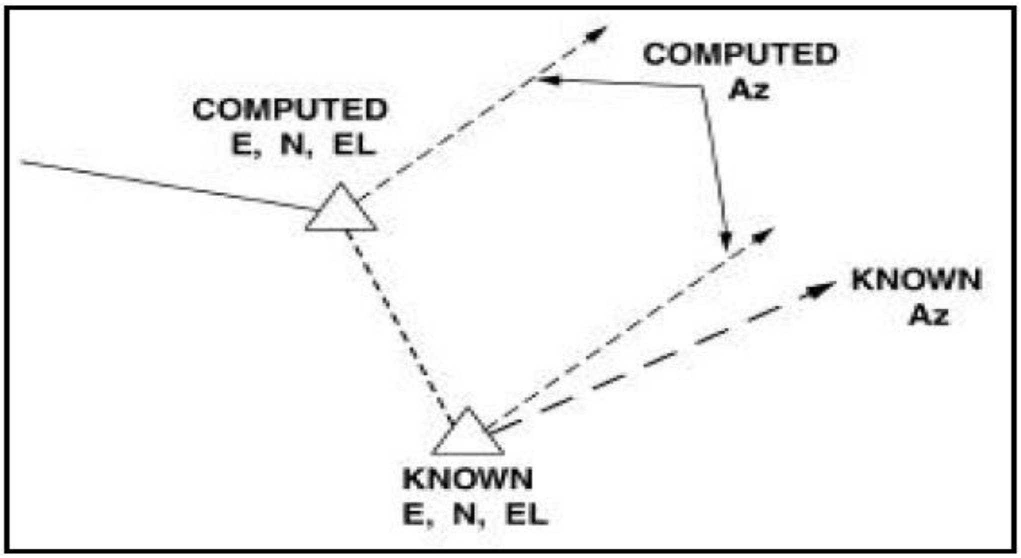


Figure 8-43. Traverse Closing Data Comparison

8-31. Radial Error

a. A comparison between known and computed coordinates of the closing station is performed to produce an RE of closure. The RE is the distance from the known coordinates to the computed coordinates (Figure 8-44 page 8-42).

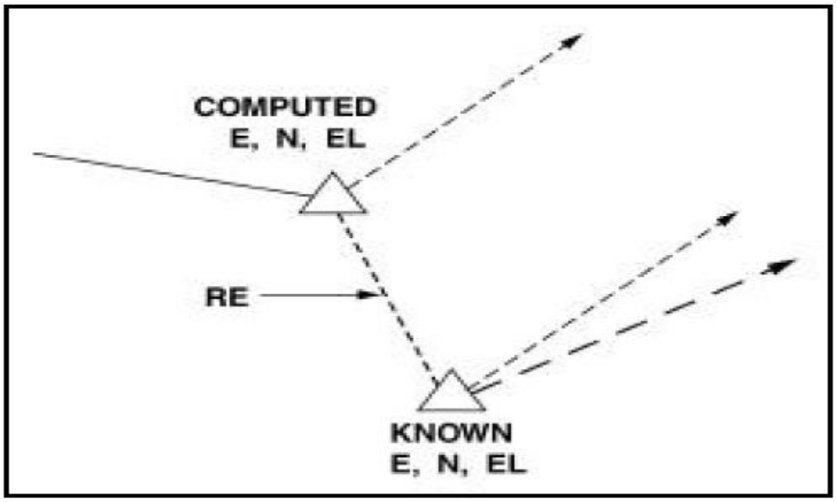


Figure 8-44. Radial Error of Closure

b. There are several ways to determine the RE. If the traverse was computed on a survey computer system, the RE is computed automatically. It can be verified by using the azimuth and distance program or with the Pythagorean Theorem, manually.

c. RE can be determined by performing the azimuth and distance computations available in survey computer programs. Data should be entered from the known coordinates to the computed coordinates. This is because the azimuth provided by these computations is the azimuth of the error that may be necessary to determine the location of traverse errors should the survey not meet specifications.

d. The Pythagorean Theorem considers the RE as the hypotenuse of a right triangle and the error easting (eE) and error northing (eN) as sides of the triangle (Figure 8-45).

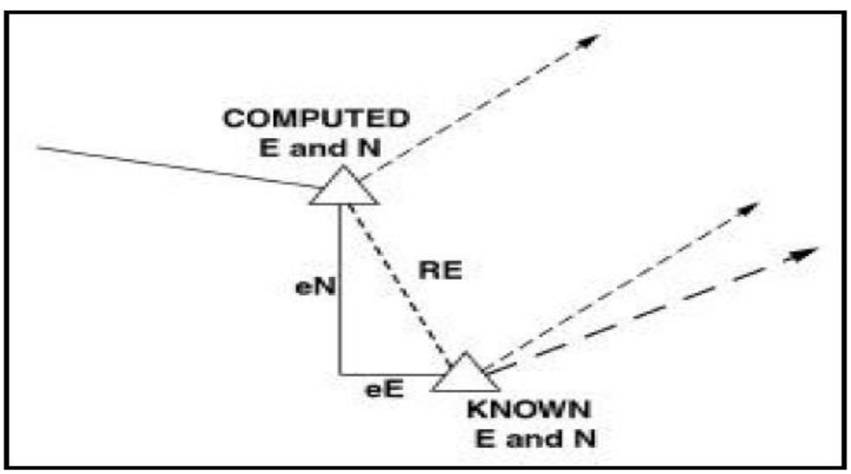


Figure 8-45. Pythagorean Theorem

(1) The Pythagorean Theorem states that in a right triangle, the square of the hypotenuse is equal to the sum of the squares of the sides. That formula can be expressed as:

$$C = \sqrt{A^2+B^2}$$

(2) Where C is the hypotenuse, and A and B are the sides of the triangle.

(3) The eE, eN, and RE can be substituted into the formula as:

$$RE = \sqrt{eE^2 + eN^2}$$

(4) The eE is the difference between the known and computed easting. If the known easting value is a larger number than the computed easting value, the eE is negative. If the known easting value is a smaller number than the computed, the eE is positive.

(5) The eN is the difference between the known and computed northing. If the known northing value is a larger number than the computed, the eN is negative; if the known northing value is a smaller number than the computed, the eN is positive.

(6) The following example uses the Pythagorean Theorem to compute RE.

(a) Determine eE and eN:

Known	E: 5 17265.98	N: 38 27648.32
Computed	E: 5 17265.54	N: 38 27649.02
Error (meters)	dE–0.44	dN+0.70

(b) Determine RE:

$$RE = \sqrt{0.44^2 + 0.70^2} = 0.83 \text{ meters}$$

e. The allowable position closure (RE) for a traverse depends on the order of survey and the total traverse length (TTL).

(1) If a fourth order traverse length is less than 9 kilometers, the allowable RE in closure is 1:3000 or 1 meter of RE for each 3,000 meters of traverse. Determine the allowable RE by dividing the total traverse length by 3,000. For example, if the traverse length of a fourth order survey is 3,469.910 meters, the allowable RE is 1.16 meters (3,469.910/3,000 = 1.1566).

(2) If a fourth order traverse length is greater than 9 kilometers, the accuracy achieved may be better than 1:3000, yet the RE may be excessive. Determine the allowable RE by the following formula: square root of *K* whereas *K* equals the TTL in kilometers. If the TTL is 10,983.760 meters, then *K* equals 10.983760. In this example, allowable RE equals 3.314175613935 or 3.31 meters. If the TTL were divided by 3,000, the allowable RE would be 3.66 meters, 0.35 meters more than with the square root of *K*.

(3) The allowable RE for a fifth order traverse is 1:1000 or 1 meter of RE for each 1,000 meters of traverse. Determine the allowable RE by dividing the total traverse

length by 1,000. For example, if the traverse length of a fifth order survey is 2,986.321 meters, the allowable RE is 2.99 meters (2,986.321/1,000 = 2.986321). Allowable RE for a fifth order traverse equals *K* (TTL in kilometers).

f. If the RE of a traverse exceeds the specifications listed above for allowable RE, the traverse has “busted.” The traverse error location must be determined and corrected.

8-32. Elevation Error

a. A comparison between known and computed elevations of the closing station is performed to produce an elevation error (eH). The eH is the vertical distance from the known elevation to the computed elevation (Figure 8-46).

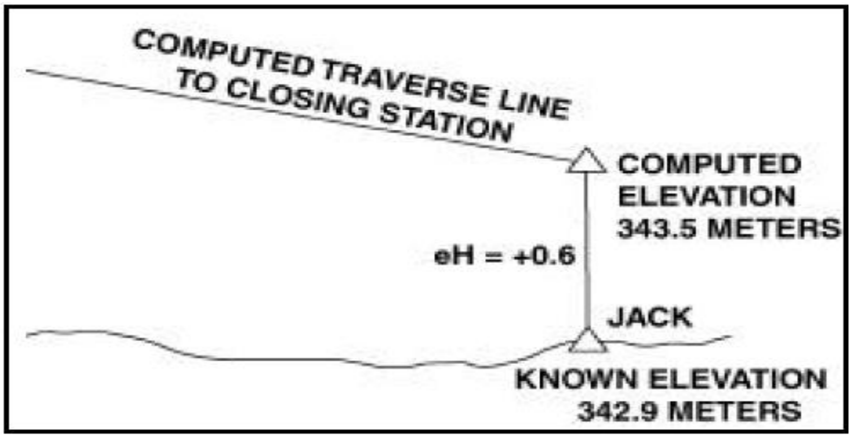


Figure 8-46. Elevation Error

b. If the known elevation is a larger number than the computed, the eH is negative. If the known elevation is a smaller number than the computed, the eH is positive. Figure 8-46 shows station Jack with a known elevation of 342.9 meters and a computed elevation of 343.5 meters. The difference between the two values is 0.6 meters. Since the computed elevation is higher than the known, the sign is positive. The eH is written as +0.6 meters.

c. The eH is computed automatically by survey computer systems. Sometimes the value displayed by the program is the elevation correction. Elevation correction is the same value as eH with the opposite sign and is used for traverse adjustments.

d. The allowable eH for a traverse depends on the order of survey and the TTL. For fourth order, the allowable eH equals the $\sqrt{K}$ when K is the TTL in kilometers. For example, if the total traverse length of a fourth order survey equals 7643.765 meters, K is equal to 7.643765. Allowable eH in this example equals 2.764735972928 or 2.8 meters.

e. The allowable eH for a fifth order traverse whose TTL is less than 4,000 meters is ±2 meters. As long as the computed elevation is within 2 meters of the known, the elevation closes.

f. The allowable eH for a fifth order traverse whose TTL is equal to or greater than 4,000 meters is determined from the formula:

$$1.2 \times \sqrt{K}$$

When K is the TTL in kilometers. For example, if the TTL is 6843.874 meters, *K* is equal to 6.843874. Allowable elevation error in this example is equal to 3.139 or 3.14 meters.

g. If the eH of a traverse exceeds the specifications listed above for allowable eH, the traverse has "busted." Determine the eH location and correct.

8-33. Azimuth Error

a. A comparison between known and computed azimuths at the closing station is performed to produce an azimuth error (eAz). The azimuth error is the angular difference between the known azimuth and the computed azimuth from the closing station to the azimuth mark (Figure 8-47).

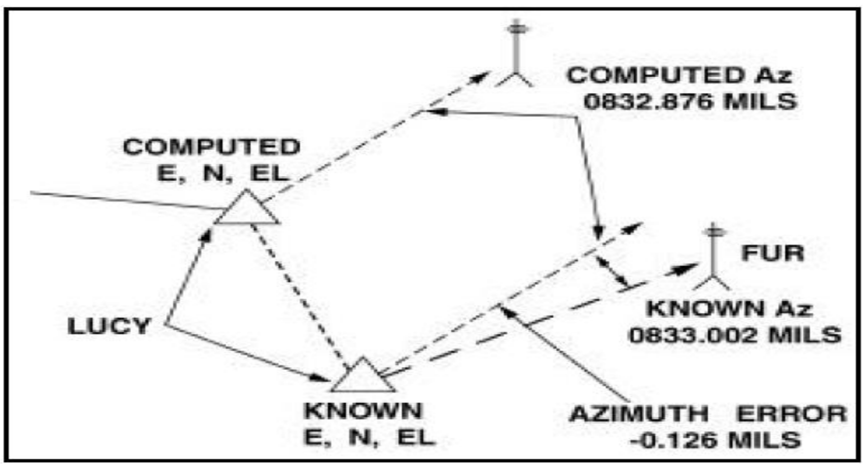


Figure 8-47. Azimuth Error

b. If the known azimuth is a larger value than the computed, the eAz is negative. If the known azimuth is a smaller number than the computed, the eAz is positive. Figure 8-47 shows a known azimuth of 0833.002 mils and a computed azimuth of 0832.876 mils. The difference between the two values is 0.126 mils. Since the computed azimuth is lower than the known, the sign is negative. The azimuth error is written as -0.126 mils.

c. The eAz is computed automatically by survey computer programs. Sometimes the value displayed by the computer system is the azimuth correction. Azimuth correction is the same value as azimuth error with the opposite sign and is used for traverse adjustments.

d. The allowable eAz for a traverse depends on the order of survey and the number of main scheme angles, including the closing angle, in the traverse.

e. The allowable eAz for a fourth order traverse with six or fewer main scheme angles is determined from the formula allowable eAz = 0.04 mils × N; when N equals the number of main scheme angles, including the closing angle. For example, if a fourth order traverse contains 5 main scheme angles, the allowable eAz = 0.04 mils × 5 = 0.200 mils.

f. The allowable eAz for a fourth order traverse with seven or more main scheme angles is determined from the formula $0.1 \text{ X } \sqrt{N}$ when N equals the number of main scheme angles, including the closing angle. For example, if a fourth order traverse contains 8 main scheme angles, the allowable eAz = 0.283 mils.

g. The allowable eAz for a fifth order traverse is determined using the formula allowable eAz = 0.1 mils × N; when N equals the number of main scheme angles, including the closing angle. For example, if a fifth order traverse contains 12 main scheme angles; the allowable eAz equals 1.2 mils.

h. If the eAz of a traverse exceeds the specifications listed above for allowable eAz, the traverse has "busted." Location of the traverse error must be determined and corrected.

8-34. Accuracy Ratio

a. Certain minimum position accuracy requirements are prescribed for survey field work and computations. To determine whether this position requirement has been met for a closed traverse, an AR is computed.

b. An AR is the ratio of position error to TTL. TTL is sum of the main scheme grid distances used to compute the traverse. Accuracy ratio is computed by dividing the TTL by the RE. For example, if the TTL of a traverse is 9843.785 meters and the RE is 2.01 meters, then AR = 9843.785/2.01 = 4897.405472637.

c. Accuracy ratio may be expressed as either a fraction with a numerator of one (i.e., 1/3000) or as a ratio (i.e., 1:3000). An AR is read as one to the computed value; e.g., one to three thousand.

d. After the AR has been computed, the denominator of the fraction is always reduced to the next lower hundred; e.g., 1/4897 is recorded as 1/4800.

e. The minimum accepted value for an AR depends on the order of survey being performed. A traverse performed to fifth order specifications must produce an AR equal to or higher than 1/1000. A traverse performed to fourth order specifications must produce an AR equal to or higher than 1/3000. However, if the TTL exceeds 9 kilometers, the RE must be within specifications.

f. If the computed accuracy ratio of a traverse does not meet the specifications listed above for minimum AR, the traverse has "busted." The traverse error location must be determined and corrected.

8-35. Specifications

To verify that a traverse closes, compare computed errors to the following specifications:

TRAVERSE CLOSURE SPECIFICATIONS

REQUIREMENT	FOURTH ORDER		FIFTH ORDER	
ADJUSTED	Yes		No	
POSITION CLOSURE - aRE				
If traverse length is:				
Less than 9,000 meters	1:3000	TTL / 3000	1:1000	TTL / 1000
More than 9,000 meters	$\sqrt{K}$	K = TTL/1000	1:1000	TTL / 1000
HEIGHT CLOSURE - aeH				
If traverse length is:				
Less than 4,000 meters	$\sqrt{K}$	K = TTL/1000	± 2 meters	
More than 4,000 meters	$\sqrt{K}$	K = TTL/1000	$1.2 \times \sqrt{K}$	K = TTL/1000
AZIMUTH CLOSURE - aAzE				
Six or fewer stations	0.04 x N	N = Number of occupied stations	0.1 x N	N = Number of occupied stations
Seven or more stations	$0.1 \times \sqrt{N}$	N = Number of occupied stations	0.1 x N	N = Number of occupied stations
ACCURACY RATIO - aAR	1/3000		1/1000	

EXAMPLE:

Total traverse length for a traverse is 4,569.354 meters and had 7 occupied stations. Compute 4th and 5th order allowable errors.

	FOURTH ORDER		FIFTH ORDER	
aRE:	1:3000	4,569.354 / 3000 = 1.523118	1:1000	4,569.354 / 1000= 4.569354
aeH:	$\sqrt{K}$	$\sqrt{4.569354} = 2.137604734$	$1.2 \times \sqrt{K}$	$1.2 \times \sqrt{4.569354} = 2.565125681$
aAzE:	$0.1 \times \sqrt{N}$	$0.1 \times \sqrt{7} = 0.264575131$	0.1 x N	0.1 x 7 = 0.7
aAR:	The accuracy ratio will be computed by the survey software. The ratio must meet or exceed 1/3000 for fourth order survey. The ratio must meet or exceed 1/1000 for fifth order survey.			

Section VI. TRAVERSE ADJUSTMENT

8-36. Adjusting the Traverse

a. An adjusted traverse is where errors have been distributed systematically so that the computed closing station coincides with the known closing station. In artillery survey, only fourth order traverses are adjusted.

b. There is no way to determine the true magnitude of errors in the angle and distance measurements that occur throughout a traverse. A traverse adjustment is based on the assumption that errors have accumulated gradually and corrections are made accordingly. A traverse adjustment is also based on the assumption that all errors causing non-closure in the traverse are from field measurements (no errors are brought into the closure from previous adjustments or a lack of commonality).

c. Three adjustments must be made when adjusting a traverse: azimuth, coordinates, and elevation. These adjustments eliminate the effects of systematic (accumulative) errors assuming they have been constant in magnitude and direction over each traverse leg. Traverse adjustment cannot compensate for blunders such as improperly recorded data or misread angles.

d. A traverse that does not meet the closure specifications listed in section V is not adjusted. It is checked and corrected using the traverse error location procedures in section VII.

e. Usually a traverse will close within specifications, but because some error sources cannot always be accounted for, closure will not be absolute. There will always be some measure of position, elevation, and azimuth error.

f. Most errors causing survey non-closure are cumulative. A cumulative error will generally be of the same magnitude, in the same direction, and occur in every measurement of that type; e.g., errors introduced by instruments that are not properly adjusted.

g. Random errors are those errors that cannot be accounted for. They vary in magnitude and direction and do not occur in all measurements; e.g., plumbing, leveling, and sighting errors.

h. Survey computer systems automatically adjust the main scheme portion of a traverse if so prompted.

8-37. Azimuth

a. To determine azimuth correction when adjusting a traverse, the azimuths used to compute those easting and northing differences are adjusted first. The total amount of azimuth adjustment is the azimuth correction, determined by computing the eAz. The azimuth correction is the eAz with the proper sign affixed so that the computed azimuth with the azimuth correction applied equals the known azimuth. The azimuth correction is the same value as the eAz with the opposite sign.

b. The azimuth correction is distributed equally among the main scheme angles of the traverse with any remainder distributed to the larger angles. For example, assume a traverse has five main scheme angles, including the closing angle and the eAz for the traverse equals +0.966 mils. The azimuth correction equals -0.966 mils and is divided by the number of angles in the traverse. In this case, -0.966 mils/5 equals -0.193 mils per angle with a remainder of 0.001 mil. Each of the five angles will be adjusted by -0.193 mils and the largest angle will be adjusted by an additional 0.001 mil each to compensate for the remainder (Figure 8-48).

Occupied Station	Horizontal Angle	Azimuth Correction	Adjusted Angle
Carl	2520.254	-0.193	2520.061
Andy	1895.364	-0.193	1895.171
John	3725.468	-0.194	3725.274
Jim	1564.258	-0.193	1564.065
Jack	2635.842	-0.193	2635.649

Figure 8-48. Azimuth Adjustment

c. After the main scheme angles have been adjusted, the entire traverse is recomputed using the adjusted angles. This produces new coordinates and closing data for the traverse with an azimuth error of zero mils. There will be no change in eH or TTL. It is now assumed that all eAz has been eliminated. Any remaining error is assumed to be a distance error.

8-38. Coordinate

a. The total easting and northing corrections for the traverse are determined by algebraically subtracting the coordinates of the closing station (after azimuth adjustment computations) from the known coordinates of the closing station. Use the following example to determine easting and northing corrections:

	Easting	Northing
Known	5 21874.98	34 87698.23
– Computed	5 21874.71	34 87698.68
Correction	(tcE) +0.27	(tcN) –0.45

b. The easting and northing corrections determined above are for the entire traverse. It is assumed that errors causing coordinate non-closure are accumulated proportionately throughout the traverse. The corrections must be distributed proportionately throughout the traverse. The amount of coordinate correction to be applied to each main scheme station (cE, cN) is determined by multiplying the total easting or northing correction by the partial traverse length (= sum of the distance of the traverse legs up to that station), then dividing by the TTL. As an example, for a traverse with a TTL of 6734.973 meters and total coordinate corrections as determined above, the cE and cN for station Jack whose partial traverse length is 3974.652 meters is determined as:

cE = +0.16 meters   cN = –0.27 meters

c. Adjusted coordinates for a main scheme station in a traverse are determined by algebraically adding the easting and northing coordinate corrections (cE, cN) to the coordinates of the stations that were determined by the azimuth adjustment computations. The following example shows how to determine adjusted coordinates using the coordinate corrections determined above:

	Easting	Northing
Jack (Az Adj)	5 24987.56	34 85673.87
Correction	+0.16	–0.27
Jack (Adjusted)	5 24987.72	34 85673.60

d. There is no requirement to adjust offset legs. Even so, the computations performed for azimuth adjustment produced a new set of coordinates for the occupied station to determine the offset station coordinates. To ensure relativity, adjust offset legs by re-computing a single traverse leg using the adjusted coordinates of the occupied station and the adjusted azimuth from the occupied station to the rear station.

8-39. Elevation

a. Since elevation is the least important of the three elements of survey, it can be assumed that elevation closure error is accumulated in equal amounts at each traverse station.

b. Compare the computed elevation of the closing station with the known elevation of the closing station and apply a sign (±) that causes the established height to equal the known height. The elevation correction is the same value as the elevation error with the opposite sign. For example, if the known elevation for station Jack is 342.9 meters and the computed elevation is 343.5 meters, the elevation correction is -0.6 meters (342.9 - 343.5 = -0.6). For the elevation determined by traverse to equal the correct elevation, subtract 0.6 meters from the elevation of the computed closing station.

c. The elevation correction is distributed equally among the stations of the traverse with any remainder distributed to those stations computed from the longest legs. Assume that the traverse for the elevation correction consists of five stations. To distribute the elevation correction throughout the traverse, divide the elevation correction by the total number of stations in the traverse excluding the starting station (a known height), in this case four, if the elevation correction is -0.6 meters. The elevation correction is determined from the formula -0.6/4 equals 0.1 with a remainder of .2 meters. The adjustment is an accumulation of the correction since the correction applies to the differences in elevation between the stations and not directly applied to their elevations.

8-40. Discretion Adjustment

There will be times in the field when a sensor team chief will rely on judgment alone. Error/correction may be distributed arbitrarily in accordance with the sensor team chief's estimation of field conditions. It is reasonable to assume that heat waves will introduce larger errors over long lines than over short lines. Larger angular errors would be expected when lines of sight are steep and visibility is poor than when observing conditions are relatively favorable. The sensor team chief should not use this method of adjustment unless experienced and have a extensive knowledge of where errors are most likely to occur and of their effect on the overall survey. In any event, the field recorder's notebook should contain a detailed account of any unfavorable survey conditions so that is may be used to substantiate any arbitrary adjustments.

Section VII. LOCATION OF TRAVERSE ERRORS

8-41. Traverse Errors

The sensor support Marine must isolate errors and determine their causes. Often, a critical analysis of the field work and the computations will locate blunders of a traverse in error. This will eliminate the need to conduct the location of traverse errors.

8-42. Sources of Error

a. Many error sources exist that can cause a survey to bust. When trying to locate a traverse error it is assumed that only one error exists and that the error exists in the field work or computations. Trig lists from higher or adjacent echelon survey sections may sometimes contain errors. These errors are usually a misprint in the trig list and must be reported to the publishing agency as soon as possible.

b. Sometimes the error may be due to several sets of coordinates being established over the same point from different surveys or different survey agencies and the wrong set of coordinates being published. The GIC must determine the most accurate with respect to commonality.

(1) A coordinate error will slide the entire traverse if closed on the same known station. The survey will appear to close but an unknown amount of position error will exist at each station.

(2) A coordinate will appear as if a distance error is present in the survey if the traverse is closed on a second known point.

c. When a trig list includes a misprint of a station's elevation, it is generally a typographical error. Sometimes, as with coordinates, more than one elevation may exist for the same station. The GIC must determine the most accurate with respect to commonality.

(1) An elevation error will raise or lower an entire traverse if closed on the same station. The survey will appear to close but an unknown amount of elevation error will exist at each station.

(2) Elevation error will appear as if a vertical angle error exists in the traverse if the traverse is closed on a second known station. The survey will close for coordinates and azimuth but not for elevation.

d. When a trig list includes a misprint of an azimuth between two stations, it is usually a typographical error of a computed or astronomic azimuth. Sometimes the azimuth may have been computed correctly but the stations were not common or as with some coordinate errors, the wrong station coordinates were used when more than one set of values were available. Always perform your own computation of an azimuth when using a computed azimuth from a trig list.

(1) An azimuth error will swing the traverse around the starting point if closed on the same station. The traverse will appear to close but it will contain an unknown amount of coordinate and azimuth errors.

(2) An azimuth error list will appear as if an angle error exists in the traverse if the traverse is closed on a second station.

e. Errors from field work will generally be of four types: distance, horizontal angle, vertical angle, and computational. The largest errors will be found in computations and recording. For the most part, field measurements made with the proper procedures will not include errors large enough to cause a survey to bust, especially with the precision available in current instrumentation. Most errors can generally be attributed to a lack of precise actions (attention to detail) on the part of the sensor support Marine. Proper training, planning, organization, and field procedures will eliminate most errors. If field work and computations are done properly, the cause of position, azimuth, and elevation errors will be primarily due to the commonality of the survey control. In most cases, this will not bust a survey. The following are examples of errors caused by that lack of precise action.

(1) All instrument readings must be clearly read to the recorder, and then read back to the instrument operator. The instrument operator must be viewing the scales when the values are read back, not turning to the next station or measuring the next distance.

(2) Recording errors are generally found in the meaning of the recorded data. When possible and practical, the instrument operator or team chief should verify those means before march ordering the equipment. The recorder must record the entire reading from the instrument operator then read back what was written, not what was heard. The recorder must listen for the command “bubble level”, indicating the use of the automatic index by the instrument operator, before recording vertical readings. Improper recording procedures can result in distance, horizontal angle, and vertical angle errors.

(3) Computer errors are generally attributed to improper computation and check computation procedures. Computations and check computations must be performed independently.

(4) Pointing errors can be located by measuring a direct and reverse reading over each station. Especially when a station is hard to pinpoint due to long distance or heat waves, a pointing error will result in horizontal or vertical angle errors that create a measure of azimuth and/or elevation error at closure. Very small distance errors are introduced in a survey that includes vertical angle errors and slope distances. This is because the vertical angle converts the slope distance to a horizontal distance.

(5) Forward stations must be properly plumb and level. When the theodolite is set up over that station in the same tribrach as the target set, it must be already plumb and

level, except for minor adjustments. If large plumb and level adjustments are made, the angle and distance measurements from that station will be made from a different position than they were made to on the previous angle. This introduces small angle and distance errors.

8-43. Locating a Traverse Error

a. Procedures for locating an error in a traverse will isolate a suspect station (horizontal or vertical angle) or leg (distance). These procedures assume that only one error is present that is large enough to cause the excessive non-closure. They also assume the error is not in the control. Location of traverse error procedures may designate a suspected station or leg even when multiple errors are present.

b. Locating and correcting traverse errors are performed in five steps:

(1) Close the traverse.

(2) Determine the eAz, RE, and eH.

(3) Determine the type of error indicated.

(4) Isolate the suspect station or leg.

(5) Check the field recorder's notebook and computations for math errors. If no error is found, return to the field and re-measure the necessary segments of the traverse.

8-44. Traverse Error Indicators

a. Figure 8-49 shows the indicated traverse error based on the type of traverse and the status of the azimuth and coordinate non-closure.

		Close On Starting Station	Close On Second Station
Azimuth	**Coordinates**	**Error Indication**	
Good	Good	Good Traverse	Good Traverse
Good	Bust	Distance Error	Distance Error
Bust	Good	Opening or Closing Angle	Closing Angle
Bust	Bust	Angle Error	Opening or Station Angle

Figure 8-49. Error Indicators

b. Obviously, if both azimuth and coordinates close, the traverse is good.

c. Whether closing on the starting point or on a second point, if azimuth meets specifications but coordinates do not, the indicated error is a distance error. If an angle in the survey were bad, azimuth would bust also.

d. When closing on the starting point, if azimuth busts and the coordinates are good, the error must be in the starting (opening) or closing angle. If an angle other than the opening or closing were in error or if a distance error were present, coordinates would not have closed. When closing on a second known point, if azimuth busts and the coordinates are good, the error must be in the closing angle. An angular or distance error anywhere else in the traverse would create a coordinate non-closure.

e. When closing on the starting point, if azimuth and coordinates bust, the error must be an angle other than the opening or closing angle. A distance is not the indicated error. If it were, the azimuth would be good. When closing on a second known point, if azimuth and coordinates bust, the error must be in the starting angle or a station angle, not the closing angle. The closing angle is not the indicated error, as the coordinates would have closed.

f. If coordinates close and azimuth close but height busts, see next paragraph.

8-45. Isolation of Distance Errors

a. A distance error is indicated when the azimuth for a traverse closes within tolerance but coordinate closure (RE) exceeds allowable specifications for that level of accuracy. Two methods of isolating a distance error can be used: the parallel line method and the computation of azimuth of RE. Both methods work on the assumption that the azimuth of the RE is the same as the azimuth of the line with the distance error, whether the error is short or long.

b. Use the parallel line method to determine which line in a traverse contains a distance error. It identifies the indicated line by creating a line that lies along the same azimuth or parallel to the error.

c. Plot the traverse on a 1/25,000 grid sheet using the largest scale possible to make small errors easier to see. Label the stations, including known and computed closing stations (Figure 8-50 page 8-56).

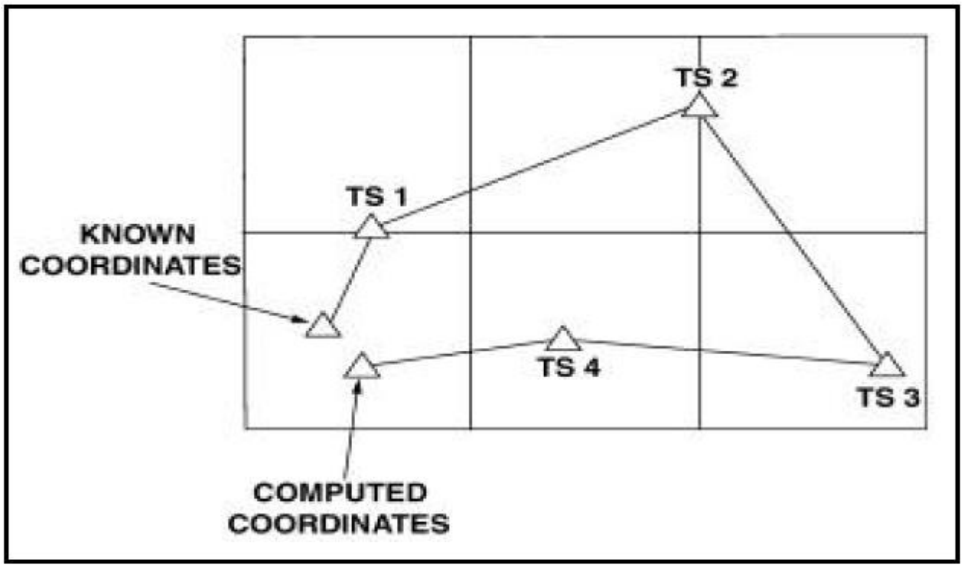


Figure 8-50. Plotting the Traverse

d. Using a straight edge, trace a line between the known and computed closing stations. Allow this line to extend beyond the plotted points (Figure 8-51). Identify the leg containing the error. The leg containing the error lies roughly parallel to the line traced above. Figure 8-51 shows the leg between TS-2 and TS-3 contains the distance error. Another way to locate a distance error in a traverse is to compute the azimuth of the RE. Compute from the known closing coordinates to the computed closing coordinates with the Survey program on the AN/PYG-1.

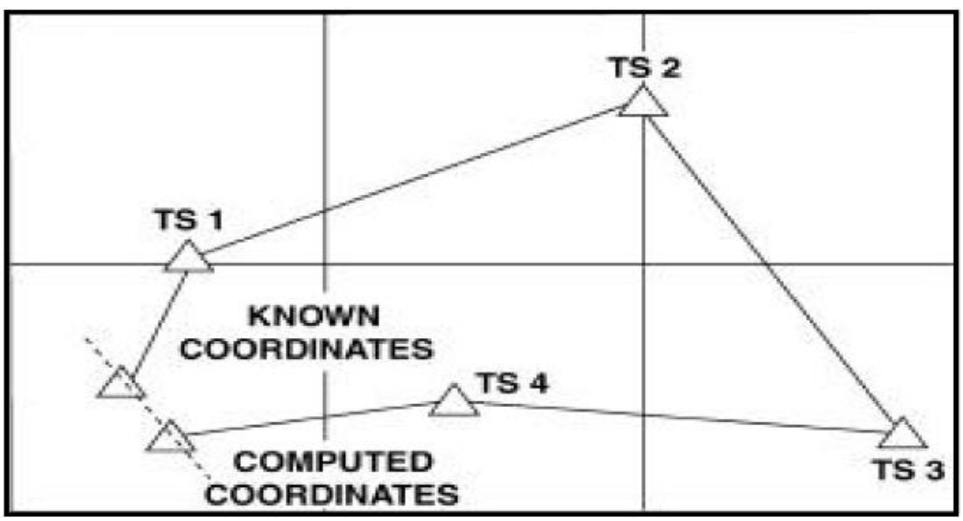


Figure 8-51. Determining the Error Leg – Parallel Line Method

e. On the traverse form or the printout find an azimuth to rear that roughly matches the azimuth of the RE. The suspect leg is the leg with an azimuth or back azimuth closest to the computed azimuth.

f. In analyzing an error like this, some tolerance and judgment must be used to determine the traverse leg in error. In angular and distance measurements, minor errors occur that have a large effect on the overall accuracy but are small enough to make error analysis difficult. In some traverses, several legs with azimuths nearly parallel to the azimuth of the RE could be indicated as the leg with the error. Check the recorded data first, then the computations for each suspected leg. If there is no error in recorded data or computations, then each suspected leg must be re-measured until the leg containing the error is found.

8-46. Isolation of Angle Errors

a. An angle error is indicated when the azimuth does not meet allowable closure specifications for that level of survey. Sometimes an angle error, depending on its location, will result in coordinate error exceeding allowable RE. Two ways of isolating an angle error can be used: the perpendicular bisector method and the mil relation formula (WeRM rule).

b. To determine which station in a traverse contains an angle error, use the perpendicular bisector by creating a line that passes over or near the station.

(1) Plot the traverse on a 1/25,000 grid sheet using the largest scale possible to make small errors easier to see. Label the stations, including the known and computed closing stations (Figure 8-52).

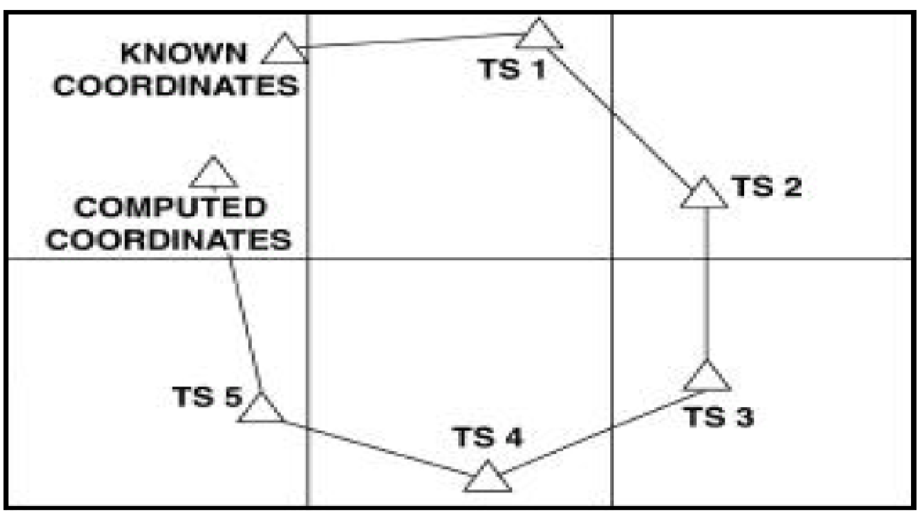


Figure 8-52. Plotting the Traverse – Isolation

(2) Using a straight edge, trace a line between the known and computed closing stations. Allow this line to extend beyond the plotted points. Place a dot on the line midway between the known and computed station. If the RE is large enough, divide it by 2 and measure the distance to ensure the dot is halfway between the points.

(3) Using a protractor, trace a line perpendicular to the RE line, extending into the survey.

(4) Identify the station containing the error. The line traced in step 3 will pass through

or near the station with the angle error. The example in figure 8-53 indicates that station TS-3 contains the angle error.

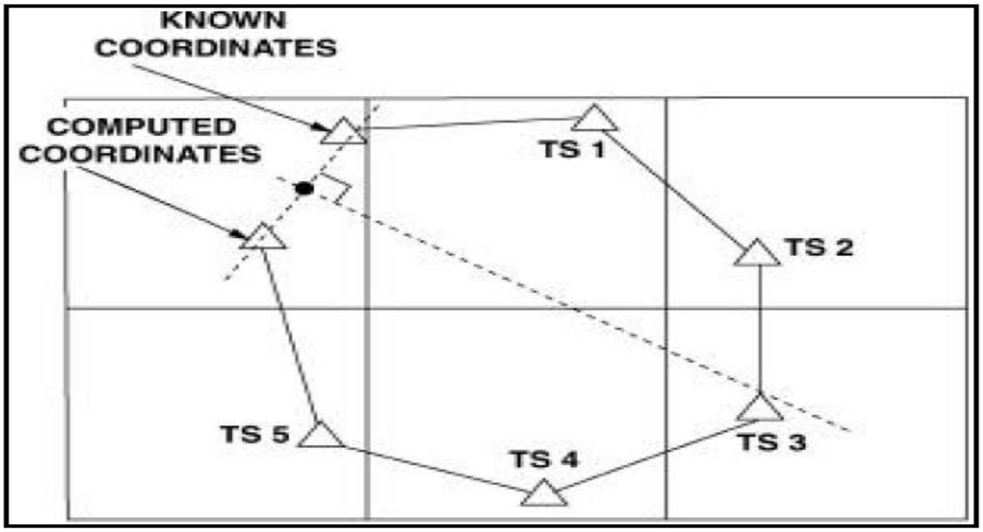


Figure 8-53. Determining the Error Station

c. Especially when closed on a second station or when the traverse follows a linear path, more than one suspect station could be identified by the perpendicular bisector method. The WeRM rule is a very good tool to isolate the error station.

d. The mil relation formula states that 1 mil of angle over a 1 kilometer distance will cause a 1-meter shift at the other end (Figure 8-54).

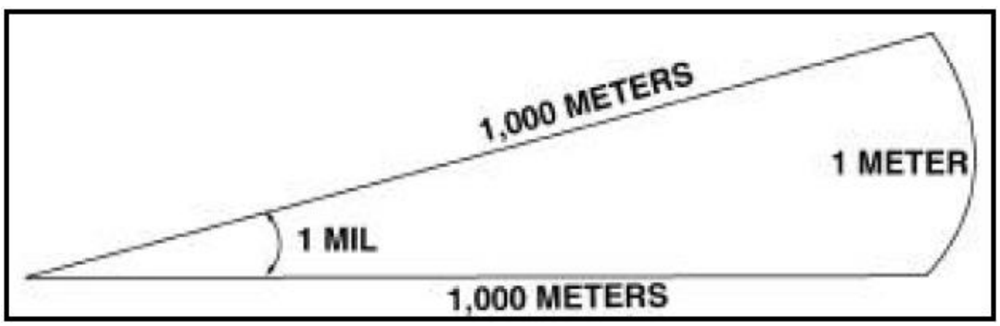


Figure 8-54. Mil Relation Formula (WeRM)

e. The WeRM rule uses this relationship between angle and distance to determine a distance to a station containing an angle error that corresponds to the RE. The distance in kilometers to the station containing the angle error is computed by dividing the RE by the azimuth error. Determine—

R = W/m when—
R is the range in kilometers
W is the radial error of closure
m is the azimuth error

f. Once the distance in kilometers is computed, locate a station that is that distance from the known station on the grid sheet used to plot the perpendicular bisector. The station in error should lie close to the distance. Following is an example:

Using a busted traverse that follows a linear path along a highway, the sensor team chief has determined that an angle error exists. The sensor cheif isolates three possible stations that may contain the error using the perpendicular bisector method. The RE of closure is 66.32 meters; the azimuth error is 10.178 mils. Using the WeRM rule, the distance to the suspect station is determined as—

$$R = 66.32/10.178$$
$$R = 6.516 \text{ kilometers } (6{,}516 \text{ meters})$$

g. In analyzing an error of this nature, some tolerance and judgment must be used to determine the traverse station in error. In angular and distance measurements, minor errors occur that have a large effect on the overall accuracy but are small enough to make error analysis difficult. In some traverses, several stations could be indicated as the one containing the error. Check the recorded data first, then the computations for each suspected station. If there is no error in recorded data or computations, then each suspected angle must be re-measured until the station containing the error is found.

8-47. Isolation of Multiple Errors

Multiple errors are errors in azimuth and distance or more than one error in either azimuth or distance. When multiple errors are in a traverse, indications are the same as for an azimuth error. It is possible that using the procedure for azimuth error determination definite suspect stations will be located, but an analysis will not reveal the error. The entire traverse should be performed again to locate the errors that were made.

8-48. Isolation of Elevation Errors

Vertical angle errors cause elevation errors. When a traverse does not meet allowable elevation error specifications, the suspect station can usually be isolated by comparing computed elevations and map spot elevations. At some point in the comparison, the elevation difference between computed and map spot elevations will change indicating a vertical angle error at the prior station. Check the recorded data and the computations at that station to locate the error. If the error cannot be located in the recorded data or the computations, return to the field and re-measure.

Section VIII. INTERSECTION

8-49. Intersection Method

Intersection is a survey method used to determine the location of a station which cannot be occupied. It requires the determination of the azimuths from the last two known stations to the intersected station. It requires an accurate elevation at one of the occupied stations and is the primary method of determining target location. Intersection can be performed using an S7 Total Station for survey control, or using a M2A2 aiming circle for target area survey.

8-50. Planning

When selecting the OPs for a target area survey the sensor support Marine must ensure proper geometry of the triangle. The distance angles must be at least 400 mils and preferably 533 mils, and the apex angle must be at least 150 mil and preferably 300 mils. When intersection is used for any other reason the apex angle has the same requirements as the distance angles, at least 400 mils and preferably 533 mils.

8-51. Execution

a. The known points can be either inter-visible or non-inter-visible. If the points are inter-visible (Figure 8-55), measure a horizontal angle from each point to the unknown point, using the other point as the rear station. Measure a vertical angle from 01 to the unknown point. Compute the azimuth between the two points by using the survey program on the AN/PYG-1. Then separately add each angle to the azimuth or back-azimuth to determine the azimuths from 01 and 02 to the unknown point. Example:

Horizontal angle at 01:	5549.113	Horizontal angle at 02:	1415.894
Azimuth 01 to 02:	+4957.572	Azimuth 02 to 01:	+1757.572
	10506.685	Azimuth to unknown	3173.466
	-6400.000	if azimuth is over 6400 mils, subtract 6400 mils	
Azimuth to unknown:	4106.685		

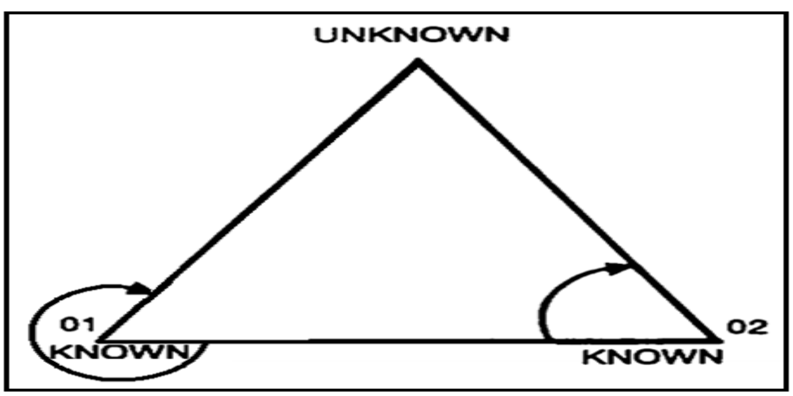


Figure 8-55. Inter-visible Points

b. Determine if the apex angle meets the requirements by doing the procedure below.

(1) Determine the back-azimuths from the unknown point back to the known points by adding or subtracting 3,200 mils. Example:

Azimuth 01 to unknown point: 4106.685		Azimuth 02 to unknown point: 3173.466
-3200.000		+3200.000
Azimuth unknown point to 01: 0906.685		Azimuth unknown point to 02: 6373.466

(2) Imagine yourself standing at the unknown point looking back at the known points. Point 02 is located to the left side and point 01 to the right. Subtract the azimuths from left to right. Example:

Azimuth unknown point to 01:	0906.685
	+6400.000
	7306.685
Azimuth unknown point to 02:	-6373.466
	0933.219

If the azimuth to the right is smaller than the azimuth to the left add an entire circle (6400 mils) to the azimuth on the right.

c. If the points are non-inter-visible (Figure 8-56 page 8-62), do the procedure below.

(1) Measure a horizontal angle from both points to the unknown point by using a point with a known azimuth as a rear station. Each angle is then added separately to the known azimuth to determine the azimuths from 01 and 02 to the unknown point.

(2) Determine if the apex angle meets the requirements. Example:

Azimuth 01 to azimuth mark:	0409.1	Azimuth 02 to azimuth mark: 2594.8
Angle 01 to the unknown:	3015.5	Angle 02 to unknown:
	+3576.0	
	7110.6	Azimuth 02 to unknown: 6170.8
	-6400.0	
Azimuth 01 to the unknown	0710.6	

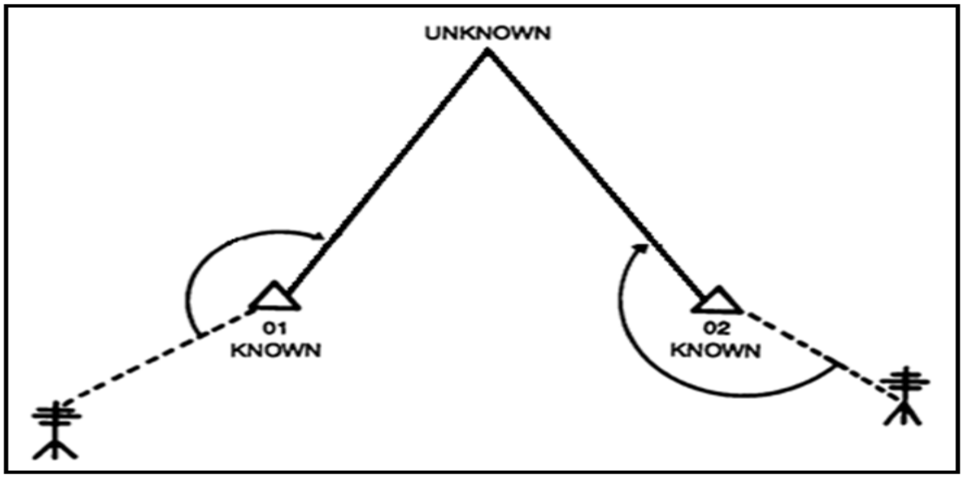


Figure 8-56. Non-inter-visible Points

d. Intersection computations are done with the survey program on the AN/PYG-1.

e. To determine the accuracy of an intersection, conduct the following procedures.

(1) Conduct another intersection to the unknown point by using either one or two other observation points.

(2) Perform computations from the points designated as 01 and 02 to the unknown point.

(3) Compute the azimuth and distance between the computed coordinates of first intersection to the computed coordinates of the second intersection. (This will be the radial error.)

(4) Divide the radial error into the shorter of the two distances, 01A to the unknown point or 01B to the unknown point. This is the accuracy ratio of the intersection. The accuracy ratio must agree within the prescribed accuracy limits for the type of survey being performed (1:1,000 for fifth order, 1:3,000 for fourth order).

(5) Once the accuracy ratio has been computed and meets specifications described in d above, determine the mean coordinates and elevation for the unknown point.

Section IX. CONVERTING TO COMMON CONTROL

8-52. Echelon of Survey

The highest echelon survey unit in the area establishes the common grid. Missions of lower echelon units require they initiate survey operations immediately without waiting for control to be established by higher echelon units. A firing battery must use hasty methods to establish survey so that it can provide support immediately. It cannot wait on control from the battalion sensor section. Battalion sensor support Marines must provide control to the firing batteries and target acquisition assets assigned to that battalion. TAP sensor support Marines must establish control immediately throughout the division area without waiting for topographic surveyors or recovery of existing control currently in enemy territory. These initial surveys are not considered to be on a common grid so conversion to a common grid will be required.

8-53. Comparisons

a. Conversion to common control is performed by making a comparison between the higher and lower echelon data and converting the lower echelon to the higher echelon based on that comparison. Data is converted to common control when higher and lower echelon data differ by:

(1) 2 mils or more in azimuth.

(2) 10 meters or more in radial error.

(3) 2 meters or more in elevation.

b. When a comparison is made between the azimuths of a line that is included in the higher and the lower echelon network, the lower echelon network must be converted to common control if the azimuths differ by 2 or more mils. For example, a firing battery uses the hasty astronomic method and determines an azimuth from the OS to the EOL of 2319.0 mils. The battalion sensor team determines an azimuth of 2321.6 mils over the same line. The difference between the higher and lower data is 2.6 mils. The azimuth must be converted.

c. When a comparison is made between the coordinates of a point that is included in the higher and lower echelon networks, the lower echelon network must be converted to common control when the radial error (RE) between the stations is 10 meters or more. RE in this case is not the RE computed for a traverse closure. It is the straight-line distance between the higher and lower echelon coordinates of the same station.

d. When a comparison is made between the elevations of a point that is included in the higher and lower echelon networks, the lower echelon network must be converted to common control when the difference between the elevations is 2 meters or more. For example, a firing battery uses hasty survey methods to determine an OS elevation of 432 meters; the battalion sensor team uses RTK methods to determine an OS elevation of

437.4 meters. The difference between the two elevations is 5.4 meters. The lower echelon data must be converted to common control.

8-54. Swinging the Grid

Several methods of converting data to a common network are available. The method used depends on the type and amount of azimuth, coordinate, and/or elevation error between the higher and lower echelon data. The rest of this section discusses methods to convert data.

a. Swinging the grid converts a lower echelon network to the higher echelon network when the azimuth difference is 2 mils or greater and the RE is less than 10 meters (Figure 8-57). This is necessary when an azimuth is assumed in conventional survey methods. For An azimuth from the IPADS-G or differential GPS should meet the 2-mil specification. If 2 mils is exceeded, an equipment malfunction should be considered.

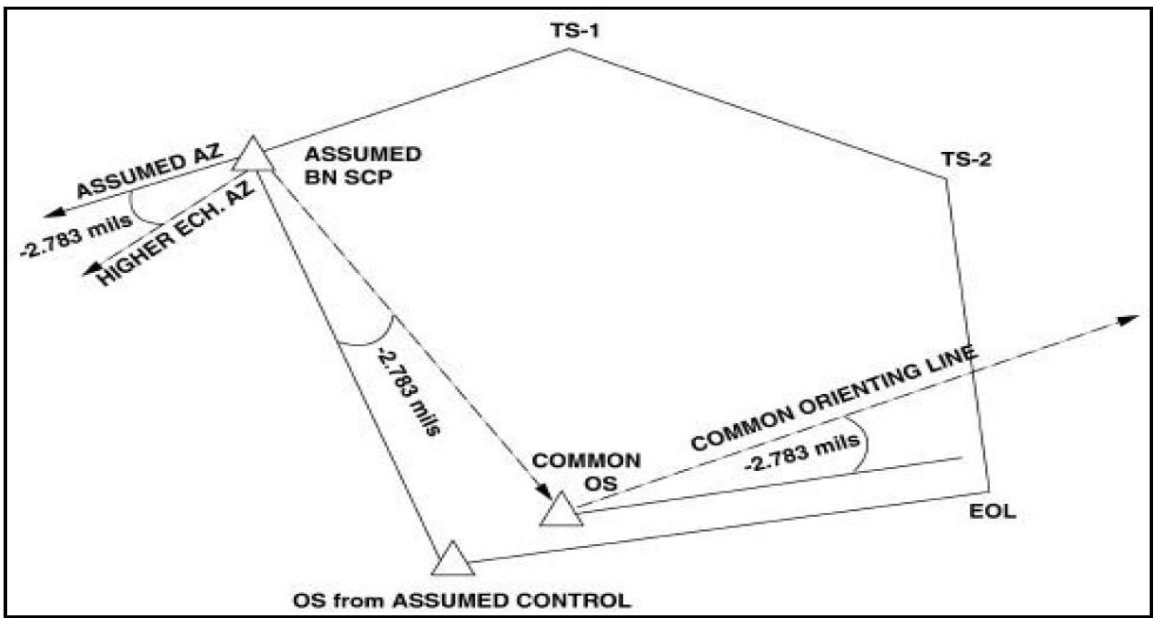


Figure 8-57. Swinging the Grid

b. As long as a survey is maintained in the memory of a survey computer program, the easiest way to convert a lower echelon network to the higher echelon grid is to enter the higher echelon data in the survey computer and re-compute the survey.

c. Sometimes it is not necessary to re-compute the entire traverse. For example, if a traverse has 20 legs and only 4 of those legs are between critical stations, it may be faster to compute individual legs. When swinging the grid over individual legs, perform Steps 1 through 4.

(1) Determine the azimuth correction by subtracting the lower echelon azimuth from the higher echelon azimuth. For example, the azimuth assumed by a battalion sensor section is 4390 mils, the azimuth over that leg as determined by the higher echelon section is 4387.217 mils. Determine the correction as:

Higher	4387.217	
Lower	4390.000	
Correction	–2.783	mils

(2) Compute the azimuth and distance between the starting station and each critical station using the coordinates determined in the lower echelon survey.

(3) Determine the adjusted azimuth to each critical station by applying the azimuth correction determined in Step 1 to each azimuth determined in Step 2. For example, if the azimuth computed in Step 2 from the starting station to the OS is 2745.354 mils, determine the adjusted azimuth as:

Computed	2745.354	
Correction	–2.783	
Adjusted Azimuth	2742.571	mils

(4) Using the adjusted azimuth from Step 3 and the computed distance from Step 2, compute a dogleg (offset) coordinate for each station. This step places the critical station on common grid.

d. Apply the azimuth correction from Step 1 to the azimuth determined in the original computations. This places the azimuth line on a common grid. For example, if the azimuth from the OS to the EOL in the original computations was 1537.876 mils, determine the adjusted (common) azimuth as:

Computed	1537.876	
Correction	–2.783	
Common Adjusted Azimuth	1535.093	mils

8-55. Sliding the Grid

a. This method converts a lower echelon network to the higher echelon network when the azimuth difference is less than 2 mils, and the RE is 10 meters or greater. This is usually necessary when a position is assumed. Sliding the grid converts to common control with the IPADS-G and differential GPS operations (Figure 8-58 page 8-66).

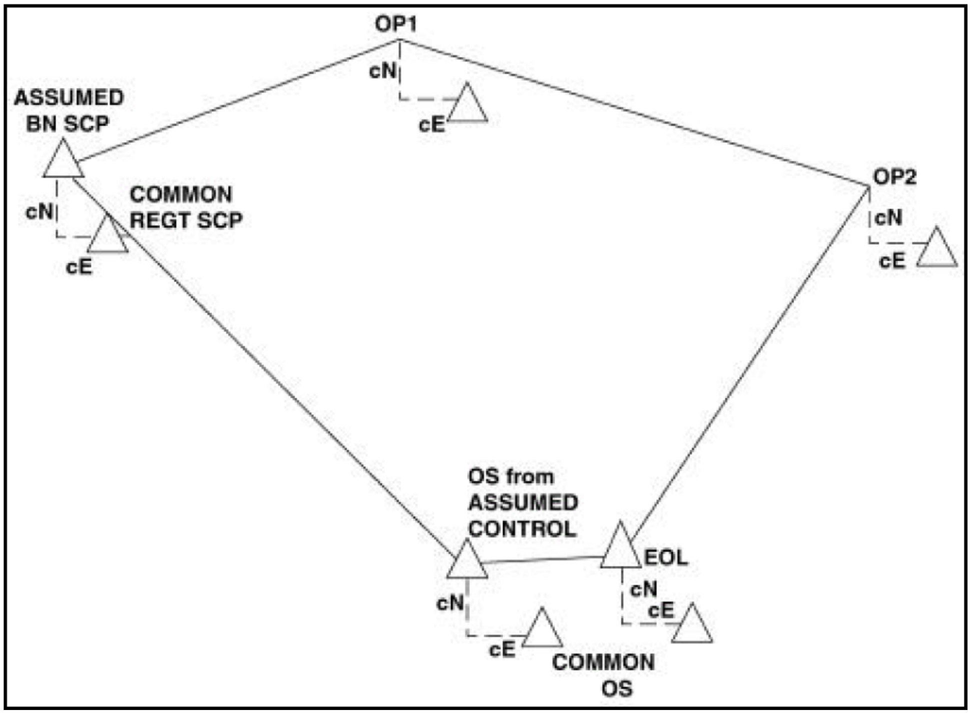


Figure 8-58. Sliding the Grid

b. For a static GPS network conversion to common control is performed by changing the fixed position of the assumed station in the post-processing software.

c. For differential GPS and IPADS-G operations, there is no way to convert stored stations to common control internally to GPS or IPADS-G. Converting individual stations is performed as shown in Steps 1 and 2.

(1) Determine the easting and northing correction between the lower and higher echelon data by subtracting the lower echelon easting and northing from the higher echelon easting and northing. For example, a battalion sensor section updates its IPADS-G with a DAGR grid of E: 555267 N: 3835216. A TAP sensor team later provides common control over that station using differential GPS methods and determines a grid of E: 555278.32 N: 3835211.87. Determine the correction as:

	Easting	Northing
Higher	555278.32	3835211.87
– Lower	555267.00	3835216.00
Correction	+11.32 meters (+11.3 meters)	–4.13 meters (–4.1 meters)

(2) Apply the corrections determined in Step 1 to the easting and northing coordinates of each critical station in the survey. For example, if the coordinates for an OS as determined by the IPADS-G are E: 556782.9 N: 3836346.9, determine the common grid coordinates as—

	Easting	Northing
OS	56782.9	3836346.9
Correction	+11.3	−4.1
Common OS	56794.2	3836342.8

8-56. Swinging and Sliding the Grid

Swinging and sliding the grid converts a lower echelon network to the higher echelon network when the azimuth difference is 2 mils or greater and the RE is 10 meters or greater. This is usually necessary when position and azimuth is assumed in conventional survey methods. If an azimuth is determined by the IPADS-G, differential GPS methods or astronomic observations, the azimuths between higher and lower echelons will usually be within the 2-mil specification (Figure 8-59).

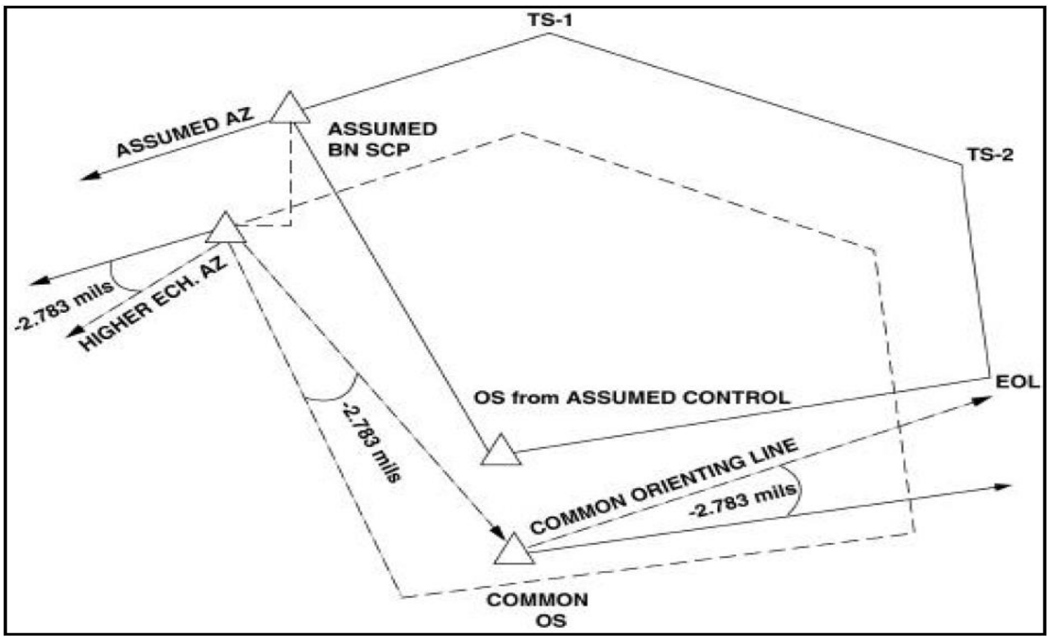


Figure 8-59. Swinging and Sliding the Grid

a. As long as a survey is maintained in the memory of a survey computer program, the easiest way to convert a lower echelon network to the higher echelon grid is to enter the higher echelon data in the survey computer and re-compute the survey.

b. Swinging and sliding the grid are performed at the same time. When swinging and sliding the grid over individual legs, perform Steps 1 through 5.

(1) Determine the azimuth correction between the higher and lower echelon networks. For example, the azimuth assumed by a battalion sensor section is 4390 mils, the azimuth over that leg as determined by the higher echelon section is 4387.217 mils. Determine the correction as—

Higher	4387.217	
Lower	–4390.000	
Correction	–2.783	mils

(2) Compute the azimuth and distance between the starting station and each critical station using the coordinates determined in the lower echelon survey.

(3) Determine the adjusted azimuth to each critical station by applying the azimuth correction determined in Step 1 to each azimuth determined in Step 2. For example, if the azimuth computed in Step 2 from the starting station to the OS is 2745.354 mils, determine the adjusted azimuth as—

Computed	2745.354	
Correction	–2.783	
Adjusted Azimuth	2742.571	mils

(4) To place the critical station on common grid, use the higher echelon coordinates, the adjusted azimuth from Step 3, and the computed distance from Step 2, compute a dogleg (offset) coordinate for each station.

(5) To determine the common azimuth of a critical line; e.g., orienting line or target area base, apply the azimuth correction from Step 1 to the azimuth determined in the original computations. This places the azimuth line on a common grid. For example, if the azimuth from the OS to the EOL in the original computations was 1537.876 mils, determine the adjusted (common) azimuth as—

Computed	1537.876	
Correction	–2.783	
Common Azimuth	1535.093	mils

8-57. Leveling the Grid

a. Leveling the grid converts a lower echelon network to the higher echelon network when the elevation difference is 2 meters or greater. This will usually occur with a map spot and an absolute GPS elevation. Leveling the grid is performed at the same time as the other conversion to common methods.

b. When conventional methods are used, it may be easier to re-compute the survey.

c. For a static GPS network conversion to common control is performed by changing the fixed position of the assumed station in the post-processing software.

d. Leveling the grid for IPADS-G or differential GPS is conducted by converting individual stations as shown in Steps 1 through 3.

(1) When leveling or leveling and sliding the grid, determine the elevation correction between the lower and higher echelon data by subtracting the lower echelon

elevation from the higher echelon elevation. For example, a battalion Sensor section updates its IPADS-G with a DAGR elevation of 356 meters. A TAP sensor team later provides common control over that station using differential GPS methods and determines an elevation of 352.8.

Higher	352.8	
– Lower	356.0	
Correction	–3.2	mils

(2) Apply the corrections determined above to the elevation of each critical station in the survey. For example, if the elevation for an OS as determined by IPADS-G is 398.3, the common grid elevation is determined as:

OS	398.3	
Correction	–3.2	
Common OS	395.1	meters

(3) When leveling the grid is performed with swinging or swinging and sliding the grid, the higher echelon elevation is used in place of the lower echelon elevation in the computations of the doglegs to each critical station.

CHAPTER 9 ARTILLERY ASTRONOMIC OBSERVATIONS

Section I. BASIC ASTRONOMY

9-1. General

Understanding the geodetic relationship of the earth to the surrounding celestial bodies is critical to conducting the various methods of artillery astronomic observations. Chapter eleven will include the principles and methods of artillery astronomic observations, identification diagrams during star selection and the proper techniques for recording observations. This chapter will emphasis methods of gaining directional control using astronomic observations.

9-2. The Tilted Polar Axis and Movement of the Earth

a. The Earth can best be visualized as an ellipsoid. The line connecting the flattened ends or the shorter axis is the Earth's rotating axis. The points on the Earth where this axis intersects the surface are the north and south poles; therefore, the rotating axis is also referred to as the polar axis. If the Earth's polar axis were perpendicular to its orbit around the Sun, there would be no change in seasons; the Sun's rays would always be directed at the equator. Because the Earth's axis is tilted at an angle of approximately 23° 30' (417.78 mils), the Sun's rays are directed at different portions of the Earth as it orbits the Sun (Figure 9-1).

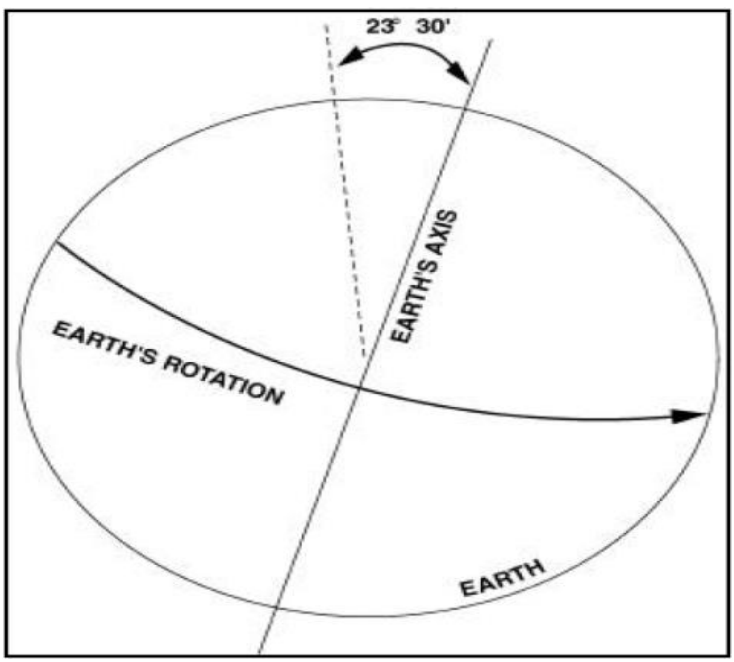


Figure 9-1. Earth's Rotational Axis

b. The Earth and its motions are of primary interest to the artillery sensor support Marine. These motions form a complex pattern, all of which affect the Earth's relationship to the stars and other planets. The Earth makes one 360° rotation on its axis every 23 hours 56 minutes 04.09 seconds. Rotation is from west to east. Because of revolution, the Earth must rotate more than 360° for the same point to face directly at the Sun on subsequent days. The Earth revolves around the Sun approximately once every 365 days over a 600 million mile orbit at a rate of 18.5 miles per second. The counter-clockwise orbit is elliptical with an average distance to the Sun of about 93 million miles. Other types of motion affect the Earth. The north and south poles are not stationary; they vary through rough circles approximately 40 feet in diameter. There is solar motion of 12 miles per second, while the Earth's portion of the galaxy is moving through space at approximately 170 miles per second.

9-3. Celestial Sphere

a. For purposes of practical astronomy, we assume that the Earth is at the center of the universe and that everything else (the Sun, stars, planets, etc.) falls on the surface of a sphere of infinite radius referred to as the celestial sphere (Figure 9-2). We also assume that the Earth is stationary and that the celestial sphere rotates around the Earth from east to west. This is because the Earth rotates west to east (counter-clockwise), so the apparent motion of celestial bodies is the opposite direction.

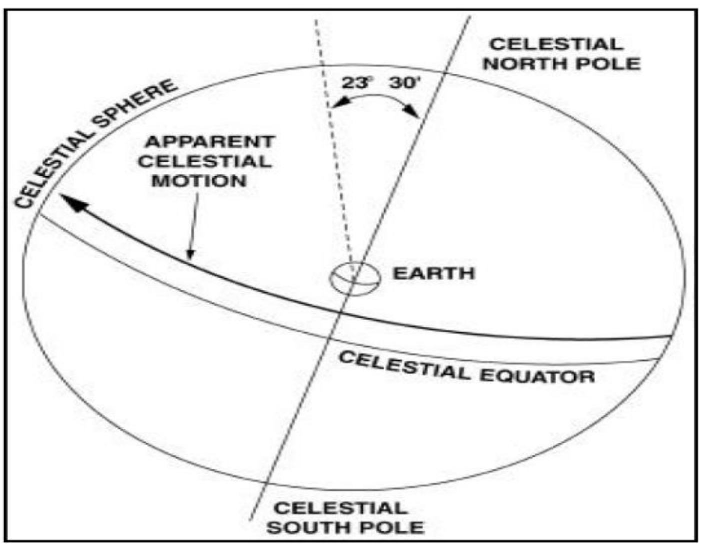


Figure 9-2. Celestial Sphere

b. The celestial sphere rotates around the stationary Earth on an axis that coincides with the polar axis of the Earth. Locations of the celestial poles are at the point in the sphere where the Earth's polar axis would intersect the sphere if they were extended into space. If the plane of the Earth's equator was extended into space, the point where that plane intersects the celestial sphere is the celestial equator.

9-4. Celestial Coordinates

a. Computations of astronomic observations are performed in part using the celestial coordinates of points on the celestial sphere. Since these coordinates are located on the surface of a sphere, they are referred to as spherical coordinates. Generally, there are two systems of spherical coordinates: the horizon system and the equator system. For artillery survey methods, the equator system is used.

b. Any circle on the surface of the celestial sphere whose plane passes through the center of the celestial sphere is called a great circle. For example, the celestial equator is a great circle. When that plane is set perpendicular to the celestial equator it is referred to as an hour circle and includes both poles of the celestial sphere.

c. The observer's meridian is an hour circle that includes the plane of the observer's longitude. The upper transit of the observer's meridian is that part that includes the observer's longitude and the observer's zenith (the observer's plumb line extended upward to the celestial sphere). The lower transit of the observer's meridian is 180° from the upper transit and includes the observer's nadir (the observer's plumb line extended downward to the celestial sphere).

d. The position of the observer on the surface of the Earth is located by latitude and longitude. When the observer's plumb line is extended upward to the celestial sphere, a point referred to as the observer's zenith or the zenith position is established. The zenith position is also located by latitude and longitude and provides a fixed position of the observer's instrument on the celestial sphere. The zenith latitude is the arc distance from the celestial equator to the observer's zenith. The zenith longitude is the arc distance along the celestial equator from the plane of the prime meridian (Greenwich Meridian) to the plane of the observer's meridian extended to intersect the celestial sphere. Zenith longitude is also the angle between those two planes as measured at the celestial poles (Figure 9-3).

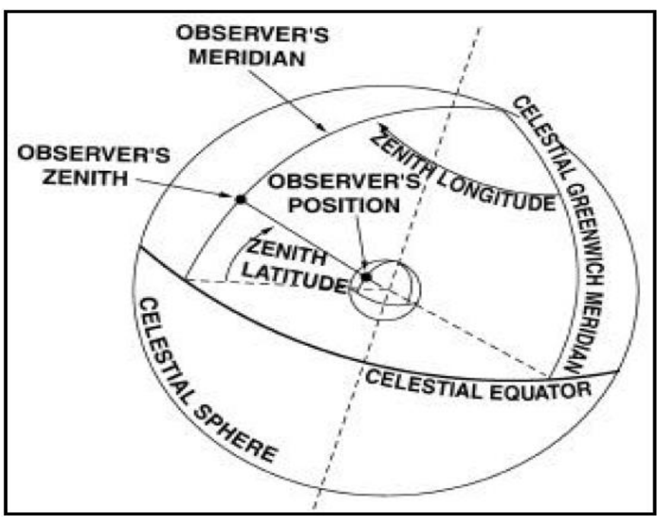


Figure 9-3. Zenith Position

e. The prime vertical for the position of an observer is a great circle on the celestial sphere that is perpendicular to the observer's meridian at the zenith and intersects the observer's horizon at points due east and west of the observer.

f. The position of a star on the celestial sphere is defined in terms of right ascension and declination.

g. As the Sun moves across the celestial sphere it traces a path referred to as the ecliptic. The ecliptic is tilted approximately 23° 30’ (417.78 mils) from the celestial equator (Figure 9-4) due to the tilt of the celestial sphere on its axis. It crosses the celestial equator at two points along its path. The point where the ecliptic crosses the celestial equator from the southern hemisphere to the northern hemisphere is the vernal equinox, the first day of spring usually around March 21.

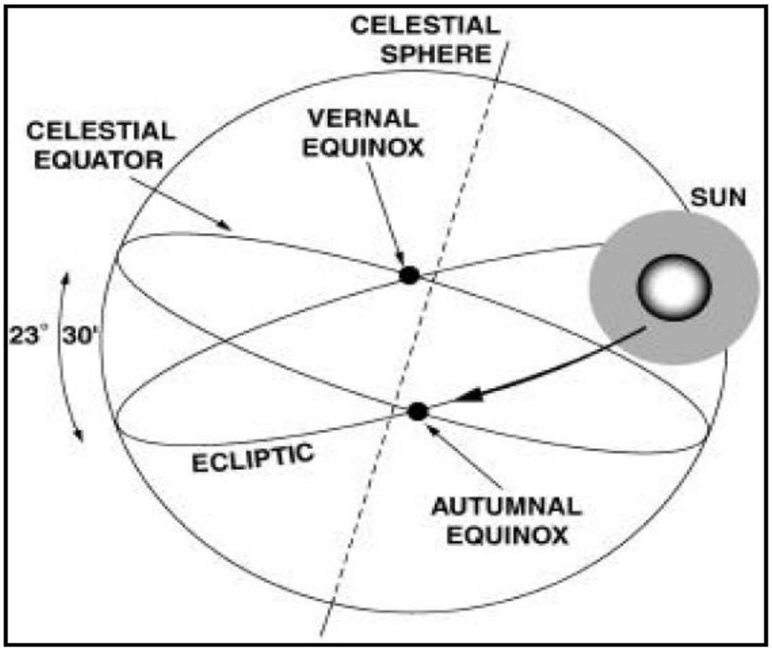


Figure 9-4. Ecliptic and Vernal Equinox

h. Right ascension is the arc distance eastward along the celestial equator measured from the vernal equinox (Figure 9-5 page 9-5) to the hour circle of a celestial body. In most cases, right ascension is expressed in terms of arc time; i.e., hours: h, minutes: m, and seconds: s. It can vary from 0h to 24h east of the vernal equinox. Declination is the arc distance measured from the celestial equator to the body along the hour circle of the star. It can be north (+) or south (-) of the celestial equator and is usually expressed in terms of degrees (°), minutes (’), and seconds (“). It can be expressed in terms of mils. Declination can vary from 0° to 90° north or south of the celestial equator.

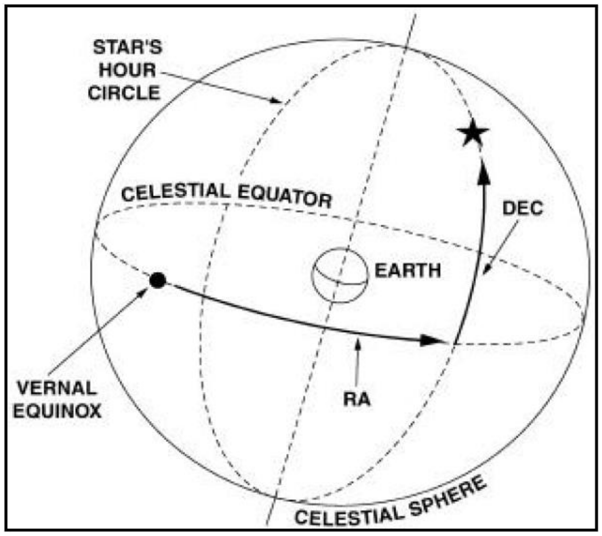


Figure 9-5. Right Ascension and Declination

9-5. Astronomic Triangle (PZS Triangle)

a. Determining an astronomic azimuth requires on the solution of a spherical triangle located on the surface of the celestial sphere. This triangle (Figure 9-6) is referred to as the PZS triangle. The PZS triangle has vertices at the celestial north pole, at the observer's zenith, and at the star (or Sun). These vertices are the intersections of great circles that include the triangle's sides (Figure 9-6). The method of astronomic observation determines the sides and vertices of the triangle to be solved.

b. The sides of the PZS triangle are segments of great circles passing through any two of the vertices. Sides are arcs and as such are measured with angular values. The three sides of the triangle are the polar distance, the coaltitude, and the colatitude.

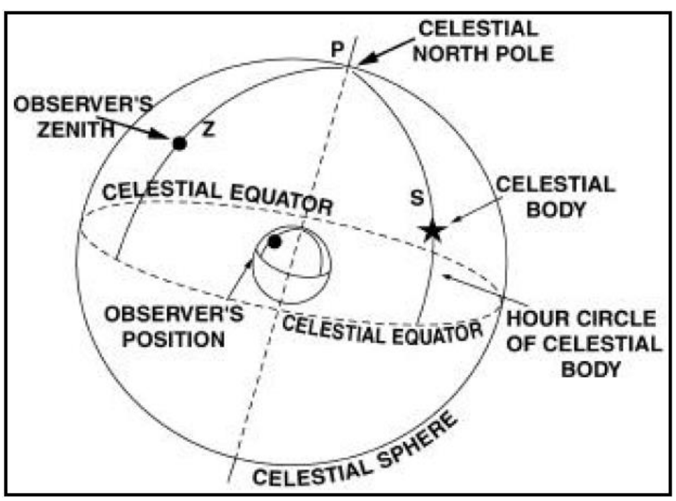


Figure 9-6. Vertices of the PZS Triangle

c. Polar distance (Figure 9-7 page 9-6) is a segment of the hour circle of the celestial body. It is the arc length of the side of the PZS triangle from the celestial north pole to the celestial body (the PS side). It is determined by applying the celestial body's declination to 90°. In other words, if the declination is north (+), the polar distance equals 90° minus the declination; if the declination is south (–), the polar distance equals 90° plus the declination.

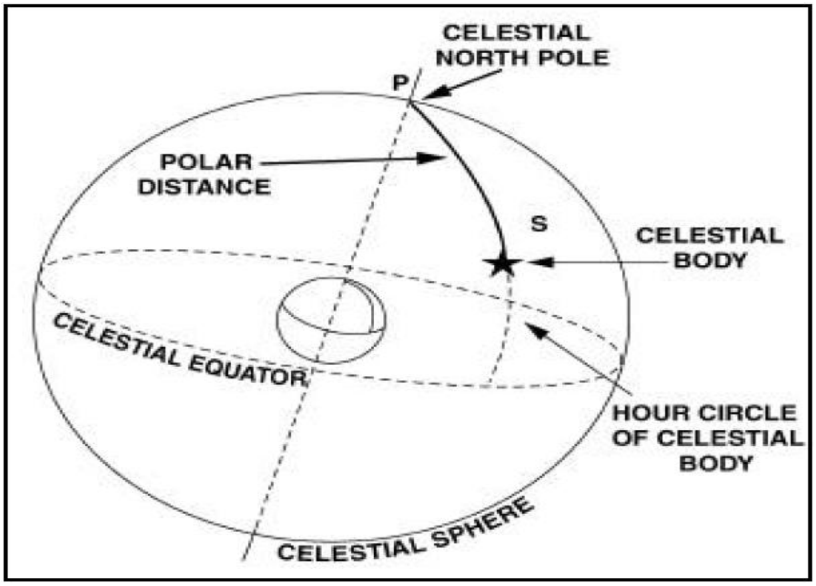


Figure 9-7. Polar Distance

d. Coaltitude (Figure 9-8) is the arc length of the side of the PZS triangle from the celestial body to the observer's zenith. The observer's horizon is a plane that is tangent to the surface of the Earth at the observer's position. It is also perpendicular to the observer's zenith.

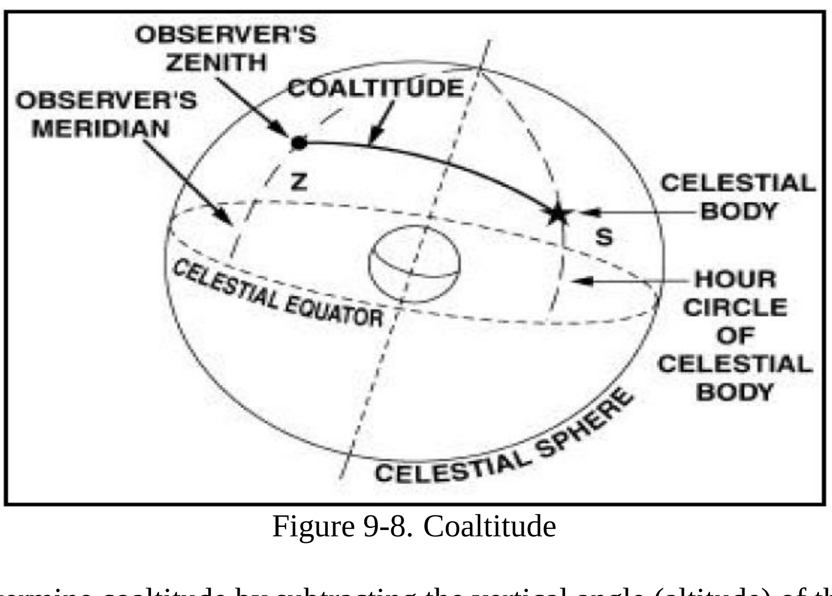


Figure 9-8. Coaltitude

(1) Determine coaltitude by subtracting the vertical angle (altitude) of the celestial body from 90° (1600 mils). This vertical angle must be corrected for refraction and parallax for sun observations and corrected for refraction for star observations. The

resultant angle is side ZS of the PZS triangle and is referred to as the zenith angle of the celestial body (Figure 9-9).

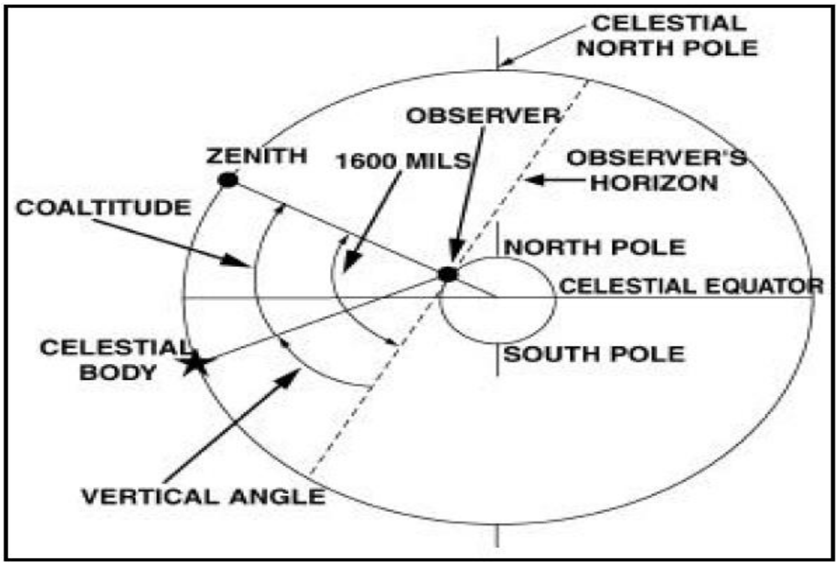


Figure 9-9. Zenith Angle

(2) Parallax (Figure 9-10) can be defined as the apparent displacement of a body on the celestial sphere caused by a change in position of the observer. In other words, the observed altitude, or vertical angle, of a celestial body must be corrected for the error introduced by the observer's location on the surface of the Earth vice the center of the Earth. The nearest star is 26 x 10^{12} miles from Earth; the Sun is only 93 x 10^{6} miles from Earth; because the stars are so distant, the apparent displacement of the stars is nearly immeasurable. For this reason, parallax corrections are used for observations on the Sun only. Parallax on the Sun varies from +9" when it is on the observer's horizon (vertical angle 0 mils) to 0" when it is on the observer's meridian. For artillery survey, a constant value of +7" (0.04 mils) is used.

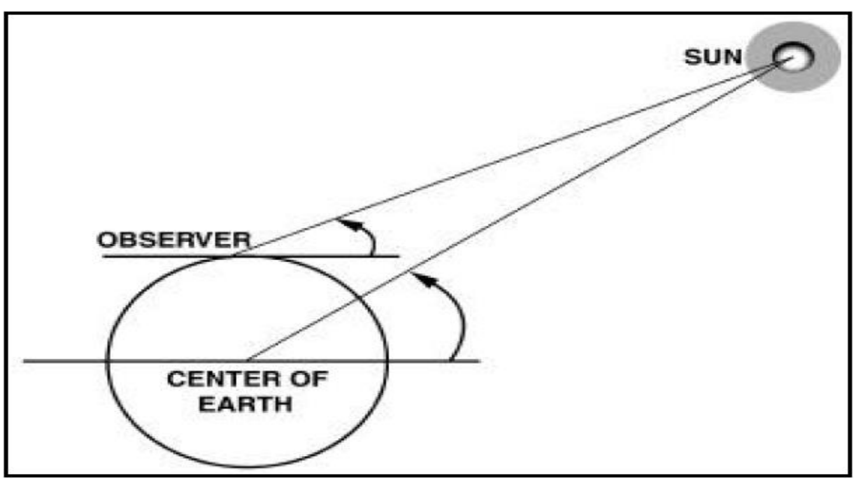


Figure 9-10. Parallax

(3) Refraction (Figure 9-11) can be defined as the apparent displacement of a body on the celestial sphere caused by the deflection of light rays as those rays pass through the Earth's atmosphere. A ray of light passing through the Earth's atmosphere at a large angle of incidence, (the angle formed by the line of the light ray and a line which is perpendicular to the atmosphere), will have a larger refraction correction than a ray of light passing through an area close to the observer's zenith. Refraction of a body varies according to the altitude (vertical angle) of the body above the horizon and the temperature. For example, refraction of a celestial body located on the observer's horizon (0 mils) at a temperature of 70° is 10.26 mils; refraction of a body located on the observer's zenith is 0 mils. Refraction increases with an increase in barometric pressure and a decrease in temperature. Refraction corrections are always negative.

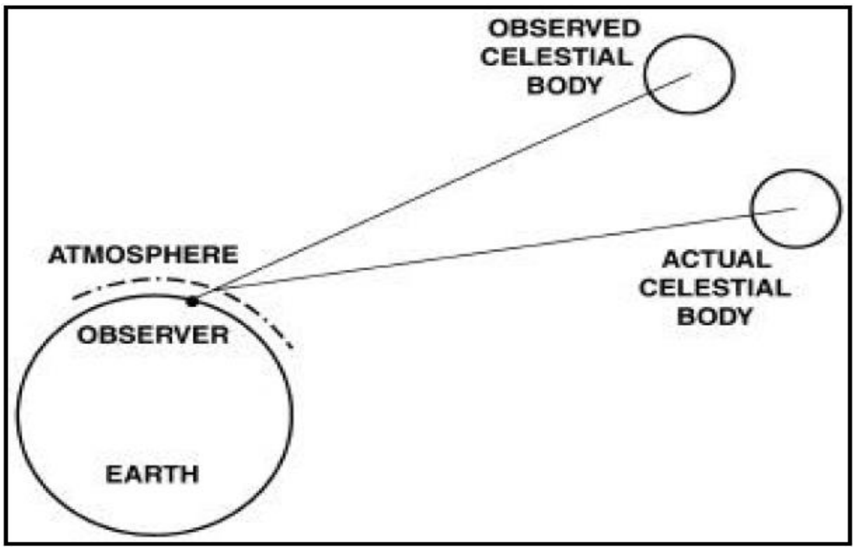


Figure 9-11. Refraction

e. Man hour circle known as the observer's meridian. It is the arc length of the side of the PZS triangle from the celestial north pole to the observer's zenith (the PZ side). It is determined by applying the observer's latitude to 90°. If the observer's latitude is north (+), the colatitude equals 90° minus the observer's latitude. If the observer's latitude is south (–), colatitude equals 90° plus the observer's latitude (Figure 9-12 page 9-9).

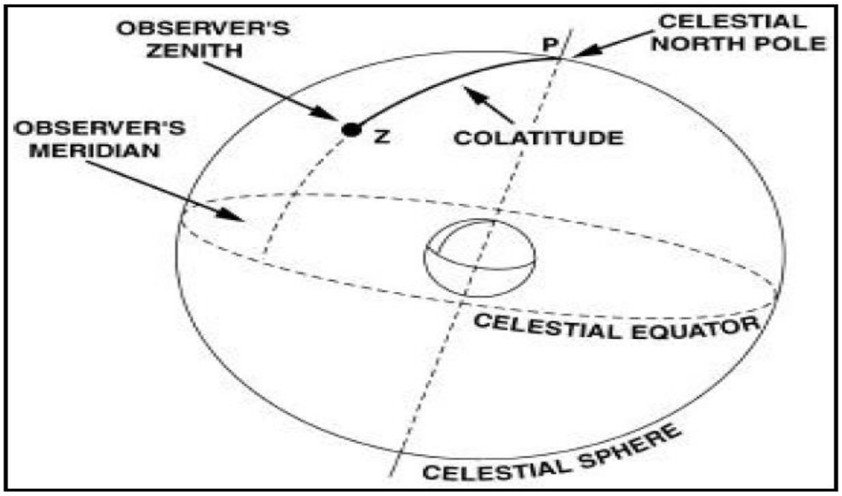


Figure 9-12. Colatitude

f. The three angles formed by the intersection of the three sides of the PZS triangle are the parallactic angle, the hour angle (time angle), and the zenith angle.

(1) The interior angle at the celestial body formed by the intersection of the polar distance side (PS side) and the coaltitude side (ZS side) is the parallactic angle (Figure 9-13). It is used in determining astronomic azimuths but is canceled out during the computations.

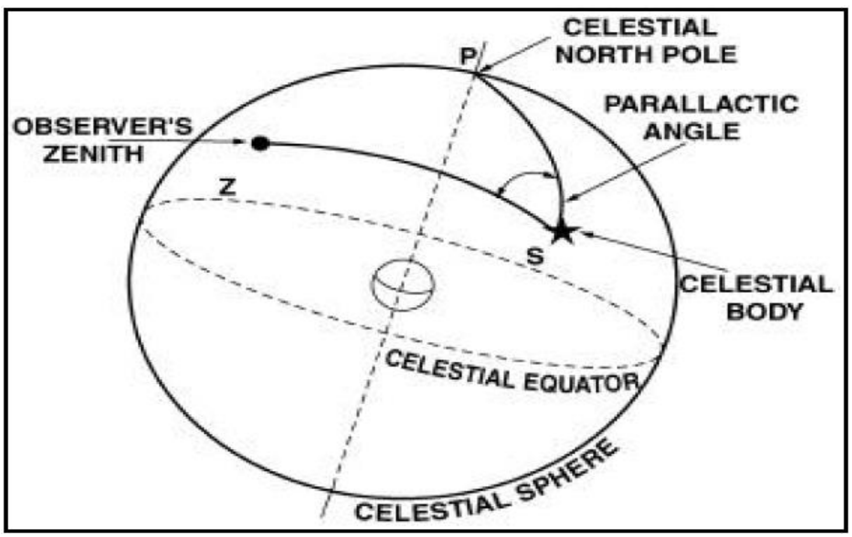


Figure 9-13. Parallactic Angle

(2) The interior angle at the celestial north pole formed by the intersection of the polar distance side (PS side) and the colatitude side (PZ side) is the hour angle. The letter "t" designates the hour angle. The local hour angle represents the elapsed time since the celestial body crossed the observer's meridian (Figure 9-14 page 9-10).

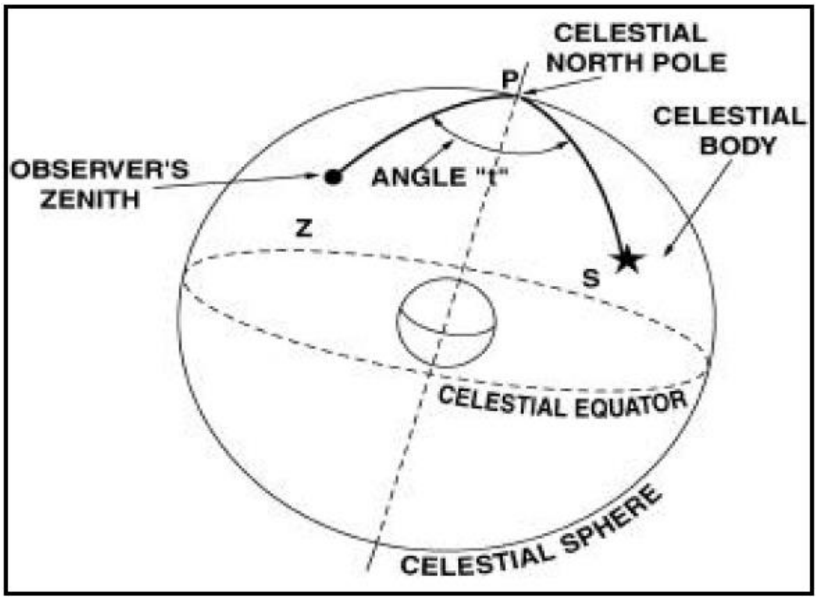


Figure 9-14. Hour Angle (Time Angle or Angle t)

(3) The interior angle at the zenith formed by the intersection of the coaltitude side (ZS side) and the colatitude side (PZ side) is the azimuth angle (Figure 9-15) or zenith angle. This angle is the product of computations and is the angle used to compute the true azimuth from the observer to the celestial body. When the celestial body is east of the observer's meridian, the true azimuth is equal to the azimuth angle. When the celestial body is west of the observer's meridian, the true azimuth is equal to 360° (6400 mils) minus the azimuth angle.

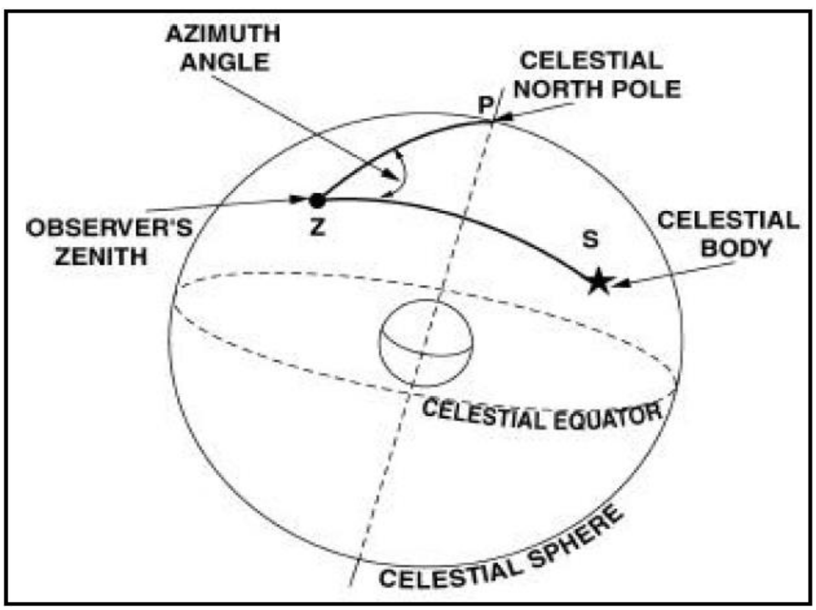


Figure 9-15. Azimuth Angle

(4) If any three elements of the PZS triangle are known, the other three elements of the PZS triangle can be determined by spherical trigonometry. In the end, the element

that must be solved is the azimuth angle. This angle is necessary to establish a true azimuth on the ground. Figure 9-16 depicts the complete PZS triangle.

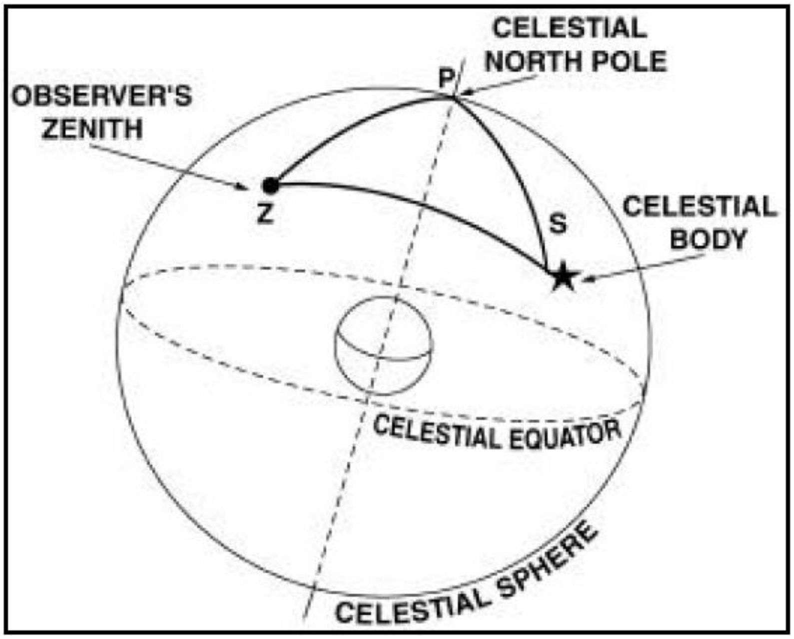


Figure 9-16. PZS Triangle

9-6. The Relationship between Solar Time and Sidereal Time

a. Since the celestial bodies are in constant motion with the apparent rotation of the celestial sphere, the PZS triangle for each body is constantly changing. In order to compute an astronomic azimuth, the precise moment of each observation must be fixed in time as to fix the position of the observer with respect to the position of the vertices of the PZS triangle. Because the rotation of the Earth is extremely constant, it is an excellent timekeeper. In the field of practical astronomy two classes of time are used; solar time and sidereal time.

b. Both classes of time are based on one rotation of the Earth with respect to a reference point. The reference point is the difference between the two time classes. Solar time is referenced to the Sun and a solar day is the amount of time necessary for two successive passes of the sun over a meridian of longitude. Sidereal time is referenced to the stars and a sidereal day is the amount of time necessary for two successive passes of the vernal equinox over a meridian of longitude.

c. Since there are approximately 365 days in a year, it can be said that the Earth moves nearly 1° of its 360° orbit around the Sun in one day. Note that the Earth must rotate nearly a full degree more for a successive pass of a meridian in a solar day than it has to in a sidereal day. This creates an apparent motion of the Sun among the stars of nearly 1°. In practical astronomy, with the Earth fixed and the celestial sphere rotating about the Earth, intervals between transits of the Sun over the observer’s meridian are nearly four minutes longer than transits of the vernal equinox over the observer’s meridian. One solar day is 24 hours while a sidereal day equals 23 hours 56 minutes 04.091 seconds. (Figure 9-17).

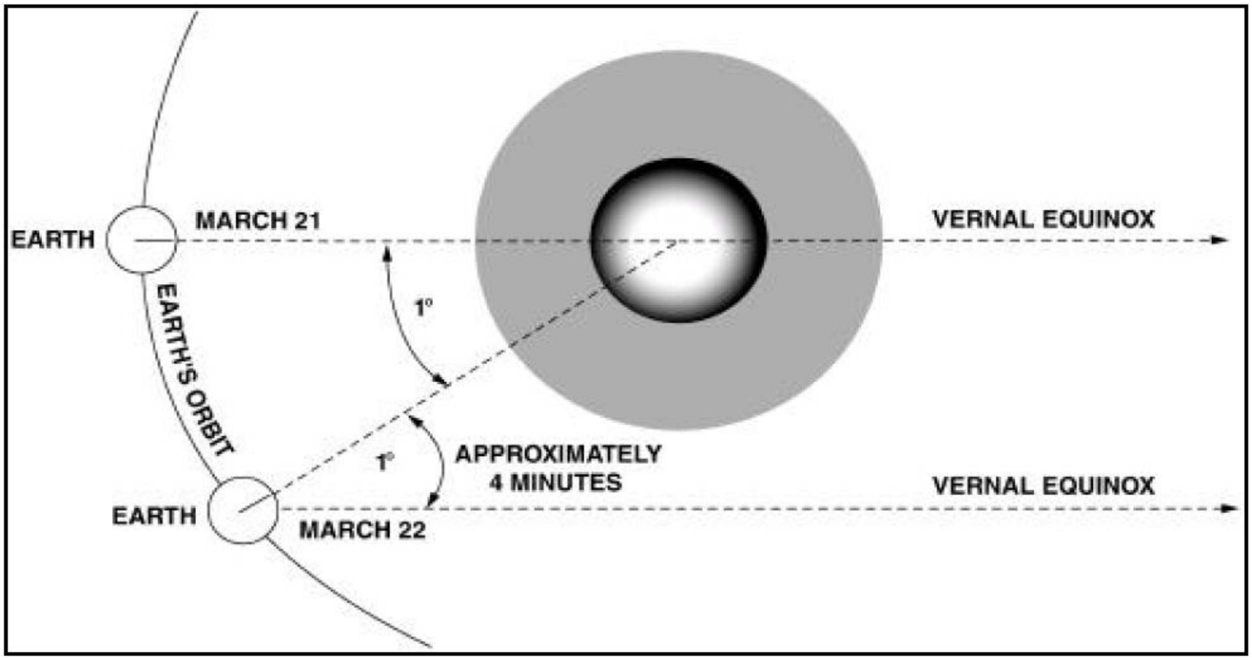


Figure 9-17. Relationship between Solar Time and Sidereal Time

d. One apparent 360° rotation of the celestial sphere is completed in a sidereal day. A star rises at nearly the same sidereal time throughout the year. On solar time, it rises about four minutes earlier from night to night or two hours earlier each month. At the same hour, day-by-day, the star moves slowly westward across the sky as the year lengthens.

e. The solar day is considered the most natural unit of time for ordinary purposes. The solar day begins at solar midnight or the point when the Sun crosses the observer’s lower transit. Solar noon is when the Sun crosses the observer’s upper transit.

f. Time indicated by the position of the actual Sun is called apparent solar time. Apparent solar time for any point is the amount of time that has elapsed since the apparent Sun last crossed the meridian at that point. Greenwich apparent time (GAT) is the amount of time that has elapsed since the apparent sun last crossed the lower transit of the Greenwich meridian (180° long.). Local apparent time is the amount of time that has elapsed since the apparent Sun last crossed the lower transit of the observer’s meridian (solar midnight). Since the calendar day begins at solar midnight, the apparent solar time at any instant is equal to the hour angle of the Sun plus or minus 12 hours (Figure 9-18 page 9-13). Apparent solar time is not usually considered accurate enough for most modern applications. For several reasons the length of an apparent solar day varies from season to season. Movement of the Sun is along the ecliptic and not the celestial sphere. The rate of this movement is not uniform. The Earth’s orbit is elliptical and not circular. Thus, December 25 is 50 seconds longer than September 13 and days in January average 15 seconds longer than days in July.

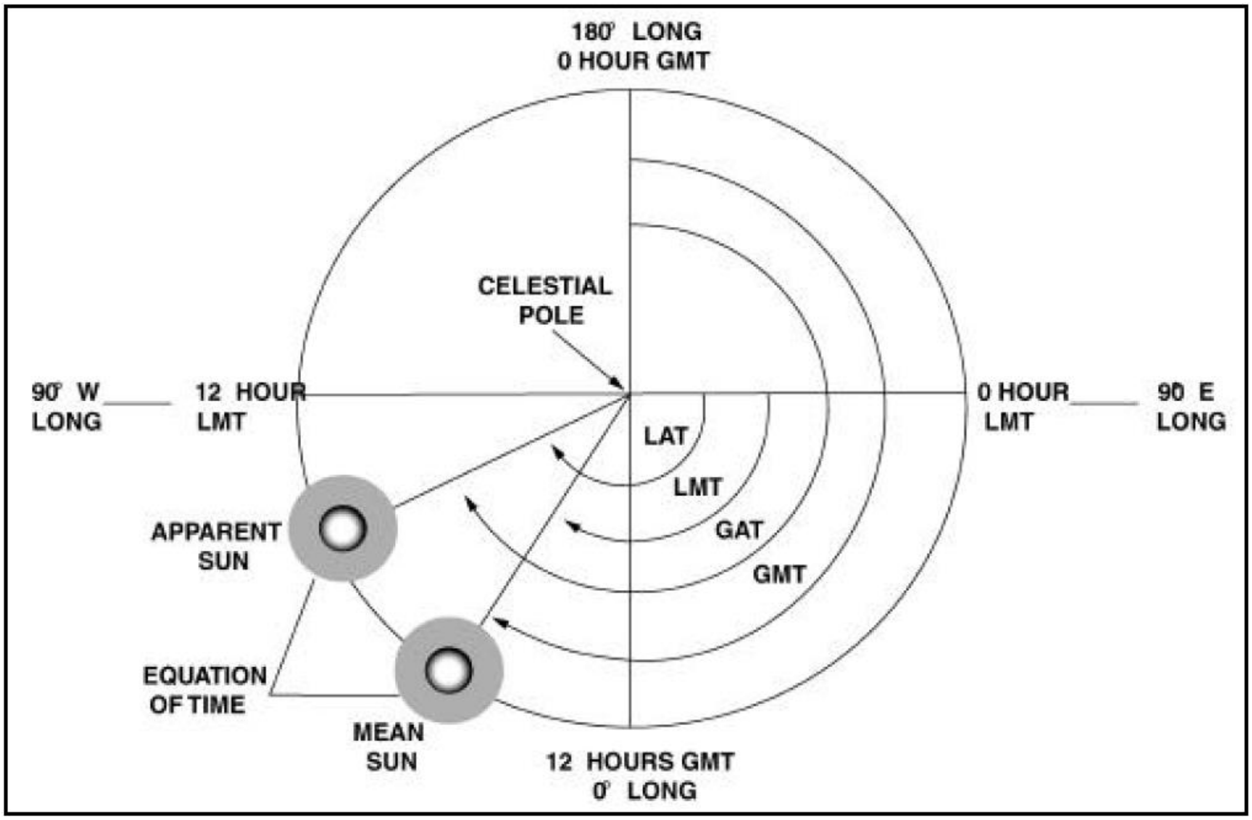


Figure 9-18. Concepts of Solar Time

g. Because a more consistent measure of time is needed, a fictitious sun moving at a uniform rate along the celestial equator was computed from the average apparent solar time. Time measured by the position of the mean sun is referred to as mean solar time. Mean solar time is numbered from 0-24 uniform hours; each hour consists of 15° of arc or longitude (360° x 24 hours = 15° per hour). Solar noon occurs when the mean sun crosses the observer's meridian.

(1) Mean solar time for any point is the amount of time that has elapsed since the mean sun last crossed the meridian at that point. Greenwich mean time (GMT) is the amount of time that has elapsed since the mean sun last crossed the lower transit of the Greenwich meridian (180° long.). Local mean time (LMT) is the amount of time that has elapsed since the mean sun last crossed the lower transit of the observer's meridian (solar midnight).

(2) The difference between apparent solar time and mean solar time is called the equation of time. This value can vary from +16 minutes (mean sun slow) to -14 minutes (mean sun fast), depending on the season.

h. A year can be defined as one complete revolution of the Earth around the Sun. A solar year is defined by 365.2422 mean solar days and can be referred to as a tropical year.

i. The sidereal day begins when the vernal equinox crosses the observer's meridian at the upper transit (sidereal Noon). Sidereal time for any point is the amount of time that has elapsed since the vernal equinox last passed the meridian at that point. Local sidereal time is the amount of time that has elapsed since the vernal equinox last passed the observer's meridian; Greenwich sidereal time is the amount of time that has elapsed since the vernal equinox last passed the Greenwich meridian (Figure 9-19).

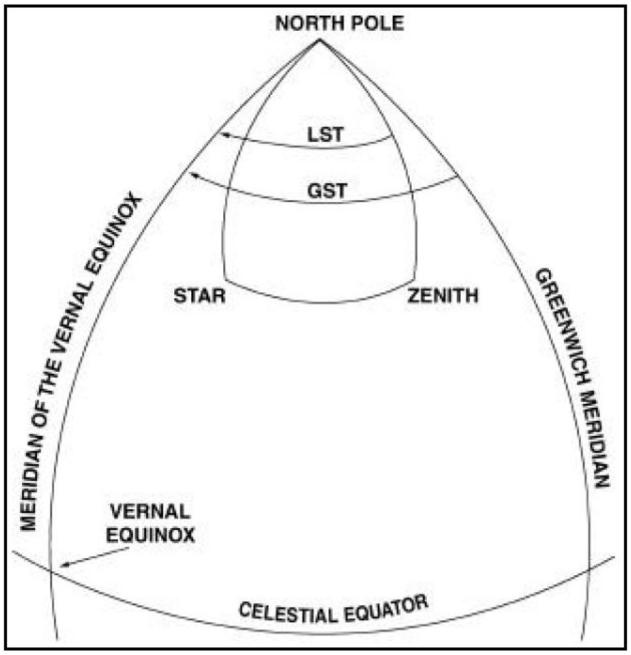


Figure 9-19. Concepts of Sidereal Time

j. The annual apparent motion of the Sun along the ecliptic is opposite in direction to its daily path. Consequently, the relationship between solar time and sidereal time is variable. For example, on September 21 at the instant the vernal equinox crosses the observer's meridian; the mean sun is crossing the lower transit of the observer's meridian. At this instant, the sidereal clock of the observer will read 0h 0m 0s and a solar (civil) clock will read 0h 0m 0s. Twenty-four sidereal hours later, the vernal equinox will again cross the observer's meridian, but the mean sun will not yet have crossed the lower transit of the meridian. From this, we observe the solar clock reads 23h 56m 04.091s which shows the sidereal clock gains on the solar clock about 4m per sidereal day. This interval is accumulated throughout the tropical year so that while a solar year contains 365.2422 mean solar days, a sidereal year contains 366.2422 days.

9-7. Time Zones

a. The mean sun revolves around the Earth once every 24 mean solar hours (one mean solar day) and each hour the mean sun travels along an arc that is 15° wide. Each of these 15° arcs is referred to as a time zone.

b. The prime meridian is used as a basis of reference for time zones. Time at a point lying 15° west of the prime meridian is 1 hour earlier than at the prime meridian because the

Sun has not yet crossed 15° W longitude. The opposite is true for a point lying 15° east of the prime meridian. Time is 1 hour later since the Sun has already crossed 15° E longitude. The difference in local time between two places equals the difference in longitude between the two places (Figure 9-20). Each 15° meridian east and west of the prime meridian is referred to as a standard meridian. Each zone extends 7.5° east and west of the standard meridian. The time zone including the prime meridian extends from 7.5° E longitude to 7.5° W longitude; the time zone with a standard meridian at 90° W longitude extends from 97.5° W to 82.5° W. Four of these meridians (75°, 90°, 105°, and 120°) cross the United States (Figure 9-21).

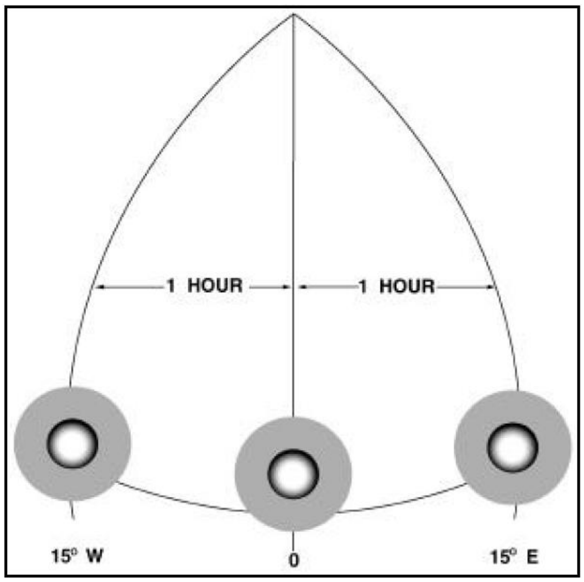


Figure 9-20. Time and Apparent Motion of the Sun

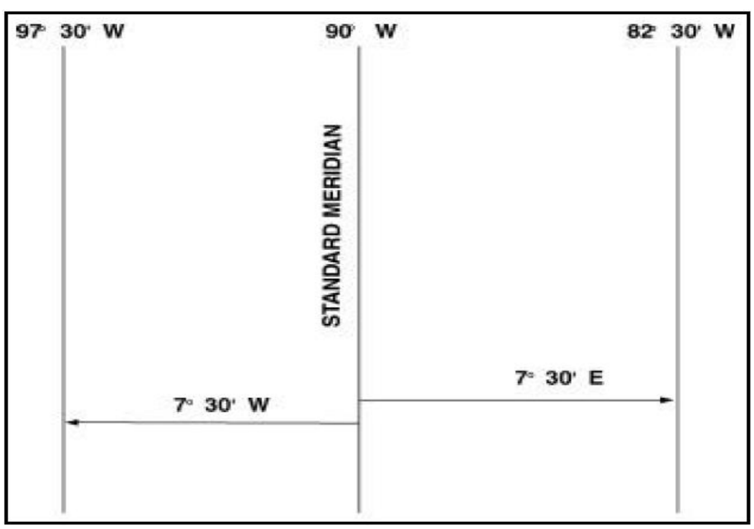


Figure 9-21. Time Zone Boundaries

c. Standard time zone boundaries are often irregular, especially over land areas. Time zones generally follow the 7.5° boundary rule except when those boundaries are shifted to conform to geographical or political boundaries (Figure 9-22 page 9-16). For example, Ft. Sill, Oklahoma lies closer to the 105° W standard meridian, but for political boundary purposes, all of Oklahoma is located in the time zone using the 90° W standard meridian. Sensor support Marines use the term LMT in referring to standard time or local mean time in a referenced locale. The time used by the local inhabitants is local mean time unless a nonstandard time is in use.

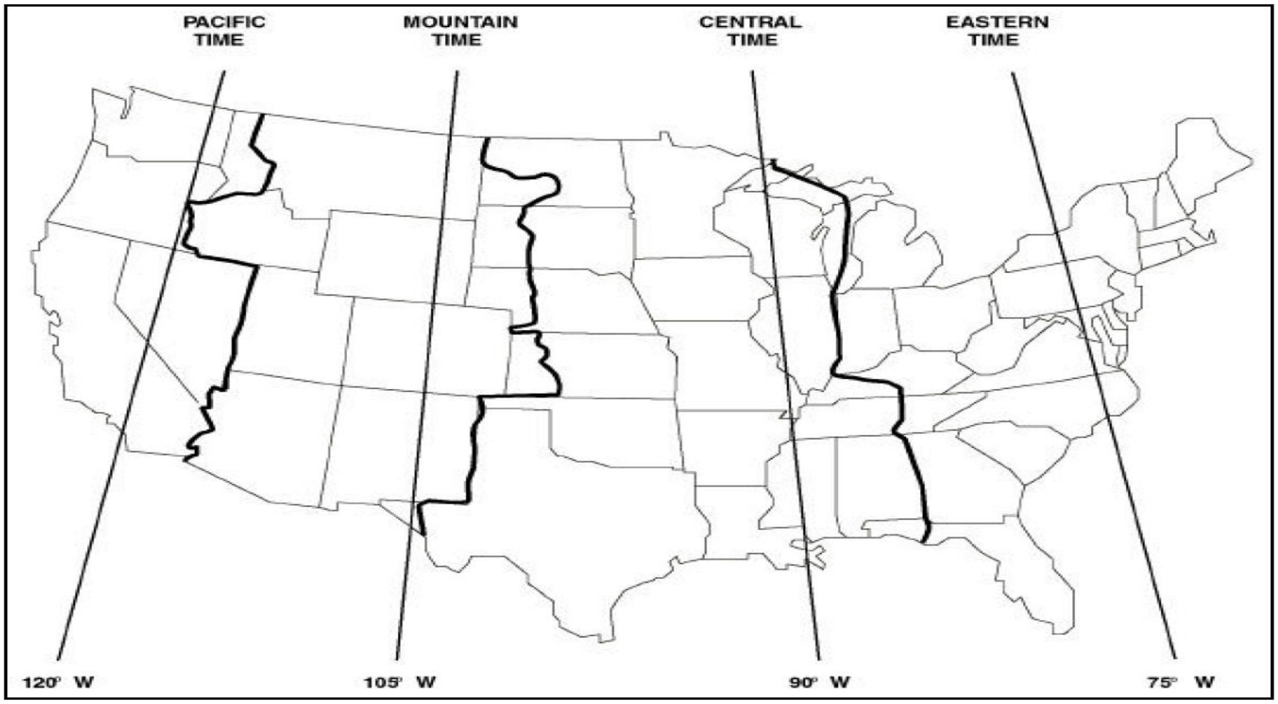


Figure 9-22. Political Time Zones for the US

d. Each of the 24 time zones is designated by a letter A-Z (J omitted). To preclude the problem of compiling and publishing time data for each of the 24 time zones, data was computed pertaining to one standard time zone. Standard time zone Z, which uses the Greenwich meridian as a standard meridian, was chosen. Greenwich standard time (Zulu time), GMT or universal time, is defined as the length of time since the mean sun last crossed the 180th meridian (lower transit of the Greenwich meridian) or solar midnight. This time can be expressed as the reading of the standard 24-hour clock at the Greenwich observatory at the moment an observation is made on a celestial body. Hence, it is the same time throughout the world. Since the observer’s clock is usually set to standard (local) time, that time (LMT) must be converted to GMT (Figure 9-23 page 9-17).

Standard Meridian	Letter	Time Zone Correction	Standard Meridian	Letter	Time Zone Correction
0°	Z	0	0°	Z	0
15° E	A	-1	15° W	N	+1
30° E	B	-2	30° W	O	+2
45° E	C	-3	45° W	P	+3
60° E	D	-4	60° W	Q	+4
75° E	E	-5	75° W	R	+5
90° E	F	-6	90° W	S	+6
105° E	G	-7	105° W	T	+7
120° E	H	-8	120° W	U	+8
135° E	I	-9	135° W	V	+9
150° E	K	-10	150° W	W	+10
165° E	L	-11	165° W	X	+11
180° E	M	-12	180° W	Y	+12

Figure 9-23. Time Zone Letter Designations and Corrections

9-8. Daylight Saving Time

The Energy Policy Act of 2005 extended daylight saving time in the United States changing to new dates beginning in 2007. Daylight saving time is the advancing of standard time by one hour. Effective at 2:00 AM local time on the second Sunday of March and ends at 2:00 AM local time on the first Sunday of November. Daylight Savings Time is not observed in Hawaii or Arizona.

9-9. Converting Local Mean Time to Greenwich Mean Time

a. LMT can easily be converted to GMT by applying a time zone correction.

b. For the western hemisphere, divide the value of the standard meridian of the local time zone by 15°. The result is the time zone correction in hours. Add this correction to the LMT to determine GMT. If this result is greater than 24 hours, subtract 24 hours and add one day to obtain the Greenwich time and date.

c. For the eastern hemisphere, divide the value of the standard meridian of the local time zone by 15°. The result is the time zone correction in hours. Subtract this correction from the LMT to determine the GMT.

9-10. Converting Greenwich Apparent Time to Greenwich Mean Time

When the sensor support Marine observes the Sun, he or she actually observes the apparent sun on the celestial sphere and not the mean sun on which the clock is based. Consequently, the sensor support Marine must convert GAT to GMT. This correction is contained within the artillery astronomical (hour angle) program and need not be determined manually.

9-11. Determining the Local Hour Angle and Angle t

a. When the position of the apparent sun at the time of observation has been determined and related to the Greenwich meridian, the time is referred to as GAT. By adding or subtracting 12 hours to or from the GAT, the sensor support Marine determines the value of the Greenwich hour angle (GHA). GHA is the time that has elapsed since the Sun last crossed the Greenwich upper meridian (upper transit). To determine the local hour angle (LHA) in mils of arc, the GHA and the observer's longitude must be converted to mils of arc.

b. In the western hemisphere, determine the LHA by subtracting the observer's longitude (mils of arc) from the GHA in mils. In the eastern hemisphere, determine the LHA by adding the observer's longitude (mils of arc) to the GHA in mils.

c. Angle t is the angle in the PZS triangle at the polar vertex. If the LHA is greater than 3200 mils, angle t equals 6400 mils minus the LHA. If the local hour angle is less than 3200 mils, angle t equals the LHA.

Section II. ARTILLERY ASTRONIMIC METHOD

9-12. Artillery Astronomic Method

This section details the theory, principles and computations required when utilizing celestial bodies in the artillery astronomic method to gain directional control in support of artillery operations.

a. The primary astronomic method sensor support Marines use is the artillery astronomical observation. Artillery astronomical observation is based on the hour angle method and can be used with the Sun or stars. With the advent of the DAGR and single-channel ground and airborne radio system (SINCGARS), accurate time is now readily available to sensor support Marines, making artillery astronomical observation the preferred method. At the battery level the hasty artillery astronomical observation method of observation will be used.

b. Using two sides and the included angle solves the azimuth angle of the PZS triangle (Figure 9-24). The sides are the polar distance and the colatitude; the angle is the local hour angle (angle t). In addition to the horizontal angle from an azimuth mark to the observed body, three elements must be determined:

(1) Latitude of the observer to determine the side colatitude.

(2) Declination of the observed body to determine the side polar distance.

(3) Accurate time of the observation to determine the LHA.

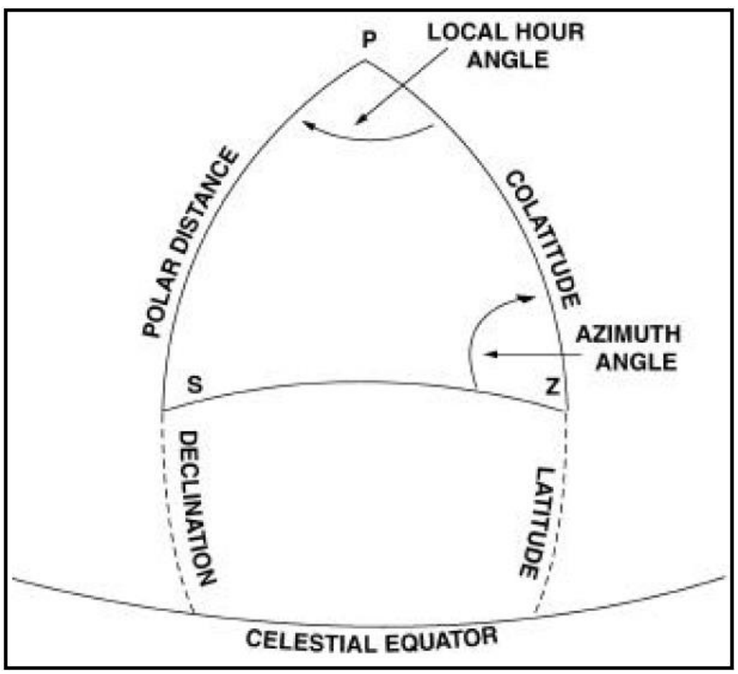


Figure 9-24. Solving the Artillery Astronomic Method

9-13. Artillery Astronomic Method (Sun)

a. The artillery astronomical observation method may be used to determine azimuths from Sun observations. The artillery astronomical observation method does not require measuring a vertical angle or temperature and computations do not include a refraction or parallax correction. This method was once referred to as the hour angle method because the solution of the PZS triangle depends on solving the LHA.

b. For the Sun to be suitable for use with the artillery astronomical observation method, it must not be within 1 hour of the observer's meridian. It must be between 175 mils and 1300 mils (preferably between 175 and 800) above the observer's meridian. An experienced instrument operator may observe the Sun above 800 mils with an elbow telescope.

c. In the artillery astronomical observation method (Sun), time is critical to accurately determine local hour angle. Time must be accurate to one second. Accurate time is available through radio time signals and GPS receivers; i.e., DAGR, GPS-S, and SINCGARS.

d. The formula for solving the PZS triangle has been arranged to require only determining the LHA. The two sides are stated in the formula in terms of declination of the Sun and latitude, thus eliminating the need for the computations of polar distance and colatitude. For the hour angle solution, the element of the PZS triangle that is necessary is the LHA. Determine this angle by using the time of the observation. Generally, the LHA is determined by converting the local mean time (watch time) to GMT, to GAT, to GHA, and finally to the LHA.

(1) Local Mean Time
+ time zone correction
=Greenwich mean time

(2) ±equation of time for 0h

(3) ± daily change for portion of day

(4) =Greenwich apparent time

(5) ± 12 hours
=Greenwich hour angle

(6) ±longitude
=Local hour angle

e. Greenwich mean time watch time of the observation is referred to as local mean time. This watch time is standard time for the area of operation. By applying a time zone correction the GMT (zulu time) is obtained. This step can be skipped if the watch is set to zulu time.

f. Greenwich apparent time is the time that has elapsed since the last passage of the apparent sun over the lower transit of the Greenwich meridian. Greenwich apparent time is obtained by applying the equation of time and the proportionate part of the daily change in the equation of time to the GMT.

g. Greenwich hour angle is the amount of time that has elapsed since the sun last crossed the Greenwich meridian. Therefore, GAT is always ±12 hours from the GHA. To determine the GHA, add or subtract 12 hours to or from the GAT. Remember: the result must be between 0 and 24 hours.

h. Local hour angle (LHA) of a celestial body is the time that has elapsed since that celestial body last crossed the observer's meridian. The formula to determine the LHA depends on the hemisphere (east or west) of the observer. In the western hemisphere, longitude and GHA are measured west from the Greenwich meridian. The LHA equals the GHA minus longitude (LHA = GHA - Long). In the eastern hemisphere, longitude is measured to the east; the GHA is still measured to the west. The LHA in the Eastern Hemisphere equals the sum of the GHA and the longitude minus 360° (LHA = (GHA + Long) - 360°).

(1) Several formulas can be derived for the solution of the spherical triangle when two sides and an included angle are known. The following formula was selected for use in artillery survey because of its simplicity:

$$\tan \tfrac{1}{2}(A + q) = \frac{\cos \tfrac{1}{2}(\mathrm{Lat} - \mathrm{Dec}) \cot \tfrac{1}{2} t}{\sin \tfrac{1}{2}(\mathrm{Lat} + \mathrm{Dec})}$$

$$\tan \tfrac{1}{2}(A - q) = \frac{\sin \tfrac{1}{2}(\mathrm{Lat} - \mathrm{Dec}) \cot \tfrac{1}{2} t}{\cos \tfrac{1}{2}(\mathrm{Lat} + \mathrm{Dec})}$$

Where: $\boldsymbol{A}$ is the astronomic azimuth (true) of the Sun measured east or west of the meridian.

$\boldsymbol{q}$ is the parallactic angle (cancels out in computations).

(2) Lat is the latitude of the station.

(3) Declination is the apparent declination of the Sun.

(4) t is the local hour angle (less than 12 hours) of the Sun.

i. Survey computer systems contain the artillery astronomical observation program that easily computes an azimuth from the astronomic observations performed. The required ephemeris data and time calculations are completed within the program and do not require any manual computation.

9-14. Artillery Astronomic Method (Star)

a. The artillery astronomical observation method may be used to determine azimuths from observations on any of the 73 survey stars. Observations of the stars are generally considered to be preferred over those of the Sun due to more accurate sighting. The preferred star for this method in the northern hemisphere is Polaris. It displays the least apparent motion being a circumpolar star. In the southern hemisphere the preferred star is Alpha Acrux.

b. Polaris may be observed any time it is visible, but best results are obtained when it is 175 mils or higher above the observer's horizon. The 175-mil restriction minimizes the effects of refraction.

c. In the artillery astronomical observation method (star), time is critical to the accurate determination of the local hour angle. Time must be accurate to 10 seconds for observations on Polaris and 1 second for observations on east-west stars.

d. The formula for solving the PZS triangle with star observations is the same as for the Sun. The only difference in the computations is sidereal time determines the LHA. See below:

<u>Local Mean Time</u>

(1) + time zone correction
= Greenwich mean time

(2) ± sidereal time for 0h GMT
± correction for GMT
= Greenwich sidereal time

(3) ± right ascension of the star
= Greenwich hour angle

(4) ± longitude
= local hour angle

9-15. Azimuth Specifications

a. The artillery astronomical observation method can determine fourth or fifth order azimuth. For sensor support Marines, an S7 total station is used in each echelon of survey.

b. At least three sets of observations must be made on the celestial body. For fifth order, mean the three sets and reject any set that varies from the mean by more than 0.3 mils. For fourth order, mean the three sets and reject any set that varies from the mean by more than 0.15 mils. At least two sets must remain to determine the final azimuth for fourth and fifth order. The considered accuracy for a fifth order astronomic azimuth is 0.3 mils and 0.15 mils for a fourth order azimuth.

9-16. Selecting Methods of Observation

Sensor support Marines must consider the following:

a. Day or night, north or south latitude.

b. Accuracy of the watch time.

c. Positions of celestial bodies at specific times.

d. Degree of accuracy required.

e. Observer's position accuracy. This is more important for the computation of UTM grid convergence (true azimuth to grid azimuth) than for the actual observation computations.

f. The experience of the instrument operator.

9-17. Observation and Tracking Procedures for Sun and Stars

a. While tracking procedures are virtually the same for the Sun and star methods, observation is slightly different. Tracking a star is much more accurate than tracking the Sun due to the enormous distances involved. Stars appear as pinpoints of light even through the telescope, and offer a more defined target than the large fiery mass of the Sun.

b. When observing a star to determine astronomic azimuth the most difficult part is locating the desired celestial body. The instrument operator, with the telescope in the direct position, sights in on the azimuth mark to the desired direction. The initial circle setting is placed on the scales and recorded in the recorder's book. The instrument operator turns to the constellation containing the desired star and locates the star in the telescope. It is important to observe the movement of the star momentarily to determine its path in the telescope.

c. Once the star's direction and rate of movement are determined, tracking begins. The instrument operator announces "tracking." The recorder keeps time while the instrument operator repeatedly announces "tracking" until instrument operator has the star centered in the cross hairs of the telescope. The instrument operator announces "TIP." Immediately at TIP, the recorder notes and records the time of observation in the recorder's notebook. The instrument operator reads the horizontal circle reading to the recorder who reads it back. Three direct readings are taken this way. Only after the third direct reading does the instrument operator plunge the scope and take three reverse readings using the same procedures, as required.

d. When observing the Sun, the instrument operator, with the telescope in the direct position, sights in on the azimuth mark to which direction is desired. The initial circle setting is placed on the scales, and recorded in the recorder's book. The instrument operator then places the sun filter on the telescope and turns to the Sun. The Sun must never be viewed through the telescope without a sun filter. Inspect the filter before use to ensure that the coated surface is free from any scratches or other defects. Serious eye damage will result if proper precautions are not taken. The Sun should also be observed momentarily to determine its path and rate of movement before tracking is announced.

e. The preferred position of the Sun in the telescope is centered in the solar circle as opposed to using the leading or trailing edge of the Sun. The instrument operator announces "tracking" repeatedly until the Sun appears in the center of the reticle. Instrument operator then announces "TIP." The time is immediately noted and recorded in the recorder's notebook. The instrument operator reads the horizontal circle reading to the recorder who reads it back. Three direct readings are taken this way. Only after the third direct reading does the instrument operator plunge the scope and take three reverse readings using the same procedures, if required.

f. Reverse readings are required for fourth order azimuths only. Three direct readings may be taken consecutively, and as stated above, the telescope is plunged and the three reverse readings are taken. No matter which order is performed, the angle must close to ± 0.150 from direct to reverse.

Section III. STAR SELECTION

9-18. Star Selection

This section explains the star selection process including geodetic, weather, and physical considerations. It will also discuss identification diagrams available to assist in identification of constellations and selection of associated survey stars when conducting astronomic survey methods.

a. There are important advantages to using stars rather than the Sun as a source for astronomic azimuths. Stars appear as pinpoints of light in the telescope and are easier to track. At least one of the 73 survey stars can be found in a position that allows for astronomic observation, regardless of the observer's location or the time of night.

b. Polaris should always be used when it is visible. It is the most desirable star to observe because it is usually easy to locate and its slow apparent motion makes it easy to track. Due to weather conditions, ambient light, LOS barriers, or the observer's latitude, Polaris may not be available. In this case, an east-west star must be used. East-west stars are selected based on their position relative to the observer.

9-19. Orbit of Polaris

Polaris appears to move in a small, elliptical, counterclockwise orbit about the celestial north pole. The size of this apparent orbit varies slightly with the observer's latitude; at 35° N latitude, its minor diameter is about 45 mils. Because Polaris stays so close to the celestial north pole, it is visible throughout the night in most of the northern hemisphere. When the Polaris LHA is 0 or 12 hours, the star is said to be in its upper or lower culmination, respectively. When the Polaris LHA is 6 or 18 hours, it is said to be in its western or eastern elongation. The small orbit of Polaris results in a very slow apparent motion, so the star may be observed at any point in its orbit. The least chance of error will occur when Polaris is in elongation (Figure 9-25).

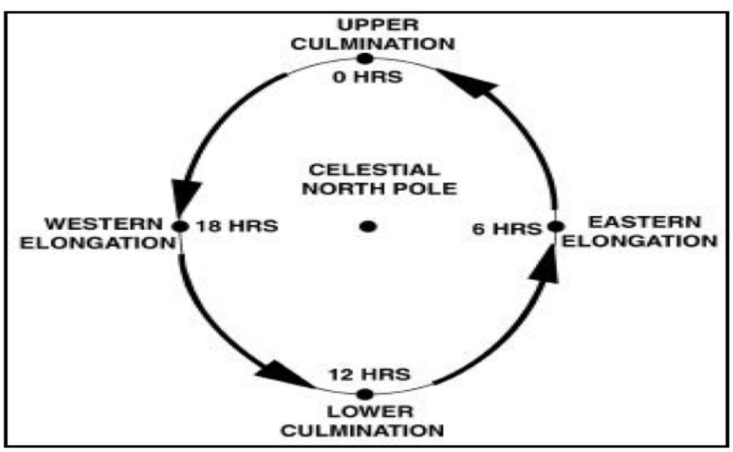


Figure 9-25. Orbit of Polaris

9-20. Identifying Polaris

a. Polaris is the brightest star in the constellation Ursa Minor (Little Dipper), which is near the constellations Ursa Major (Big Dipper) and Cassiopeia (Lazy W). Polaris is the anchor (end) star of the handle of the Little Dipper.

b. Polaris can be identified by its relative position to Ursa Major. The two stars forming the side of the bowl farthest from the handle of the Big Dipper are called the pointer stars. An imaginary line extended through the pointer stars towards Cassiopeia nearly passes through the celestial north pole. Polaris is approximately five times the distance between the pointer stars along the imaginary line from the Big Dipper (Figure 9-26).

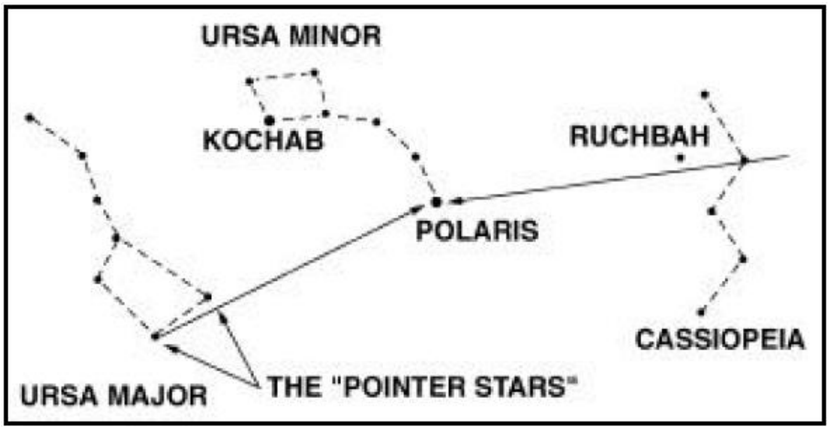


Figure 9-26. Identifying Polaris

c. Polaris can also be identified by its relative position to Cassiopeia. Since Cassiopeia is on the same side of the celestial north pole as Polaris, its position relative to the pole is approximately the same as Polaris'. Therefore, Cassiopeia can be used to determine whether Polaris is in elongation or culmination. A line drawn from the star Ruchbah, bisecting the shallow side of Cassiopeia, will pass closely by Polaris.

d. The vertical angle to the celestial north pole equals the observer's latitude. Therefore, the vertical angle to Polaris is approximately equal to the observer's latitude (Figure 9-27 page 9-27). Because the celestial sphere (and therefore the celestial north pole) is an infinite distance from the Earth, the line to the celestial north pole from the observer can be considered the same as the line of the rotational axis of the Earth (and celestial sphere). Angle A represents the observer's latitude; angle B the vertical angle to the celestial north pole. The laws of geometry prove that since the observer's zenith is perpendicular to the observer's horizon and since the line to the celestial north pole is perpendicular to the plane of the celestial Equator, angles A and B must be equal.

e. When the observer's latitude in mils is subtracted from 1600 mils, the result is the vertical reading to the celestial north pole, angle C in Figure 9-27. When that vertical reading is set on the vertical scale of the theodolite in the direct mode, Polaris will appear in the field of view. If the star is at elongation, its vertical angle is equal to the observer's latitude. When Polaris is moving from eastern to western elongation, its vertical angle is greater than the observer's latitude; when Polaris is moving from western to eastern elongation, its vertical angle is less than the observer's latitude.

f. When a pointing is made on Polaris, the observer will see two other stars nearby which are not visible to the naked eye. However, when the reticle pattern in the telescope is illuminated, Polaris will be the only visible star.

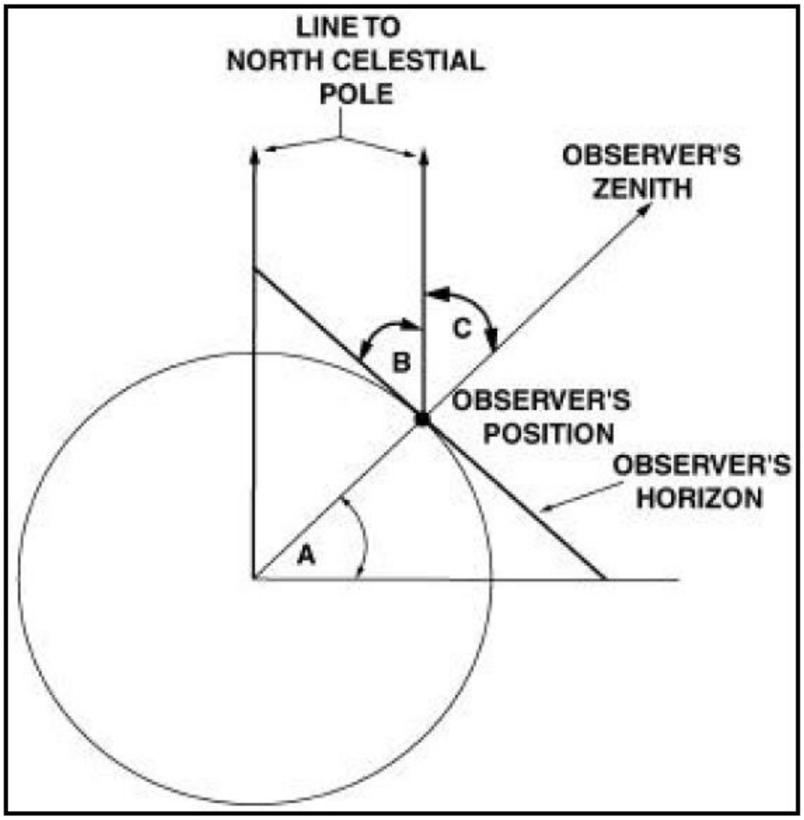


Figure 9-27. Relationship Between the Observer's Latitude-Vertical Angle to the Celestial North Pole

9-21. Identifying Survey Stars

a. The apparent motion of a celestial body has two components-a horizontal motion, representing change in azimuth and a vertical motion, representing change in altitude. An error in measuring the altitude of a celestial body will result in a final azimuth error related to the ratio between the two components of the apparent motion of the body (Figure 9-28 page 9-28).

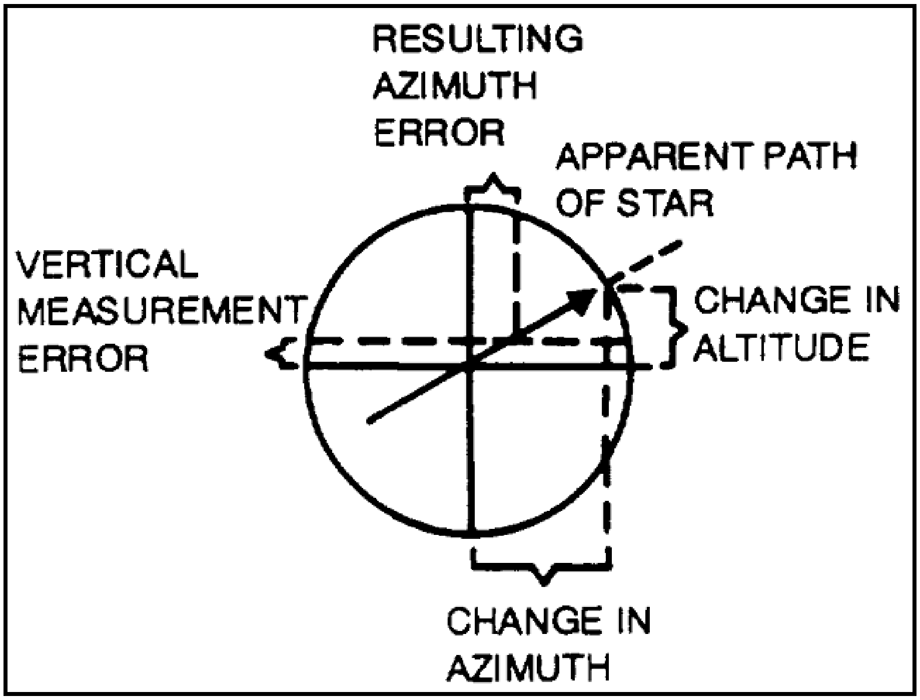


Figure 9-28. Apparent Motion

b. When a star is moving at a small angle to the horizon, an error in measuring the altitude will result in a greater error in final azimuth than it would if the star were moving at a large angle to the horizon (Figure 9-29).

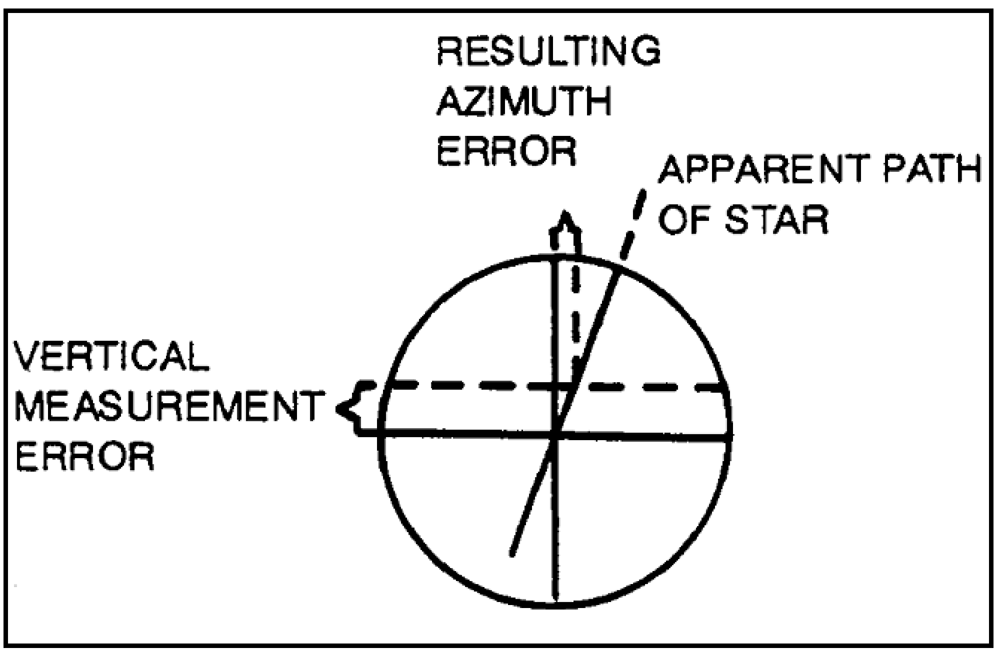


Figure 9-29. Motion of a Star Viewed Through a Surveying Instrument—Low Star Rate

c. This relationship is called the star rate which is the ratio of resulting azimuth error to error in vertical measurement. A star that changes in altitude but not in azimuth will have a star rate of 0, since an error in altitude measurement will result in no error in azimuth. A star that changes rapidly in azimuth and slowly in altitude that a 1-mil error in attitude measurement will result in a 3-mil azimuth error has a star rate of 3.

(1) For altitude method observations, select the stars with the lowest star rates, since both azimuth and altitude are measured. Low star rates are not essential for artillery astronomical observation observations, because altitude is not measured. However, stars with low star rates will be moving more slowly in azimuth and will be easier to track than those with high star rates. Although Polaris has a high star rate in its culminations, its apparent motion is so slow that it can be observed successfully at any time. Avoid observing stars below 175 mils in altitude because of possible errors caused by refraction.

(2) The easiest way to identify stars and fix their locations in relation to each other is to learn something about constellations. Since stars are fixed in definite points in the sky with relation to each other, the relative position of stars has remained about the same for many centuries. In certain groups of stars, primitive stargazers saw the shapes of creatures or heroes of their folklore. Names were applied to the shapes of these various groups of stare. Later, people saw in the stars the shapes of household implements with which they worked. The development of the names of stars began early in the history of man and finally resulted in a catalog of the visible stars. The named shapes became constellations, and the individual stars were identified by name with the constellation of which they were a part. From this primitive development the constellations were given Latin names. Other groups of stars were assigned names of gods and goddesses and creatures of land and sea that figured in Roman and Greek mythology. Much later in history, our forefather saw in the many constellations objects common to their mode of living. Thus, the Big Bear came to be known as the Big Dipper. To the English, this same constellation is the Plough. Some of the more familiar starts and constellations are described below.

d. The familiar constellation called the Big Dipper is only part of the constellation Ursa Major (Figure 9-30 page 9-30). The seven stars of the dipper are easy to find on almost any clear night. The two outer stars of the bowl point toward the North Star, Polaris, which is about 30° away. The distance between the pointers is about 5°. Both measurements are very helpful when the star finder and identifier are being used.

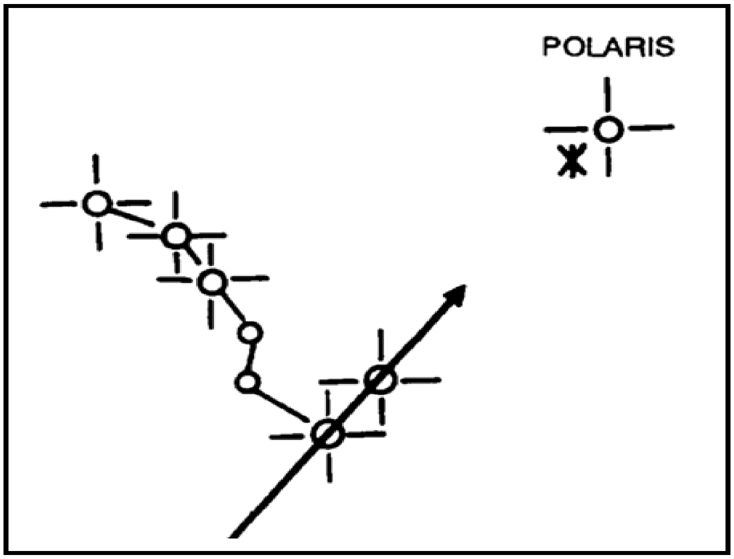


Figure 9-30. Ursa Major

(1) Cassiopeia (Figure 9-31) is a prominent northern constellation. It is found directly across the celestial north pole, opposite the Big Dipper. When the Big Dipper is below the horizon, Polaris can be found by drawing a line from the star Ruchbah bisecting the angle formed by the shallow side in Cassiopeia. The bisecting line points almost through Polaris.

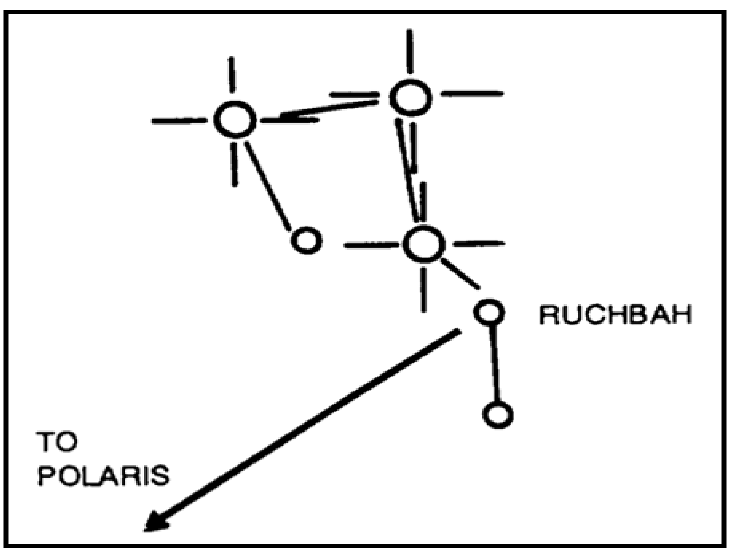


Figure 9-31. Cassiopeia

(2) Polaris, the polestar, is the alpha star in the constellation Ursa Minor (Figure 9-32 page 9-31), commonly called the Little Dipper. On a clear night, the Little Dipper is easily seen. The handle of the dipper has a reverse curve, and Polaris is the last star in the handle.

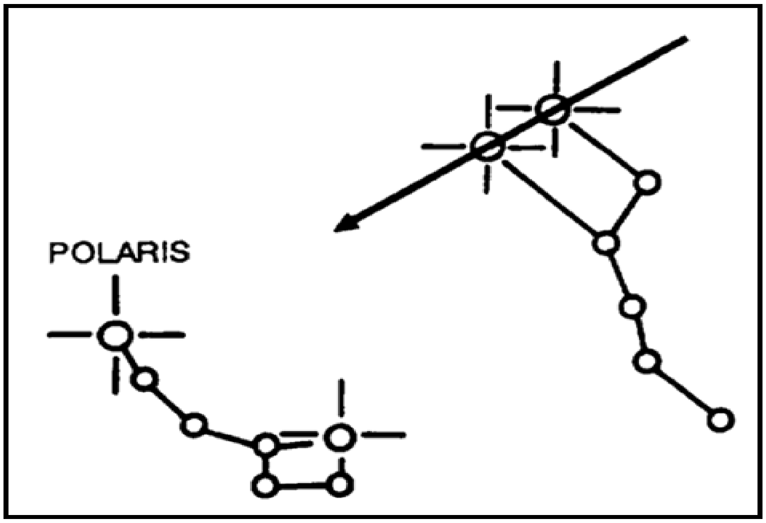


Figure 9-32. Ursa Minor

(3) The first prominent constellation after the vernal equinox has risen in the east is Taurus, the Bull. (Figure 9-33.) On the forehead of Taurus is a red star of the first magnitude, Aldebaran. It is a royal star, one of the four stars most commonly used by navigators. On the upper foreleg of Taurus is the Pleiades. This aggregation is a tight cluster of stars, which is also called the Seven Sisters.

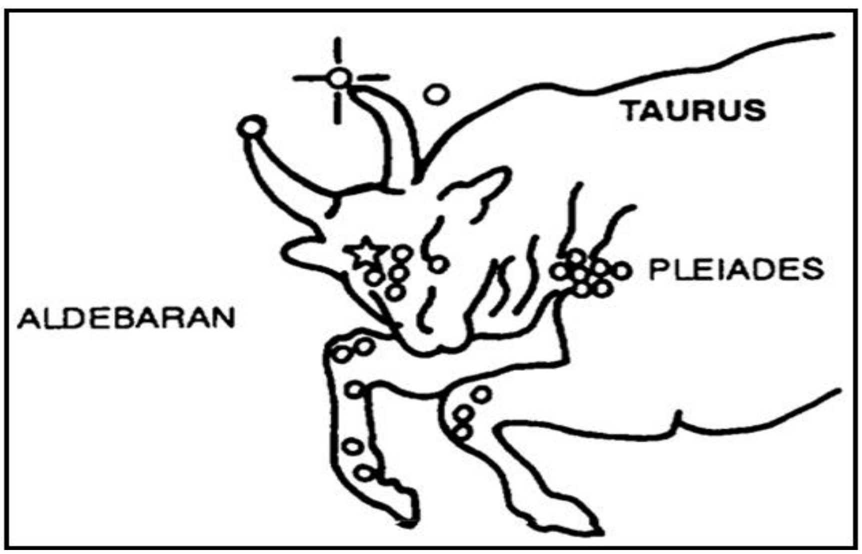


Figure 9-33. Taurus

(4) Chasing these seven stars and the bull is Orion, the Hunter. (Figure 9-34 page 9-32). There are two very bright stars in Orion. The hunter's right shoulder is Betelgeuse (*A* Orionis); the left knee is Rigel (*B* Orionis). Close on the heels are Orion's two dogs, Canis Major and Canis Minor. In the big dog is the brightest star in the sky, Sirius. It is a brilliant blue-white star. Slightly behind Canis Major is the smaller dog in which Procyon is found.

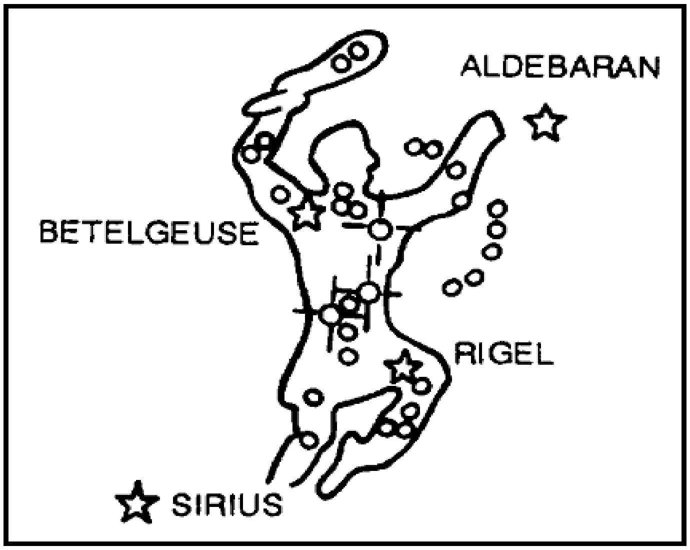


Figure 9-34. Orion

(5) At about the same right ascension with the canine constellation is Gemini, the Twins. (Figure 9-35) Think of Gemini as a wedge pointed straight toward Orion. The bright star at the base of the wedge is Pollux (ß Geminorum); the one above it is Castor Geminorum).

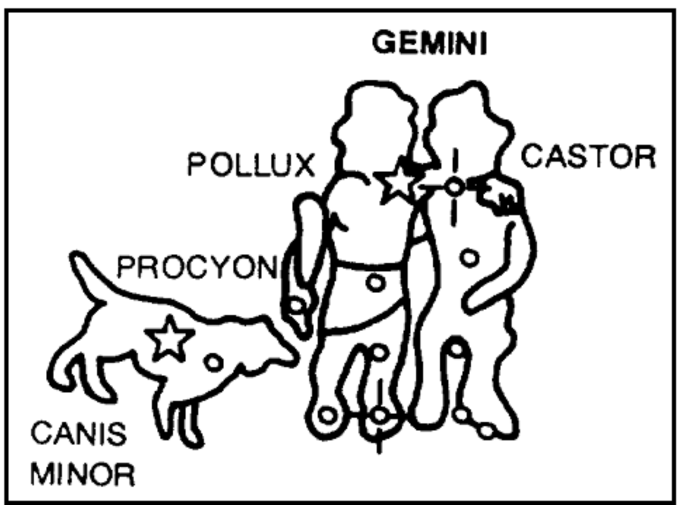


Figure 9-35. Gemini

(6) About two hours behind Gemini and Canis Minor is Leo, the Lion (Figure 9-36 page 9-33). The head and forequarter of Leo are sometimes known as the Sickle. The body and tail extend off to the east. The heart of Leo is Regulus Leonis. Regulus is another of the four royal stare. It is brilliant white, whereas the others are red.

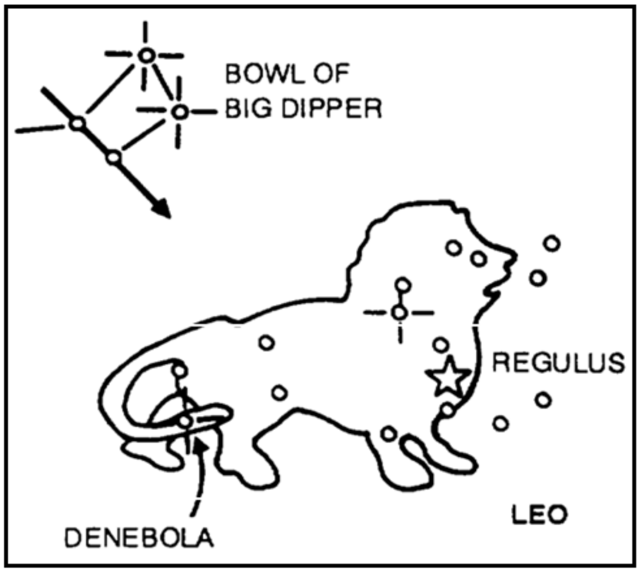


Figure 9-36. Leo

(7) As soon as Leo is well up in the sky, Virgo (Figure 9-37) will rise in the east. The bright star in Virgo, called Spica (a Virginis). It makes an approximately equilateral triangle with Denebola (ß Leonis) and Arcturus Bootis. This triangle is sometimes called the Virgo triangle.

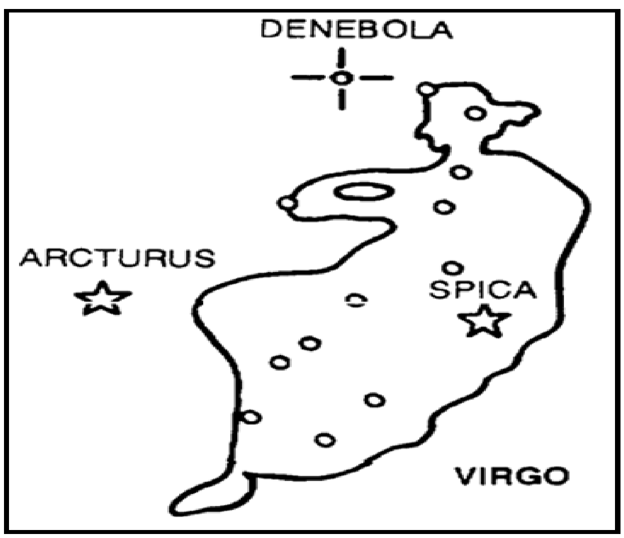


Figure 9-37. Virgo

(8) One of the most easily recognized constellations is Scorpio (Figure 9-38 page 9-34). However, it is so far south that in northern latitudes it is visible during evening hours only through July and August. Antares Scorpii is another of the four royal stars.

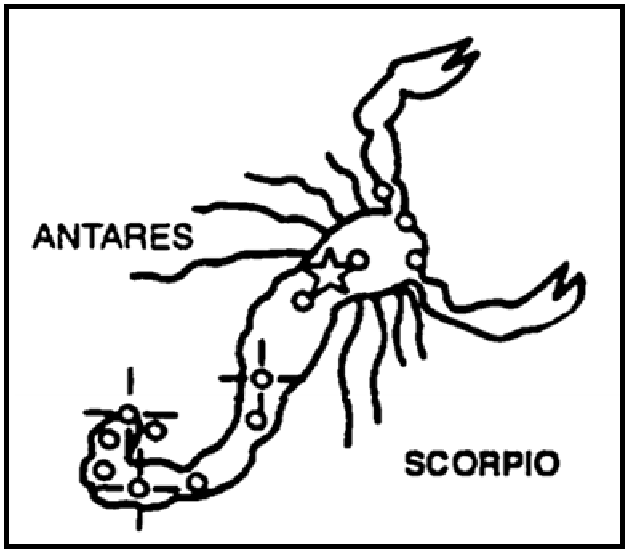


Figure 9-38. Scorpio

(9) The Northern Cross, Cygnus, is found very close to the circumpolar region. (Figure 9-39). This is a very prominent constellation, and in northern latitudes in the fall, it will be nearly overhead in the evening. The head of the cross is Deneb Cygni. There are two neighbor stars in this sector of the sky-Vega Lyrae, which rises just before the cross, and Altair Acquilae, which trails it somewhat to the south. Cygnus is imagined by some to be a cross; to others, it takes the shape of a swan from which the name is derived.

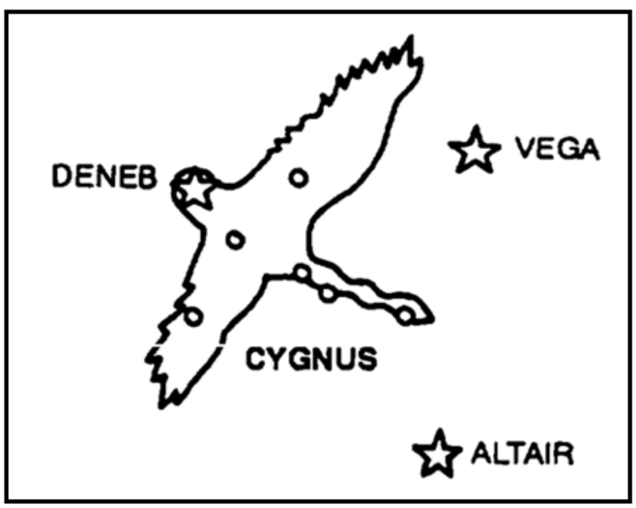


Figure 9-39. Cygnus

(10) Pegasus (Figure 9-40 on page 9-35), which includes the Great Square, straddles the hour circle of the vernal equinox. This is the constellation of the flying horse, a very prominent sky mark.

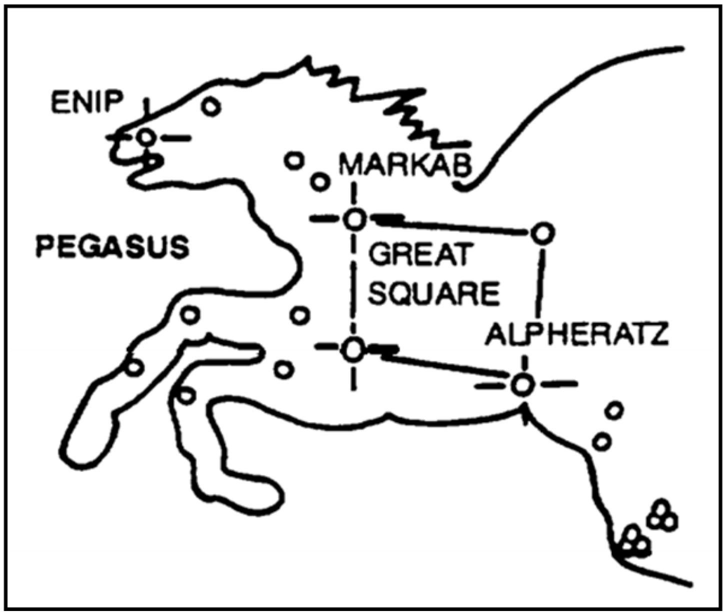


Figure 9-40. Pegasus

CHAPTER 10 HASTY SURVEY OPERATIONS

10-1. General

If no known control exists, control may be assumed through the best available sources. Assuming control allows all units to start their mission immediately without waiting for survey teams to provide control. Once higher echelon control is available, conversion to common control procedures must be performed by all lower echelon units.

10-2. Hasty Position Determination Method

a. An absolute position from the GPS-S is one source of assumed control. This will provide a sufficient position (10 meter CEP) and elevation. An azimuth must be determined by another means. Never use an azimuth computed between two absolute stations, even for assumed control.

b. If no GPS-S absolute points are available, the DAGR (AN/PSN-13) is the next best source of assumed control. Using the DAGR in the averaging mode will provide a sufficient absolute position (10 meter CEP) and elevation. An azimuth must be determined by another means. Never use an azimuth computed between two DAGR stations, even for assumed control.

c. Accuracy of positions determined by GPS absolute survey depends mostly on the amount of averaging time allowed. When properly set up and operated, the DAGR can provide the following accuracy: local area differential GPS: Less than 2.4 meters horizontal (95%); wide area GPS enhancements: Less than 5.1 meters horizontal (95%); PPS: Less than 11.1 meters horizontal (95%). These values assume the presence of a valid daily crypto key and correct datum selection.

d. A careful map inspection may determine assumed control. If possible, determine the azimuth from a source other than a map such as cursor-on-target and Precision Strike Suite-Special Operations Forces. All positions determined by these hasty methods must be verified by a map spot to reduce the incidence of blunders.

e. Map spot position accuracy depends on the scale of the map sheet and the abilities of the sensor support Marine. In practice, a map spot position can be considered accurate to approximately 100 meters on a 1:50,000 scale map.

10-3. Hasty Elevation Determination Method

a. There are several different methods for determining hasty elevation. GPS methods, Precision Strike Suite-Special Operations Forces, DAGR, altimetric observations and by map spot. Elevation is the weakest component of a GPS absolute position. When a GPS elevation is determined, that elevation must be verified by map spot. A properly operated GPS can provide elevations accurate to ±10 meters.

b. Altimetric elevation accuracy depends largely on the quality of the barometer in the altimeter. All altimetric elevations must be verified by map spot. Contour lines on a NIMA topographic map (1:50,000 scale) are considered accurate to 1/2 contour interval 90 percent of the time. In other words, a map spot elevation should never be considered more accurate than 1 contour interval for that map sheet.

10-4. Hasty Azimuth Determination Method

a. Methods of assuming an azimuth are:

(1) Dual DAGR

(2) Hasty astronomic observation.

(3) Simultaneous observation.

(4) Declinated aiming circle.

(5) Directional traverse.

(6) Scaled from a map or imagery.

(7) Compass; e.g., M2 or lensatic.

b. For any method above, the considered accuracy is ±2 mils when determined with an M2A2 aiming circle. Azimuth accuracy of a directional traverse using an aiming circle is determined by multiplying the number of horizontal angles measured by 0.5 mils.

c. An azimuth determined by a declinated aiming circle (declination performed at a surveyed declination station) is considered accurate to ±10 mils, not counting the effects of local magnetic attraction. If the declination was made from a map grid magnetic (G-M) angle, the accuracy is diminished by the age of the map's declination diagram information.

d. Azimuth accuracy determined by a compass (M2 or lensatic) depends on the accuracy of the type of grid to magnetic conversion used and local magnetic attraction (generally 10 to 20 mils).

e. Azimuth accuracy determined by scaling from a map depends on the accuracy of the plotted positions, map scale, and whether or not the map is generated from a conformal projection (in practice, 10 to 100 mils).

f. All azimuths determined by these hasty methods must be verified by a map spot to reduce the incidence of blunders. The preferred hasty method of determining azimuth is the one that provides the most accuracy for that particular situation.

10-5. Polaris Kochab

a. Observation of Polaris is another technique for establishing directional control to within two mils. It is simple, fast and has the distinct advantage of requiring no radio or wire communications. The instrument operator must be trained in finding the stars Polaris and Kochab, which are in the constellation known as Ursa Minor (Little Dipper).

(1) Polaris. Polaris is one of the two brightest stars in the constellation Ursa Minor. Because it appears to move in a small elliptical orbit about the north pole, it is commonly referred to as the North Star. Polaris is the last star in the handle of the Little Dipper (Figure 10-1). Two stars in the bowl of the Big Dipper actually point toward Polaris and are called the Pointers. Polaris is approximately five times the distance between the Pointers along an imaginary line from the Big Dipper. On the side opposite the Little Dipper is the constellation Cassiopeia, which looks like a lazy W.

(2) Kochab. The second star needed to perform the observation is Kochab, which is the other bright star (as bright as Polaris) in the Little Dipper. It is the front star of the bowl and is the only bright star between Polaris and the Big Dipper. Of the two front stars in the bowl of the Little Dipper, Kochab is the brighter and the closer to Polaris.

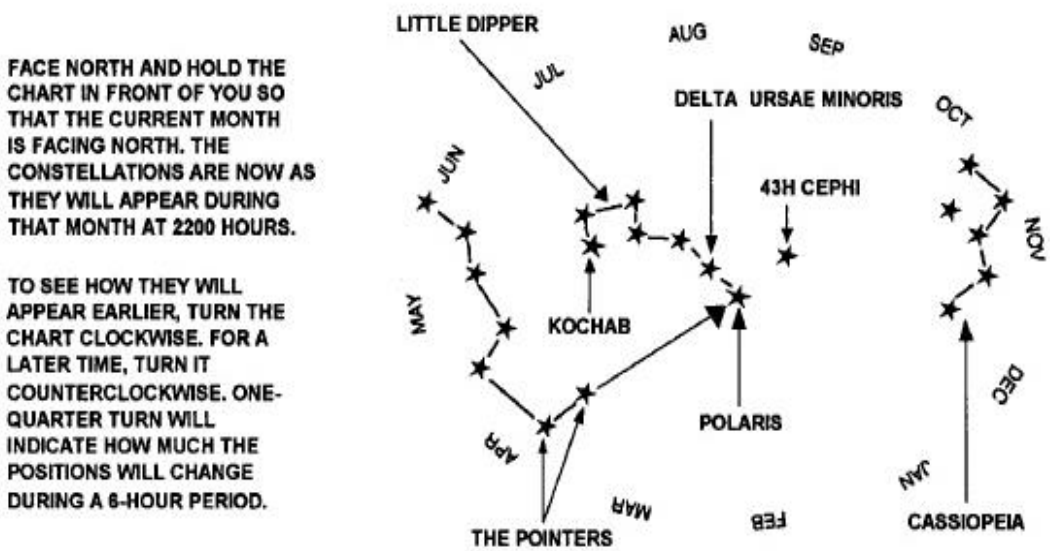


Figure 10-1. Star Locations

b. For rough orientation of the aiming circle, the operator first sets the declination constant on the upper motion and centers the magnetic needle with the lower motion. Next, the operator determines the latitude, to the nearest degree, from a map and converts it to mils by multiplying by 18. The operator then sets this value on the elevation scale of the aiming circle. This should place the operator’s line of sight very close to Polaris. As instrument operators become more proficient at identifying Polaris through an aiming circle, they can eliminate this orientation procedure.

c. To establish the orienting line, the horizontal clockwise angle from Kochab to Polaris is measured. Then the true azimuth is extracted from the appropriate table and the true azimuth is converted to a grid azimuth. The steps for establishing direction by observing Polaris are as follows:

(1) Measure the angle.

(a) Set up and level the aiming circle over the selected point.

(b) Using the upper motion, set 0.0 mils on the azimuth scale.

(c) Place the vertical cross hair of the instrument on Kochab using the lower motion and the elevation micrometer knob.

(d) Turn the azimuth micrometer knob (upper motion) clockwise until the vertical cross hair is centered on Polaris. (The telescope may have to be elevated or depressed.)

(e) Read the value on the azimuth scale to the nearest mil. (This is the entry value used to enter Tables 10-2 through 10-5).

(f) Depress the telescope to ground level. Emplace an aiming post, at least 30 meters, along the line of sight of the vertical cross hair line. This will serve as the EOL, and the Aiming circle becomes the OS.

(2) Extract the true azimuth to Polaris.

(a) Select Table 10-1, 10-2, 10-3, or 10-4, whichever pertains to the latitude closest to that of the instrument operator. If the instrument operator's location is exactly half-way between the latitudes listed on any two tables, either table may be used.

(b) Enter the appropriate table on the left side with the value from the upper motion of the aiming circle. Visually interpolate, if necessary, by using the value from (1)(e) above.

(c) Determine whether to intersect with Graph 1 (Kochab is below Polaris) or Graph 2 (Kochab is above Polaris). If in doubt, compare the vertical angle of the two stars.

(d) From the intersection of the measured angle from Kochab to Polaris on the appropriate graph, read the true azimuth to Polaris from the bottom of the table. Interpolate for odd-numbered values.

(3) Convert true azimuth to grid azimuth.

(a) Determine the grid convergence (the angle between true north and grid north) in mils, from the map sheet for the area of operations; or obtain it from the Sensor section.

(b) Convert the true azimuth to grid azimuth as shown in Figure 10-2.

(c) This computation results in the determination of the grid azimuth from the OS to the EOL.

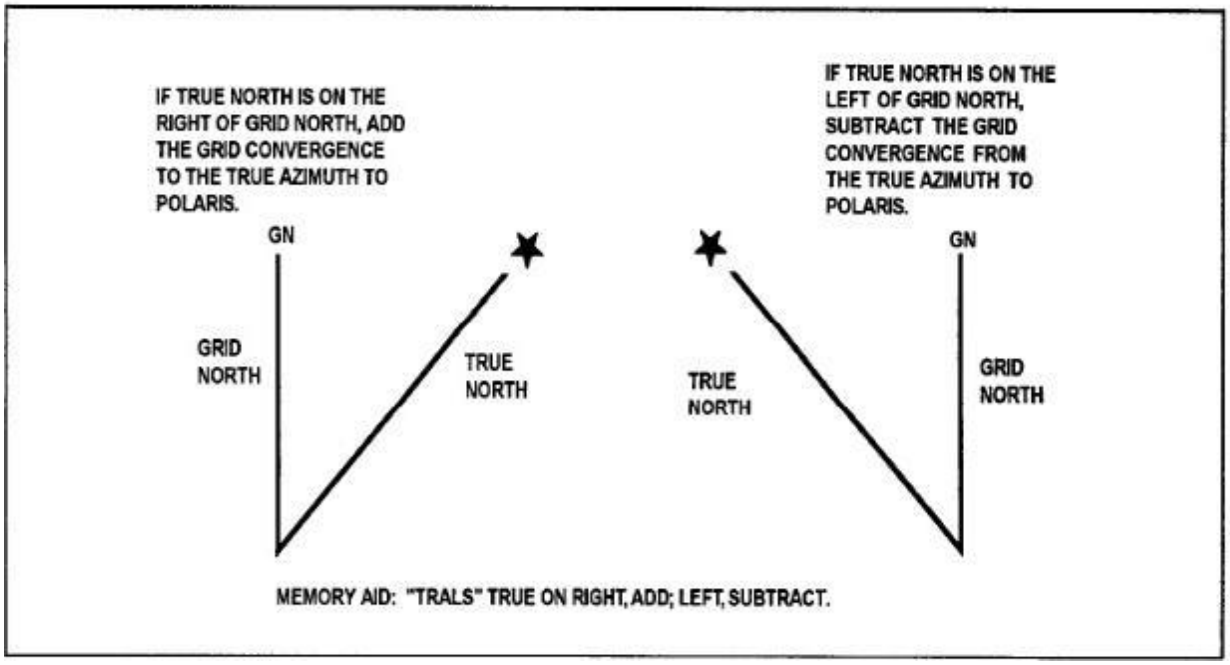


Figure 10-2. Application of Grid Convergence

Table 10-1. Polaris-Kochab 20º North Latitude

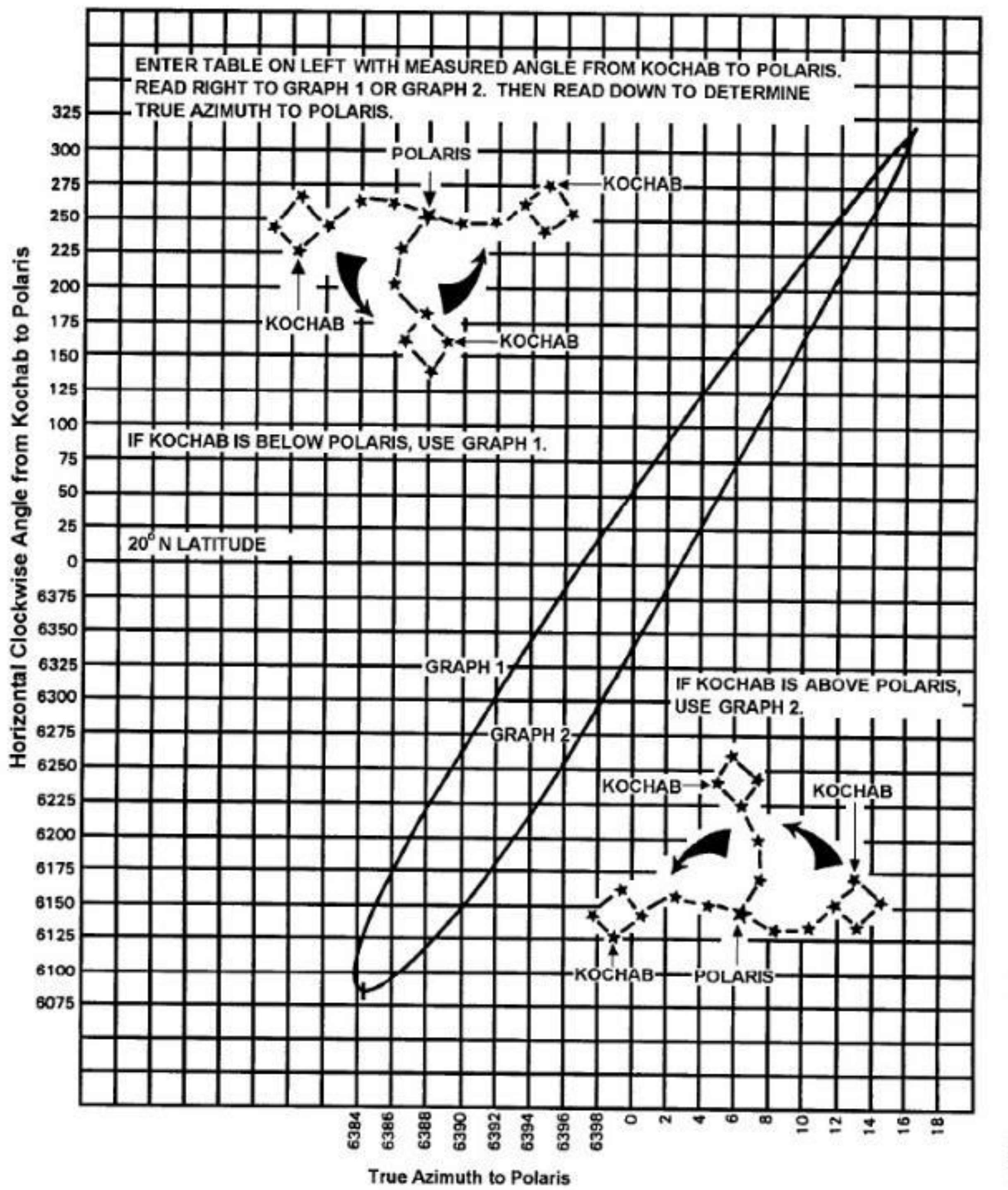


Table 10-2. Polaris-Kochab 35º North Latitude

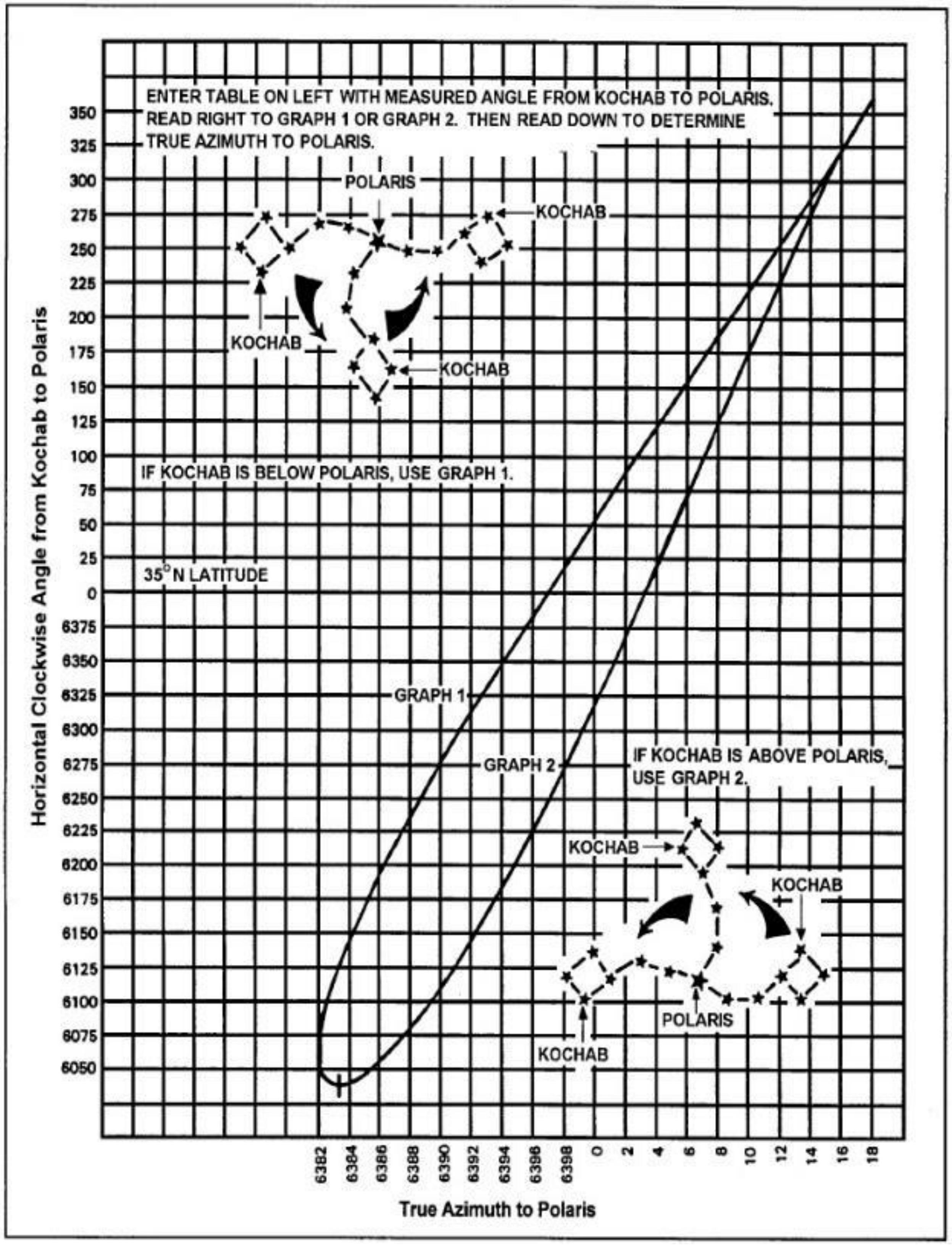


Table 10-3. Polaris-Kochab 42º North Latitude

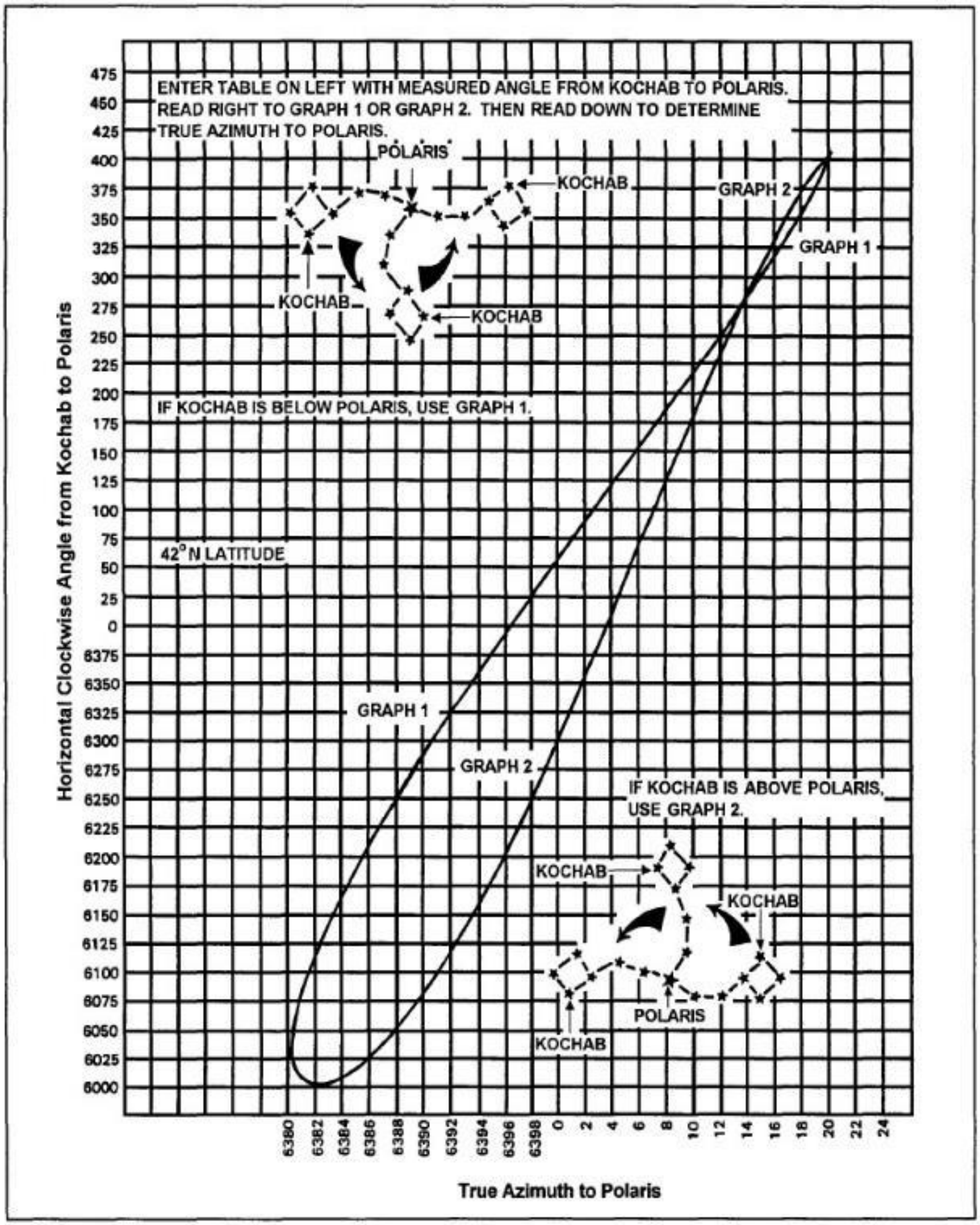
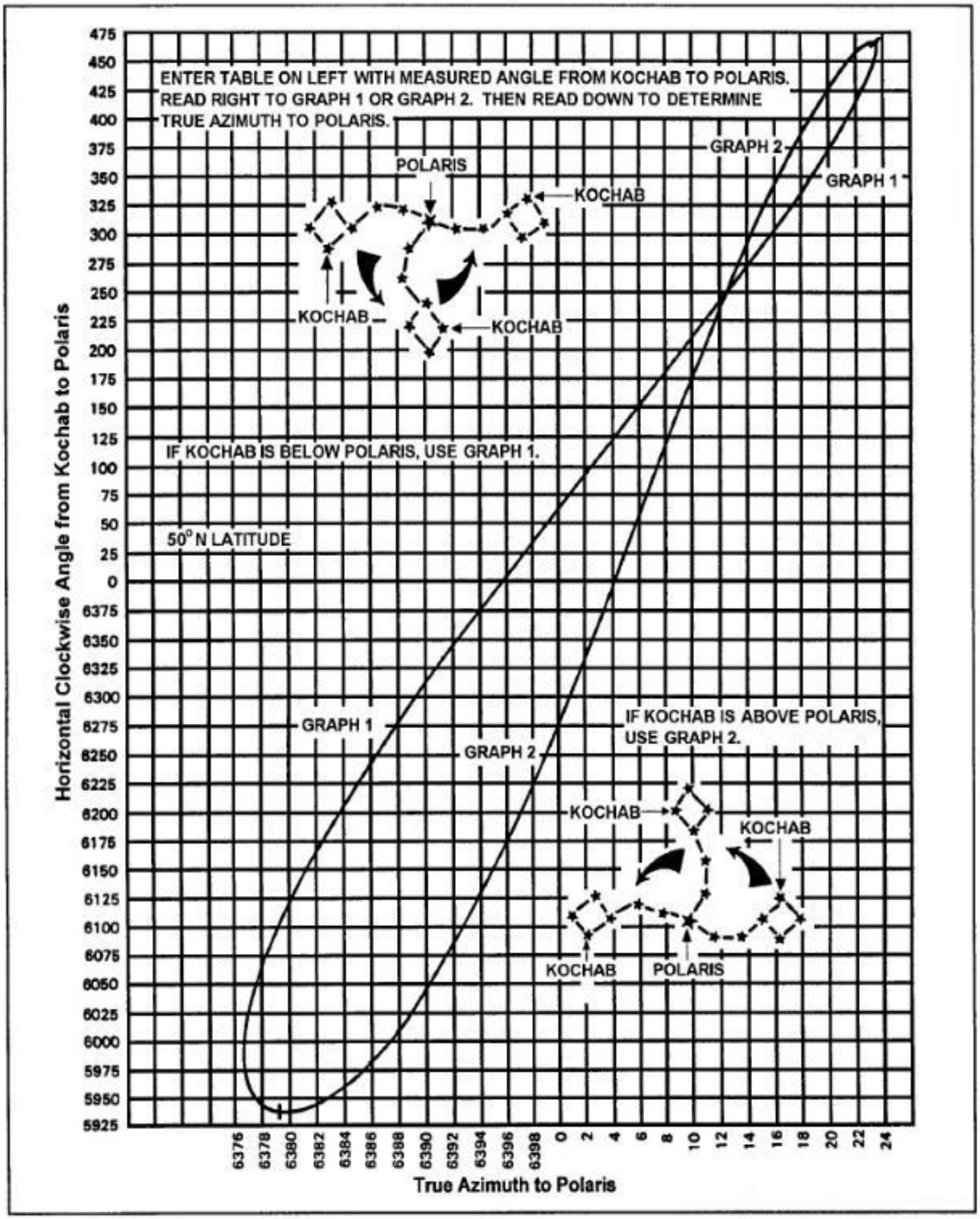


Table 10-4. Polaris-Kochab 50º North Latitude



10-6. Polaris 2 Method

Polaris 2 is a hasty survey technique used to establish accurate direction. It is simple, fast and has the distinct advantage of requiring no radio or wire communications. The instrument operator, however, must be in the northern hemisphere and must be able to locate the stars 43H Cephei, Polaris, and Delta Ursa Minoris. The Polaris II reticle will exceed its original service life in January 1996. In January 1996, the accuracy is 2.5 mils. The reticle can still be used, but the accuracy is degraded 0.1 mils each year after January 1996. The procedures for establishing direction by the Polaris 2 method are as follows:

a. Locate the stars.

(1) Locate Polaris by using the procedures in paragraphs 13-5a or 13-5b.

(2) To locate Delta Ursa Minoris and 43H Cephei, the instrument operator may have to reduce the light intensity in the telescope. The three brightest stars appearing in the operator's field of view will be Polaris, 43H Cephei, and Delta Ursa Minoris. When Polaris is used as the vertex, the angle formed by Delta Ursa Minoris and 43H Cephei is about 1,800 mils (Figure 10-3). This relationship remains the same and rotates counterclockwise at about 150 each hour.

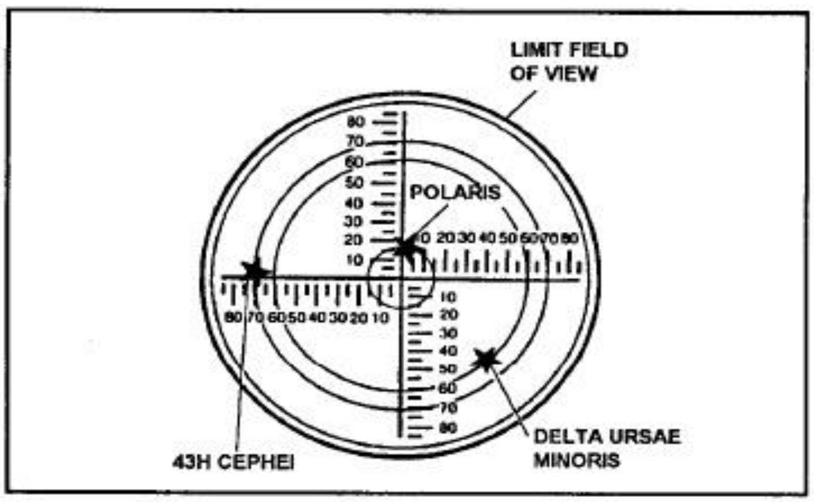


Figure 10-3. Polaris 2 with Stars in Tangent

b. Establish direction.

(1) Determine the grid convergence (the angle between true north and grid north) in mils, from the map sheet for the area of operation or from a survey section (Figure 10-4 page 10-11). Record this information.

(2) Set up and level the aiming circle over the selected point.

(3) Using the azimuth micrometer knob (upper motion), set the grid convergence on the azimuth scale.

(4) Using the elevation micrometer knob, set the predetermined elevation to Polaris on the elevation scale.

(5) Using the orienting knob (lower motion), sight on Polaris. Ensure that the grid convergence remains correctly set on the azimuth scales.

(6) When Polaris is in the field of view, use the elevation knob and lower motion to place the stars on their respective circles. There is no specific point on the circle on which the stars must be positioned. (The actual location of the stars on the circle depends on the time of year and the time of observation.)

(7) Emplace an aiming post, at least 30 meters from the aiming circle, at the desired location of the EOL.

(8) Using the elevation knob, lower the telescope. Use the upper motion to rotate the instrument clockwise until the vertical hairline is centered and at the lowest visible point on the aiming post.

(9) Read the azimuth to the nearest 0.5 mil directly from the azimuth scales.

(10) Using the procedures in paragraphs (3) through (9) above, determine a second azimuth to the EOL.

(11) The two azimuths determined to the EOL must agree within ±2 mils. If the two azimuths agree within these limits, determine the mean grid azimuth. This is the grid azimuth to the EOL.

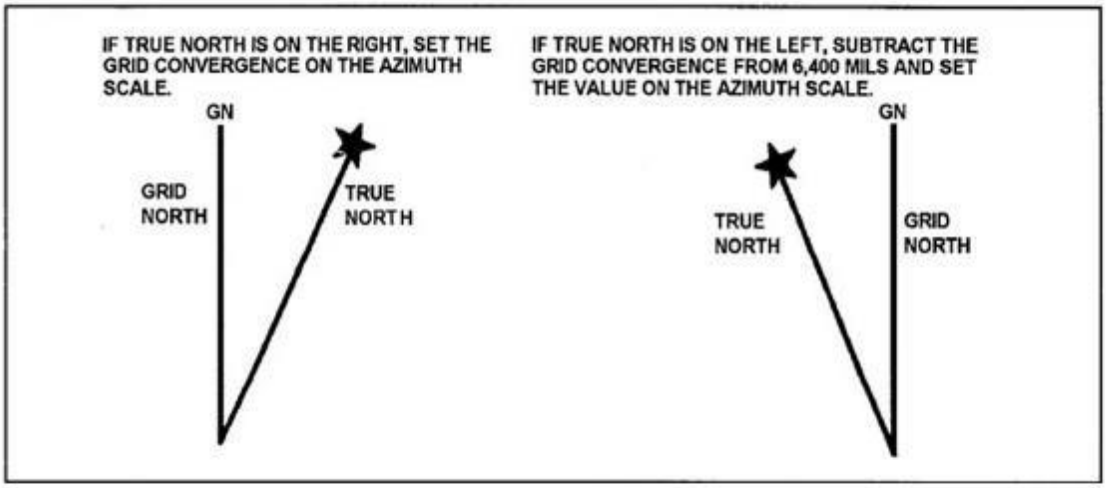


Figure 10-4. Convergences Rules (Polaris 2)

10-7. Hasty Astronomic Observation

a. Hasty astronomic observation is performed to determine an azimuth to the Sun or a star.

b. Fieldwork procedures. (instrument operator): sets up and levels the aiming circle over the OS. (RCDR): sets up the DAGR and records whether using zulu or local time (daylight savings time), date, time figure of merit, and the star (name & number) to be tracked. (instrument operator): sets 0.0 on scales using upper motion. (instrument operator): turns to and tracks sun or star using lower motion and announces “prepare to track”. (RCDR): when ready, announces “prepared to track”. (instrument operator): announces “tracking, tracking, tracking” and when sun/star is centered in scope, announces “tip”. At tip: (instrument operator): stops tracking the celestial body. (RCDR): records the time of tip seconds first, then hours and minutes. (instrument operator): depresses scope and sends a runner to set stake in the vertical cross hair using hand/arm signals. Runner: sets stake at least 100 meters from OS to the as per the instrument operator’s direction. (instrument operator): turns to and tracks sun or star using upper motion and announces “prepare to track”. (RCDR): when ready, announces “prepared to track”. (instrument operator): announces “tracking, tracking, tracking” and when sun/star is centered in scope, announces “tip”. At tip: (instrument operator): stops tracking the celestial body and reads reading from the scales to RCDR (this is the check angle from the aiming circle) (RCDR): records the time of tip seconds first, then hours and minutes and the reading from the scales.

c. Complete the appropriate computation recording form. Compute the hasty astronomic observation using the survey program in the handheld computer system (use all recorded field data from computation form for entries) the computed azimuth from the handheld computer system is the azimuth to the stake. Compare the check angle of the aiming circle to the check angle from the handheld computer system. They must agree ± 2.0 mils. If they differ by more than ± 2.0 mils repeat the procedure. Conduct a magnetic check of the computed Azimuth.

10-8. Subtense

The subtense method is the fastest of three distance-measuring procedures. It yields accuracy equivalent to that obtained with a premeasured piece of wire. An advantage is that a horizontal distance is obtained indirectly; that is, the distance is computed, rather than measured. This allows subtense to be used over terrain where obstacles, such as streams, ravines, or steep slopes may prohibit pacing or the use of wire.

a. The subtense method uses precise values with a trigonometric solution (listed in tables 5-6 through 5-8 in MCRP 3-10E.3, *Tactics, Techniques, and Procedures for Field Artillery Manual Cannon Gunnery*). Subtense is based on a principle of visual perspective–the farther away an object is the smaller it appears.

b. There are two procedures involved in subtense measurement:

(1) Establishing a base of known length.

(2) Measuring the angle of that base with the use of the aiming circle.

c. The subtense base may be any desired length. However, if a 60 meter base, a two meter bar, or the length of an M-16A4 rifle is used, pre-computed subtense tables are available. The M-16A4 or 2 meter bar must be held perpendicular to the line of sight by a Marine facing the aiming circle. The instrument operator sights on one end of the M-16A4 or 2 meter bar and measures the horizontal clockwise angle to the other end of the rifle or bar. The instrument operator performs this twice and means the angles. The instrument operator then enters the appropriate subtense table with the mean angle and extracts the distance. Accurate distances can be obtained with the M-l6A4out to approximately 150 meters, with the 2 meter bar out to 250 meters, and with the 60 meter base out to 1,000 meters. If a base of another length is desired, a distance can be computed by using the following formula:

$$\text{Distance} = \frac{\text{1/2 BASE (in meters)}}{\text{tan (1/2 angle) (in mils)}}$$

CHAPTER 11 WEATHER AND ITS EFFECTS

11-1. Field Artillery Meteorology

a. This section describes what and how different atmospheric conditions effect artillery fires. The conditions along the trajectory and velocity of a projectile or rocket directly affect its accuracy, which may cause the projectile or rocket to miss the desired point of impact. A 5 to 10 percent effect on the firing tables is possible even with stable atmospheric conditions. For example, tests in Southwest Asia demonstrated that firing artillery at maximum ranges in extreme heat and low air density resulted in MET corrections of up to 4,700 meters.

b. With the emphasis on first round fire for effect and trends toward longer ranges, accurate MET corrections for artillery fires are crucial. The use of invalid or no MET corrections could cause artillery projectiles to impact friendly forces, especially during danger close missions. Accurate MET data must be obtained and appropriate corrections applied to all fires in order to:

(1) Conserve ammunition.

(2) Decrease time in adjustment.

(3) Obtain a greater surprise effect.

(4) Reduce the potential for fratricide.

c. Despite automation, Sensor sections require an understanding of atmospheric and ballistic terms and effects of MET conditions on artillery fires. Sensor officers and chiefs must be able to recognize major weather changes that negate MET accuracy.

d. In addition to the weather-related terms, there are other atmospheric terms used. They are ballistic meteorological terms and are discussed in the following paragraphs.

e. When computing trajectories, ordnance ballisticians use the International Civil Aviation Organization standard atmosphere. This standard atmosphere is the basis for all data of the ballistic solution and as a point of departure for ballistic MET corrections. The International Civil Aviation Organization atmosphere at mean sea level is:

(1) Dry air

(2) No wind

(3) Surface temperature of 15° Celsius degrees with a decrease, or lapse rate, of -6.5° Celsius degrees per 1,000 meters up to a height of 11,000 meters and a constant temperature of 56.5° Celsius degrees between 11,000 and 25,000 meters.

(4) Surface pressure of 1,013.25 millibars, decreasing with height.

(5) Surface density of 1,225 grams per cubic meter, decreasing with height.

f. For convenience in computing, reporting, and applying corrections, the standard atmosphere is identified by atmospheric zones. The atmospheric zones for various MET messages and the thickness and heights of those zones are listed in Table 11-1 on page 11-3.

Table 11-1. Atmospheric Structure of MET Message

HEIGHT (meters)	LINE (ZONE) NUMBERS COMPUTER	BALLISTIC	TARGET ACQUISITION	SOUND RANGING	FALLOUT
SURFACE	0	0	0	0	0
50			1		
100	1	1	2	1	
200			3		
300			4		
400	2	2	5	2	
500			6		
600			7	3	
700			8		
800	3	3	9	4	
900			10		
1,000			11		1
1,100			12		
1,200			13		
1,300	4	4	14		
1,400			15		
1,500			16		
1,600			17		
1,700			18		
1,800	5	5	19		
1,900			20		
2,000			21		
2,100			22		
2,200			23		
2,300	6		24		
2,400		6	25		
2,500			26		
2,600			27		2
3,000	7				
3,500	8				
4,000	9	7			
4,500	10				
5,000	11	8			3
6,000	12	9			
7,000	13				
8,000	14	10			4
9,000	15				
10,000	16	11			5
11,000	17				
12,000	18	12			6
13,000	19				
14,000	20	13			7
15,000	21				
16,000	22	14			8
18,000	24				
19,000	25				
20,000	26				10
------					-----
30,000					15

g. Ballistic wind is a wind of constant speed and direction that has the same effect on a projectile during its flight as all the varying winds serially encountered by the projectile. Ballistic density is a constant density, expressed as a percentage of standard density that has the same effect on a projectile's trajectory as the varying densities serially encountered by the projectile. Ballistic temperature is a constant vertical temperature, expressed as a percentage of standard temperature that has the same effect on a projectile in flight as the varying temperatures serially encountered by the projectile.

h. It is important to identify the weather effects on artillery because it provides sensor support Marines understanding of the importance of the MET mission. The following provides detailed information and graphical explanations of how certain aspects of weather affects the artillery:

(1) The effects of wind on a projectile are easy to understand. In terms of artillery, a tail wind causes an increase in range, and a head wind causes a decrease in range. A crosswind blows the projectile to the right or left, which causes a deflection error. Fire direction center personnel convert ballistic wind measurements into range and deflection and apply corrections to the deflection and elevation of the artillery piece. Figures 11-1 and 11-2 show the effects of a 20-knot wind on a 155-millimeter howitzer firing at a range of 11,000 meters, charge 3 H.

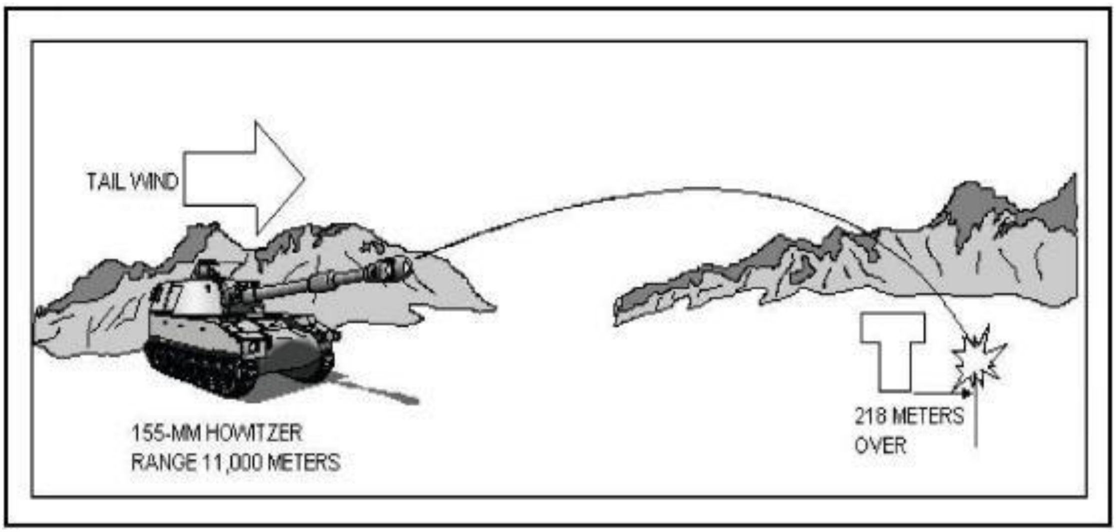


Figure 11-1. Effects of a 20 Knot Tail Wind

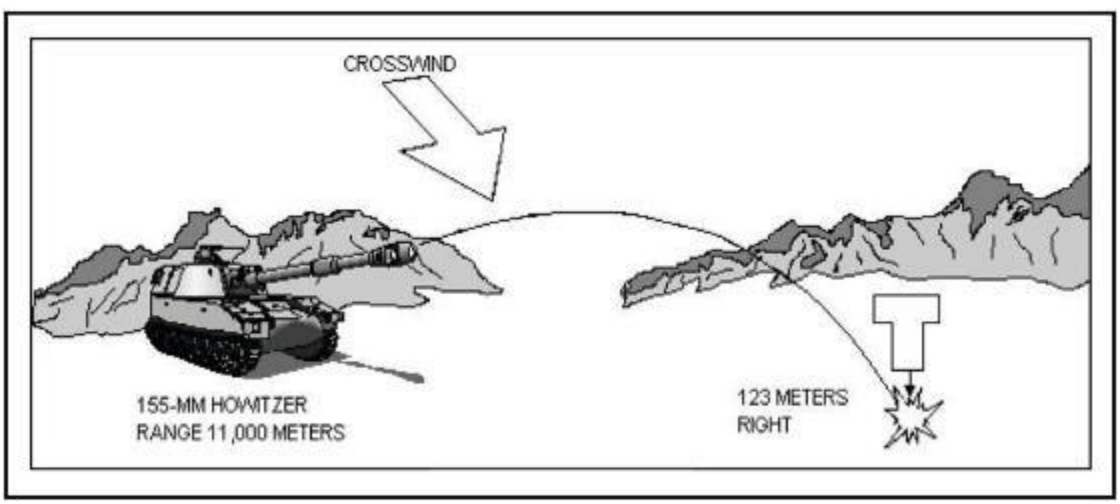


Figure 11-2. Effects of a 20 Knot Cross Wind

(2) Variations in air temperature cause two separate effects on a projectile. One effect is caused by the inverse variation of density with temperature (equation of state). This effect is compensated for when density effects are considered. The second effect is regarded as the true temperature effect. It is the result of the relationship between the speed of the projectile and the speed of the air compression waves that form in front of or behind the projectile. These air compression waves move with the speed of sound, which is directly proportional to the air temperature. The relationship between the variation in air temperature and the drag on the projectile is difficult to determine. This is particularly true for supersonic projectiles since they break through the air compression waves after they are formed. As firing tables indicate, an increase in air temperature may increase, decrease, or have no effect on achieved range, depending on the initial elevation and muzzle velocity of the weapon. Figure 11-3 shows the effect of a 5-percent deviation from standard temperature.

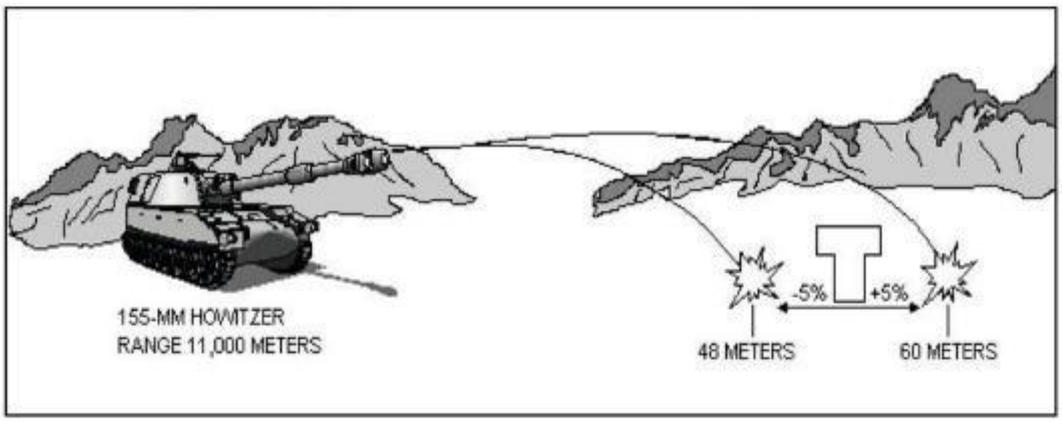


Figure 11-3. Effects of a ± 5% Difference In Temperature

(3) Density of the air through which a projectile passes creates friction that affects the forward movement of the projectile. This affects the distance the projectile travels. The density effect is inversely proportional to the projectile ranges; that is, an increase in density causes a decrease in range. Figure 11-4 on page 11-6 shows the effect of a 5-percent deviation from the standard air density. Air density decreases rapidly with height. Therefore, the altitude of the firing battery and the ordinate of the trajectory have a direct effect on the magnitude of the density correction. Given equal deviations from standard of each MET effect on the flight of a projectile, air density has the greatest range effect.

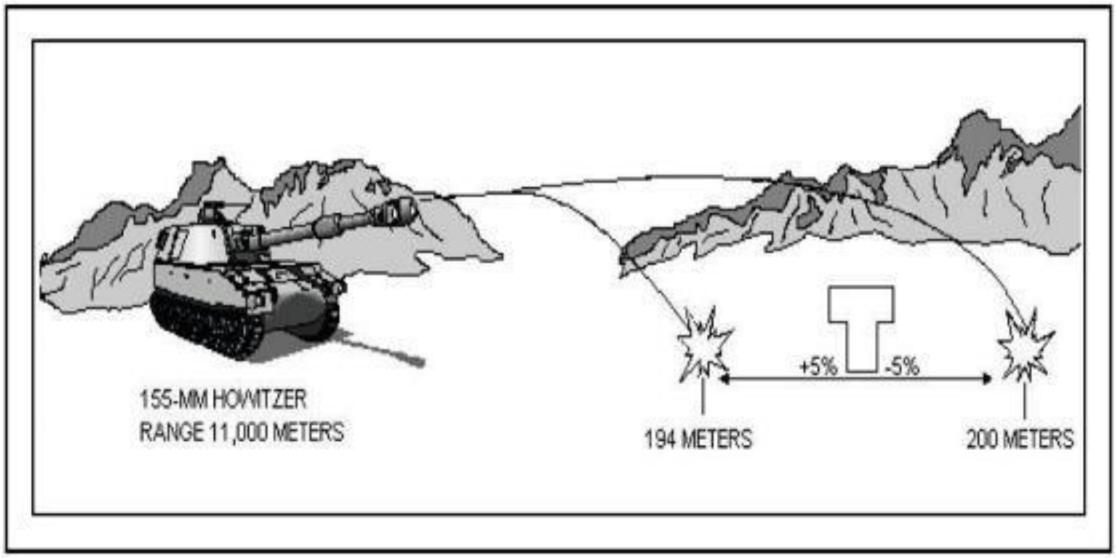


Figure 11-4. Effects of a ± 5% Difference in Density

11-2. Atmospheric Modeling

a. Advances in technology have allowed meteorologists to measure weather phenomenon on a global scale. This large scale data is of little use in predicting weather until it is evaluated against the factors affecting weather (terrain, temperature, bodies of water, vegetation, and others) and applied to a specific area. Scientists have developed computer modeling programs to evaluate the massive amounts of data, giving meteorologists a tool to accurately predict weather.

b. Artillery MET is concerned with modeling the atmosphere to produce a MET message, which is used by artillery units to develop more accurate firing solutions. For almost half a century, artillery MET messages have been produced utilizing balloons and/or radiosondes in one fashion or another. While these methods produce extremely accurate MET messages at the balloon release point, the further away the firing unit is located from that release point, the less effective the data for computing firing solutions.

c. The sensor section utilizes mesoscale modeling as the software modeling engine to the computer met data-profiler. Together, the software and the hardware form the modeled meteorological information manager (MMIM). The following offers more detail with respect to mesoscale modeling version 5 (MM5) application and NWP:

(1) MM5 is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. It is supported by several auxiliary programs, which are referred to collectively as the MM5 modeling system. This is illustrated in (Figure 11-5 page 11-7). Terrestrial and isobaric meteorological data are horizontally interpolated (TERRAIN and REGRID) from a latitude-longitude mesh to a variable high-resolution domain on a mercator, Lambert conformal, or polar stereographic projection. Since the interpolation does not provide mesoscale detail, the data may

be enhanced with observations from the standard network of surface stations. Program INTERPF performs the vertical interpolation from pressure levels to the sigma coordinate system of MM5. Sigma surfaces near the ground closely follow the terrain, and the higher-level sigma surfaces tend to approximate isobaric surfaces. Since the vertical and horizontal resolution and domain size are variable, the modeling package programs employ parameterized dimensions requiring a variable amount of core memory. Some peripheral storage devices are also used. Since MM5 is a regional model, it requires an initial condition as well as lateral boundary condition to run. To produce lateral boundary condition for a model run, one needs gridded data to cover the entire time period that the model is integrated. The development and scientific support for the MM5 ceased in 2004 yet it is still able to be utilized to produce artillery MET messages.

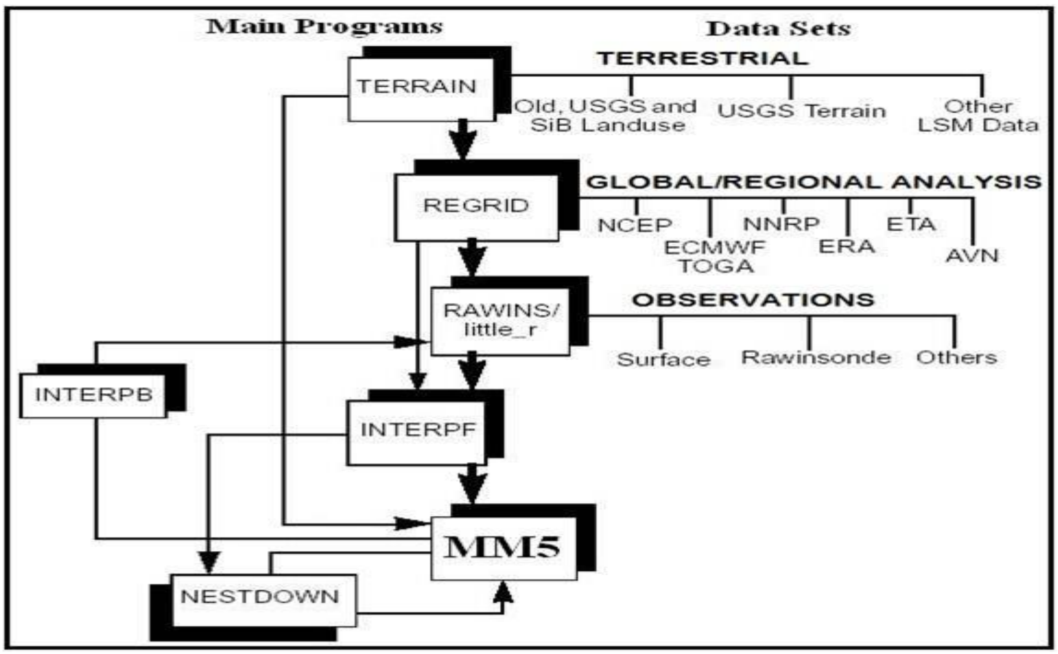


Figure 11-5. MM5 Modeling System

(2) It is important to understand that the MET messages produced using modeling capabilities are forecasted messages. Being forecasted messages, they can be produced for near future operations (usually up to 48 hours in advance). Those future missions can be provided with MET messages without the use of expendables and with an extremely small battlefield footprint.

(3) Each model will have a forecast period that it can produce messages out to. These forecast periods are dependent on the resolution being utilized. The greater the resolution size, the further out the forecast period. Because atmospheric models are run on computers, the more data being computed, the amount of forecasts being generated decreases. The resolution of each model is how refined the model calculates MET data. Think in terms of a digital camera's megapixel capability and a one gigabyte memory card inside it. The megapixel capability would be like a resolution and the memory card being the "forecast period". A one megapixel

camera could produce distinguishable photos, though not very crisp, and hold about a 1,000 on the memory card. A five megapixel camera would take clearer photos but only would be able to store 500 on the memory card. A ten megapixel camera would take phenomenal, crystal clear photos but only be able to store 100 on the memory card. This concept holds true in terms of model resolution and forecast periods because of the computing power required to further refine the data into ever increasing accurate MET messages.

(4) The modeling resolution, like stated in the above paragraph, is how refined MET data is computed to generate a MET message. Raw MET data is ingested by the model and then it's refined into more and more accurate MET messages. A graphical display of different resolutions for MET models is shown in Figure 11-6 (figure does not reflect all different resolutions but shows the trend that they break down into a third of the next larger resolution). They convey the concept that the larger the resolution, the less accurate the MET message. This in no way means that there are accuracy issues with MET models but that one resolution isn't as accurate as the next. The smallest available resolution should be utilized whenever possible (example would be using a 15km, when both that and the 45km are available).

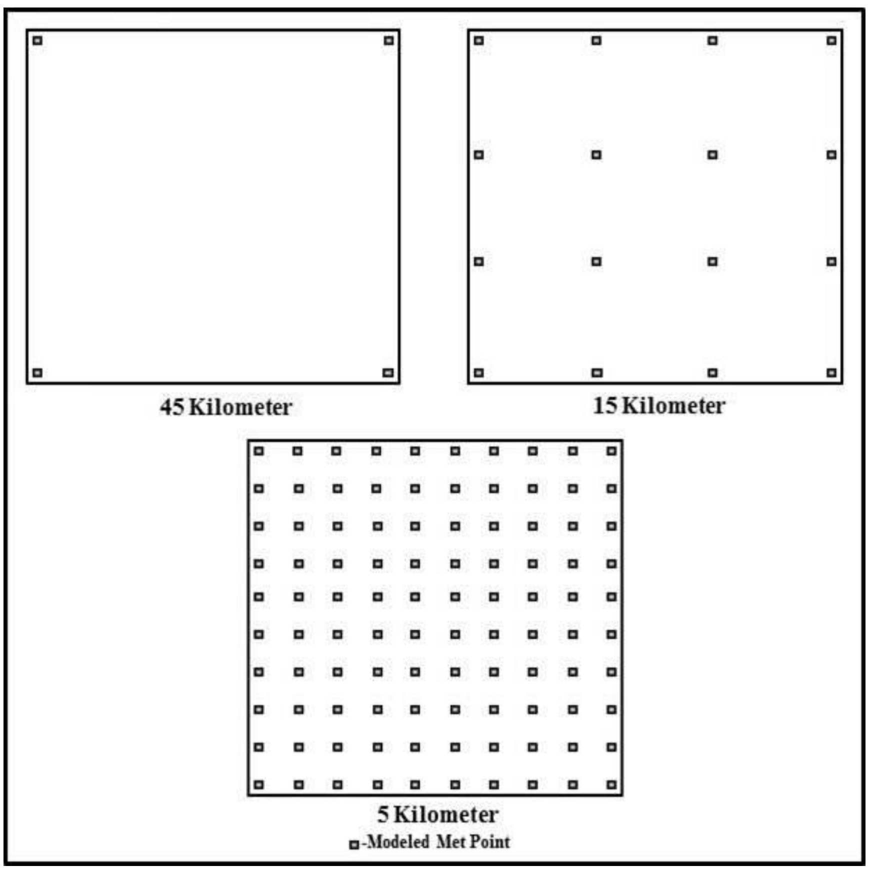


Figure 11-6. Model Resolutions

(5) The forecast period, data post period, and model cycle run time for each model is dependent on the model and platform it's produced on, as well as which resolution

it's running. There are common trends no matter which model is utilized in terms of these factors. Forecast periods are in twenty-four hour blocks and increase with a decrease in resolution accuracy, being ran every four or twelve hours (times are always in Greenwich mean time/GMT/Zulu). Messages are then produced every three hours or every hour, again dependent on the resolution requested/provided for a given area. There is a model cycle time that also runs every four or twelve hours and those times fit in between the forecast periods. Figure 11-7 provides an example of model cycle times and forecast periods. How the different systems apply the modeled data and their operations will be discussed in their respective portions of this publication.

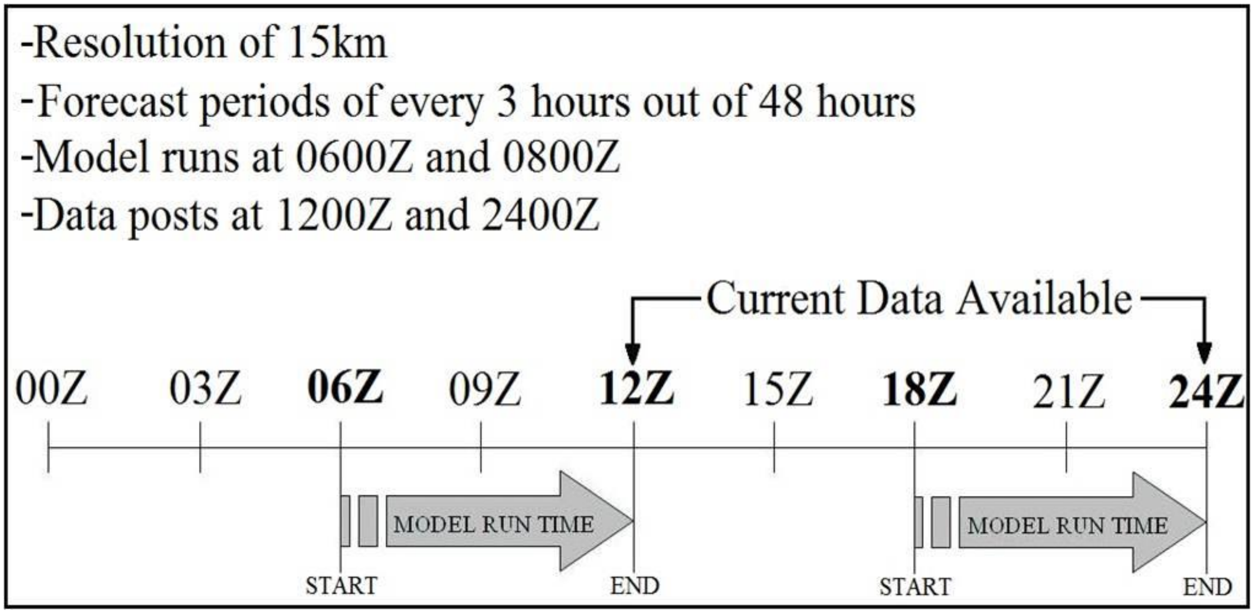


Figure 11-7. Model Forecast Periods, Run Times, & Data Post times

11-3. MET Effects on Precision Munitions

a. MET conditions at the target location effects the accuracy of smart munitions. Smart munitions are subject to the same effects of wind, temperature, and humidity as a free flight projectile. These effects are moderated by the ability of smart munitions to make in-flight corrections using guidance methods. The greatest effect of MET conditions on smart munitions is the effect of conditions on the ability of the smart munitions acquiring targets. Smart munitions that acquire targets by visual means can have difficulty identifying targets when the target area is obscured by clouds or blowing sand and other adverse conditions.

b. Environmental effects of weather can influence the use of precision-guided munitions (PGMs). In order to brief weather conditions that may affect PGMs, an understanding of their operation is important.

(1) Visible Systems. Passive systems which respond to naturally emitted or reflected electromagnetic radiation in the visible spectrum. Environmental limitations are:

(a) Clouds or fog

(b) Precipitation, blowing snow or spray

(c) Poor illumination

(d) Low sun angle

(2) Near-infrared (IR) passive systems. A TV-silicon vidacon which senses radiation between .5 and 1.2 microns. The longer wavelength of these systems enhances the sensor's ability to penetrate atmospheric aerosols such as haze. Near-IR systems cause an increase in contrast between natural and painted objects at visual wavelengths. Environmental limitations are the same for visible systems except that atmospheric aerosols are less of a problem.

(3) IR semi-active systems. These employ a laser designator operating at IR wavelengths. The point of maximum reflected energy is sensed and tracked using a centroid tracker. These systems have the advantage of day or night operations. Environmental limitations:

(a) Clouds/fog, other than very thin (they absorb IR energy)

(b) Haze and other dry aerosols (for near IR systems only)

(c) High humidity (for far IR and far IR systems only)

(4) Middle and Far IR passive systems. These systems respond to naturally emitted electromagnetic radiation from terrestrial objects in the middle and far IR wavelengths. Threshold thermal contrasts must be met for IR lock-on. These systems may be used for day or night operations. Resolution is poor due to long wavelength. Environmental limitations:

(a) Clouds/fog other than very thin

(b) High humidity (for far IR only)

(5) Millimeter Wave/Microwave Systems. These systems respond primarily to emitted, but also to reflected energy at millimeter wave or microwave wavelengths. Most of these systems are passive, such as the "SHRIKE" anti-radiation missile which has a microwave sensor and home in on microwave or radar emissions. Day or night operations are possible, but resolution is poor due to long wavelength. Environmental limitations:

(a) Dense clouds of high liquid water content.

(b) Precipitation causes attenuation.

(6) Environmental conditions can affect target acquisition anywhere in the cycle:

(a) Severe (or greater) turbulence can break lock-on

(b) Icing of any kind can coat sensor cover which blinds it or the ice can cause aerodynamic problems (changes shape and add weight). Icing can also jam the controls of the tracker.

(c) Ablation or erosion of the sensor cover by pitting may occur when the PGM passes through hard atmospheric particles such as hail or sand.

(d) Lightning or Triboelectrification (static charge buildup) can foul electronic circuitry lightning can cause detonation of PGM.

(7) Sun angle:

(a) Mie scattering (path radiance) causes problems for TV and near-IR systems.

(b) Low sun angle can create shadows which may cause false lock-on.

(c) Thermal contrast is affected as the different parts of the target heat up and cool down at various rates as the sun rises and sets

(8) Target Size and shape determines the range at which target acquisition and lock-on can be accomplished

(9) Soil moisture content and precipitation:

(a) Change in moisture content of soil can change its color and the inherent contrast. It can also change the soil temperature, and thus affect thermal contrast (moist soil warmer than dry).

(b) Rain or snow in the target area will affect the temperatures of targets and backgrounds, affecting thermal contrast.

(c) Snow cover has a strong influence on contrast.

(d) The inherent contrast can decrease.

(e) Path radiance problem for visual imaging sensor sensors.

(f) Patchy snow cover creates alternating hot/cold spots in background, affecting thermal contrast

(10) Radiative temperature crossover is a function of the diurnal temperature cycle. It occurs when the target and background achieve the same radiative temperatures and is caused by the different rates at which the target and background heat up and cool down.

(11) Strong surface winds can decrease thermal contrast.

(12) Thermal clutter is hot or cold spots surrounding the target which can confuse or distract the IR sensor by momentarily altering or wiping out the thermal contrast.

(13) A target area MET message provides data that is very useful when dealing with PGMs. This target area can be used to increase the accuracy of smart munitions or can influence the decision to utilize these expensive munitions. The MET conditions may be such that fire planners will select a different asset to engage the target. It is important to know that a target area MET message is produced only utilizing atmospheric modeling

CHAPTER 12 METEOROLOGICAL OPERATIONS

Section I. MODELED METEOROLOGICAL INFORMATION MANAGER

12-1. General

Chapter 12 describes the assets and methods used to determine meteorological data required to provide for accurate meteorological data. These methods in order of preference are MMIM, PiBal, and extrapolated MET. For specific operating instructions for the MIMM, see Marine Corps TM 12122A-OR/1, *Operator and Field Maintenance Manual for Computer, Meteorological Data AN/GMK-2 (Profiler)*.

12-2. Modeled Meteorological Information Manager Overview

The MMIM is the primary method used for determining MET. The MMIM can generate computer MET, basic wind report MET, target acquisition MET, and target area MET. It is an upper air meteorological data collection, processing, and dissemination system. The MMIM is integrated hardware and software, known as the computer met data-profiler. The hardware is an AN/GMK-2 laptop computer. Software performs communications, device interface, meteorological data processing and modeling, and utility functions. This system operates within the Marine Corps fire support systems architecture specifically at the regimental headquarters battery TPC. The MMIM interoperates with the target processing system, Global Broadcast Service (GBS), satellite antenna, and AFATDS.

a. The MMIM is designed for rapid set up and ease of operation. The MMIM is a computer system generally located within the COC or GIC environment and is connected via the local area network to an AFATDS. The MMIM can receive and process requests for meteorological data from a secure online connection.

b. The MMIM receives global air-land weather exploitation model (GALWEM) forecast data via Non-classified Internet Protocol Router Network or the global broadcasting service receive suite for processing. The GBS is a ground-mounted dish antenna system that receives GALWEM and World Meteorological Organization data via geostationary satellites. GALWEM is transmitted every 6 hours by Air Force Weather Agency (AFWA).

c. The MMIM generates and transmits MET messages for target areas up to 500 km based on a fusing of GALWEM , MM5, and post processing technology. While the MMIM is connected to the GBS, the MM5 model is updated every three minutes with the most current available MET data.

12-3. Modeled MET

The NWP is utilized in an artillery meteorologist’s capacity to produce MET messages based on computer models. These models are based upon data from sensors located around the globe. By definition, atmospheric modeling is a mathematical model constructed around the full set of dynamical equations which govern atmospheric motions. Dynamical equations are simply equations for the physics and dynamics of the atmosphere. These equations are nonlinear and are impossible to solve exactly, which causes each model to differ slightly. For artillery meteorology, these models are broken down into global or regional models.

a. Global modeling covers the entire globe. Data for a global model comes from sensors dispersed over the entire globe and are able to produce coarsely accurate meteorological information anywhere on the earth. Global models are not directly utilized to produce MET messages. This global data is further refined to generate regional models. A global model is basically a foundation to produce regional models which are directly utilized for MET message production.

b. Regional modeling is generated to cover certain areas of the world. These are also called limited area models. Regional models are developed via refined global model data. Regions are broken down in large areas, e.g., North America, Southwest Asia, or the South Pacific. The regional model is utilized to develop local MET messages for artillery purposes.

c. There are several different models that are currently available to produce usable data for forming MET messages. The most common models are MM5 and the weather research and forecasting model. The MM5 has a wider area of coverage, whereas weather research and forecasting model uses smaller regional models and digital terrain elevation data information to provide more accurate data at the surface lines of a MET message. Currently, the MMIM operates using the MM5 model to produce artillery MET messages.

d. MET messages are generated using regional models that cover a specific area of interest. For MMIM operations, these domains are 36, 12, and 4 kilometers. The finer the resolution for the model, the more accurate the meteorology information. However, the finer resolutions require more data be gathered and complied.

e. Model cycle times is a set time line that the model will begin to ingest raw data in order to initialize the model. This raw data comes from the sensors dispersed in the region and at the resolution requested. The resolution size will determine how long it takes each model to run. But for MMIM purposes, GALWEM data posts at 0000, 0600, 1200 and 1800Z will provide 72 hours of data per .tar file, which will include all three resolution sizes. If the MMIM is connected to the internet, the user will be able to track the model cycle times on the interface.

f. The MMIM is able to model a 500 km by 500 km by 30 km high cube of atmosphere. Any units within this area requiring MET can be supported by a single MMIM.

12-4. Global Broadcasting Service

The GBS Receive Suite, AN/TSR-8 is a transportable ground receive suite that receives one-way satellite transmission of video, weather data, and imagery for support of joint forces. It is capable of both classified and unclassified products. It is a ground-mounted dish antenna system that receives GALWEM data and World Real-time Observation Data via geostationary satellites. The GBS antenna is maintained at Regiment COC. The GBS is the primary means for providing weather data to the MMIM. The AFWA broadcasts GALWEM data to a space segment satellite, which in turn transmits the GALWEM data to the AN/TSR-8 Receive Suite. The transportable ground receive suite then transmits the data to the MMIM, then takes this GALWEM data and turns it into a MET Message which is then sent to AFATDS subscriber terminals.

12-5. GALWEM Coverage

The GALWEM provides coverage for the complete globe. The globe is divided into 8 separate regions as shown in (Figure 12-1). Meteorology information can be requested for any of these 8 regions. In the South Pacific region, MET can only be received online, via an Army Knowledge Online website.

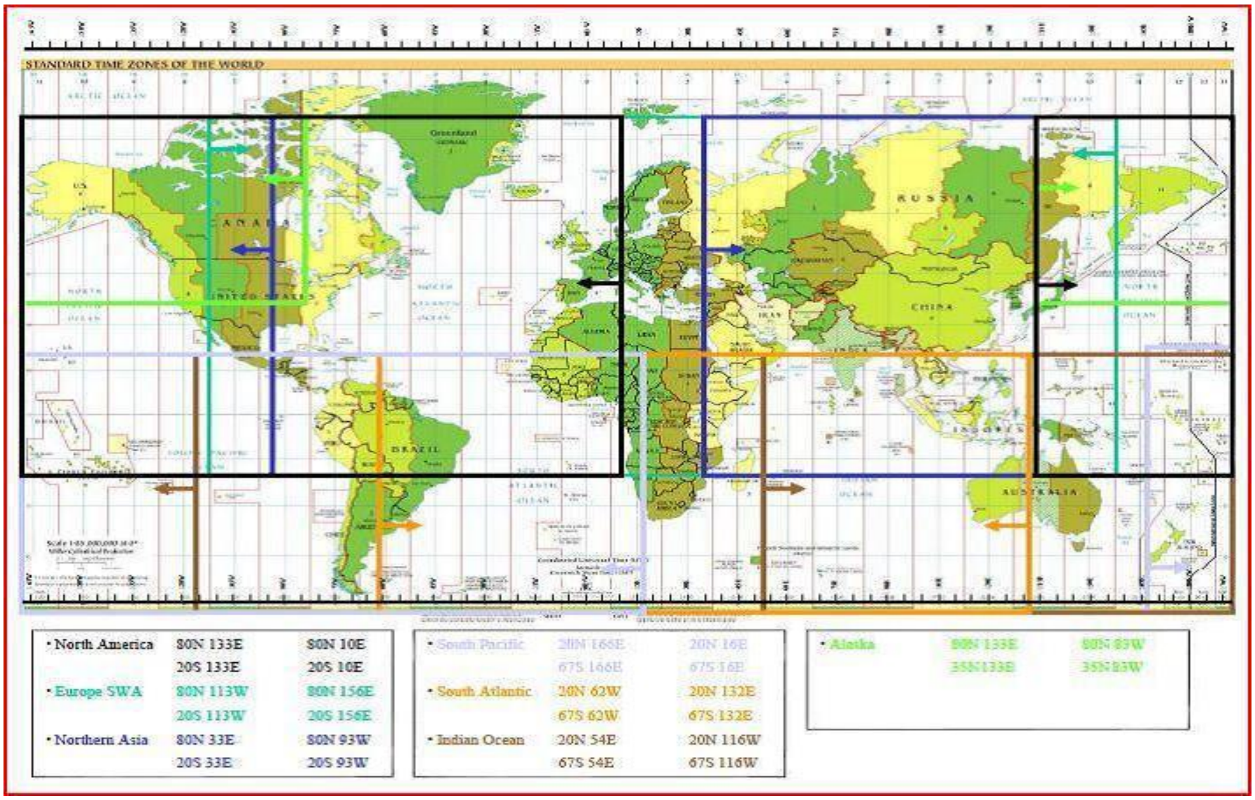


Figure 12-1. GALWEM Regions

12-6. Pre-Mission Planning

A GBS mission request (GMR) is used when initiating, adding, dropping, or changing GBS services. The initial GMR must be submitted early enough to ensure the theater information manager receives it 14 days prior to required delivery date for CONUS operations and 25 days prior to required delivery date for outside CONUS operations. All GMR’s must be approved by the theater information manager.

12-7. Modeled Meteorological Information Manager Updates

While the GBS is functioning, data will be automatically pushed to the system. The model will receive updates of regional area observations data packs every three minutes. If any of these data packs pertain to the current coverage area, they will be applied to the current running model. The MMIM will reinitialize itself every six hours after it has received the updated GALWEM data automatically. During this time, the MMIM will not be able to process MET requests for up to 30 minutes. The model will be set to update around 0000Z, 0600Z, 1200Z and 1800Z, however, this can be adjusted by the operator. The operator must ensure prior coordination is made with supported units before beginning the initialization process.

Section II. PILOT BALLOON

12-8. Pilot Balloon Overview

a. The primary means to determine meteorological data is using the MMIM. When electronic meteorological equipment fails or is not available, MET data may be determined from observation of pilot balloons along with approved MET software. MET data determined from PiBal observation is not as accurate as MET data determined from electronic meteorological equipment. PiBal is only accurate in the form of wind speed and wind direction. Temperature and pressure are derived from a set lapse rate based off the surface readings the operator provides to the visual meteorology computer program.

b. Pilot balloons are issued in two sizes, 30-gram and 100-gram (representing the weights of the deflated balloons). Under various sky conditions, some colors are more easily detected by the eye than others. For this reason, PiBals are issued in several colors. The most common being white, red, and black. The rule to remember when deciding which color balloon to use is “darker the sky the darker the balloon.”

c. The rate of rise of the 30-gram balloon is approximately 180 meters per minute after a steady rate of rise is attained. The rate of rise of a 100-gram balloon is approximately 300 meters per minute after a steady rate of rise is attained.

d. Approximate cloud heights may be determined by timing the ascent of PiBal and multiplying the time by the rate of rise to determine the height of the balloon. When timing the ascent of the PiBal to determine cloud height, the balloon is timed until it is obscured by the lowest level of clouds. Computing cloud height in this manner provides an approximate cloud height. When computing cloud height it is important to remember that it is height above sea level. The current elevation must be added to the height that was obtained while timing the balloon to get the actual cloud height.

12-9. Balloons

a. Balloons should be kept sealed in their original containers until just before use. They should be stored in a dry place and at moderate temperatures. All balloons deteriorate with age; therefore, oldest balloons should be used first.

b. Pilot balloons provide a means of determining the speed and direction of winds aloft. The theodolite operator can observe a pilot balloon to a height of about 14,000 meters.

12-10. Night Lighting

The Chemlight provides a light source that allows the tracking of pilot balloons at night.

12-11. Balloon Inflation

While the MET theodolite is being set-up, the sensor squad leader dispatches two sensor support Marines to the balloon inflation area to inflate a balloon. Since balloon inflation is time consuming, the team should begin task as soon as it arrives at the site. The balloons are inflated using compressed gas.

12-12. Gas Used For Inflation

a. The sensor support Marine inflates all balloons with helium gas. Helium is available commercially in compressed gas cylinders. Normally, cylinders containing about 200 cubic feet (5.67 cubic meters) of gas are used for MET operations. The sensor squad leader must plan time carefully to ensure that a balloon is fully inflated and ready for release at the scheduled release time.

b. Helium is the safest gas to use because it is not explosive, but it cannot be made artificially. Helium is extracted from mines, stored in heavy cylinders, and shipped in cylinders for MET use.

12-13. Commercial Gas Regulators

Pressure regulators along with associated couplings with commercial helium cylinders are used to control the pressure of the compressed gas being released for inflation of a balloon. The regulator also indicates the amount of gas remaining in the cylinder. The regulators are adjusted to allow no more than 10 PSI (.7032 kilogram/centimeter) of gas to be released into the balloon.

12-14. Preparation of Balloons for Inflation

a. After exposure to relatively low temperatures and extended periods in storage, neoprene balloons lose some of their elasticity through crystallization of the balloon film. Neoprene balloons burst prematurely if used in this state. Sensor Support Marines should use the oldest balloons first. Balloons are inspected prior to their use and any that are brittle should be discarded. Discard any balloons older than 5 years.

b. Usually, exposure of the balloon to room temperature (21°C) for 24 hours is all the conditioning required. Store balloons in their sealed package and do not expose to direct light or heat. Discoloration has no effect on the balloon film as long as it is not the result of exposure to direct sunlight for several hours. In direct sunlight and in most types of artificial lighting, discoloration is caused by the antioxidant included in the compounding.

c. A balloon may be inflated immediately after conditioning, or it may be kept under normal storage conditions and then inflated. All balloons should be at room temperature before inflation.

d. When using balloons in temperatures under 45 degrees Fahrenheit, the sensor support Marines should keep balloons in their pockets at least two hours before inflation to ensure they remain conditioned and do not fail prematurely during flight.

12-15. Determining Lift for Balloons

a. A sensor support Marine determines the amount of gas required for the balloon before beginning the inflation process. The procedure below is used to determine the amount of gas required.

b. Free lift is the net upward force required for the balloon to ascend at a given rate. The ascent rate of the balloon mainly depends on the amount of gas in the balloon. Other factors affecting ascent rate are the shape, size, and physical texture of the balloon and the state of the atmosphere through which the balloon travels.

12-16. Nozzles and Weights

a. Inflation nozzle ML-373/GM and ML-196 are component parts of the MET station. They are used in the weighing-off procedure performed in an inflation shelter or in an area of still air. They provide a connection between the hose ML-81 and the balloon during inflation and act as a calibrated weight in determining the correct amount of total lift during weigh-off.

b. The ML-373 nozzles are used to inflate the pilot balloon. The correct free lift for a 100-gram pilot balloon is 500 grams. The ML-373 with its collar weight compensates for the free lift. The nozzle by itself is compensates for the weight required for a 30-gram pilot balloon. If conducting a pilot balloon mission at night the weight for the Chemlight needs to be accounted for by tying the Chemlight to the nozzle while inflating the balloon.

c. Crew members must keep the nozzles free of dirt, lime, or other foreign matter that will alter its weight or obstruct the gas passages.

12-17. Balloon Inflation

a. A sensor support Marine will initially shake the balloon to remove the powder inside and then rolls it up to expel any air. To expel the air and debris from the hose and connections to the gas source, briefly turn the gas on and immediately shut the gas off. The balloon is weighed-off properly when it hangs suspended in midair with appropriate weights attached. When inflating the pilot balloon, a sensor support Marine must install weights, when required, on the neck of the nozzle. If a night-lighting device is to be attached to the balloon, the Marine must add additional weights to the nozzle to compensate for the greater air resistance caused by the increased size of the balloon. The additional weights required are 70 grams for the 30-gram pilot balloon and 50 grams for the 100-gram pilot balloon. Once the weights are added to the nozzle, stretch the neck of the balloon over the connection of the nozzle.

b. Once the proper weights are attached to the nozzle, free lift must be obtained. Free lift is the net upward force required for the balloon to ascend at a given rate. Simply stated, the balloon must be inflated until it is suspended in midair with the nozzle and additional weights (if any were needed) still attached to the balloon without the hose. Once free lift is achieved, you may now disconnect the balloon from the nozzle and tie the balloon off.

12-18. Tying Off the Balloon

The balloon is now properly inflated and the sensor support Marine will firmly seal the balloon neck with twine and disconnect the hose from the inflation nozzle. The inflation nozzle and any weights used on the tied off balloon are removed. Figure 12-2 shows the correct procedures.

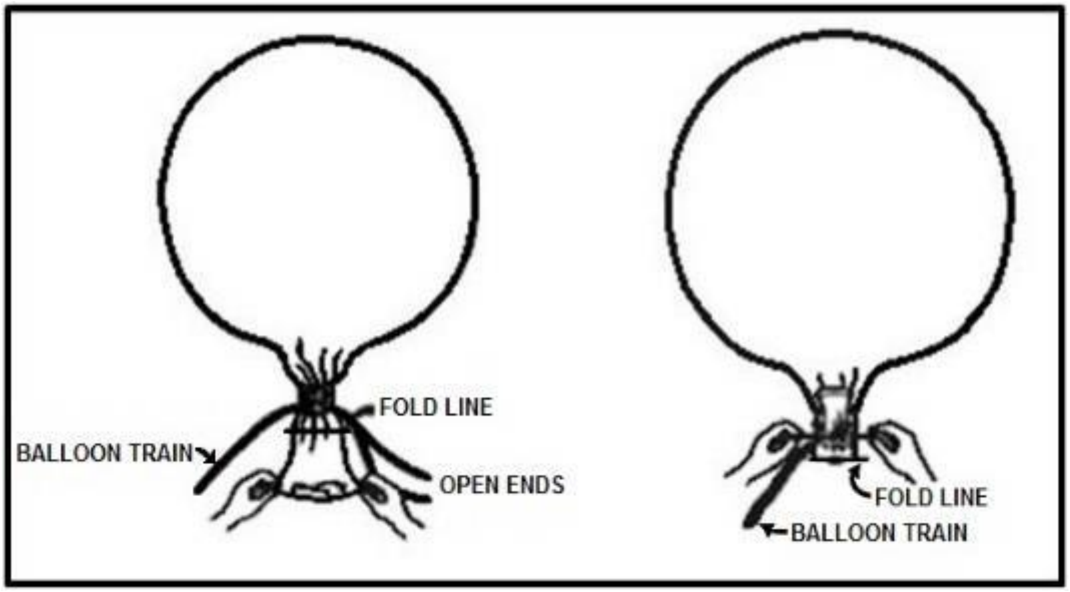


Figure 12-2. Tying off the Balloon

12-19. Balloon Release

While there are no specific procedures on releasing the balloon, the sensor support Marine must ensure no overhead obstructions exist and that the balloon is downwind from the theodolite to prevent it from flying directly over the theodolite.

12-20. Tracking and Recording Procedures

a. The primary function of the theodolite in the meteorology section is to visually observe an ascending balloon while providing azimuth and elevation angles from the theodolite to the balloon. The azimuth and elevation angles are observed and recorded at predetermined times. These times are the time it takes the balloon to reach specific heights. The times for specific heights are determined based on a known ascent rate of the balloon. For example, if the balloon rises at 200 meters per minute, it would take five minutes for the balloon to reach 1,000 meters.

b. The recording worksheet will contain the times at which azimuth and elevation angles should be read and recorded. This form will also contain all of the surface readings and information needed by the operators prior to release of the balloon. Ensure before release, the balloon is downwind from the theodolite so it does not fly directly over the theodolite and that the recorder records the offset azimuth. The offset azimuth is the azimuth from the theodolite to the balloon just before it is released. It is important that the azimuth and elevation angles are read at the exact time identified on the worksheet.

c. Additionally, when the elevation and azimuth angles are read, the balloon should be centered in the crosshairs of the eyepiece of the theodolite. The timer/recorder must alert the theodolite operator when it is approaching the time the azimuth and elevation angles are to be read so that the theodolite operator in can ensure the balloon is in the center of the crosshairs at precisely the moment the azimuth and elevation angles are read.

d. The timer/recorder must alert the operator at least five seconds before the azimuth and elevation angles are to be read. The timer/recorder alerts the theodolite operator with the command "WARNING". Once the command "WARNING" is given, the theodolite operator should ensure the balloon is exactly centered in the crosshairs of the theodolite's eyepiece.

e. After the "WARNING" command is given, the timer/recorder should voice the command "READ" at the moment the predetermined times are reached. The timer/recorder may record the azimuth and elevation angles from one of the digital displays on the theodolite, or the theodolite operator may read the angles from the mechanical angles located in the eyepiece of the theodolite.

f. The azimuth and elevation angles are recorded on the form provided to tenth of degree accuracy. The azimuth and elevation angles from the form will be entered in data fields of a visual meteorology computer program. The computer program will process the information and produce a formatted meteorology computer message (METCM) that may be delivered by courier, voice radio or entered into a digital communication device for digital transmission.

12-21. Pilot Balloon Computations

Pilot balloon computations are done immediately following the flight. These computations are done on the Climo program, a MET computer program that is loaded onto a ruggedized personal data assistant (RPDA). The Climo is often referred to as the PiBal program.

12-22. RTHD Procedures

a. The PiBal program must be loaded on the RTHD. Once the password is entered and "unlock" is selected, select "Start," "Sensor," "Menu," and "MET-P."

b. Input Octant, Location (in Lat/Lon), Date (in GMT), Time (in GMT), and station height. The DAGR is the preferred method used to determine the location. If a DAGR is not available, a map spot will suffice. Sensor teams use latitude and longitude to a tenth of a degree to report their position. This is computed by taking the minutes of the latitude and longitude and dividing the number by six. For example, if the latitude or the longitude is

34º24’, 34.6 would be entered into the program. The date and time is also entered on this screen, the date and time are entered in GMT. An octant is also needed data for this menu. To determine the octant use the latitude and longitude that was determined with the DAGR and the octant map located in appendix E Para 1. The duration will default to zero, that is the correct setting for all MET messages. The station height is entered into the PiBal program in tens of meters. For example, if the station height was determined to be 360 meters above sea level, 036 would be entered into the station height block. This is accomplished by dividing the station height by 10. This is very important because the pressure and temperature calculations are all based off of the station height.

c. After all of the MET ID information is added, click on the EQUIP tab. This tab is used to enter either degrees or mils and what type of gas was used, either helium or hydrogen and which balloon was used, either a 30 gram or 100 gram.

d. The next menu is found in the SURFACE tab. This menu is where the surface observations are entered. The pressure, dry bulb temperature, which is the ambient temperature, and the wet bulb temperature are entered here. All of these readings are taken with the Kestrel. Pressure is entered into the program in whole mbs. Both of the temperatures are entered in to a tenth of a degree Celsius. The program automatically calculates the humidity for you based off of the temperatures that were entered.

e. The next menu that is entered is in the ORIENTATION tab. This menu is where the offset azimuth and distance (the azimuth and distance to the balloon from the theodolite before it is released) is entered.

f. Next is the actual observations tab. In this tab, the actual observations from tracking the balloon are entered into the program. First, select either METCM or BALLISTIC MET depending on which message that needs to be generated. After selecting the appropriate message hit the start button and begin entering in the data. The data is entered with the numbers at the bottom of the screen. The decimal point needs to be omitted when entering in the numbers but the program requires three numbers in the elevation. For example, if elevation was 7.6 enter it as 076. Next, the azimuth must be entered and again the decimal will be omitted. The program requires four numbers for this field. For example, if your azimuth is 7.6 you will enter 0076.

g. Once all observations are entered into the program, click on the MESSAGE tab. Two prompts will pop up on the screen, the first one will be the MET Climo prompt. This prompt is asking if you want to apply the Climo data to the message. This is going to provide eighteen lines of data even if you did not track eighteen lines of data. This is going to extrapolate the lines of data that were not recorded, up to eighteen lines. For example, if only nine lines of data were tracked, it is going to apply the Climo data to give nine more lines of extrapolated MET. The second prompt that will pop up is a window stating that the message just created is being saved onto the database of the RPDA. Close this prompt. The METCM or BALLISTIC MET message will populate and can be recorded on to the appropriate form.

Section III. EXTRAPOLATED MET

12-23. Introduction

Extrapolated MET is only accurate on the first line (Line 00) of the MET message, all data in subsequent lines are derived from algorithms built into the software. Because of this, it is the least preferred means of generating a MET message. An extrapolated MET should only be used when all other means of generating a MET message fail or are not available. Extrapolated MET can be produced with the RPDA using the Climo program and Kestrel.

12-24. RPDA and Kestrel Procedures

a. The PiBal program needs to be entered in the same as above to generate an extrapolated MET message. The same information is required for the location information tab as was required to do a PiBal MET message.

b. The next tab the EQUIP tab is going to default to degrees, helium, and 30 gram balloon. All of this information is correct for computing an extrapolated MET, so click on the next tab.

c. In the SURFACE tab, the pressure, dry bulb temperature, and the wet bulb temperature that was recorded off of the Kestrel need to be entered into the program in the same manner that they were entered in for a PiBal MET message.

d. In the ORIENTATION tab the numbers are going to default to zero for the offset azimuth and for the distance. These numbers are correct for computing an extrapolated MET message.

e. In the OBS tab, the Sensor Support Marine must select the type of message that needs to be produced, either a METCM or Ballistic. Select the message needed and hit the start button. For elevation enter 555, and for the azimuth enter 1234. Once this is done tap the message tab.

f. A MET Climo window is going to appear once the message tab is tapped. Select yes from the MET Climo window. A second window is going to appear stating the message is being saved onto the hard drive of the RPDA, click ok on this tab. The MET message is going to appear either a METCM or a Ballistic MET message depending on which one was chosen.

g. The ID line can be filled out with the information that is on the RPDA. Leave the wind speed and wind direction fields blank, they will be filled out after the temperature and the pressure is filled out. Record the temperature and the pressure fields as they appear on the RPDA. Once they are filled out the wind speed and the wind direction needs to be determined. Using the Kestrel, get the wind speed and the wind direction. That wind direction needs to be converted to mils. To do this, divide the direction by 0.05625. The wind direction now needs to be expressed to 100’s of mils for a METCM and 10’s of mils for a Ballistic MET message. Record this wind direction all the way down to the amount of required information. Take the wind speed that was received off of the Kestrel and record that on the form all the way down to the required information.

CHAPTER 13 ACOUSTIC THEORY

13-1. General

This chapter will discuss the scientific and physical characteristics which dictate and influence the propagation of sound waves as they relate to acquisition of ballistic acoustic reports using the GCFS.

13-2. Sound Propagation

a. For an acoustic artillery locator such as the GCFS to locate a weapon or firing system it must be able to model time of flight of the sound from the source weapon system to each of the arrayed sensors or microphones. In order to understand the technical concept of a sound ranging system we must understand acoustic theory and sound propagation.

b. Sounds function at different wavelengths, sounds at the frequency of interest to long range propagation has a relatively long wavelength. It may propagate in several modes; along the ground, through the air, refracted from atmospheric inversions, or even scattered by turbulent airflows. We typically consider the speed of sound to be fairly constant such as counting the number of seconds from a lightning flash to the audible boom, then dividing the seconds by three to determine how many kilometers away the event occurred, a rough estimate. The speed of sound is the distance traveled during a unit of time by a sound wave propagating through an elastic medium. In dry air at 20 °C (68 °F), the speed of sound is 343.2 meters per second (1,126 ft/s). This is 1,236 kilometers per hour (768 mph), or about one kilometer in three seconds or approximately one mile in five seconds. Therefore in reality, there are significant variations over the distance involved in acoustic weapons location in order to determine the point of origin to within a very small error. The uncertainties in the acoustic propagation are foremost in determining the accuracy with which acoustic events can be located.

c. In artillery target acquisition, sound ranging is a method of determining the coordinates of a hostile artillery battery using data derived from the sound of its guns, mortars, or rockets firing. The same methods can also be used to direct artillery fire at a position with known coordinates.

d. Sound ranging is sometimes confused with sound locating, which is a collection of techniques used to locate the source of other sounds that may originate in the air, on the ground or on or below the sea's surface. We are primarily concerned with sound ranging. Sound ranging was one of three methods of locating hostile artillery that rapidly developed in World War I. The others were air reconnaissance and flash spotting.

e. Sound ranging using aural and stop-watch methods had emerged before World War I. Stop-watch methods involved spotting a gun firing; measuring the bearing and the length of time it took the sound to arrive. Aural methods typically involved a man listening to a pair of microphones a few kilometers apart and measuring the time between the sounds arriving at the microphones. These methods appear to have been used by the Germans throughout that war, but were quickly discarded as ineffective by the western allies. These allies developed scientific methods of sound ranging whose descendants are used today as we will discuss in this chapter.

f. The basis of scientific sound ranging is to use pairs of microphones to produce a bearing to the source of the sound. The intersection of these bearings gives the location of the battery. The bearings were derived from the differences in the time of arrival at the microphones.

g. The basic method was to use microphones in pairs and measure the difference in the time of arrival of a sound wave at each microphone in the pair (inner microphones are members of two pairs). From this a bearing to the origin of the sound can be found from the point mid-way between the two microphones. The intersection of at least three bearings will be the location of the sound source.

13-3. Meteorological Dependencies

a. The speed of sound is dependent on the square root of absolute temperature. Sound waves move along with the air through which they are propagating. The presence of wind therefore results in sound propagation that is no longer isotropic (equal across all measurements) when viewed from the reference frame of the ground, this is known as refraction.

b. Refraction are sound waves traveling at different speeds through air with different densities. In the atmosphere, sound waves travel faster in warm air than in cold air. The sound wave traveling in warmer air at lower levels can change direction or bend, much like light passing through a prism. If the sound wave suddenly passes through a cold air mass it slows and is refracted downward into the ground. This is why the meteorological sensor input is critical to successful sound ranging operations.

c. The wind speed and temperature vary with height, generally with an increase in wind velocity and drop in temperature. In some cases these parameters might change suddenly or reverse due to frontal activity. Under these circumstances, sounds that are propagating upwards can be refracted such that they travel back down to the ground. It is therefore necessary to model existing meteorological conditions at or near the sound propagation in order to account for the non-standard conditions as they relate to formulating a point of origin of the sound. It is also possible to account for upper air propagation if upper air meteorological data is available.

d. In common everyday speech, speed of sound refers to the speed of sound waves in air. However, the speed of sound varies from substance to substance. Sound travels faster in liquids and non-porous solids than it does in air. It travels about 4.3 times faster in water (1,484 m/s), and nearly 15 times as fast in iron (5,120 m/s), than in air at 20 degrees Celsius (°C). Table 13-1 depicts the effect changes in temperature have on the speed of sound.

Table 13-1. Effects of Temperature

Effect of temperature			
Temperature	**Speed of sound**	**Density of air**	**Acoustic impedance**
ϑ in °C	**c in m·s^{-1}**	**ρ in kg·m^{-3}**	**Z in N·s·m^{-3}**
+35	351.96	1.1455	403.2
+30	349.08	1.1644	406.5
+25	346.18	1.1839	409.4
+20	343.26	1.2041	413.3
+15	340.31	1.2250	416.9
+10	337.33	1.2466	420.5
+5	334.33	1.2690	424.3
±0	331.30	1.2920	428.0
-5	328.24	1.3163	432.1
-10	325.16	1.3413	436.1
-15	322.04	1.3673	440.3
-20	318.89	1.3943	444.6
-25	315.72	1.4224	449.1

e. In solids, sound waves propagate as two different types. A longitudinal wave is associated with compression and decompression in the direction of travel, which is the same process as all sound waves in gases and liquids. A transverse wave, often called shear wave, is due to elastic deformation of the medium perpendicular to the direction of wave travel. The direction of deformation is called the polarization of the wave. In general, transverse waves occur as a pair of orthogonal polarizations. These different waves (compression waves and the different polarizations of shear waves) may have different speeds at the same frequency. Therefore, they arrive at an observer at different times, an extreme example being an earthquake, where sharp compression waves arrive first, and rocking transverse waves arrive seconds later.

13-4. Terrain Dependencies

If the terrain was absolutely flat and a sound wave travels along that terrain we could assume that the modeled distance would be the same as the actual distance. If the ground is not flat, we must assume that the true distance (slope distance) would be greater than the flat point to point distance. Remember that the speed of sound is dependent on temperature, and that temperature usually drops with height. This means that the speed of sound is non-uniform if the ground is mountainous or undulating even in the absence of wind. Thus a ground profile or terrain model such as digital terrain elevation data is required to model natural terrain effects on the sound waves. Table 13-2 depicts how a change in altitude can affect the speed of sound. It is also important to take into account man made features which may affect sound propagation such as buildings or structures that may not be accounted for in digital mapping products. Manmade objects should be accounted for in the planning process so that microphones are not placed in close proximity. The following definitions are important in understanding sound propagation and are graphically depicted in Figure 13-1.

Table 13-2. Altitude Effects on Speed of Sound

Altitude	**Temperature**	**$m \cdot s^{-1}$**	**$km \cdot h^{-1}$**	**mph**	**knots**
Sea level	15 °C (59 °F)	340	1225	761	661
11,000 m−20,000 m (Cruising altitude of commercial jets)	−57 °C (−70 °F)	295	1062	660	573
29,000 m	−48 °C (−53 °F)	301	1083	673	585

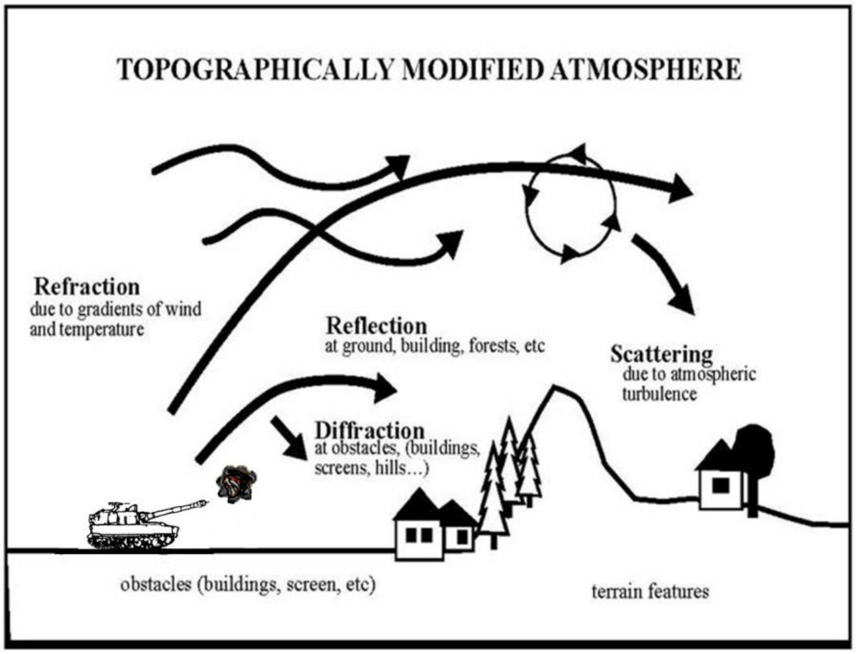


Figure 13-1. Terrain Effects

a. Reflection. Sound waves are reflected from any large surface, such as a large building or mountain. These objects will produce echoes that may confuse Sensor microphones.

b. Diffraction. If small terrain features, like buildings or small hills, are in the path of a sound wave, the sound wave must travel around the object. A sound wave that arrives at a SP located behind the terrain object will have a longer travel time to an SP located in front of the object. Behind such objects, regions of low intensity, or sound shadows, may be produced. SPs located in sound shadows will be insensitive.

c. Scattering. The process by which small particles (i.e., dust, rain, water vapor, and ice crystals) suspend in the atmosphere diffuse the sound wave causing it to change in different directions. SPs located in fog or rain will be insensitive to detections.

d. Sound Shadow. The acoustic shadow caused by placing microphones in too close proximity to an obstruction such as depicted in Figure 13-2 (page 13-5). In such instances where a microphone must be placed in close proximity to an obstruction, as a rule the following formula applies; five times the height of the obstacle (Height(X) x 5 = Distance away from obstruction of microphone).

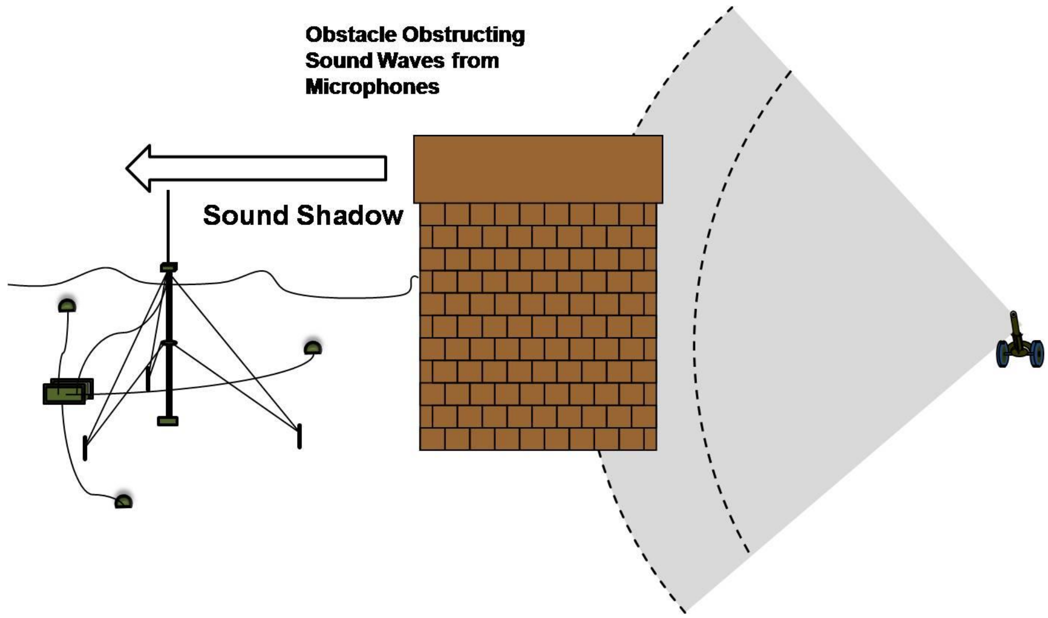


Figure 13-2. Sound Shadow

13-5. Ground Counter Fire Sensor

We further explore the theory of sound and sound propagation in the application of our currently fielded acoustic sensor the GCFS. As previously discussed weather and terrain have significant effects on sound propagation, therefore the following guidance is provided:

a. Optimum Terrain. Flat and level ground with no obstructions directly in front of any of the microphone or antenna locations is the optimum.

b. Other Terrain. In mountainous terrain microphones should be placed on the forward slope near the crest. In urban or wooded terrain the SP may take longer to set up if the equipment has to be carried over long distances. If vehicle access is limited, SP sites may be selected to make best use of roads and trails. Avoid emplacing the SP in areas such as vehicle traffic routes, generator sites, swamps, minefields, forests, or other sources of constant loud noise. These areas will adversely affect the locating capability and radio communications between the SP and the CP.

c. Elevated Sites. If the SP has to be located on a roof or other elevated site, it should be set up in the center, away from the edge of the building or structure. The difference in height between ground level and the elevated site must be applied to the elevation and inputted into the CPC. Figure 13-3 on page 13-6 depicts GCFS sensor posts arrayed on a digital map with elevation data accounting for terrain undulations. The tolerance between microphone elevations cannot exceed ± 2 meters. Microphones, sensors, and antennas should be secured to the surface of the building or structures but ensure that anything used to secure them will not interfere with their performance.

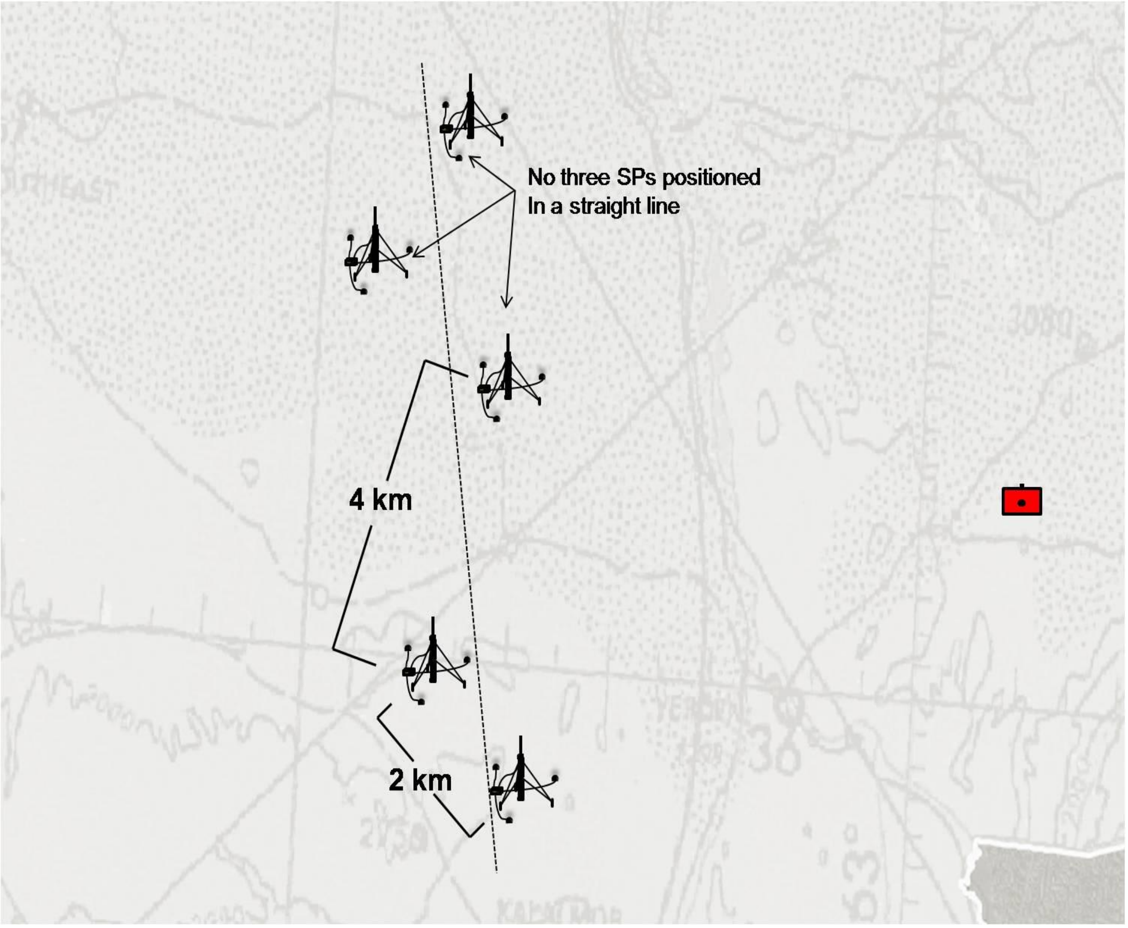


Figure 13-3. GCFS Sensor Post

CHAPTER 14 SENSOR PLANNING

Section I. THE SENSOR PLAN

14-1. General

The sensor plan is an integral part of and critical aspect of the artillery fire plan. Detailed planning and war gaming of the sensor plan should be conducted in coordination with the supporting artillery operations section planning efforts. This chapter will cover the planning process for survey, meteorological, and acoustic assets to provide an understanding of how each of these support the artillery fire plan. Each plan will detail techniques, coordination, and considerations and will use the Marine Corps planning process (MCPP) as a guide to conducting such planning.

14-2. Marine Corps Planning Process

a. Sound planning is required to effectively cover the battlespace with sensor assets. Sensor planning is both tactical and technical in scope and is conducted at all levels as an integral part of the planning process. This ensures sensor assets are fully integrated into the overall collection and fire support plans. The field artillery headquarters is responsible for employing sensor assets in accordance with the operational plan; however, close liaison with the supported command must be maintained in order to ensure the sensor plan supports the maneuver commander's objectives. The MCPP is a continuous assessment of mission requirements, organic target acquisition capabilities, and the threat that drives the target acquisition plan. Remember, planning is continuous and often dynamic, sometimes a quick "huddle" by key decision makers will suffice. Figure 14-1 depicts the MCCP.

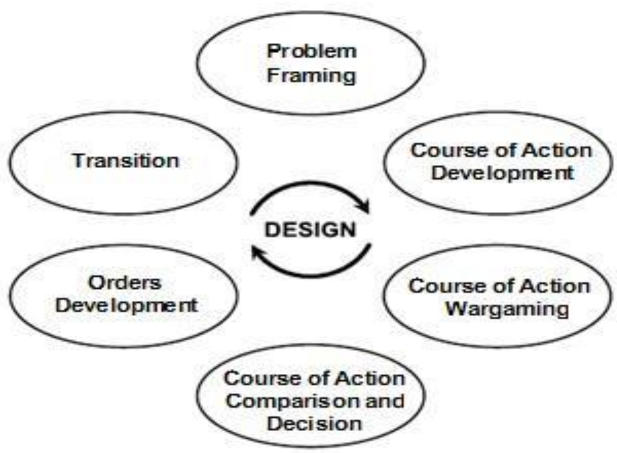


Figure 14-1. Marine Corps Planning Process

b. Planning is initiated with the receipt of the warning order. This may be oral or written and should provide a sufficient amount of information allowing the process to start. An OPT is established at all echelons and staffs will work recommended courses of action as a plan comes together. The sensor plan is no different than any other element of an operations plan/order. It is planned and written concurrently with other elements of the entire plan/order. The MCPP is discussed in Marine Corps Warfighting Publication 5-10, *Marine Corps Planning Process*.

c. The sensor plan is an exhibit within the overall operation order (OPORD). It is Exhibit 7 (Sensor Plan) to TAB B (Artillery Fire Plan) to Appendix 17 (Fire Support Plan) to Annex C (Operations) to a named OPORD. It is written in the standard five-paragraph order format and may have attachments to amplify information in the plan.

d. The sensor plan must be simple and adaptable to the chaotic and rapidly changing environment of the battlespace. It must provide required control, provide checks, and be timely.

e. Ultimately, the sensor plan will result in an order issued to the sensor section. Execution of the order will ensure accurate and timely fires are delivered, and help alleviate any lapse in fire support to the maneuver commander.

f. Sensor planning is conducted at all echelons at the same time. Coordination between higher, lower, and adjacent sensor sections during planning will ensure even distribution of the work load, eliminate duplication of work, and provide a focus of effort in establishing a common grid, establish meteorological requirements, and acoustic employment.

g. The sensors officer must have a thorough understanding of the commander's intent and concept of operations up to two levels above. The sensor officer will be a member of the OPT drafting the artillery fire plan. The artillery fire plan and information from the fire support plan and the Annex B (Intelligence) will provide the bulk of the information necessary to write the sensor plan. Coordination with the commander's staff in developing the sensor plan (primarily with the S-3 and intelligence officer/intelligence office (S-2)) is paramount.

14-3. The Artillery Fire Plan

a. The artillery fire plan Tab B to Appendix 17 is part of the maneuver commander's OPORD. It contains information on how artillery will support the maneuver element. The artillery fire plan is discussed in detail in MCTP 3-10E, *Artillery Operations*.

b. Elements of the artillery fire plan will be in the form of an Exhibit (See Table 14-1 page 14-3) and covers the following:

(1) Provides information necessary to plan and execute the artillery fires in support of the GCE.

(2) Focuses on organic and attached artillery assets.

(3) Discusses the use of reinforcing fires from other agencies.

Table 14-1. TAB B Exhibits

EXHIBITS
Artillery Target List
Artillery Synchronization Matrix
Artillery Target Overlay
Schedules of Fire
Observation Plan
Radar Plan
Sensor Plan

14-4. Sensor Plan

The sensor plan is primarily concerned with sensor employment in support of artillery headquarters and the supported maneuver commander. This is accomplished through close coordination across the warfighting functions. Coordination is critical as sensors will play a key role in the artillery headquarters ability to support the maneuver commander. The five-paragraph order as it pertains to the sensor plan is as follows:

a. Situation. This paragraph should include the friendly situation, supported units and other sensor assets in sector. Include specific threat and friendly assessments that form a basis for threat assessments required on the radar deployment order.

b. Mission. This paragraph should be a clear and concise statement of the sensor mission.

c. Execution. This paragraph contains the following sub-paragraphs:

(1) Concept of Operation. This subparagraph gives the commander's concept for sensor employment. It is a summary of how the operation will be accomplished. It amplifies paragraph two by providing method, end state and other considerations. Specific sensor teams are not identified. This guidance may include general instructions for offensive and defensive phases of the operation. Specific cueing guidance is listed in the coordination subparagraph.

(2) Tasks. This identifies tasks to specific sensor teams. Each task assigned will include a purpose of the task, as in "in order to…". Each sensor team attached or organic that is executing a task will have a separate numbered subparagraph.

(3) Coordinating Instructions. This subparagraph contains instructions that pertain to two or more sensor teams such as coordinating details and control measures that are applicable to the Sensor section and time or conditions when the plan is to be executed. It may often refer to other annexes and appendixes.

d. Administration and Logistics. This paragraph provides information to ensure service support is adequate for the mission; e.g., rations, ammunition, aid stations, or handling of prisoners.

e. Command and Signal. This paragraph provides information such as the location of the sensors/target acquisition officer, sensors chief, chain of command, frequencies, call signs, and communications between sensor teams and GIC/COC.

14-5. Detailed Sensor Employment Planning

For planning the employment of the sensor section use the six troop leading steps.

a. Begin Planning. Review the commander's intent, scheme of maneuver, and the artillery fire plan. This information is used with trig lists and intelligence information to develop maps and overlays that include survey control, current and planned firing positions, and fire support asset locations. Such information will help in formulating the allocation of assets and requirement for any type of meteorological support and scheduling as well as potential sites for GCFS employment.

(1) Priorities of survey work can be determined at this time as to the installations or control that will be surveyed first. A warning order should be issued to the sensor chief and sensor squad chief to allow preparation of personnel and equipment to conduct the reconnaissance and what equipment should be loaded in the reconnaissance vehicles.

(2) Using the information above and knowledge of the capabilities and limitations of the section's personnel and equipment, make a tentative plan. Also perform a map reconnaissance and mentally walk through the tentative plan to ensure it will meet all requirements.

(3) As the current mission progresses and the situation changes, subsequent orders will be issued as fragmentary orders. The sensor chief must maintain close liaison with and add to the sensor officer's situational awareness.

(4) A schedule for Modeled MET support can be drafted and data can be downloaded for the MMIM. Coordination must be made with the communications officer for satellite communication access to AFWA for downloading the GALWEM.

(5) Determination of units requiring augmentation of visual or modeled meteorological assets can be assessed and accounted for in the plan.

(6) Locations for GCFS SPs should be included on the map and a planned vehicle reconnaissance conducted. The need for security during the reconnaissance and set-up of the SPs should also be identified.

b. Arrange for Reconnaissance. Once the tentative plan is formulated, a thorough ground reconnaissance should be made (if time and the tactical situation permit). The sensor chief ensures the required personnel and equipment are prepared to conduct the reconnaissance. The route of march (with check points) and a brief itinerary should be provided to the GIC, S-2, and S-3. This will allow for coordination with higher, lower, and adjacent units, ensuring safe passage of the teams involved. Consideration should be given to challenges, passwords, and communications during the reconnaissance. Coordination of the logistics requirements of the reconnaissance should be addressed to the S-4. Supplies, fuel, repairs, etc., may be provided by units located in or near the area to be reconnoitered. Additional security requirements should also be requested through the battalion.

c. Make Reconnaissance. Only those Marines essential to accomplish the reconnaissance should accompany the sensor officer. Limit the amount of equipment taken. During the reconnaissance mission the sensor officer should:

(1) Verify map data.

(2) Determine the plan's validity.

(3) Assess trafficability of routes and the condition of terrain.

(4) Note weather conditions.

(5) Note changes to any intelligence information received from the S-2.

(6) Make any changes necessary.

d. Complete the Plan. Upon returning from the reconnaissance the sensor officer finalizes the plan. The sensor plan is written and briefed to the S-3. The S-2 is briefed on all changes observed during the reconnaissance to the intelligence picture, including changes which may specifically affect the fire support plan.

e. Issue the Order. The sensor officer issues the sensor plan to the entire section in the form of a five-paragraph order. The order may be written or oral. If oral, certain information should be provided to the sensor teams separately, i.e., strip maps or trig lists, equipment lists, and unit/OP locations. Ground counter fire sensor sites (if part of the plan) should be identified as well as maintenance for the SPs.

(1) The order should be simple, direct, and thorough. All the information required to complete the mission should be given to the sensor support Marines to allow for action in the absence of further orders. The order should describe what needs to be accomplished and when. The priorities, accuracy, and the methods to be used should be stated together. Once teams depart they must be able to use their initiative and the information from the order to deal with the friction that is bound to occur.

(2) Use of a terrain model and/or a map during the brief is of great importance for

Marines to visualize the mission and what is expected of them.

(3) Time should be provided at the end of the brief for any questions that may arise. This ensures a thorough understanding of the mission. Any acceptable deviations from current SOP should be specifically noted.

f. Supervise. Once the sensor plan is issued and teams begin to execute their portions of the plan, the sensor chief supervises the conduct of the mission. The sensor officer begins the planning process all over again through coordination with the S-3 on future operations.

Section II. SURVEY PLANNING

14-6. Survey Planning

Survey planning must take into account all aspects of the artillery fire plan and is conducted concurrent with the operations section planning process. In the contemporary operating environment, planning for survey and support will become increasingly important. Coordination must be conducted with the artillery headquarters and supported units. The following are considerations for the survey plan.

14-7. Mission, Enemy, Terrain and Weather, Troops and Support Available-Time Available

When forming the survey plan, the sensor officer or battalion target acquisition officer and sensor chief must estimate the situation considering the following:

a. <u>Mission.</u> The tactical mission of the artillery unit and supported unit(s) will determine the priority of survey work and the accuracy required. It also gives an understanding of the tactical situation sensor support Marines will be operating in (defensive, offensive, high intensity or low intensity). Rules of engagement, fire support coordination measures, and maneuver control measures may hinder survey operations by restricting survey methods or access to SCPs.

b. <u>Enemy</u>. The enemy situation has a tremendous influence on survey operations. Disposition of enemy troops may interfere with or limit the movement and capabilities of sensor support personnel. Communications restrictions (radio silence or jamming) can greatly reduce a sensor support team’s effectiveness. The ability of the enemy to degrade survey operations by denying terrain or route of march is a prime consideration. The sensor section must be equipped and trained to take immediate action to respond to the type of enemy force they may encounter (regular troops, militia, guerrillas, etc.). Enemy air capabilities are also of importance due to the vulnerability of sensor teams. Initialization times with IPADS-G or occupying traverse and GPS stations leave sensor support Marines exposed to air attack and observation.

c. <u>Terrain and Weather.</u> Terrain and weather encountered will be a primary factor in determining the survey method, and to some extent, the priority of installations to be surveyed. The weather conditions may greatly reduce the capability of the survey teams. Fog, rain, snow, or dust can make observation through optical instruments difficult. Extreme heat or cold may decrease efficiency, and increase the time needed to complete survey operations. Reconnaissance to determine the suitability of terrain for the installation to be surveyed is vital. Alternative areas may be required once the proposed position has been reconnoitered.

d. <u>Troops and Support Available.</u> Personnel and equipment available to perform the survey mission greatly affects the plan. The level of training determines the methods and time required to complete the mission. Availability and condition of surveying equipment may further dictate what methods can be used and the time required. Availability of support depends largely on the tactical mission of the artillery unit.

e. Time Available. The time available to complete the survey is critical in planning. Providing the required data within the time allotted may result in a loss of accuracy. The artillery commander must be advised of any possible loss in accuracy due to time constraints and decide if this is acceptable. Time limitations may often be implied or ambiguous and require clarification. METT-T elements are interrelated and must be considered together. It is a dynamic framework, not a checklist. Other factors may have an effect on a survey plan but are not necessarily covered in METT-T; e.g., refugees or political/diplomatic agreements.

14-8. Space and Logistics

a. For the sensor planner, space is generally restricted to an operational area, within a unit's boundaries. Available survey control may only exist outside these boundaries thus requiring additional coordination and planning.

b. Availability of logistical support must be considered in all planning. The sensor section has a wide array of equipment that may need servicing or repair. Regardless of the survey method used, sensor support Marines rely heavily on their motor transport assets to complete their mission. At the same time, they are operating over a broad area far from their logistics base. chow, ammunition, water, and petroleum, oils, and lubricants. These are just some of the supply issues that must be addressed.

c. In addition to evaluating the factors of METT-T, the sensor officer must also understand the characteristics of the different survey methods, their advantages and disadvantages, and their impact on mission accomplishment.

d. The IPADS-G is a vital survey asset. When aided by GPS, the requirement for zero velocity updates is removed, and the system operates without any radial and total distance limitations. Its primary advantage is how fast it provides survey data. Refer to Marine Corps TM 11039A-OR/1&P for details on the IPADS-G. When planning, consider the following:

(1) Is existing control accessible with a military vehicle? If not, is existing control within 99.9 meters of a location that will allow auto-reflection?

(2) Is the mission within the IPADS-G operational limits?

(3) Speed limitations for IPADS-G vehicle:

(a) Cross-country: 10 kilometers per hour.

(b) Unimproved roads: 25 kilometers per hour.

(c) Improved roads: 50 kilometers per hour

(4) Time limitations for IPADS-G vehicle:

(a) Initialization: 10-20 minutes; GPS-aided: 15 minutes while on the move.

(b) Update/Mark: 90 seconds.

(c) Mission time: unlimited.

(5) Is existing common control available within a 75 kilometer radius and 221 kilometer total distance (unlimited when GPS-aided) of the planned update point which can be used for future updates?

(6) Does the IPADS-G support the operational ellipsoid in the OPORD? If not, is user-defined data available?

e. When utilizing conventional survey, consider the following:

(1) Is existing control available of the proper accuracy? Are azimuth marks available for computed azimuths, or do azimuths have to be determined by astronomic observations?

(2) Is the area of operations within the UTM north and south limits? If not, can the section perform manual computations?

(3) Distances traversed: 1-20 kilometers per hour LOS (line of sight-dependent).

(4) LOS clearing (jungle): 100 meters per hour.

(5) Forest: 1 kilometer per hour.

(6) How far is existing control from the area requiring survey?

(7) How much LOS cutting is required? Is engineer equipment available to help cut LOS; e.g., chain saws, weed eaters, or bulldozers?

(8) Is the control accessible by military vehicles or does equipment have to be carried into the area?

(9) What are the accuracy requirements?

(10) What means of communications between team members is available? (Radio, panel marker, hand and arm signals, etc.)

(11) Will traverse provide a timely enough response to the need for survey data?

f. Intersection is the primary method of survey used to determine target locations. Considerations for intersection include visibility, the accessibility and availability of control, azimuth marks, aspect angle, and communications between teams. Intersection can also provide update and initialization points for IPADS-G or locate other critical points other than targets.

g. Astronomic observations can be used when weather conditions allow for the observation of celestial bodies. The artillery astronomical observation method is the primary means used to determine an azimuth. The firing battery's primary method of astronomic observation is hasty astronomic observation. Consider the following:

(1) Do weather conditions allow observations of celestial bodies?

(2) Are celestial bodies within allowable observation windows relative to time and position?

(3) What is the required accuracy?

(4) Is accurate time available?

h. RTK GPS-Survey. RTK accuracy achieved is well above that required for artillery survey missions. It is the fastest method available to provide survey data. Consider the following:

(1) Does the terrain, vegetation, and satellites position support sufficient geometry during planned GPS survey operations?

(2) Is existing control available or will the base station be operated in the absolute mode?

(3) Are enough communications assets available to provide each GPS team with a voice radio and an additional AN/PRC-152 SINCGARS radio for digital communications between the receivers?

(4) Have communications lines of sight been verified in the areas requiring control? If not, has a map reconnaissance shown that communications LOS are clear?

(5) Are alternate sites available for the base station when communications are not available or the tactical situation forces evacuation of the original position?

(6) Are planned base receiver sites within 10 kilometers of positions requiring survey? If not, are supplemental positions available?

(7) What are the enemy radio direction finding capabilities?

i. Fast Static GPS Survey. Fast static survey is the most accurate method available. Fast static GPS methods provide geodetic level accuracy and establish high order survey networks. Consider the following:

(1) Is time available for occupation of sites and post processing?

(2) Is existing control of sufficient accuracy to allow for adjustment of GPS measurements?

14-9. The Environment

The sensor section must plan accordingly when performing missions in extreme environmental conditions. Personnel must be trained and have an understanding of how to sustain operations and be able to perform under difficult conditions. Changing environmental conditions will dictate required actions needed to protect equipment. For temperature specifications or heat related maintenance refer to the appropriate sensor equipment technical manuals. Consider the following recommendations:

a. Heat. Most all mechanical and electronic equipment have recommended operating temperature ranges and will be identified in the appropriate technical manual. The operator of the equipment should be familiar with these ranges to ensure damage does not occur by overheating the equipment. Equipment should be shaded or covered from direct sunlight when possible, stowed back into appropriate cases when applicable to protect from the elements.

b. Cold. When committing sensor teams to field operations in extreme cold, the effects of ice, movement, snowfall, prevailing wind, light refraction, and other cold weather conditions must be considered.

(1) Equipment malfunctions increase in cold weather conditions.

(2) Optical equipment must be acclimatized before use in cold weather conditions. Temperature equilibrium will affect both the scales and optics of equipment. Optical equipment should be stored in an area with conditions as close to possible as those conditions where they will be used.

(3) Personnel must be trained in the use of cold weather equipment and cold weather field expedients.

c. Desert Operations. Operations in desert regions are a common occurrence. While the open terrain and normally clear skies allow for long lines of sight and an abundance of celestial bodies for observation, problems do exist.

(1) Leveling vials on sensor equipment increase about two graduations past true center in temperatures above 100°F and at temperatures reaching 120°F, leveling may be impossible. Eyestrain is more prevalent and instrument operator changes are more

frequent. Observing long distances may not be possible due to heat waves.

(2) Existing control in desert areas, like arctic regions, is sparse and hard to locate. The lack of reference points and blowing sand will increase the time needed to locate these stations. Existing control along established lines of communications should be utilized.

d. Jungle Areas. Jungles provide obstacles to sensor support Marines such as heat, humidity, and a lack of adequate mapping products. LOS is a major concern, even for GPS operations, depending on the type of canopy.

(1) Jungle heat will affect the equipment much like desert heat; however, humidity will increase the effects of heat on personnel and create fogging problems for optical equipment.

(2) Maps for most jungle areas are inadequate except for coastlines, rivers, and roads.

14-10. Mapping, Charting, and Geodesy

Often, mapping products and existing control will be of a different ellipsoid, datum or projection combination than prescribed in the OPORD. Sensor support Marines may be required to perform datum-to-datum transformations from the local datum to the operational datum and develop overlays and provide insight to datum problems and transformation accuracy. Most fire support assets and survey computational devices do not provide for computations outside of the UTM system or the nonstandard grid zones (See chapter 5).

14-11. Survey Sketch

a. A survey sketch must reflect the survey order. It is prepared and provided to the sensor teams before the order is issued, so that each portion of the survey mission is understood. The sketch should be as detailed as possible without hindering the flexibility of the survey plan.

b. Draw the sketch to scale. Use a large-scale map or plotting chart for surveys covering large areas or to enlarge small surveys. Make the sketch self-explanatory. Show all known and required control. General locations (6-digit grids) can be used for required installations. Label all points. Draw a north arrow for orientation purposes if a map is not used. Include routes that must be taken for security purposes and restricted areas; e.g., hazards or obstacles.

c. For IPADS-G operations, a detailed sketch is not always necessary. Often, a strip map or route overlay that includes known and required control may suffice.

d. Prepare a sketch for an RTK roving team much the same way as that for an IPADS-G team.

e. For a Fast Static GPS survey, include all stations in the network, not just the stations planned for that team. Include prescribed routes and in some cases pre-planned observation times.

f. A conventional survey sketch must be more detailed than an IPADS-G team sketch. Along with the information above, show:

(1) All traverse stations.

(2) All horizontal angles drawn from the rear station to the forward station.

(3) Starting and closing azimuths as a dashed line with an arrow pointing towards the azimuth mark.

g. Since the survey sketch includes a large amount of information that can be useful to the enemy, it must not be compromised. Destroy it if a serious threat of capture exists.

Section III. METEOROLOGICAL PLANNING

14-12. Meteorological Planning

Accurate meteorological data is one of the five requirements for accurate fires and the most dynamic as weather is always changing and difficult to predict. Timeliness and proximity of measured upper atmospheric conditions is directly attributable to the accuracy of artillery fires and therefore must be carefully planned to support the artillery fire plan. The following are considerations in artillery meteorological planning. Combat experience has proven the importance of providing accurate and timely meteorological data to artillery. The sensor section provides data to enhance first round accuracy, effective downwind predictions, and IPB. The planning process needs to focus on what data is needed, who needs it, and how will they get it.

14-13. Operational Considerations

a. Proper scheduling and positioning of MET assets can enhance the effectiveness of MET support and maximize the effectiveness of multiple MET assets. Scheduling and positioning of those assets should be accomplished based on each systems capability to best support the mission.

b. The sensor officer with recommendations from the sensor chief is responsible for scheduling MET support within the area of operations. Units who require MET support and who are not in normal MET message dissemination schemes forward their request for MET support to the operations officer. The format for the MET request is in appendix H. The sensor officer will coordinate with firing units and other MET data users (especially the SWO for AFWA requirements and the chemical biological radiological nuclear (CBRN) officer for downwind prediction requirements) to determine if there are any special requirements that must be considered. MET data will be transmitted to units based on this schedule. In coordination with the sensor chief, the sensor officer develops a schedule based on the following:

(1) Mission requirements (altitude requirements).

(2) Area of validity based on terrain.

(3) Prevailing winds (balloon borne data collection methods).

(4) Transition periods.

(5) Availability of supplies (balloon borne data collection methods).

c. Scheduling MET for firing units that are supporting maneuver units on the move depends on the capabilities of the Sensor section. When using methods other than MMIM, areas of validity will dictate scheduling MET for firing units supporting maneuver on the move.

d. Another consideration when scheduling MET for firing units supporting maneuver units on the move is the process by which MET data is produced. When scheduling visual MET, consideration should be given to the time required to conduct an observation.

e. The sensor chief will coordinate a schedule of broadcast times and will ensure the user provides gun and target locations for the requested MET messages. If the firing units are operating in close proximity to each other and firing on the same target, the gun location for all guns may be the battery center. This will preclude having to process multiple MET messages resulting from the different locations of the guns. Additionally, the Sensor Chief will coordinate a means of broadcasts (radio, local area network, wire, courier, others).

f. Positioning MET assets and area of MET validity is determined after the sensor officer consults with the sensor chief to analyze the terrain and its effect on the area. Figure 14-2 shows the area of MET validity based on the terrain.

TYPE TERRAIN	AREA OF VALIDITY
LEVEL MOUNTAINOUS COSTAL	20-KM RADIUS 10-KM RADIUS 15 KM RADIUS

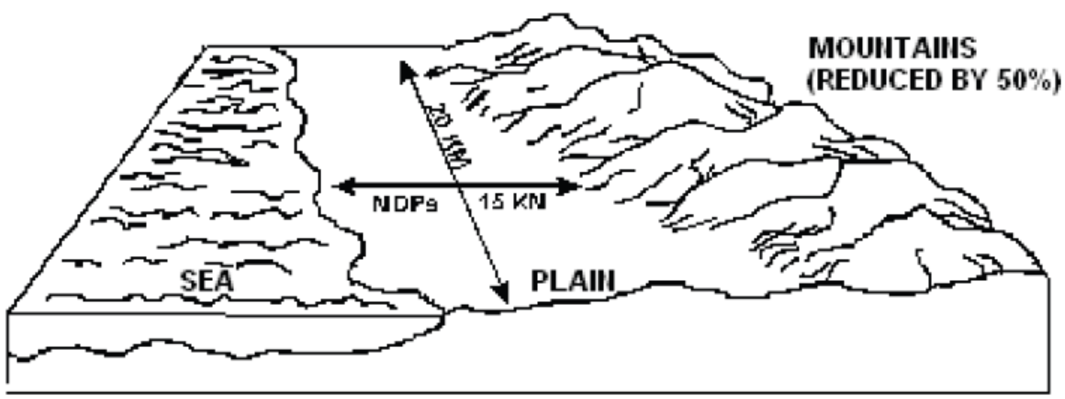


Figure 14-2. Terrain Area of MET Validity

g. Pilot balloon equipped sections are significantly affected by prevailing winds due to the need to produce data from balloon observations. The prevailing winds and their effects on the flight path of the balloon are important factors in determining release points. The measurements begin at the location where the balloon is released. The remainder of the data is acquired along the balloon path as it rises. The ideal MET asset location allows for the balloon to travel to the horizontal and vertical location corresponding to the maximum ordinate of the projectile. Using knowledge of the prevailing winds in the area, the sensor chief advises the operations officer on the sites that will provide the best MET coverage of the battlefield. Information on prevailing winds in general may be obtained from the climate data provided in the OPORD. This data can also be obtained from the supporting SWO.

(1) If the prevailing wind pattern is such that the contemplated balloon path is beyond the forward line of own troops, the assets may be employed farther from the forward line of own troops (Figure 14-3A).

(2) If the prevailing wind pattern is from a flank, (Figure 14-3B), the MET assets are employed so that the balloon will pass through the zones where most of the weapon trajectories will pass.

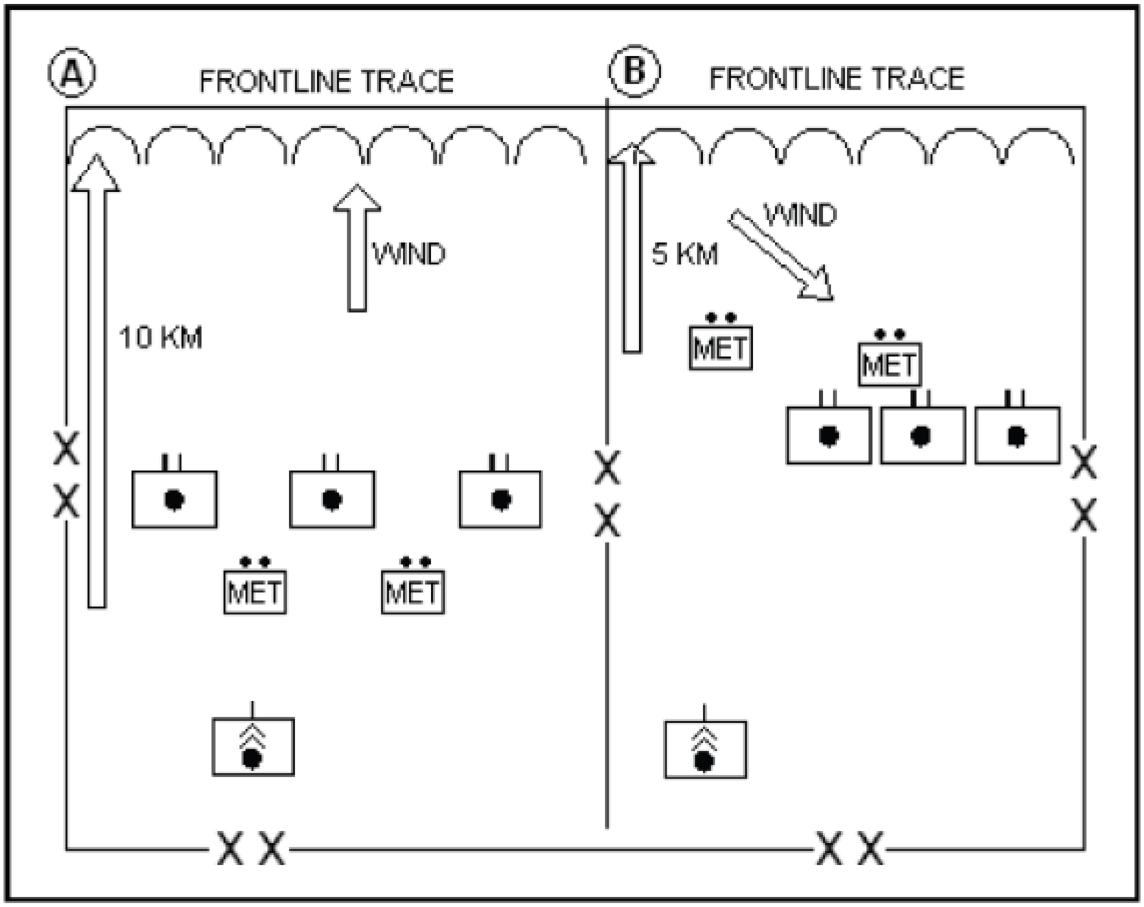


Figure 14-3. Emplacing in Terms of Prevailing Winds

h. The basic movement technique is leapfrogging. When the battle is fluid and the rate of movement is rapid, sensor teams may employ the leapfrogging technique to keep pace. In this technique, one team having established a position remains in operation while a second displaces to a new location. When the second team becomes operational, the first team is displaced by moving past the newly occupied position of the second team. This procedure is repeated as often as necessary. Control of the sensor team in the defense is normally centralized once the main battle commences. Movements are limited to ensure continuous support.

i. Operating in an area where the enemy operates in small groups and there are no defined enemy concentrations creates a nonlinear battlefield. In a nonlinear battlefield, forward operating bases (FOBs) are created. Each FOB has a responsibility for a specified area based on the capabilities of the assigned units. MET operations in a FOB are outlined in the MET plan portion of the operations order.

j. Transition Periods. The validity of a MET message decreases over time. There are no specific rules for determining how long a MET message is usable because that determination depends on the atmospheric conditions. The general guidance to help the sensor officer prepare MET schedules is discussed below. Figure 14-4 is the meteorological day chart to plan for transition periods.

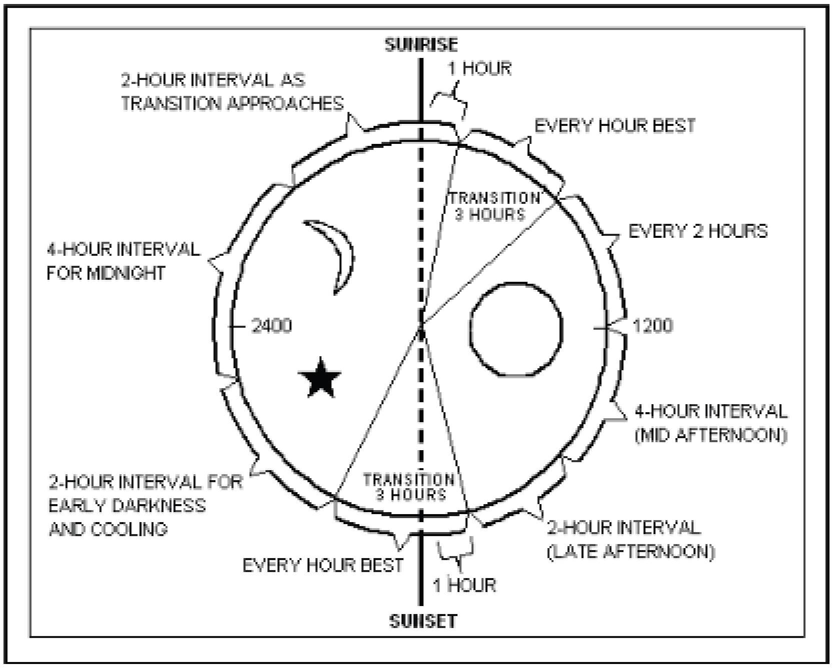


Figure 14-4. Meteorological Day Chart

(1) During and just after sunrise, temperature changes occur as the atmosphere becomes heated. Temperatures are more stable throughout the afternoon. Therefore, MET messages are produced more often (every two hours) in the morning and less often (every four hours) in the afternoon.

(2) As sunset approaches, the air cools rapidly. During this time, changing temperatures are monitored closely. MET schedules may need adjusting (to one every two hours) as the atmosphere cools. The cooling of the air stabilizes about two hours after sunset.

k. The passage of a weather front is associated with changes in current conditions. Because of this, the sensor team should produce a MET message immediately following the passage of a front. As a result, MET schedules may be adjusted. Regardless of the above, the tactical situation and the immediate needs of the field artillery commander are the main considerations that determine positioning and scheduling. The following conditions should be applied for validating a new message:

(1) Wind speeds and directions should be fairly uniform with proportional changes in altitude. Large changes in wind direction (1,000 mils when wind speeds are above 10 knots) or abrupt increases or decreases in wind speeds (10 knots) are suspect and should be investigated. Large changes in wind direction are not uncommon with wind speeds less than 10 knots.

(2) Temperature accuracy is hard to evaluate because of natural erratic changes. Any severe increase or decrease in temperature (± 20°K) is suspect and should be investigated.

l. When planning the employment of sensor section assets in the division area, the commander and staff use the Marine Corps planning process outlined in Marine Corps Warfighting Publication 5-10. The planning of MET operations in support of the commander's intent and concept of the operation should be included in this process. This planning is done by the sensor officer and the sensor chief.

m. Disseminating MET data to the firing units is an important part of the mission of the sensor section. A specific plan for disseminating MET data is necessary. The communications plan will provide critical information relating to methods of communication, coordination procedures, and operational procedures.

n. Frequency management is included within the communications plan and will be provided according to unit SOP for the sensor section requiring the ability to operate and disseminate data.

o. MET data is perishable, the timely dissemination of messages is essential. Digital communications is the primary means of MET message distribution. MET messages may be disseminated in a centralized or decentralized manner, depending on the tactical situation. Centralized dissemination normally is used when the tactical situation is stable. Decentralized dissemination may be used when the controlling headquarters is continually relocating or its capability to relay data was terminated. The communications plans must support the deployment of MET assets within the AO. The operations officer establishes communications priorities and means of dissemination and incorporates them into the MET plan. Unit plans and procedures documents should address the following:

(1) Communications means.

(2) Procedures for coordinating MET support with adjacent units.

(3) Network identification information.

(4) Procedures for passing AFWA and fall out meteorological (FOMET) messages to the SWO.

p. The sensor section normally transmits all messages to its controlling headquarters' FDC. The FDC then passes the MET messages electronically to the using elements. The FDC must pass the AFWA and FOMET messages to the controlling fire support element for dissemination to the SWO and CBRN Officers. This data is used for forecasting, downwind predictions, and close air support.

q. The sensor section typically operates in two tactical radio nets as directed by the controlling headquarters. Normally, these are the command net for command and control and an operations/fire net for MET message dissemination. When digital radio communication is not possible, the sensor section may disseminate messages by voice.

14-14. Mission, Enemy, Terrain and Weather, Troops and Support Available-Time Available

a. Mission. Selection of modes of operation and general position areas for MET assets are influenced by a thorough analysis of the mission, enemy, terrain, and weather. The type of mission assigned greatly influences the MET asset positioning. The main consideration in positioning the asset when it is providing MET data in support of artillery operations is to locate it where it provides optimum coverage for the most firing units. Other (high-altitude) MET support requirements, such as AFWA support and FOMET message production to support smoke or CBRN operations, also influence the positioning of MET assets.

b. Enemy. The enemy situation, capabilities, and probable courses of action developed by the intelligence/intelligence staff section/assistant chief of staff, intelligence/intelligence staff section during IPB greatly determine the employment of MET assets. Security of the sections must be weighed against mission requirements.

c. Terrain and Weather. Terrain acts upon the area of validity of MET messages for the PiBal method. Generally, the area of validity decreases as the distance from the user increases. Mountainous terrain and large bodies of water also affect validity areas.

Weather encountered will be a primary factor in determining the frequency of MET messages produced for dissemination. The MET planner must be familiar with the influence of weather on MET operations because adverse weather conditions greatly reduce the capability of providing PiBal support. Fog, rain, snow, or dust can make observation through optical instruments virtually impossible.

d. Troops and Support Available. Personnel and equipment must be positioned where it can provide support for the largest number of firing units. Sensor teams should be located where logistical support can be provided, and within effective and practical communications range of the units they support.

e. Time Available. The sensor officer and the sensor chief must consider how much time is required for reconnaissance, movement, and occupation of initial and subsequent sensor teams positions. Upon arrival at a location, the sensor teams require about ten minutes to emplace. Displacement time is approximately five minutes. Travel time is figured at the standard rate for the local conditions for wheeled vehicles. A sensor team may deploy anywhere on the battlefield to achieve the mission of providing support. Movement may be toward or away from the frontline trace or laterally, depending on weather conditions (mainly prevailing wind direction) and the tactical situation. The requirement to provide continuous coverage is an important consideration in determining movement schedules. A number of widely separated section positions must be planned. Additionally, an analysis of areas of MET validity is necessary. Primary, alternate, and possibly even third-choice position areas are selected. The sensor officer coordinates with the maneuver element to receive approval for occupation of positions and to obtain route clearances. Sensor teams then must conduct reconnaissance and select the most suitable sites within the areas.

14-15. Space and Logistics

a. Each sensor team must be prepared to increase the frequency of message production. Planning in support of the operation must ensure adequate supplies are available to meet increased demand. Prior planning allows the sensor teams to increase frequency of messages and transmissions of MET data.

b. Accurate, concentrated artillery fire is a key element in any operation. MET messages improve the effectiveness of the artillery response by increasing the accuracy. Control of the sensor section in the defense is normally centralized once the main battle commences. Movements are limited to ensure continuous support.

c. The availability of supplies (specifically expendable items such as balloons and helium) is a very important consideration. Ultimately, it’s the sensor chief’s responsibility to ensure that the proper amounts of supplies to support a given operation are packed with the sensor team conducting the support. When packing, ensure that a ten percent failure rate for the expendables is factored in as well as full helium bottles are taken.

Section IV. ACOUSTIC PLANNING

14-16. Acoustic Planning

Sound ranging is the process of determining the position of acoustic events (gunfire, mortar fire, explosions, etc.) quickly and accurately. Planning the positioning and employment of acoustic assets should be an integral and complimentary part of the sensor planning process. Acoustic systems such as GCFS play an important role in establishing passive, non-intrusive surveillance in both a stand-alone and a complimentary manner with other sensors. This process begins with the intelligence preparation of the battlespace and a thorough assessment of the enemy indirect fire threat. In a collaborative sense, acoustic sensors should be positioned to best compliment active RF emitters such as the Firefinder and LCMR and may be positioned to cover dead space the radars are unable to electronically cover. Acoustic sensors employ the characteristics of sound, which act much like ripples on a pond or wave front. These wave fronts cross the terrain from the acoustic event to the array of microphones at SPs deployed across the battlefield. The accurate survey of the microphones within the SP array is essential if the GCFS are to achieve the location of acoustic events caused by weapons firing. Sensor teams must understand the criteria, terms; configurations and techniques necessary for setting up an SP. Additionally, sensor teams must be thoroughly read into the acoustic positioning plan in order to ensure survey of SPs are accounted for in the survey plan.

14-17. Site Reconnaissance

Before reconnaissance can begin, several factors must be considered:

a. The deployment of SPs across the area of operations is dependent on factors such as the availability of area in which to deploy, distance from the CP, distance from the SP positions to the hostile force, suspected positions of the hostile force, and the number of SPs available to deploy.

b. The area available for deployment should exclude areas such as swamps, minefields, forests, and sources of known constant loud noise which may cause frequent false acquisitions.

14-18. Terrain

The terrain is important for two reasons:

a. Communications between the SP and CP may cause problems with normal voice radio communications by creating radio shadows or black spots. The map interface deployment aid system assists the GIC in determining some of these conditions and advises on the best acoustic and radio wave propagation strategy. The map interface deployment aid system will also provide the planning team with an electronic means for conducting site reconnaissance and position assessment before physically emplacing SPs.

b. Terrain and man-made features may also cause areas of sound shadow. During deployment, ensure the SP is not set up in a position of local sound shadow in the selected deployment area. For both these reasons, avoid sitting an SP in a dip, hollow, forest, or behind a significant obstacle. Figure 14-5 below depicts ideal SP positioning for a GCFS.

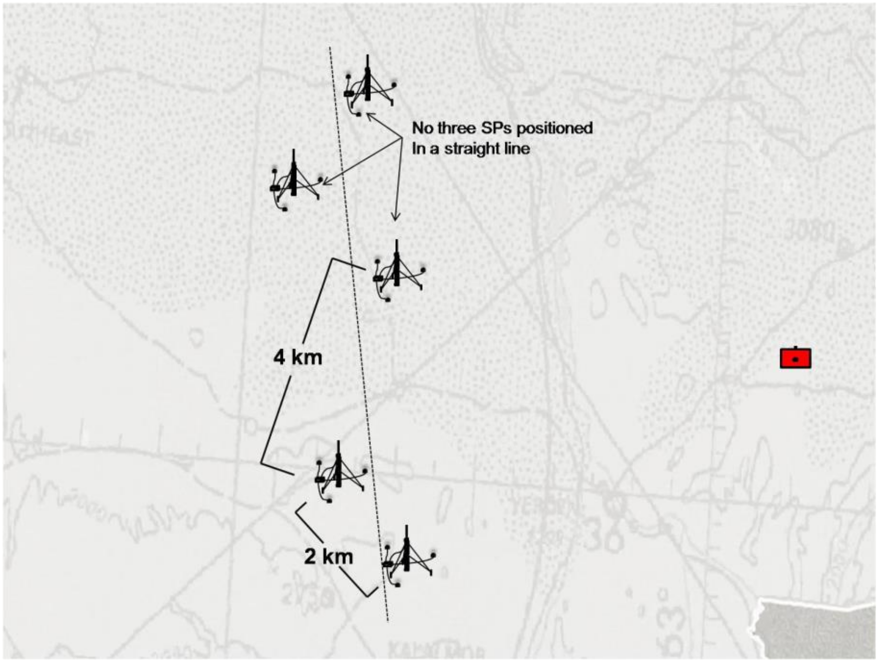


Figure 14-5. Sensor Post Positioning

14-19. Site Selection Considerations

The position of the SP must conform to the following if the system is to provide accurate results. There will almost always be some conflict of interest in determining the ideal position for an SP. An actual ground reconnaissance is invaluable in determining access to the position area, movement routes, and micro-terrain evaluation.

14-20. Terrain Mapping

Flat and level ground is obviously the ideal situation. Difference in ground height between microphones will be accounted for when terrain mapping software is loaded at the CP. Slope distance corrections must be applied when there is no terrain mapping. If the microphones are placed above the ground, this height must be applied. Technical details for such positioning may be found in the Ground Counter Fire Sensor TM 11138A-OR.

14-21. Distance from Large Obstructions

Sound shadow considerations require the deployment of the SP to be five times the height of the obstacle away from the base of the obstacle if the obstacle is between the sound source and the SP (H x 5=Distance of SP). Figure 14-6 provides a graphic representation of the sound shadow concept. Keep smaller items like packing cases, oil drums, large rocks, etc., well away from the microphones.

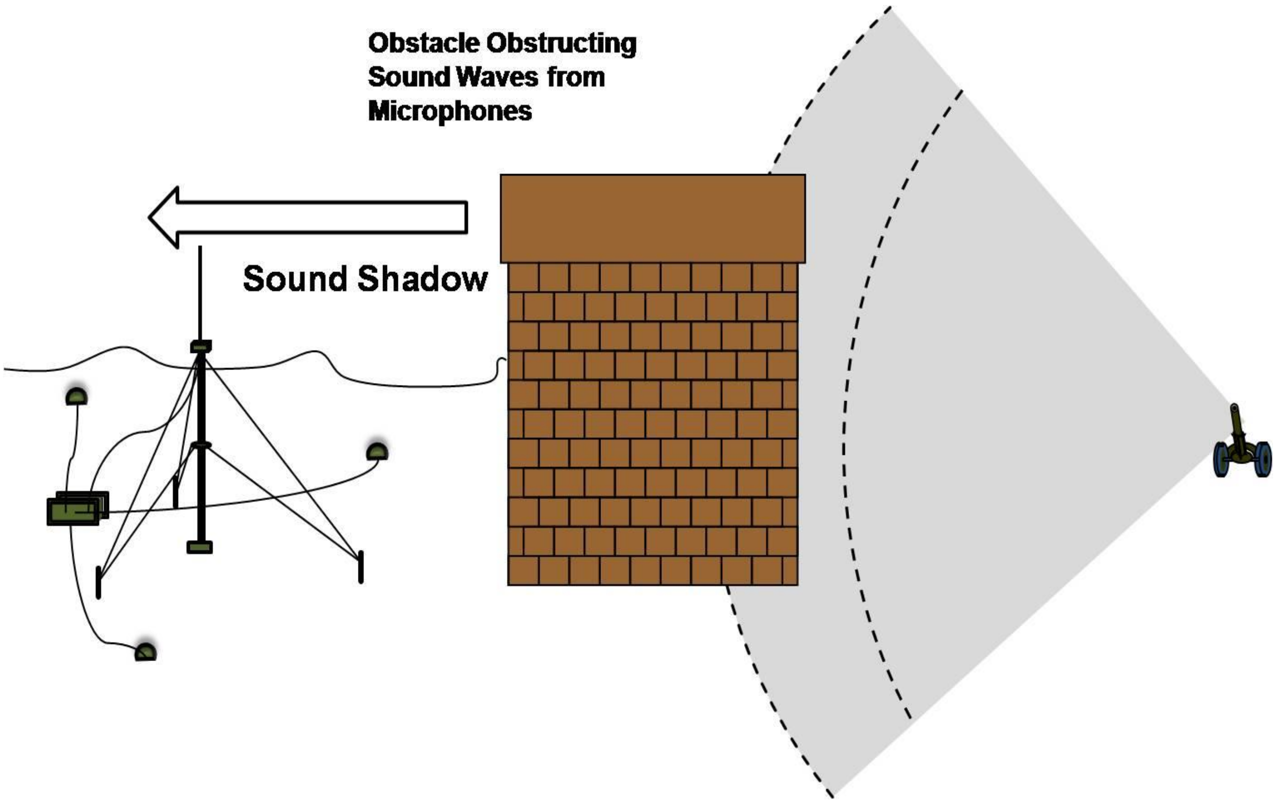


Figure 14-6. Sound Shadow

14-22. Distance from Sources of Sound

Avoid busy roads, generators, and construction or industrial sites. These can interfere with GCFS operations.

14-23. Adequate Drainage

Avoid placing the microphones on swampy ground or in puddles. Poor drainage could cause microphones to be partly submerged or coated in mud, which affects the sensitivity.

14-24. Elevated Sensor Post Microphones

When emplaced on a roof top, the SP should be set up in the center, away from the edge of the building. It should be positioned on the building without interfering the microphone’s performance (sound shadow).

14-25. Acoustic Performance

An acoustic system which has been properly planned and emplaced will provide optimal SP to hostile weapon geometry and adequate communications line of sight. This will ensure rapid and accurate reporting of hostile weapon firings. Figure 14-7 below depicts properly emplaced GCFS.

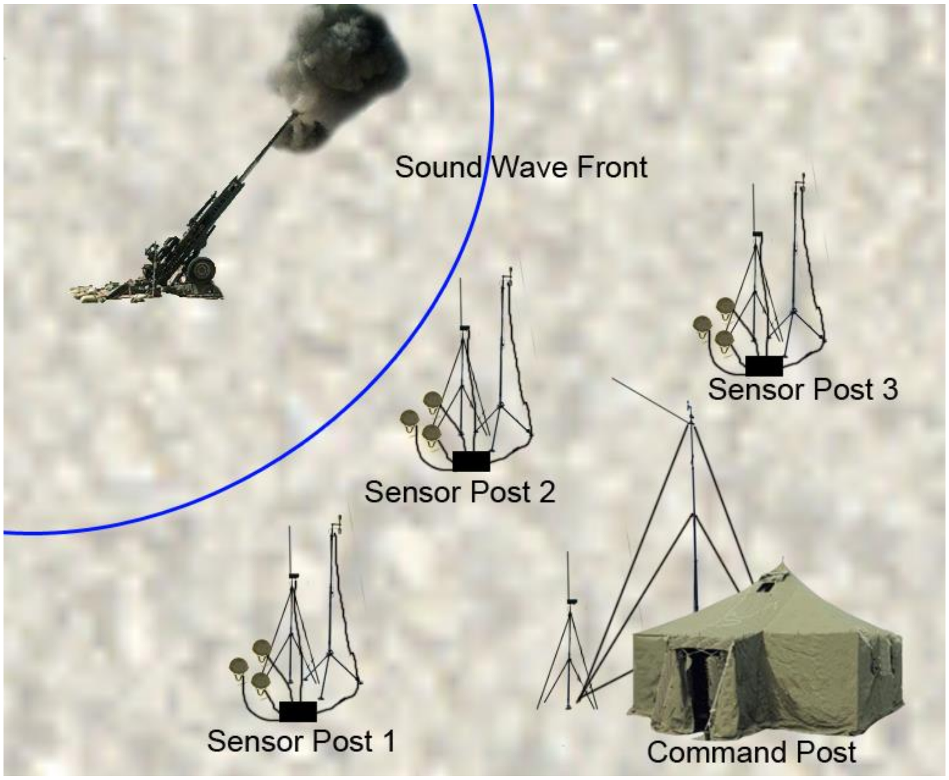


Figure 14-7. GCFS Emplacement

APPENDIX A. EXAMPLE FORMS

The following NAVMC forms can be downloaded for use on http://navalforms.daps.dla.mil.

NAVMC 11801 (1-12) (EF)

Print Form

COMPUTATION OF AZIMUTH AND DISTANCE FROM UTM COORDINATES			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER STATION NAME:		
2	ENTER UTM EASTING:		
3	ENTER UTM NORTHING:		
4	ENTER AZMK NAME:		
5	ENTER UTM EASTING:		
6	ENTER UTM NORTHING:		
RECORD OUTPUT			
7	RECORD UTM GRID AZIMUTH:		
8	RECORD GRID DISTANCE (M):		
STEP	ACTION	SET 3	SET 4
1	ENTER STATION NAME:		
2	ENTER UTM EASTING:		
3	ENTER UTM NORTHING:		
4	ENTER AZMK NAME:		
5	ENTER UTM EASTING:		
6	ENTER UTM NORTHING:		
RECORD OUTPUT			
7	RECORD UTM GRID AZIMUTH:		
8	RECORD GRID DISTANCE (M):		
REMARKS:			
COMPUTER:	CHECKER:	DATE:	
LOCALITY:	ARCHIVE FILE NAME:	SHEET ___ of ___	

FOR OFFICIAL USE ONLY

NAVMC 11803 (1-12) (EF)

COMPUTATION OF TRAVERSE CLOSURE AND ADJUSTMENT	
Survey Software for RPDA Version:	

STEP	ACTION	
1	ENTER CLOSING ANGLE (MILS):	
KNOWN DATA		
2	ENTER KNOWN AZ FWD (MILS):	
3	ENTER KNOWN ELEVATION:	
4	ENTER KNOWN EASTING:	
5	ENTER KNOWN NORTHING:	
CLOSING DATA		
6	RECORD CMPTD AZ FWD (MILS):	
7	RECORD AZ CORR (MILS):	
8	RECORD HT CORR (M):	
9	RECORD TTL (M):	
10	RECORD RADIAL ERROR (M):	
11	RECORD ACCURACY RATIO:	1/

ADJUSTED DATA				
STATION NAME	EASTING	NORTHING	ELEVATION	AZ TO REAR

COMPUTER:	CHECKER:	DATE:
LOCALITY:	ARCHIVE FILE NAME:	SHEET of

FOR OFFICIAL USE ONLY

NAVMC 11804 (1-12) (EF)

COMPUTATION OF UTM COORDINATES TO GEOGRAPHIC POSITIONS			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER STATION NAME:		
2	ENTER UTM ELLIPSOID:		
3	ENTER UTM EASTING:		
4	ENTER UTM NORTHING:		
5	ENTER LATITUDE (N/S):		
6	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
7	RECORD LAT (-S)(dd.mmsssss):		
8	RECORD LONG (-W)(ddd.mmsssss):		
STEP	ACTION	SET 3	SET 4
1	ENTER STATION NAME:		
2	ENTER UTM ELLIPSOID:		
3	ENTER UTM EASTING:		
4	ENTER UTM NORTHING:		
5	ENTER LATITUDE (N/S):		
6	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
7	RECORD LAT (-S)(dd.mmsssss):		
8	RECORD LONG (-W)(ddd.mmsssss):		
REMARKS:			
COMPUTER:	CHECKER:	DATE:	
LOCALITY:	ARCHIVE FILE NAME:	SHEET of	

FOR OFFICIAL USE ONLY

NAVMC 11805 (1-12) (EF)

CONVERSION OF GEOGRAPHIC POSITIONS TO UTM COORDINATES			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER STATION NAME:		
2	ENTER ELLIPSOID:		
3	ENTER LAT (-S)(dd.mmsssss):		
4	ENTER LONG (-W)(ddd.mmsssss):		
5	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
6	RECORD UTM EASTING:		
7	RECORD UTM NORTHING:		
STEP	ACTION	SET 3	SET 4
1	ENTER STATION NAME:		
2	ENTER ELLIPSOID:		
3	ENTER LAT (-S)(dd.mmsssss):		
4	ENTER LONG (-W)(ddd.mmsssss):		
5	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
6	RECORD UTM EASTING:		
7	RECORD UTM NORTHING:		
REMARKS:			

COMPUTER:	CHECKER:	DATE:
LOCALITY:	ARCHIVE FILE NAME:	SHEET of

FOR OFFICIAL USE ONLY

NAVMC 11806 (1-12) (EF)

COMPUTATION OF UTM ZONE TO ZONE TRANSFORMATION			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER STATION NAME:		
2	ENTER ELLIPSOID:		
3	ENTER UTM GRID ZONE 1:		
4	ENTER UTM GRID ZONE 2:		
5	ENTER UTM EASTING GZ1:		
6	ENTER UTM NORTHING GZ1:		
7	ENTER LATITUDE (N/S):		
8	ENTER AZIMUTH GZ1:		
RECORD OUTPUT			
9	RECORD UTM EASTING GZ2:		
10	RECORD UTM NORTHING GZ2:		
11	RECORD AZIMUTH GZ2:		
STEP	ACTION	SET 3	SET 4
1	ENTER STATION NAME:		
2	ENTER ELLIPSOID:		
3	ENTER UTM GRID ZONE 1:		
4	ENTER UTM GRID ZONE 2:		
5	ENTER UTM EASTING GZ1:		
6	ENTER UTM NORTHING GZ1:		
7	ENTER LATITUDE (N/S):		
8	ENTER AZIMUTH GZ1:		
RECORD OUTPUT			
9	RECORD UTM EASTING GZ2:		
10	RECORD UTM NORTHING GZ2:		
11	RECORD AZIMUTH GZ2:		
REMARKS:			
COMPUTER:	CHECKER:	DATE:	
LOCALITY:	ARCHIVE FILE NAME:	SHEET of	

FOR OFFICIAL USE ONLY

NAVMC 11807 (1-12) (EF)

COMPUTATION OF UTM GRID CONVERGENCE (TRUE TO GRID) FROM GEOGRAPHIC POSITIONS			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER AZMK NAME:		
2	ENTER STATION NAME:		
3	ENTER LAT (-S)(dd.mmsssss):		
4	ENTER LONG (-W)(ddd.mmsssss):		
5	ENTER TRUE AZIMUTH:		
6	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
7	RECORD UTM GRID CONVERGENCE:	+/-:	+/-:
8	RECORD UTM GRID AZIMUTH:		
STEP	ACTION	SET 3	SET 4
1	ENTER AZMK NAME:		
2	ENTER STATION NAME:		
3	ENTER LAT (-S)(dd.mmsssss):		
4	ENTER LONG (-W)(ddd.mmsssss):		
5	ENTER TRUE AZIMUTH:		
6	ENTER UTM GRID ZONE:		
RECORD OUTPUT			
7	RECORD UTM GRID CONVERGENCE:	+/-:	+/-:
8	RECORD UTM GRID AZIMUTH:		
REMARKS:			

COMPUTER:	CHECKER:	DATE:
LOCALITY:	ARCHIVE FILE NAME:	SHEET of

FOR OFFICIAL USE ONLY

NAVMC 11808 (1-12) (EF)

COMPUTATION OF ARTILLERY ASTRONOMIC OBSERVATIONS				
Survey Software for RPDA Version:				
STEP	ACTION			
PAGE ONE				
1	ENTER STATION NAME:			
2	ENTER ELLIPSOID:			
3	ENTER KNOWN EASTING:			
4	ENTER KNOWN NORTHING:			
5	ENTER LATITUDE (N/S):			
6	ENTER UTM GRID ZONE:			
PAGE TWO				
7	ENTER ORDER:			
8	ENTER STAR # (SUN = 0):			
9	ENTER TIME ZONE LETTER:			
10	ENTER DAYLIGHT SAVINGS:			
11	ENTER INITIAL CIRCLE SETTING:			
PAGE THREE				
	ACTION	INPUT FOR SET 1	INPUT FOR SET 2	INPUT FOR SET 3
12	ENTER OBSERVATION DATE			
13	ENTER OBSERVATION TIME (hrs:min:sec)			
14	ENTER AIMING POINT (T/L/C)			
15	ENTER HORZ READING			
RECORD OUTPUT				
16	PRESS CALC; RECORD UTM GRID AZ:			
17	RECORD MEAN UTM GRID AZIMUTH OF ACCEPTABLE SETS:			
REMARKS:				
COMPUTER:		CHECKER:		DATE:
LOCALITY:		ARCHIVE FILE NAME:		SHEET ___ of ___

FOR OFFICIAL USE ONLY

NAVMC 11809 (1-12) (EF)

COMPUTATION OF HASTY ASTRONOMIC OBSERVATIONS			
Survey Software for RPDA Version:			
STEP	ACTION		
PAGE ONE			
1	ENTER STATION NAME:		
2	ENTER ELLIPSOID:		
3	ENTER KNOWN EASTING:		
4	ENTER KNOWN NORTHING:		
5	ENTER LATITUDE (N/S):		
6	ENTER UTM GRID ZONE (1-60):		
PAGE TWO			
7	ENTER STAR # (SUN = 0):		
8	ENTER TIME ZONE LETTER:		
9	ENTER DAYLIGHT SAVINGS:		
10	ENTER OBSERVATION DATE:		
PAGE THREE			
	ACTION	INPUT FOR SET 1	INPUT FOR SET 2
11	ENTER OBSERVATION TIME (hrs:min:sec)		
12	ENTER AIMING POINT (T/L/C)		
RECORD OUTPUT			
13	RECORD COMPUTED AZIMUTH TO AZIMUTH MARK:		
14	RECORD CHECK ANGLE:		
REMARKS:			
COMPUTER:	CHECKER:		DATE:
LOCALITY:	ARCHIVE FILE NAME:		SHEET of

FOR OFFICIAL USE ONLY

NAVMC 11810 (1-12) (EF)

COMPUTATION OF HORIZONTAL DISTANCE FROM SUBTENSE			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER SUBTENDED ANGLE (MILS):		
2	ENTER BASE LENGTH (METERS):		
RECORD OUTPUT			
3	ENTER DISTANCE (METERS):		
STEP	ACTION	SET 3	SET 4
1	ENTER SUBTENDED ANGLE (MILS):		
2	ENTER BASE LENGTH (METERS):		
RECORD OUTPUT			
3	ENTER DISTANCE (METERS):		
STEP	ACTION	SET 5	SET 6
1	ENTER SUBTENDED ANGLE (MILS):		
2	ENTER BASE LENGTH (METERS):		
RECORD OUTPUT			
3	ENTER DISTANCE (METERS):		
STEP	ACTION	SET 7	SET 8
1	ENTER SUBTENDED ANGLE (MILS):		
2	ENTER BASE LENGTH (METERS):		
RECORD OUTPUT			
3	ENTER DISTANCE (METERS):		
REMARKS:			
COMPUTER:	CHECKER: REMARKS:		DATE:
LOCALITY:	ARCHIVE FILE NAME:		SHEET of

FOR OFFICIAL USE ONLY

NAVMC 11811 (1-12) (EF)

COMPUTATION OF COORDINATES AND ELEVATION FROM INTERSECTION			
Survey Software for RPDA Version:			
STEP	ACTION	SET 1	SET 2
1	ENTER O1 NAME:		
2	ENTER UTM EASTING:		
3	ENTER UTM NORTHING:		
4	ENTER ELEVATION (M):		
5	ENTER O2 NAME:		
6	ENTER UTM EASTING:		
7	ENTER UTM NORTHING:		
8	ENTER AZ 01 TO TGT:		
9	ENTER VA 01 TO TGT:		
10	ENTER AZ 02 TO TGT:		
11	RECORD DISTANCE O1-O2 (M):		
12	RECORD GRID AZ O1-O2 (MILS)		
13	RECORD UTM EASTING:		
14	RECORD UTM NORTHING:		
15	RECORD ELEVATION (M):		
REMARKS:			

COMPUTER:	CHECKER:	DATE:
LOCALITY:	ARCHIVE FILE NAME:	SHEET ___ of ___

FOR OFFICIAL USE ONLY

NAVMC 11812 (1-12) (EF)

SURVEY CONTROL POINT RECOVERY		
STATION NAME:	RECOVERED BY:	RECOVERY DATE:

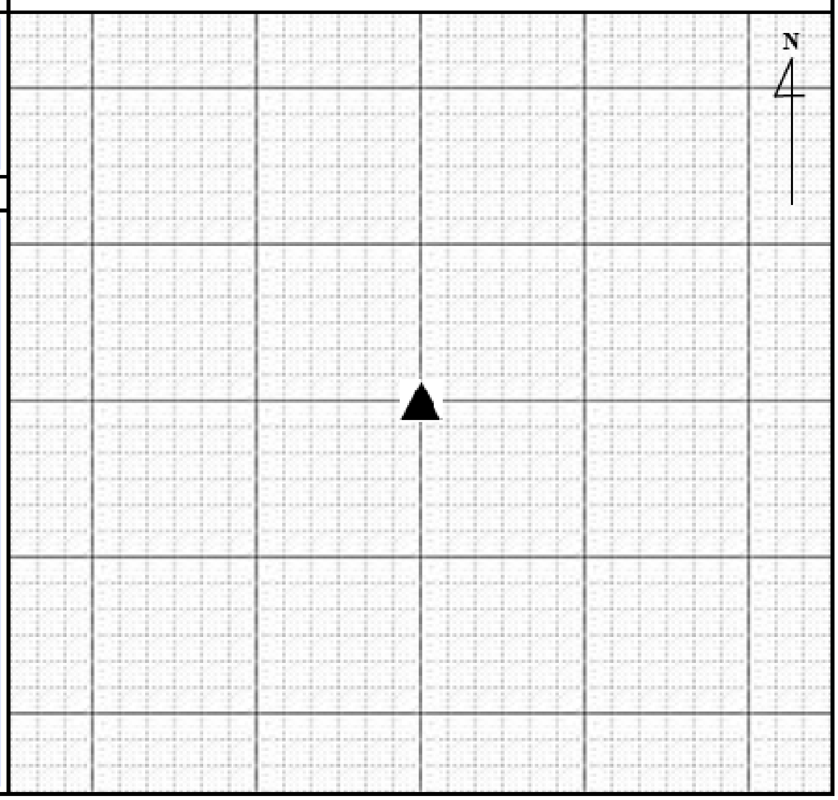
AGENCY CAST IN MARK:	IPADS ACCESSIBLE:	GPS S MASKING	STATUS

GRID (8 DIGIT):	TYPE OF MARK:	MONUMENT DESCRIPTION (IN CM'S)	STAMPING:

WITNESS MARK DESCRIPTION	DISTANCE (METERS)	DIRECTION (MILS/MAG)

TO REACH THE STATION FROM:

AZIMUTH MARK (VERIFIED)	WITNESS MARK DESCRIPTION



REMARKS

FOR OFFICIAL USE ONLY

NAVMC 11815 (01-12) (EF)

SURVEY CONTROL POINT				
Country	Sheet Name:	Sheet Number:	Station Name:	
Municipality or State:	Locality:	UTM Zone & Designator:	MGRS 100,000 Meter SQ ID:	
Established by:		Date Established:	Order Horizontal:	
Filed by:		Filed Date:	Method Horizontal:	
WGS 84 Easting:	WGS 84 Northing:	WGS 84 Latitude:	WGS 84 Longitude:	
Order Vertical:	Method Vertical:	Vertical DATUM:	Elevation (M)	Elevation (FT)

Easting (Local):	Northing (Local):	Horizontal Datum (Local):
Latitude (Local):	Longitude (Local):	Ellipsoid (Local):
Type of Mark:	Agency Cast in Mark:	Stamping:

AZIMUTH MARKS	GRID AZIMUTH DEGREES	GRID AZIMUTH MILS	DISTANCE (M)

Remarks:

Sketch:

NAVMC 11814 (1-12) (EF)

PIBAL RECORDING												
MESSAGE #:	COMPUTER MET						BALLISTIC MET					
STATION DATA	ZONE HEIGHT (M)	ZONE LINE #	30G	100G	EL ANGLE	AZ ANGLE	ZONE HEIGHT (M)	ZONE LINE #	30G	100G	EL ANGLE	AZ ANGLE
OCTANT:	SUR	00	0:15	0:09			SUR	00	0:15	0:09		
LAT LON:	200	01	0:56	0:34			200	01	0:56	0:34		
GMT DATE:	500	02	2:26	1:28			500	02	2:26	1:28		
LST TIME:	1000	03	5:03	3:04			1000	03	5:03	3:04		
GMT TIME:	1500	04	7:50	4:43			1500	04	7:50	4:43		
HEIGHT (10's M):	2000	05	10:37	6:25			2000	05	10:37	6:25		
SURFACE PRESS:	2500	06	13:23	8:09			3000	06	16:10	9:56		
DRY TEMP:	3000	07	16:10	9:56			4000	07	21:43	13:32		
WET TEMP:	3500	08	18:57	11:43			5000	08	27:17	17:12		
RELEASE DIST:	4000	09	21:43	13:32			6000	09	32:50	20:54		
OFFSET AZIMUTH:	4500	10	24:30	15:21			8000	10	43:57	28:19		
BALLOON SIZE:	5000	11	27:17	17:12			10000	11	55:03	35:43		
MILS/ DEGREES	6000	12	32:50	20:54			12000	12	66:10	43:08		
TEAM CHIEF:	7000	13	38:23	24:37								
	8000	14	43:57	28:19								
OPERATOR:	9000	15	49:30	32:01								
	10000	16	55:03	35:43								
EXPENDABLES USED:	11000	17	60:37	39:26								
	12000	18	66:10	43:08								

Remarks:

MCWP 3-16.7 / TM 10667A-OR/1

GPS STATION OBSERVATION RECORDING SHEET

STATION NAME	JOB NAME (FROM HANDHELD)	PROJECT NAME (IN TBC, STATIC ONLY)
OBSERVATION DATE	TEAM CHIEF	RECORDER
ANTENNA TYPE / SERIAL NUMBER	RECEIVER TYPE / SERIAL NUMBER	HANDHELD TYPE / SERIAL NUMBER

UTM GRID ZONE	HORZ. DATUM	VERT. DATUM	GEOID MODEL

SURVEY TYPE (CHECK ONE)	☐ **ABSOLUTE**	☐ **RTK BASE**	☐ **STATIC**
CODE TRACKING (CHECK ONE)	☐ **Y-CODE PPS**	☐ **C/A CODE SPS**	
ANTENNA HT POINT (CHECK ONE)	☐ **BOTTOM OF ANTENNA**	☐ **TOP OF NOTCH**	
ANTENNA HEIGHT (FT/M)	FIRST HEIGHT	SECOND HEIGHT	MEAN

ABSOLUTE SURVEY

EASTING	NORTHING	ELEVATION	# OF EPOCHS

RTK BASE

EASTING	NORTHING	ELEVATION	STATION INDEX

STATIC SURVEY

START TIME	# OF SATELLITES	END TIME	# OF SATELLITES

REMARKS

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NAVMC 11816 (Rev. MAR-2015) (EF)
PREVIOUS EDITIONS ARE OBSOLETE

Adobe LiveCycle Designer 9

MCWP 3-16.7 / TM 10667A-OR/1

REAL-TIME KINEMATIC ROVER RECORDING SHEET

JOB NAME	HORZ. DATUM	UTM GRID ZONE	VERT. DATUM	GEOID MODEL	DATE

TEAM CHIEF	RECEIVER TYPE / SERIAL NUMBER	HANDHELD TYPE / SERIAL NUMBER	ANTENNA TYPE / SERIAL NUMBER

RECORDER	HORZ / VERT PRECISION:	BASE NAME	BASE EASTING	BASE NORTHING	BASE ELEVATION

STATION NAME	ANT HT	EASTING	NORTHING	ELEVATION	AZMK	AZIMUTH TO AZMK

REMARKS

NAVMC 11824 (Rev. MAR-2015) (EF)
PREVIOUS EDITIONS ARE OBSOLETE

FOR OFFICIAL USE ONLY

Adobe LiveCycle Designer 9

BALLISTIC MESSAGE

For use of this form, see FM 3-09.15; the proponent agency is TRADOC.

IDENTIFI-CATION METB	TYPE MSG K	OCTANT Q	LOCATION $L_aL_aL_a$ or xxx	$L_oL_oL_o$ or xxx	DATE YY	TIME (GMT) $G_oG_oG_o$	DURATION (HOURS) G	STATION HEIGHT (10s M) hhh	MDP PRESSURE % OF STD PPP
METB									

ZONE HEIGHT (METERS)	LINE NUMBER ZZ	BALLISTIC WINDS		BALLISTIC AIR	
		DIRECTION (100s MILS) dd	SPEED (KNOTS) FF	TEMPERATURE (% OF STD) TTT	DENSITY (% OF STD) ΔΔΔ
SURFACE	00				
200	01				
500	02				
1000	03				
1500	04				
2000	05				
3000	06				
4000	07				
5000	08				
6000	09				
8000	10				
10000	11				
12000	12				
14000	13				
16000	14				
18000	15				

REMARKS		
DELIVERED TO: RECEIVED FROM:	TIME (GMT)	TIME (LST)
MESSAGE NUMBER	DATE	
RECORDER	CHECKED	

DA FORM 3675-R, MAY 1992 PREVIOUS EDITIONS ARE OBSOLETE. APD PE v1.01

COMPUTER MET MESSAGE

For use of this form, see TC 3-09.81 the proponent agency is TRADOC.

IDENTIFICATION METCM	OCTANT Q	LOCATION $L_aL_aL_a$ or XXX	$L_oL_oL_o$ or XXX	DATE YY	TIME (GMT) $G_oG_oG_o$	DURATION (HOURS) G	STATION HEIGHT (10's M) hhh	MDP PRESSURE MB $P_dP_dP_d$
METCM								

ZONE HEIGHTS METERS	LINE NUMBER ZZ	ZONE VALUES WIND DIRECTION (10s M) ddd	WIND SPEED (KNOTS) FFF	TEMPERATURE (1/10 K) TTTT	PRESSURE (MILLIBARS) PPPP
SURFACE	00				
200	01				
500	02				
1000	03				
1500	04				
2000	05				
2500	06				
3000	07				
3500	08				
4000	09				
4500	10				
5000	11				
6000	12				
7000	13				
8000	14				
9000	15				
10000	16				
11000	17				
12000	18				
13000	19				
14000	20				
15000	21				
16000	22				
17000	23				
18000	24				
19000	25				
20000	26				

FROM TO	DATE AND TIME (GMT)	DATE AND TIME (LST)
MESSAGE NUMBER	RECORDER	CHECKED

DA FORM 3677, JAN 2016 PREVIOUS EDITIONS ARE OBSOLETE. APD LC v1.00

FALLOUT MESSAGE

For use of this form, see FM 3-09.15; the proponent agency is TRADOC.

IDENTIFICATION	OCTANT	LOCATION		DATE	TIME (GMT)	DURATION (HOURS)	STATION WEIGHT (10s M)
		$L_aL_aL_a$ or xxx	$L_oL_oL_o$ or xxx				
METFM	Q			YY	GGG	G	hhh
METFM							

ZONE HEIGHT (METERS)	LINE NUMBER ZZ	TRUE WIND		ZONE HEIGHT (METERS)	LINE NUMBER ZZ	TRUE WIND	
		DIRECTION (10s MILS) ddd	SPEED (KNOTS) FFF			DIRECTION (10s MILS) ddd	SPEED (KNOTS) FFF
SURFACE	00			16000	08		
2000	01			18000	09		
4000	02			20000	10		
6000	03			22000	11		
8000	04			24000	12		
10000	05			26000	13		
12000	06			28000	14		
14000	07			30000	15		

REMARKS

RECEIVED FROM: DELIVERED TO:	DATE AND TIME (GMT)
RECORDER	
CHECKER	

DA FORM 3676-R, MAY 1992 PREVIOUS EDITIONS ARE OBSOLETE. APD PE v1.01

APPENDIX B. CRATER ANALYSIS AND REPORTING

B-1. General

a. Crater analysis is a reliable source of information that can be used to develop targetable information. Trained teams may not be available to collect the time sensitive information necessary, as such, this section provides information that personnel can utilize to analyze craters and make the proper report. Since crater analysis teams are not authorized by table of organization and equipment, sensor support Marines can be trained to conduct crater analysis.

b. Whenever and wherever hostile cannon, missile, or mortar shelling is detected, it must be reported without delay to the appropriate S-2. The S-2 can then evaluate and act on such information. When counterfire agencies are provided with sufficient information, they can implement immediate operational objectives to ensure the successful attack of hostile weapons. Observers and liaison personnel should be capable of conducting crater analysis

c. Shelling reports (SHELREPs) form the basis for effective counterfire action. The most reliable, accurate, and informative SHELREPs are visual or electronic observation supplemented by crater analysis and fragment identification.

B-2. Crater Analysis

a. The initial step in crater analysis is to locate a usable crater for use in determining the direction to the hostile weapon. The crater should be reasonably fresh and clearly defined on the ground and the area secured to prevent personnel from disturbing the site. Since the crater is the beginning point for plotting the direction to the enemy weapon, the grid coordinates of the crater should be determined as precisely as time and the method used will allow. The direction to the firing weapon must be determined by one of the methods described below, depending on the angle of the trajectory and type of fuze fired. Shell fragments must be collected for use in identifying the type and caliber of the weapon.

b. In crater analysis, differences in angle of fall, projectile burst patterns, directions of flight, and time fuze setting will help distinguish between enemy weapons firing on a given area.

B-3. Artillery Shell Craters

a. Fuze Quick Craters. The detonation of a projectile causes an inner crater. The burst and momentum of the shell carry the effect forward and to the sides, forming an arrow that points to the rear (toward the weapon from which the round was fired). The fuze continues along the line of flight, creating a fuze furrow (groove in the ground). There are two methods of obtaining a direction to a hostile weapon from this type of crater. The observer can obtain the best results by determining a mean or average of several directions from both methods.

(1) Fuze Furrow and Center of Crater Method**.** In this method, one stake is placed in the center of the crater and another is placed in the furrow at the point where the fuze was blown forward to the front of the crater (Figure C-1). A direction-measuring instrument is set up in line with the two stakes, and the direction is measured to the hostile weapon. There are five steps of the fuze tunnel and center of crater method:

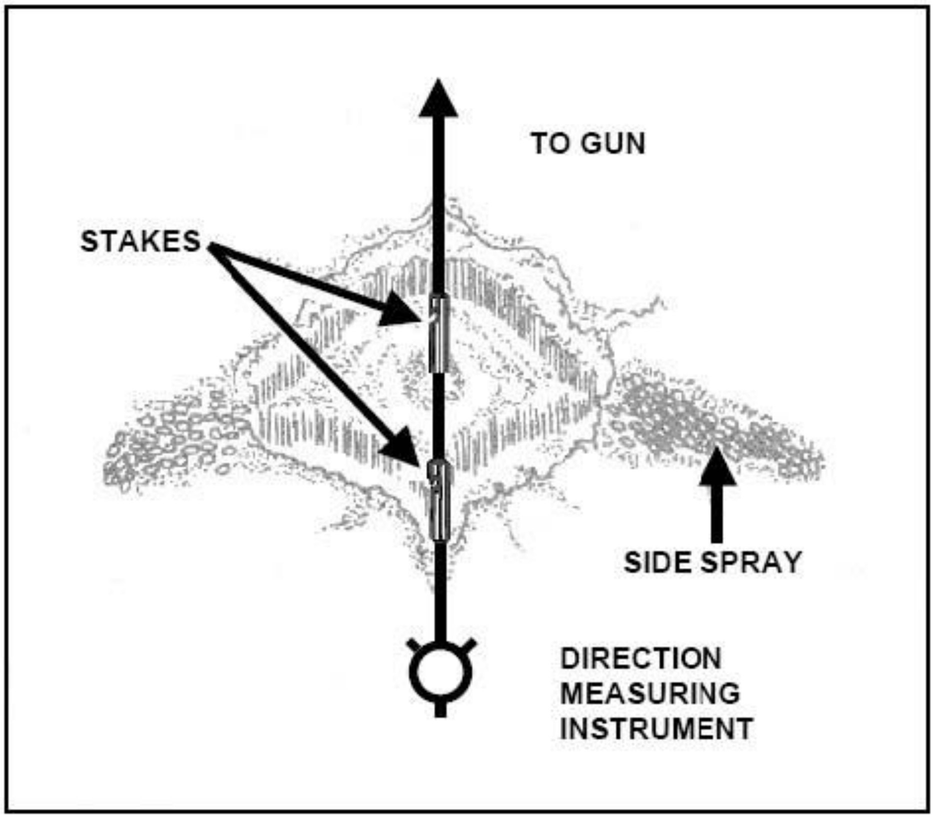


Figure B-1 Fuze Furrow and Center of Crater Method

(a) Place a stake in the center of the crater.

(b) Place a second stake in the fuze furrow.

(c) Set up a direction-measuring instrument (i.e., compass, aiming circle) in line with the stakes and away from fragments.

(d) Orient the instrument.

(e) Measure the direction to the hostile weapon.

(2) Variation of the Fuze Furrow and Center of Crater Method. A variation of this method is to place a stake where the shell entered the ground instead of in the center of the crater and determine the direction in the same manner. However, this is rarely

possible because indications of the point of entry are usually destroyed by the explosion of the shell.

(3) Side Spray Method. The side spray method involves bisecting the angle formed by the lines of the side spray by striking arcs (Figure C-2). The seven steps in measuring the direction of a fuze quick crater by the side spray method are as follows:

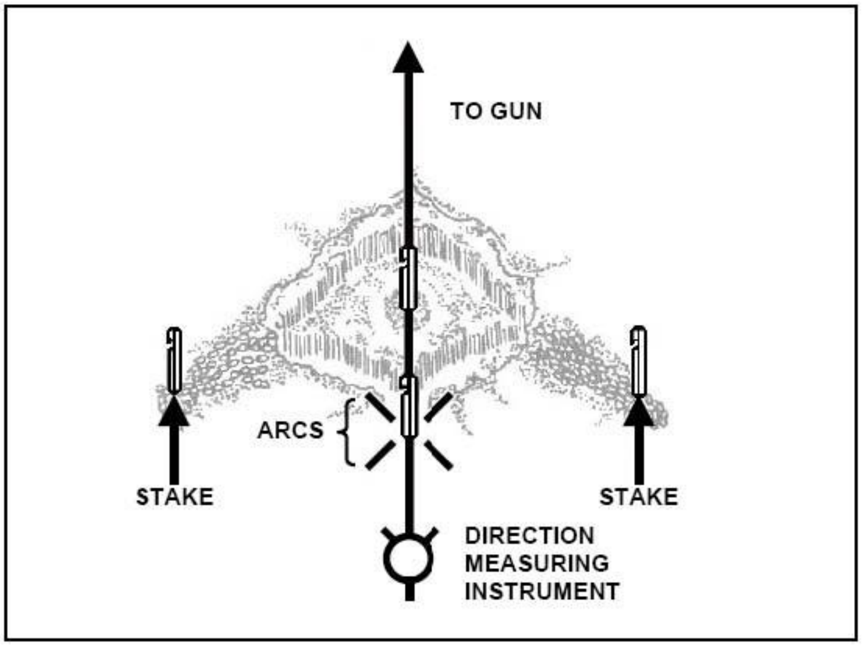


Figure B-2. Side Spray Method.

(a) Place a stake in the center of the crater.

(b) Place two stakes, one at the end of each line of side spray, equidistant from the center stake.

(c) Hold a length of WD-1 wire to each side-spray stake, and strike an arc forward of the fuze furrow.

(d) Place a stake where these arcs intersect.

(e) Set up a direction-measuring instrument in line with the stake at the intersection of the arcs and the center stake.

(f) Orient the instrument.

(g) Measure the direction to the firing weapon.

b. Fuze Delay Craters. There are two types of fuze delay craters, ricochet and mine action.

(1) Ricochet**.** The projectile enters the ground in a line following the trajectory and continues in a straight line for a few feet, causing a ricochet furrow. The projectile normally deflects upward and at the same time changes direction. The change in direction usually is to the right as a result of the spin or rotation of the projectile. The effect of the air burst can be noted on the ground (Figure C-3). Directions obtained from ricochet craters are considered to be most reliable. The five steps in determining direction from a ricochet furrow are as follows:

(a) Clean out the furrow.

(b) Place stakes at each end of a usable straight section of the furrow.

(c) Set up an instrument in line with the stakes and away from the fragments.

(d) Orient the instrument.

(e) Measure the direction to the weapon.

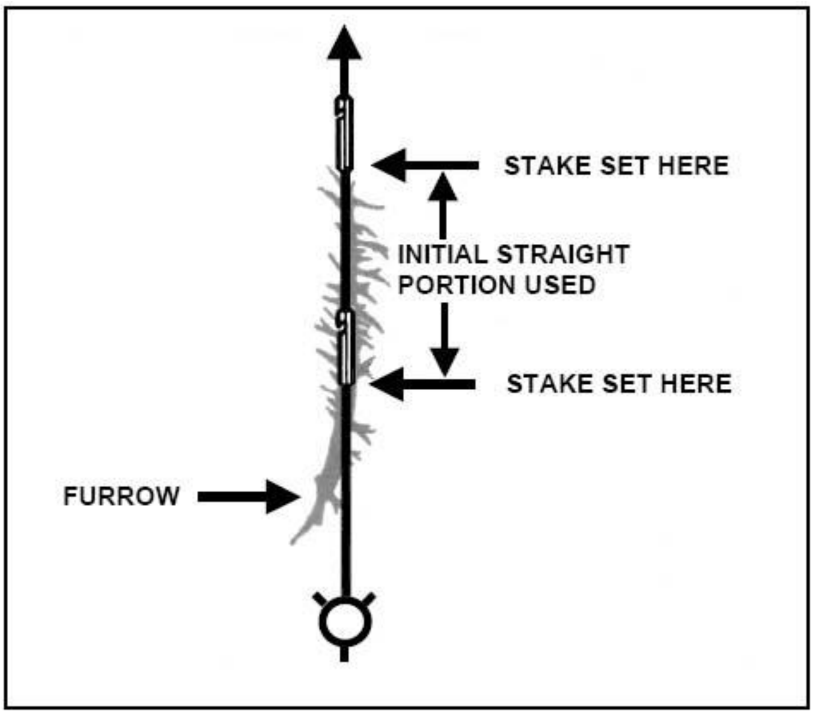


Figure B-3. Ricochet Furrow Method.

(2) Mine Action**.** Mine action occurs when a shell bursts beneath the ground. Occasionally, such a burst will leave a furrow that can be analyzed in the same manner as the ricochet furrow. A mine action crater that does not have a furrow cannot be used to determine the direction to the weapon.

B-4. Mortar Shell Craters

In a typical mortar crater, the turf at the forward edge (the direction away from the hostile mortar) is undercut (cut beneath with a portion left overhanging). The rear edge of the crater is rid of vegetation and grooved with splinters (Figure C-4.) When fresh, the crater is covered with loose earth that must be carefully removed to disclose the burnt inner crater. The ground surrounding the crater is streaked by splinter grooves that radiate from the point of detonation. The ends of the splinter grooves on the rearward side are on an approximately straight line. This line is perpendicular to the line of flight when on level ground or on slopes with contours perpendicular to the plane of fire (Figure C-5 page C-6). A fuze tunnel is caused by the fuze burying itself at the bottom of the crater in front of the point of detonation. Three methods may be used to determine direction from a mortar shell crater—main axis, splinter groove, and fuze tunnel.

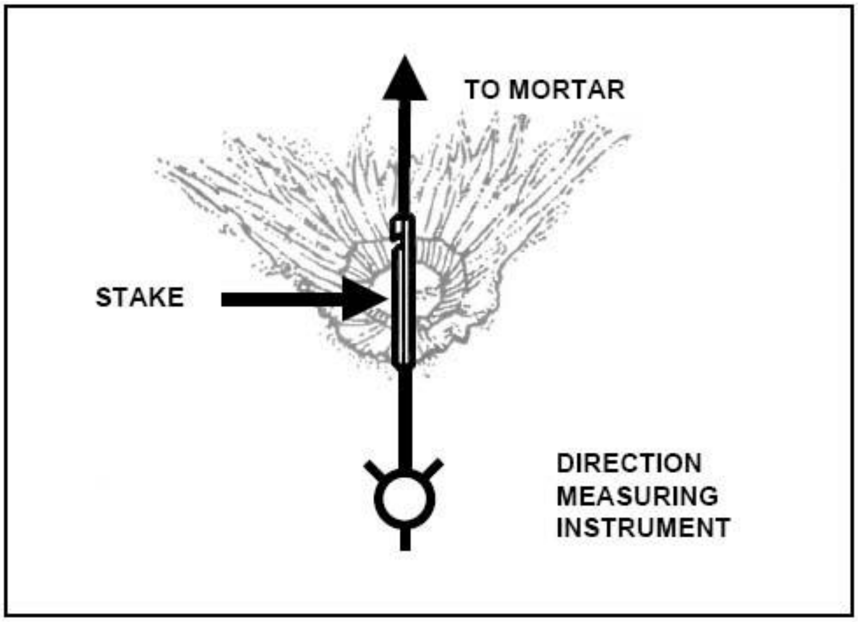


Figure B-4. Main Axis Method.

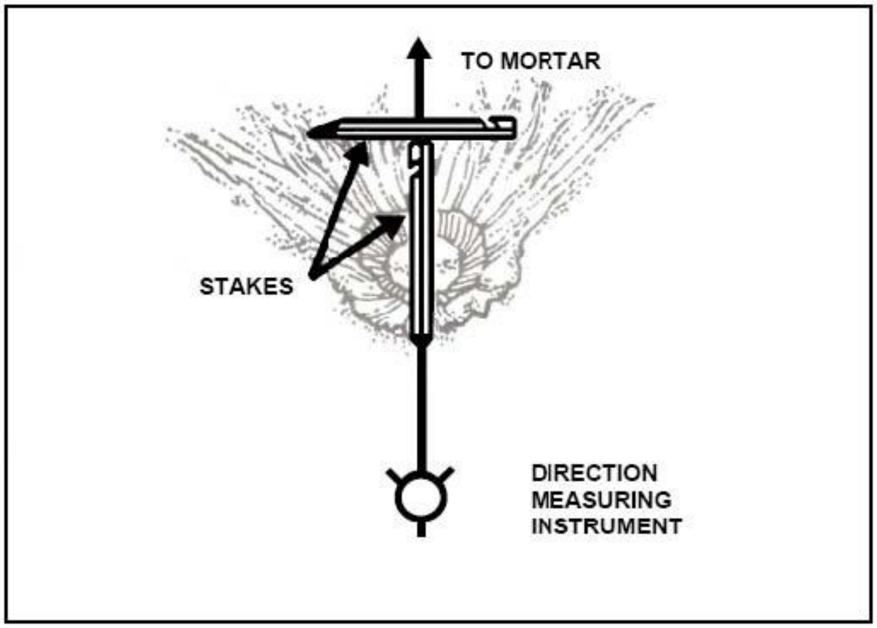


Figure B-5. Splinter Groove Method.

a. Main Axis Method. There are four steps used in determining direction by the main axis method when a definite and regular crater is formed:

   (1) Lay a stake along the main axis of the crater, dividing the crater into symmetrical halves. The stake points in the direction of the mortar.

   (2) Set up an instrument in line with the stake and away from fragments.

   (3) Orient the instrument.

   (4) Measure the direction to the weapon.

b. Splinter Groove Method. The five steps in determining direction by the splinter groove method are as follows:

   (1) Lay a stake along the ends of the splinter grooves that extend from the crater.

   (2) Lay a second stake perpendicular to the first stake through the axis of the fuze tunnel.

   (3) Set up an instrument in line with the second stake and away from fragments.

   (4) Orient the instrument.

   (5) Measure the direction to the weapon.

c. Fuze Tunnel Method**.** The four steps in determining direction by the fuze tunnel method (Figure C-6) are as follows:

(1) Place a stake in the fuze tunnel.

(2) Set up an instrument in line with the stake and away from fragments.

(3) Orient the instrument.

(4) Measure the direction to the weapon.

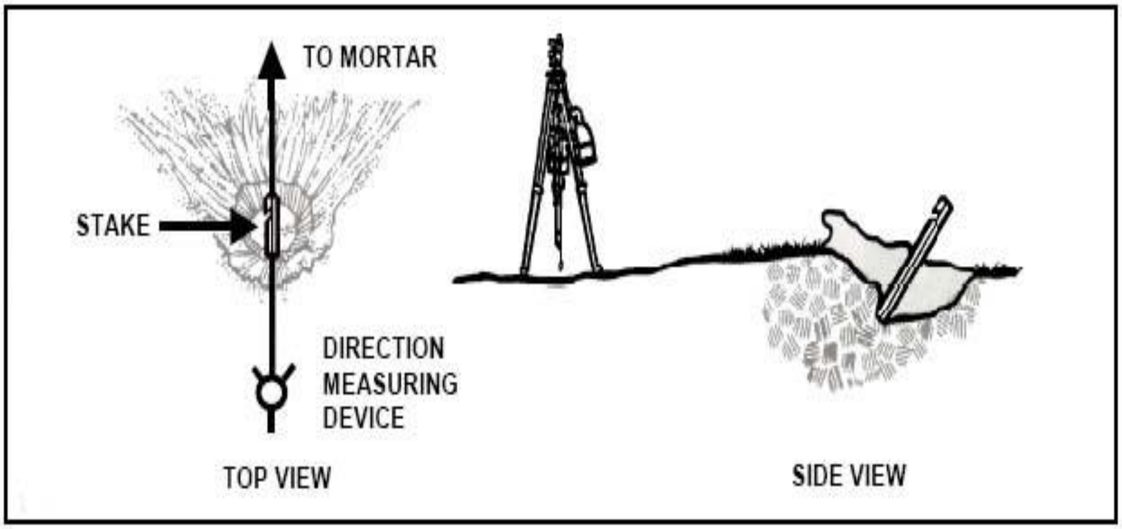


Figure B-6. Fuze Tunnel Method.

B-5. Rocket Craters

A crater resulting from a rocket impacting with a low or medium angle of fall is analyzed in the same manner as an artillery crater resulting from a projectile armed with fuze quick. However, if the rocket impacts with a high angle of fall, the crater is analyzed in the same manner as a crater resulting from a mortar round. The tail fins, rocket motor, body, and other parts of the rocket may be used to determine caliber and type of rocket fired.

B-6. Urban Craters

Urban present a unique challenge due to projectiles penetrating wall, ricocheting off hard paved surfaces or buildings (Figures B-7 and B-8 page B-8). Many of the same methods and principles applied in the preceding sections can be applied with some success.

Figure B-7. Urban Crater

Figure B-8. Urban Crater

B-7. Shell Fragment Analysis

a. Identification by weapon type and caliber may be determined from shell fragments found in shell craters. Dimensions of the parts, as well as those of the complete shell, vary according to the caliber and type of shell.

(1) Duds and Low-Order Bursts. The most logical means of identifying the caliber of a projectile is to inspect a dud of that caliber. However, since a dud may not always be available or may be too dangerous to handle, a low-order burst is the next best means of identification. When the explosive filler is not completely detonated, a low-order burst occurs and large shell fragments result. Such large pieces can be used to identify thread count, curvature, wall thickness, and so forth.

(2) High-Order Bursts. A high-order burst normally results in small-deformed fragments. These fragments are useless for identification purposes unless they include a section of either the rotating band or the rotating band seat. Fragments of either of these sections positively identify the shell, since each shell has its own distinctive rotating band markings.

(3) Rotating Bands and Band Seats. A shell may be identified (Figure C-9) as to caliber, type, and nation of origin from the:

(a) Pattern or rifling imprints on rotating bands.

(b) Width, number, and size of rotating bands.

(c) Dimensions and pattern of keying or knurling on the rotating band seat.

(d) Dimensions and pattern of rotating band seat keying and knurling impressed on the rotating band.

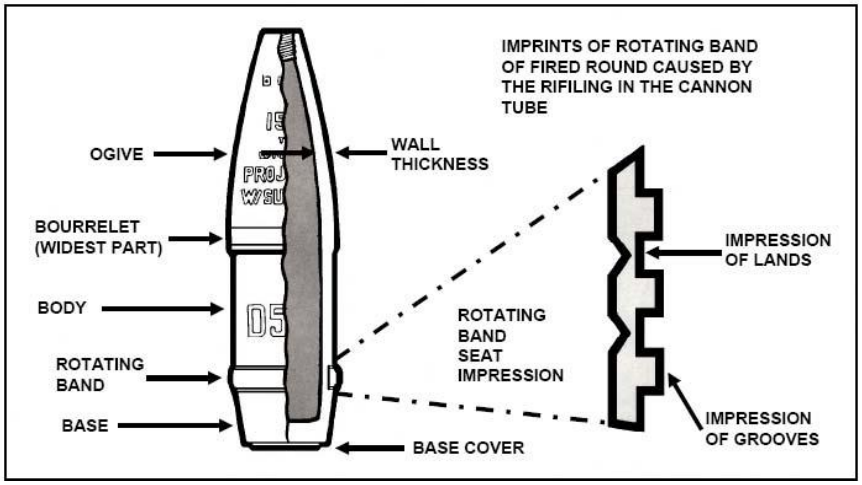


Figure B-9. Typical Artillery Shell

(4) Tail Fins. A mortar can be identified from the tail fins (Figure B-10 page B-10). Tail fins often are found in the fuze tunnel of the crater. A mortar that is not fin-stabilized may be identified from the pieces of the projectile on which the rifling is imprinted. There are mortars that have no tail fins, these mortars use “spin” stabilized munitions, much like the larger caliber cannons.

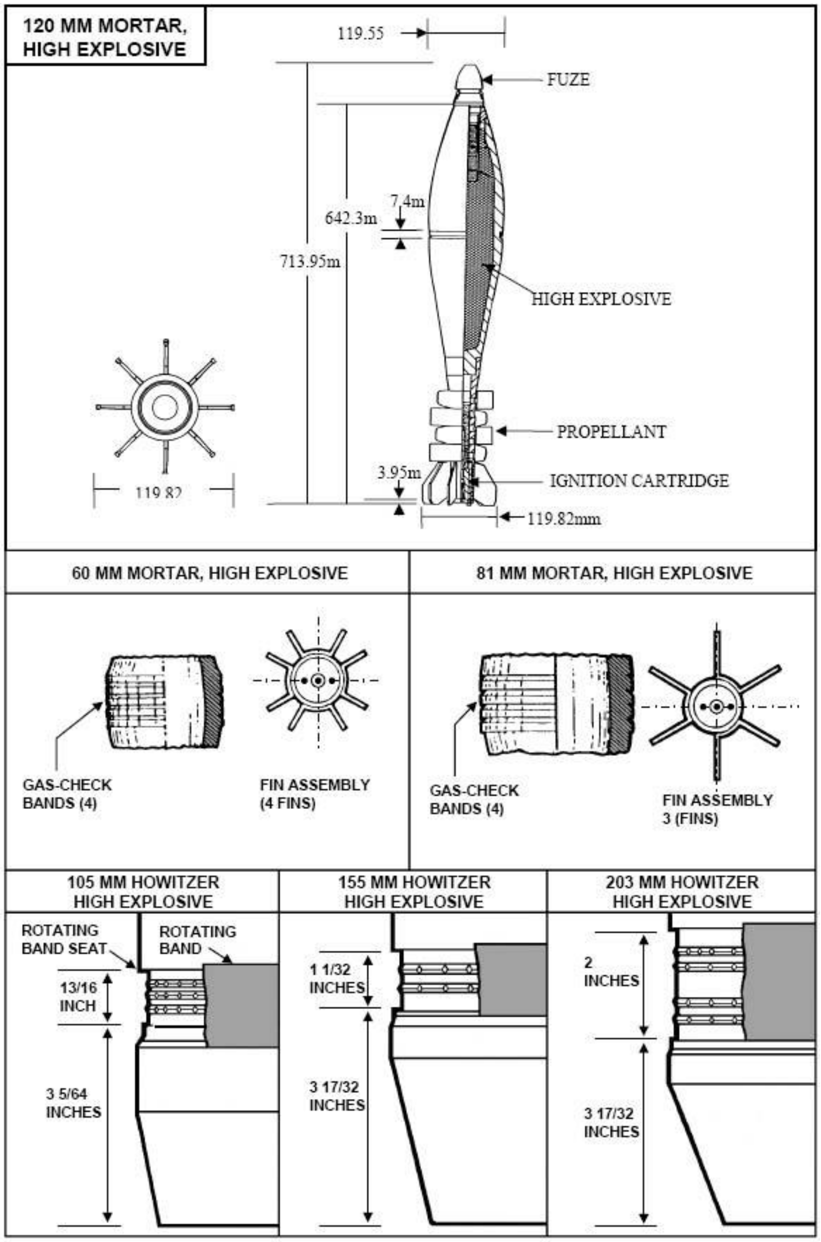


Figure B-10. Shell Fragment and Tail Fin Identification of US Ammunition

B-8. Artillery Counterfire Information Form

a. The information obtained from a crater should be forwarded by the most rapid available means in the format of DA Form 2185-R (Figure B-11 page B-11). The artillery counterfire information form standardizes reporting procedures and complies with North Atlantic Treaty Organization Standardization Agreement 2008 and Quadripartite Standardization Agreement 503. No matter how little information has been obtained, do not hesitate to forward the information. Fragmentary or incomplete information (a radio or telephone report) is often of value in supplementing or confirming existing information. This radio or telephone report may be followed by a written report on DA Form 2185-R.

b. Any usable fragments obtained from crater analysis should be tagged and sent to the intelligence section. As a minimum, the tag should include the following information:

(1) Location of the crater.

(2) Direction to the hostile weapon.

(3) Date-time group of the shelling.

c. The artillery intelligence section forwards the information contained in a SHELREP to the TPC or counterfire officer at the designated counterfire headquarters as appropriate. The TPC utilizes the SHELREP in the AFATDS to input the report or plots the location of the crater and a line representing the direction measured to the weapon on a SHELREP overlay. The TPC compares the information with that received from other sources and tries to locate enemy weapons from the intersections of direction lines to weapons of the same caliber. The AFATDS can be set to develop a target when 3 or more rays intersect.

ARTILLERY COUNTERFIRE INFORMATION

(For use of this form, see FM 6-121; the proponent agency is TRADOC.)

RECEIVED BY	FROM	TIME	NUMBER

SECTION I – BOMBER, SHELREP, MORTREP, OR ROCKREP (Cross out items not applicable.)

UNIT OF ORIGIN (Current call sign address group or code name)	POSITION OF OBSERVER (Encode if HQ or important OP or if Column F gives info on location)	DIRECTION (Grid bearing of FLASH, SOUND, or GROOVE of SHELL [state which] in mils unless otherwise stated). (Omit for aircraft)	TIME FROM	TIME TO	AREA BOMBED, SHELLED, OR MORTARED (Grid ref [in clear] or grid bearing to impact in mils and distance from observer in meters [encoded]) (Dimension of the area in meters) by (the radius) or (length and width)	NUMBER AND NATURE OF GUNS (Mortars, rocket launchers, aircraft or other methods of delivery)	NATURE OF FIRE (Adjustment, fire for effect, or harassing) (May be omitted for aircraft)	NUMBER, TYPE, AND CALIBER (State whether measured or assumed) OF SHELLS, ROCKETS (or MISSILES), AND BOMBS measured	TIME OF FLASH-TO-BANG (Omit for aircraft)	DAMAGE (Encode if required)
F22 A	NA B	4810m C	0545 D	0547 E	392841 F	4 ARTY G	H H	8 HE 122 I	NA J	NA K

	SECTION II – LOCATION REPORT						SECTION III – COUNTERFIRE ACTION		
REMARKS	SERIAL NUMBER (Each location that is produced by a locating unit is given a serial number)	TARGET NUMBER (If the weapon or activity has previously been given a target number, it will be entered here)	POSITON OF TARGET (The grid reference or grid bearing and distance of the located weapon or activity)	ACCURACY (The accuracy to which the weapon was located. CEP in meters and the means of location if possible)	TIME OF LOCATION (Actual time the location was made)	TARGET DESCRIPTION (Dimensions if possible): 1. Radius of target 2. Target length and width in meters	TIME FIRED (Against hostile target)	FIRED BY	NUMBER OF ROUNDS, TYPE OF FUZE, AND PROJECTILES
L	M	N	P	Q	R	S	T	U	V

DA FORM 2185-R, 1 APR 90 (Conforms with STANAG 2008) Edition of 1 May 78 is obsolete

Figure B-11. Artillery Counterfire Information Form

B-9. Equipment

a. Three elements, direction, dimensions, and curvature must be measured for crater analysis.

b. The equipment used by the crater analysis team should consist of the following items:

(1) Aiming circle (M2 compass), stakes, and communications wire to obtain the direction from the crater to the weapon that fired the projectile.

(2) A curvature template (Figure B-12) to measure the curvature of the fragment to determine the caliber of the shell. The template can be constructed of heavy cardboard, acetate, wood, or other appropriate material.

(3) Defense Intelligence Agency Projectile Fragment Identification Guide for measuring fragment dimensions (DST-1160-G-029-85, with Change 1, dated 27 Jan 89).

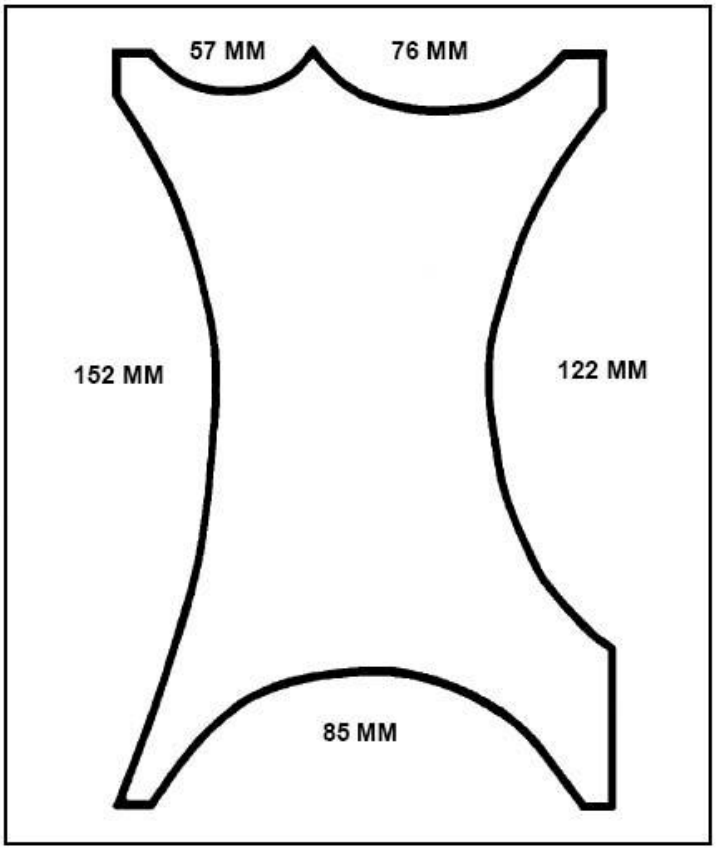
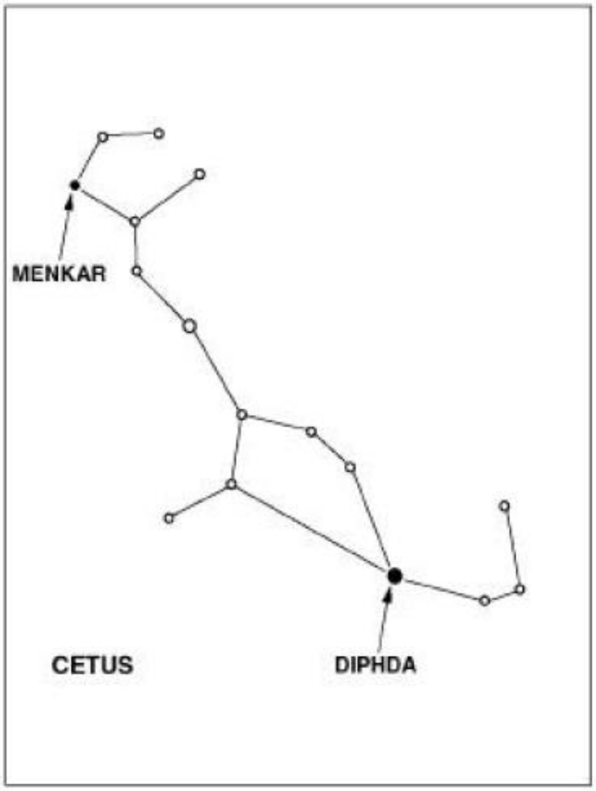


Figure B-12. Curvature Template

APPENDIX C. STAR CARDS

Constellation	Star Name and Number	Magnitude	Card
Andromeda	Alpheratz 1	2.1	9
Aquila	Altair 66	0.9	6
Aries	Hamal 11	2.2	7
Auriga	Capella 17	0.2	4
Bootes	Arcturus 51	0.2	2
Canis Major	Sirius 25	-1.6	5
	Adhara 26	1.6	5
	Wezen 27	2.0	5
Canis Minor	Procyon 29	0.5	5
Carina	Canopus 23	0.9	18
	Avior 32	1.7	18
	Miaplacidus 34	1.8	18
Cassiopeia	Schedar 5	2.3	17
	Caph 2	2.4	17
	Ruchbah 8	2.8	17
	Gamma Cassiopeia 7	1.6-2.8	17
Centaurus	Rigel Kentaurus 52	0.1	19
	Hadar 49	0.9	19
	Menkent 50	2.3	19
Cetus	Diphda 6	2.2	1
	Menkar 13	2.8	1
Corona Borealis	Alphecca 55	2.3	2
Corvus	Gienah 41	2.8	8
Crux (Southern Cross)	Acrux 42	1.0	19
	Mimosa 44	1.5	19
	Gacrux 43	1.6	19
Cygnus	Deneb 68	1.3	6
Draco	Eltanin 62	2.4	17
Eridanus	Achernar 9	0.6	12
	Acamar 12	3.4	12
Gemini	Pollux 30	1.2	4
	Castor 28	1.6	4
	Alhena 24	1.9	4
Grus	Al Nair 71	2.2	10
Hydra	Alphard 35	2.2	8
Hydrus	Beta Hydri 3	2.9	13

Constellation	Star Name and Number	Magnitude	Card
Leo	Regulus 36	1.3	14
	Denebola 39	2.2	14
Libra	Zebenelgenubi 53	2.9	15
Lyra	Vega 64	0.1	6
Octans	Nu 69	3.7	13
Ophiuchus	Rasalhague 61	2.1	15
	Sabik 59	2.6	15
Orion	Rigel 16	0.3	5
	Betelgeuse 22	0.1	5
	Bellatrix 18	1.7	5
	Alnilam 20	1.7	5
	Alnitak 21	2.0	5
Pavo	Peacock 67	2.1	11
Pegasus	Enif 70	2.5	9
	Markab 73	2.6	9
Perseus	Mirfak 14	1.9	7
Phoenix	Ankaa 4	2.4	10,12
Piscis Austrinus	Fomalhaut 72	1.3	10
Sagittarius	Kaus Ausralis 63	1.9	3
	Nunki 65	2.1	3
Scorpius	Antares 57	1.2	3,15
	Scaula 60	1.7	3
	Dschubba 56	2.5	3,15
Taurus	Aldebaran 15	1.1	4,7
	El Nath 19	1.8	4
Triangulum Australe	Atria 58	1.9	13
Ursa Major	Alioth 45	1.7	16
	Alkaid 48	1.9	16
	Dubhe 38	1.9	16
	Mizar 46	2.4	16
	Merak 37	2.4	16
	Phecda 40	2.5	16
Ursa Minor	Polaris 10	2.1	16,17
	Kochab 54	2.2	16,17
Vela	Gamma Velorum 31	1.9	18
	Suhail 33	2.2	18
Virgo	Spica 47	1.2	14



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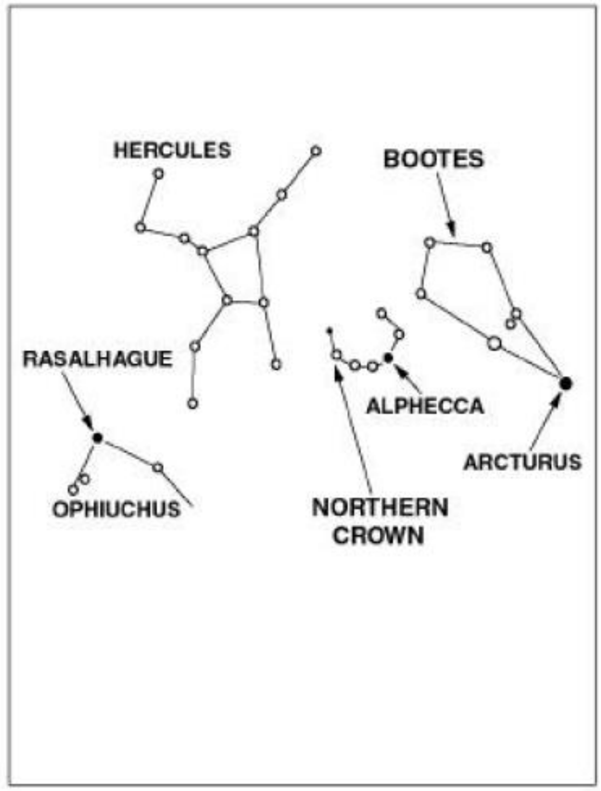

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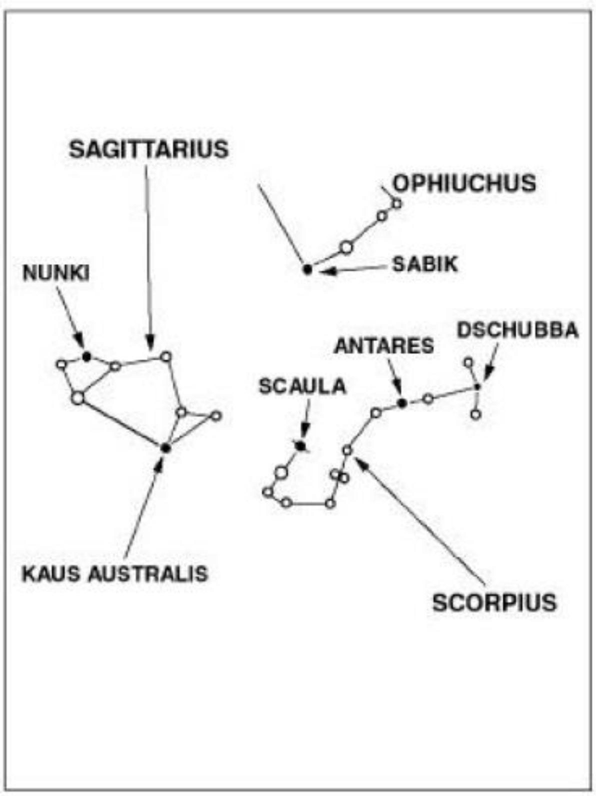

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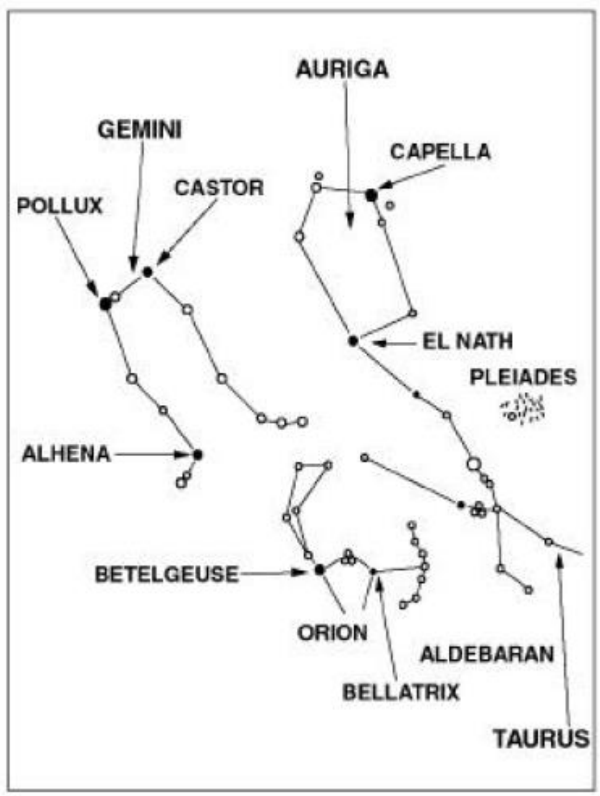

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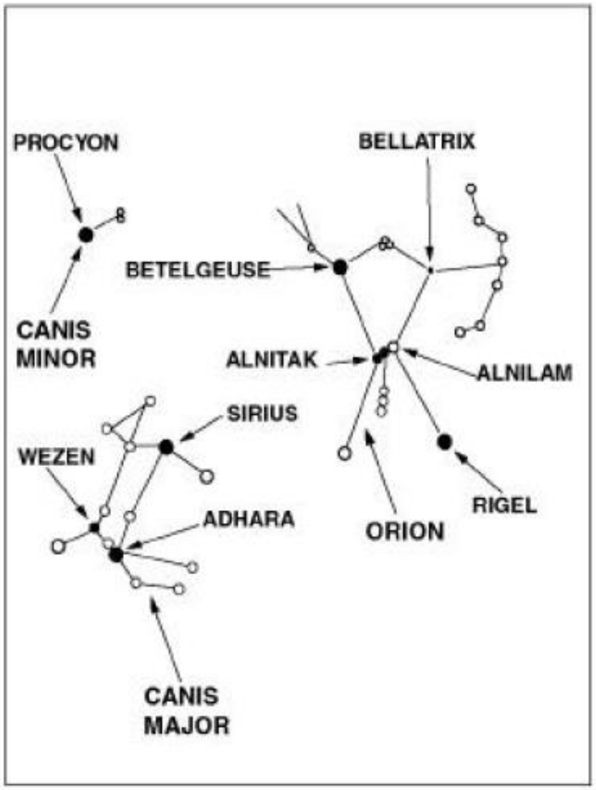

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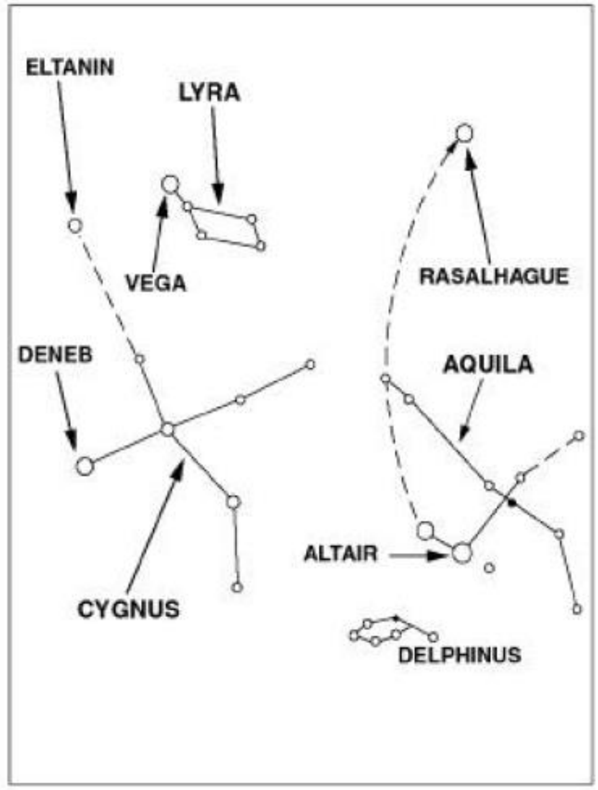

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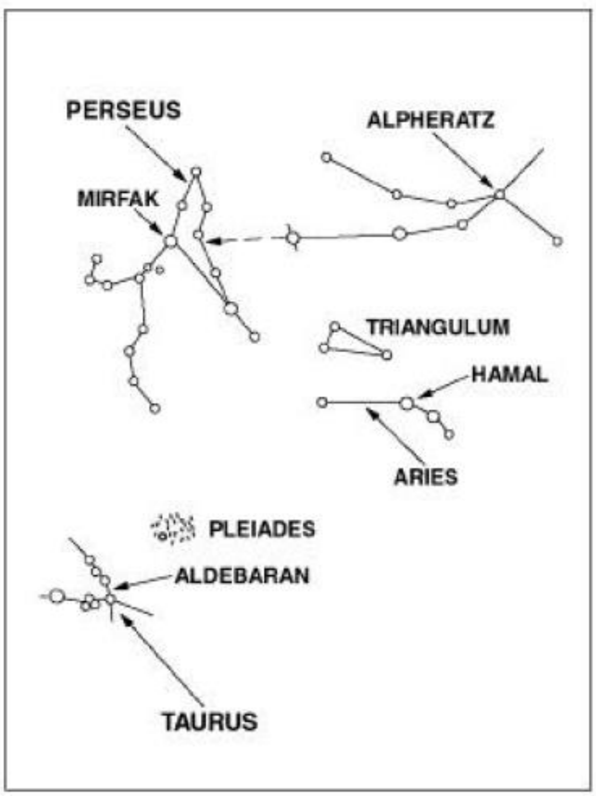

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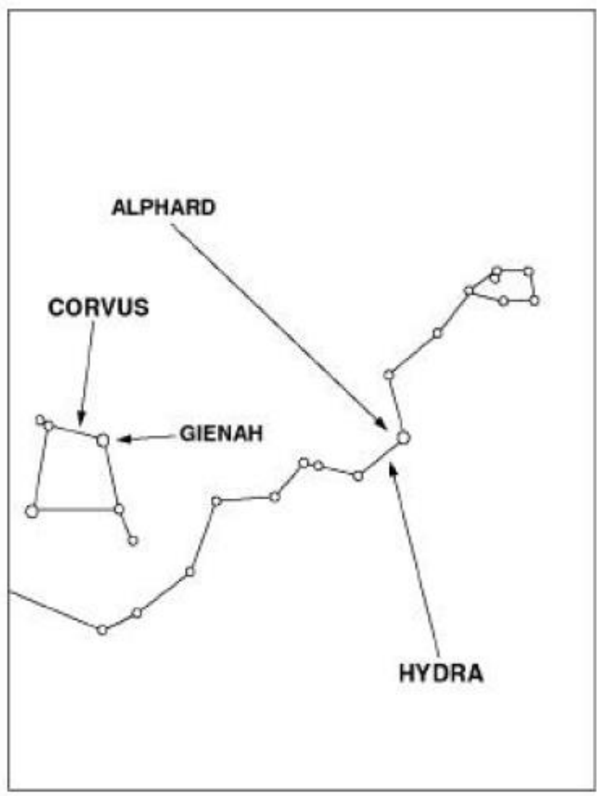

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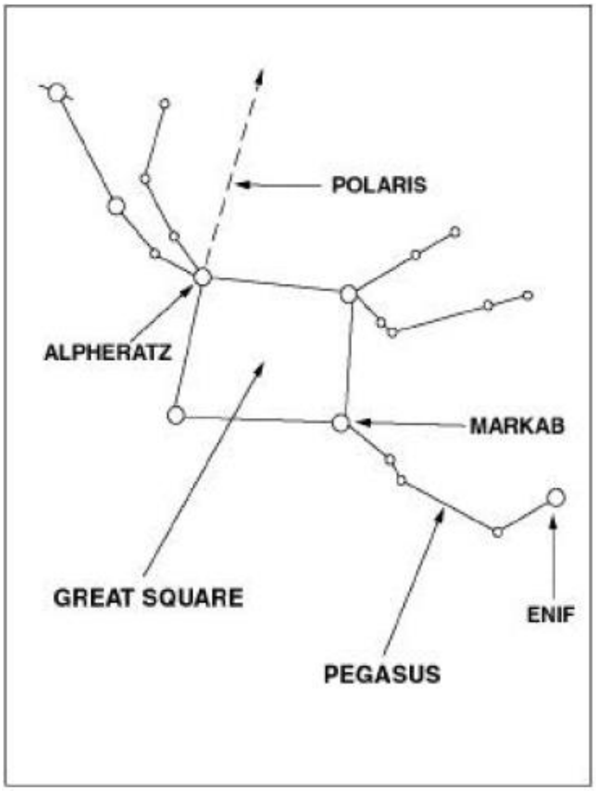

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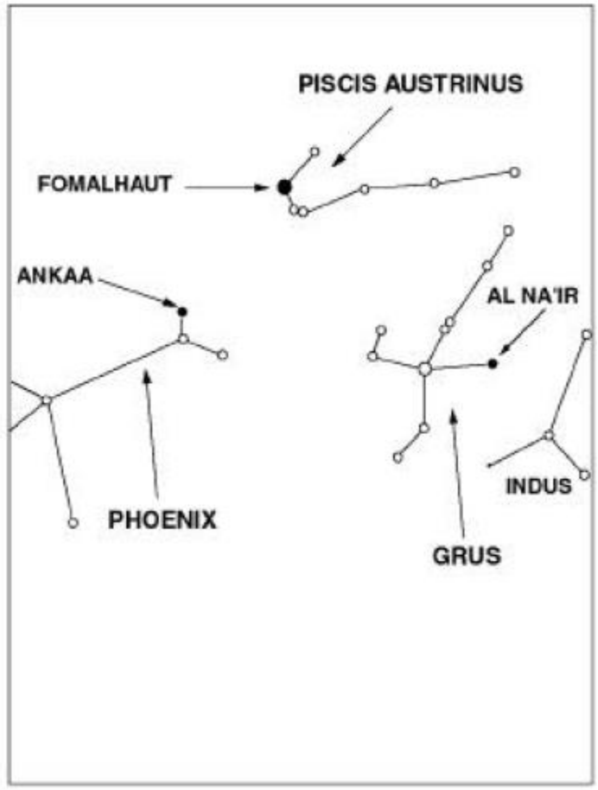

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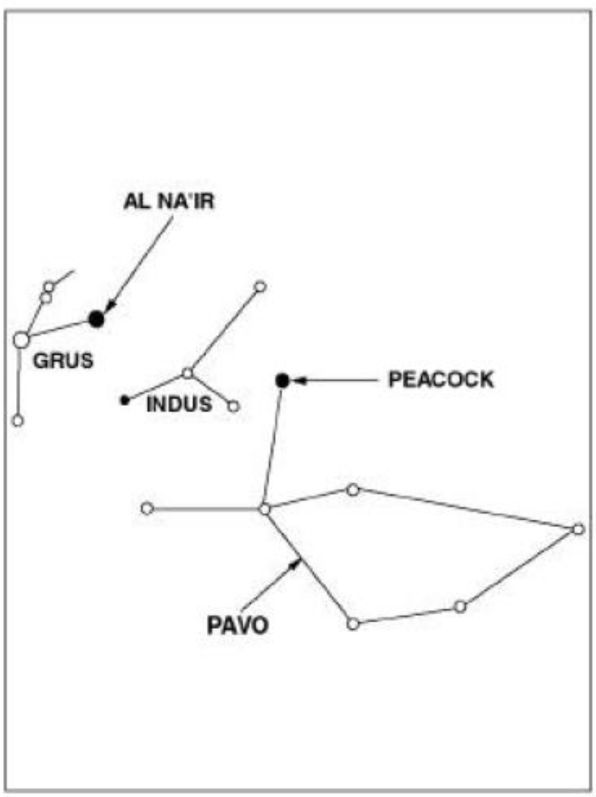

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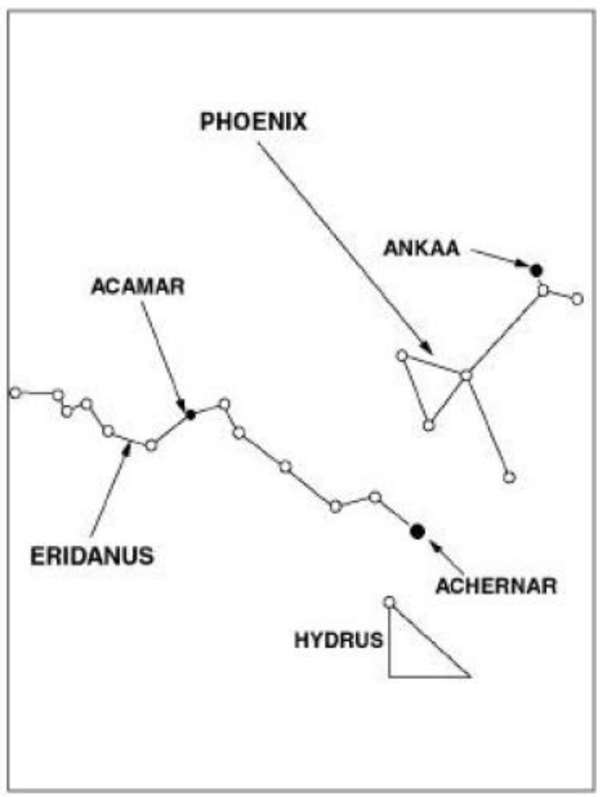

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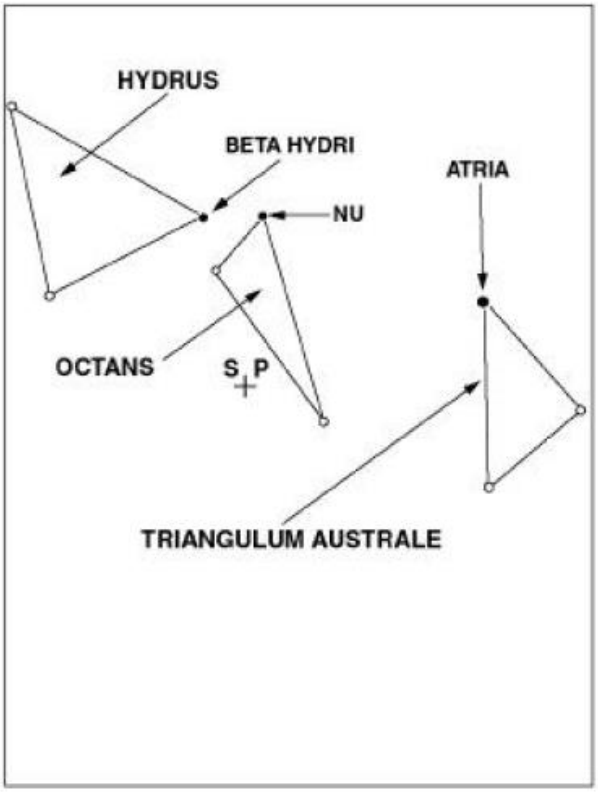

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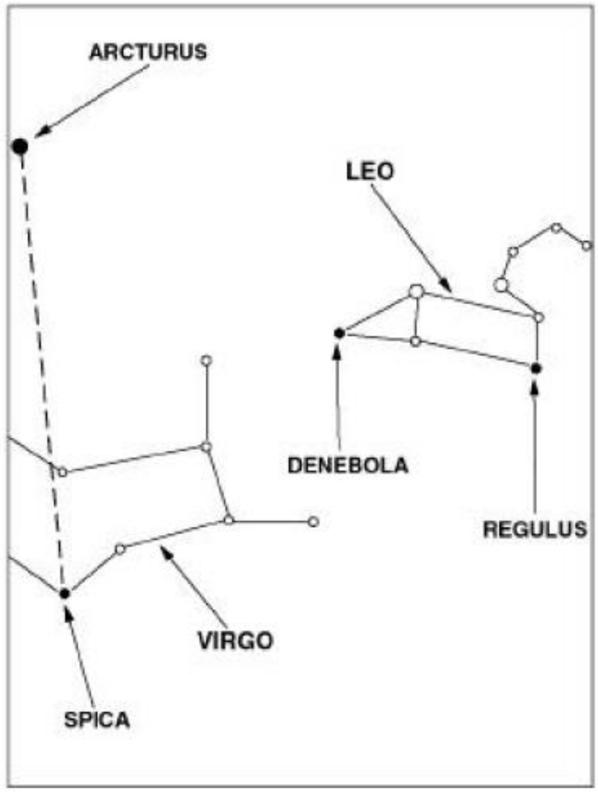

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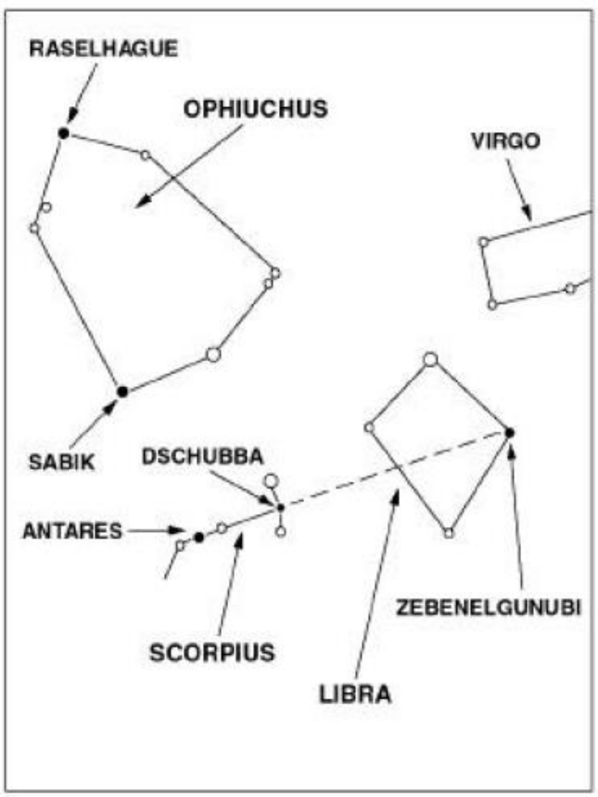

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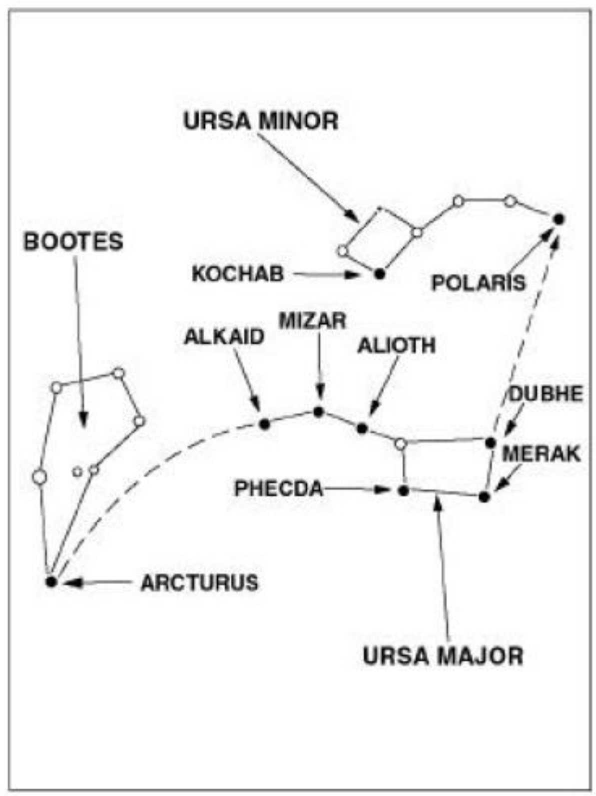

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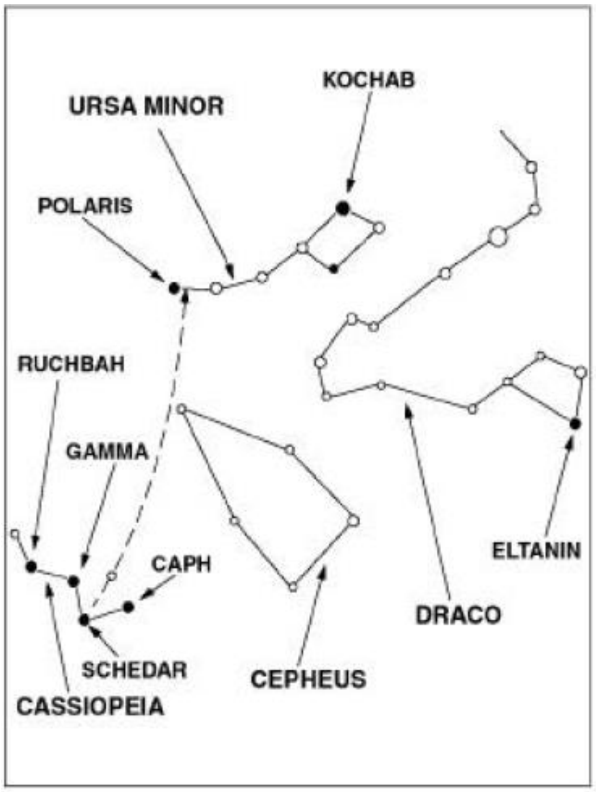

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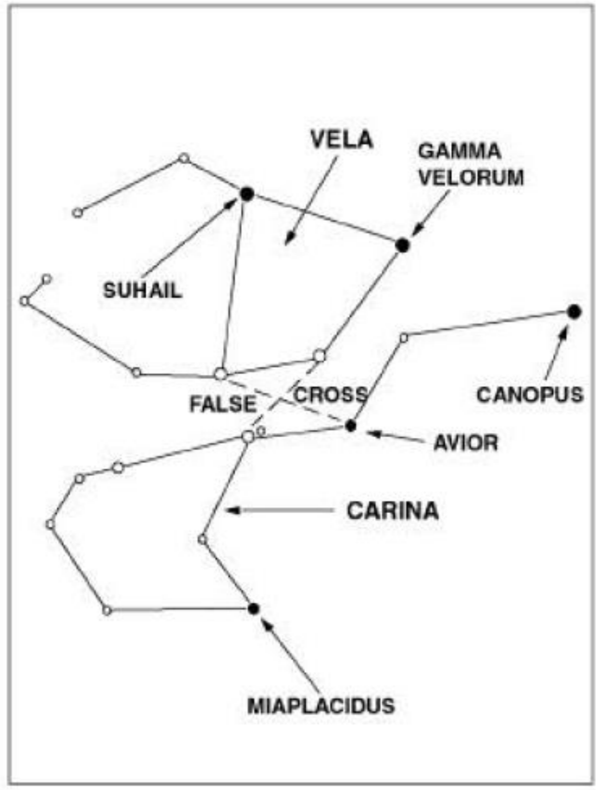

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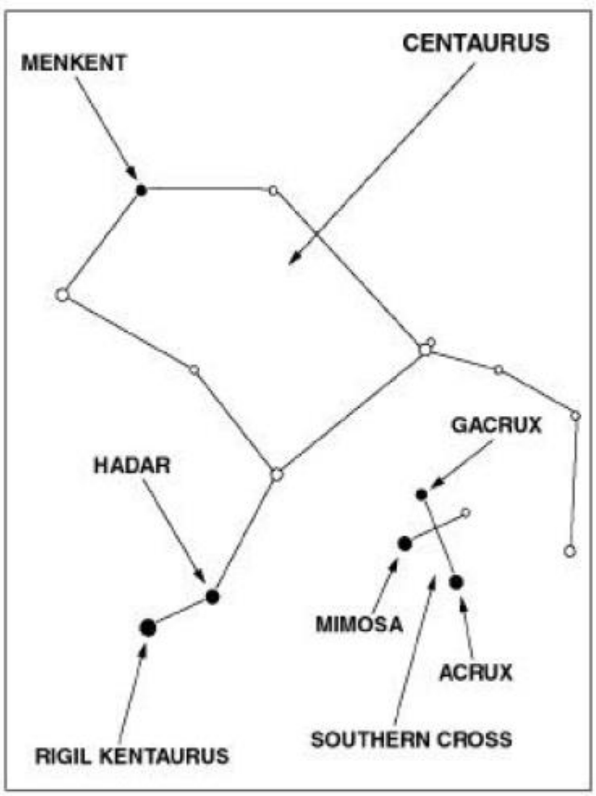


CARD 19

APPENDIX D. TIME ZONES, TIME SIGNALS, OCTANTS, AND REGIONS

D-1. General

To establish a common time and location, MET messages are reported in Greenwich Mean Time while locations are prefaced with an octant of the globe code. Figure D-1 is a world map divided into time zones, global octants, and climatic regions.

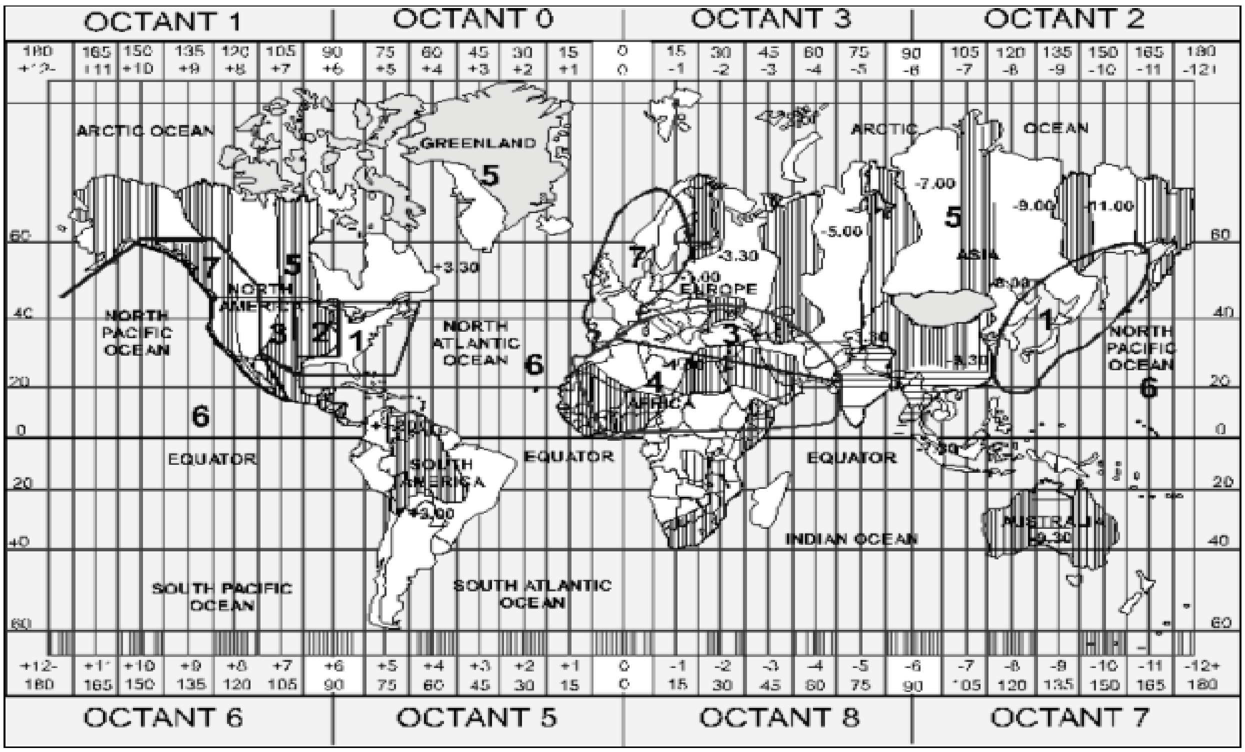


Figure D-1 Time Zones, Octants, and Regions

D-2. Time Zones

a. Time is calculated from the Greenwich meridian. The middle of the zero time zone passes through Greenwich with its east and west limits 7° 30’ on each side. Each 15-degree zone east and west of the initial zone represents 1 hour of time. The number of hours that must be added to or subtracted from local standard time to give GMT is indicated for each zone. Political boundaries in the various countries have caused modifications of the time zones. The vertical lines and clear sections are used to show which zones these divisions belong. Where a half-hour difference is legal, horizontal lines are used. Where no zone system has yet been adopted, the area is represented by small dots. Where no legal time has been established, the larger dots are used. Variations from zone time are given in hours and minutes. Enter the map with the section location and extract the time correction.

b. For selected countries listed alphabetically,(Figure D-2) the local standard time offset from Greenwich Coordinated Universal Time is given with daylight savings time where observed. These offsets can be used to convert a Coordinated Universal Time time to a local time. To determine Greenwich Mean Time from local time, a time zone correction is needed. Determine time zone corrections by changing the sign of the offset.

Country	Local Standard Time Offset
Afganistan	+4.5 hours
Albania	1 hour (Local summer +2 hours)
Algeria	+1 hour (Local summer+2 hours)
American Samoa	-11 hour
Andorra	+1 hour (Local summer+2 hours)
Angola	+1 hour
Anguilla	-4 hours
Antarctica	-2 hours (Local summer) -3 hours
Antigua	-4 hours
Argentina	-3 hours
Argentina Western Providence	-4 hours
Armenia	+4 hours (Local summer +5 hours)
Aruba	-4 hours
Ascension Island	0 hours
Australia NorthernTerritory	+9.5 hours
Australia Lord Howe Island	+10.5 hours (Local summer +11 hours)
Australia New South Wales	+10 hours (Local summer +11 hours)
Australia Queensland	+10 hours
Australia Victoria	+10 hours (Local summer +11 hours)
Australia Australian Captial Territory	+10 hours (Local summer +11 hours)
Austrialia South	+9.5 hours (Local summer +10.5 hours)
Australia Tasmania	+10 hours (Local summer +11 hours
Australia Western	+8 hours
Austria	+1 hour (Local summer +2 hours)
Azerbaijan	+3 hours
Azores	-1 hour (Local summer 0 hours)
Bahamas	-5 hours (Local summer -4 hours)
Bahrain	+3 hours
Balearic Islands	+1 hour (Local summer +2 hours)
Bangladesh	+6 hours
Barbados	-4 hours
Belarus	+2 hours (Local summer +3 hours)
Belgium	+1hour (Local summer+2 hours)
Belize	-6 hours
Benin	+1 hour
Bermuda	-4 hours (Local summer -3 hours)
Bhutan	+6 hours
Bolivia	4 hours (Local summer -3 hours)
Bonaire	-4 hours
Bosnia Herzegovian	+1 hour (Local summer +2 hours)
Botswana	+2 hours
Brazil Acre	-4 hours (Local summer -5 hours)
Brazil Atlantic Islands	-1 hour (Local summer -2 hours)
Brazil East	-3 hours (Local summer -1 hour)
Brazil West	-4 hours (Local summer-3 hours)
British Virgin Islands	-4 hours
Brunei	+8 hours
Bulgaria	+2 hours (Local summer +3 hours)
Burkina Faso	0 hours
Burundi	+2 hours
Cambodia	+7 hours
Cameroon	+1 hours
Canada Central	-6 hours (Local summer -5 hours)
Canada Eastern	-5 hours (Local summer -4 hours)
Canada Mountain	-7 hours (Local summer -6 hours)
Canada Yukon and Pacific	-8 hours (Local summer-7 hours)
Canada Atlantic	-4 hours (Local summer-3 hours)
Canada Newfoundland	-3.5 hours (Local summer -2.5 hours)

Figure D-2 Time Zone

Country	Local Standard Time Offset
Canary Islands	0 hours (Local summer +1 hour)
Canton Enderbury Islands	-11 hours
Cape Verde	-1 hour
Caroline Island	+11 hours
Cayman Islands	-5 hours
Central African Republic	+1 hour
Chad	+1 hour
Channel Islands	0 hours (Local summer +1 hour)
Chatham Islands	+12.75 hours (Local summer +13.75 hours)
Chile	-4 hours (Local summer -3 hours)
China People's Republic	+8 hours
Christmas Islands	-10 hours
Colombia	-5 hours
Congo	+1 hour
Cook Islands	-10 hours
Costa Rica	-6 hours
Cote d'Ivoire	0 hours
Croatia	+1 hour (Local summer +2 hours)
Cuba	-5 hours (Local summer-4 hours)
Curacao	-4 hours
Cyprus	+2 hours (Local summer +3 hours)
Czech Republic	+1 hour (Local summer +2 hours)
Dahomey	+1 hour
Denmark	+1 hour (Local summer +2 hours)
Djibouti	+3 hours
Dominica	-4 hours
Dominican Republic	-4 hours
Easter Island	-6 hours (Local summer -5 hours)
Ecuador	-5 hours
Egypt	+2 hours (Local summer +3 hours)
El Salvador	-6 hours
England	0 hours (Local summer +1 hour)
Equitorial Guinea	+1 hour
Eritrea	+3 hours
Estonia	+2 hours (Local summer +3 hours)
Ethiopia	+3 hours
Falkland Islands	-4 hours (Local summer -3 hours)
Faroe Islands	0 hours (Local summer +1 hour) +1 hour
Fiji	+12 hours
Finland	+2 hours (Local summer +3 hours)
France	+1 hour (Local summer +2 hours)
French Guiana	-3 hours
French Polynesia	-10 hours
Gabon	+1 hour
Galapagos Islands	-5 hours
Gambia	0 hours
Gambier Island	-9 hours
Georgia	+4 hours
Germany	+1 hour (Local summer +2 hours)
Ghana	0 hours
Gibraltar	+1 hour (Local summer +2 hours)
Greece	+2 hours (Local summer +3 hours)
Greenland	-3 hours (Local summer -2 hours)
Greenland Thule	-4 hours (Local summer -3 hours)
Greenland Scoresbysund	-1 hour (Local summer 0 hours)
Grenada	-4 hours
Grenadines	-4 hours
Guadeloupe	-4 hours
Guam	+10 hours
Guatemala	-6 hours
Guinea	0 hours
Guinea Bissau	-1 hour(Local summer 0 hours)
Guyana	-3 hours
Haiti	-5 hours (Local summer -4 hours)
Hondurast	-6 hours
Hong Kong	+8 hours
Hungary	+1 hour (Local summer +2 hours)

Figure D-2 Time Zone (Continued)

Country	Local Standard Time Offset
Iceland	0 hours
India	+5.5 hours
Indonesia Central	+8 hours
Indonesia East	+9 hours
Indonesia West	+7 hours
Iran	+3.5 hours
Iraq	+3 hours (Local summer +4 hours)
Ireland, Republic of	0 hours (Local summer +1 hour)
Israel	+2 hours (Local summer +3 hours)
Italy	+1 hour (Local summer +2 hours)
Jamaica	-5 hours
Japan	+9 hours
Johnston Island	-10 hours
Jordan	+2 hours (Local summer +3 hours)
Kazakhstan	+6 hours (Local summer +7 hours)
Kenya	+3 hours
Kiribati	+12 hours
Korea, Dem Republic of	+9 hours
Korea, Republic of	+9 hours
Kusaie	+12 hours
Kuwait	+3 hours
Kwajalein	-12 hours
Kyrgyzstan	+5 hours (Local summer +6 hours)
Laos	+7 hours
Latvia	+2 hours (Local summer +3 hours)
Lebanon	+2 hours (Local summer +3 hours
Leeward Islands	-4 hours
Lesotho	+2 hours
Liberia	0 hours
Libya	+2 hours
Lithuania	+2 hours (Local summer +3 hours)
Luxembourg	+1 hours (Local summer +2 hours)
Macedonia	+1 hour (Local summer +2 hours)
Madagascar	+3 hours
Madeira	0 hours (Local summer +1 hour)
Malawi	+2 hours
Malaysia	+8 hours
Maldives	+5 hours
Mali	0 hours
Mallorcia Islands	+1 hour (Local summer +2 hours)
Malta	+1 hour (Local summer +2 hours)
Mariana Islands	+10 hours
Marquesas Islands	-9.5 hours
Marshall Islands	+12 hours
Martinique	-4 hours
Mauritania	0 hours
Mauritius	+4 hours
Mayotte	+3 hours
Melilla	+1 hour (Local summer +2 hours)
Mexico	-6 hours
Mexico Baja California Norte	-8 hours (Local summer -7 hours)
Mexico Nayarit	-7 hours
Mexico Sinaloa	-7 hours
Mexico Sonora	-7 hours
Midway Islands	-11 hours
Moldova	+2 hours (Local summer +3 hours)
Moldovian Rep Pridnestrovye	+2 hours (Local summer +3 hours)
Monaco	+1 hour (Local summer +2 hours)
Mongolia	+8 hours
Morocco	0 hours
Mozambique	+2 hours
Myanmarr	+6.5 hours
Namibia	+1 hour (Local summer +2 hours)
Nauru, Republic of	+12 hours
Nepal	+5.75 hours
Netherlands	+1 hour (Local summer +2 hours
Netherlands Antilles	-4 hours
Nevis Montserrat	-4 hours

Figure D-2 Time Zone (Continued)

Country	Local Standard Time Offset
New Caledonia	+11 hours
New Hebrides	+11hours
New Zealand	+12 hours (Local summer +13 hours)
Nicaragua	-6 hours (Local summer -5 hours)
Niger	+1 hour
Nigeria	+1 hour
Niue Island	-11 hours
Norfolk Island	+11.5 hours
Northern Ireland	0 hours (Local summer +1 hour)
Northern Mariana Islands	+10 hours
Norway	+1 hour (Local summer +2 hours)
Oman	+4 hours
Pakistan	+5 hours
Palau	+9 hours
Panama	-5 hours
Papua New Guinea	+10 hours
Paraguay	-4 hours (Local summer -3 hours)
Peru	-5 hours
Phillippines	+8 hours
Pingelap	+12 hours
Poland	+1 hour (Local summer +2 hours)
Ponape Island	+11 hours
Portugal	+1 hour (Local summer +2 hours)
Principe Island	0 hours
Puerto Rico	-4 hours
Qatar	+3 hours
Reunion	+4 hours
Romania	+2 hours (Local summer +3 hours)
Russian Federation zone one	+2 hours (Local summer +3 hours)
Russian Federation zone two	+4 hours (Local summer +5 hours)
Russian Federation zone three	+4 hours (Local summer +5 hours)
Russian Federation zone four	+5 hours (Local summer +6 hours)
Russian Federation zone five	+6 hours (Local summer +7 hours)
Russian Federation zone six	+7 hours (Local summer +8 hours)
Russian Federation zone seven	+8 hours (Local summer +9 hours)
Russian Federation zone eight	+9 hours (Local summer +10 hours)
Russian Federation zone nine	+10 hours (Local summer +11 hours)
Russian Federation zone ten	+11 hours (Local summer +12 hours
Russian Federation zone eleven	+12 hours (Local summer +13 hours)
Rwanda	+2 hours
Saba	-4 hours
Samoa	-11 hours
San Marino	+1 hour (Local summer +2 hours)
Sao Tome and Principe	0 hours
Saudi Arabia	+3 hours
Scotland	0 hours (Local summer +1 hour)
Senegal	0 hour
Seychelles	+4 hours
Sierra Leone	0 hours
Singapore	+8 hours
Slovakia	+1 hour (Local summer +2 hours)
Slovenia	+1 hour (Local summer +2 hours)
Society Islands	-10 hours
Solomon Islands	+11 hours
Somalia	+3 hours
South Africa	+2 hours
Spain	+1 hour (Local summer +2 hours)
Sri Lanka	+5.5 hours
St.Christopher	-4 hours
St. Croix	-4 hours
St. Helena	0 hours
St. John	-4 hours
St Kitts Nevis	-4 hours
St. Lucia	-4 hours
St Maarten	-4 hours
St. Pierre and Miquelon	-3 hours (Local summer -2 hours)
St. Thomas	-4 hours
St. Vincent	-4 hours
	-4 hours

Figure D-2 Time Zone (Continued)

Country	Local Standard Time Offset
Sudan	+2 hours
Suriname	-3 hours
Swaziland	+2 hours
Sweden	+1 hour (Local summer +2 hours
Switzerland	+1 hour (Local summer +2 hours)
Syria	+2 hours (Local summer +3 hours)
Tahiti	-10 hours
Taiwan	+8 hours
Tajikistan	+6 hours
Tanzania	+3 hours
Thailand	+7 hours
Togo	0 hours
Tonga	+13 hours
Trinidad and Tobago	-4 hours
Tuamotu Island	-10 hours
Tubuai Islands	-10 hours
Tunisia	1 hour
Turkey	+2 hours (Local summer +3 hours)
Turkmenistan	+5 hours
Turks and Caicos Islands	-5 hours (Local summer -4 hours)
Tuvalu	+12 hours
Uganda	+3 hours
Ukraine	+2 hours (Local summer +3 hours)
United Arab Emirates	+4 hours
United Kingdom	0 hours (Local summer +1 hour)
USA Central	-6 hours (Local summer -5 hours)
USA Eastern	-5 hours (Local summer -4 hours)
USA Mountain	-7 hours (Local summer -6 hours
USA Arizona	-7 hours
USA Indiana East	-5 hours
USA Pacific	-8 hours (Local summer -7 hours)
USA Alaska	-9 hours (Local summer -8 hours)
USA Aleutian	-10 hours
USA Hawaii	-10 hours
Uruguay	-3 hours
Uzbekistan	+5 hours
Vanuatu	-+11 hours (Local summer +12 hours)
Vatican City	+1 hour (Local summer +2 hours)
Venezuela	-4 hours
Vietnam	+7 hours
Virgin Islands	-4 hours
Wake Island	+12 hours
Wales	0 hours (Local summer +1 hour)
Wallis and Futuna Islands	+12 hours
Windward Islands	-4 hours
Yemen	+3 hours
Yugoslavia	+1 hour (Local summer +2 hours)
Zaire Kasai	+2 hours
Zaire Kinshasa Mbandaka	+1 hour
Zaire Haut Zaire	+2 hours
Zaire Kivu	+2 hour
Zaire Shaba	+2 hours
Zambia	+2 hours
Zimbabwe	+2 hours

Figure D-2 Time Zone (Continued)

D-3. Radio Transmitting Stations for Time Signals

The following chart depicts stations for time signals.

Call Sign	Location and Position	Frequency (MHz)
BPV	Shanghai, China N 31° 12 E 121° 26'	5.0 10.0 15.0
CHU	Ottawa, Canada N 45° 18' W 75° 45'	3.330 7.335 14.670
HBG	Prangins, Switzerland N 46° 24' E 06° 15'	0.075
JJY	Koganie,Tokyo, Japan N 35° 42' E 139° 31'	2.5 5.0 10.0 15.0
LOL1	Buenos Aires, Argentina S 34° 27' W 58° 21'	5.0 10.0 15.0
MSF	Rugby, United Kingdom N 52° 22' W 01° 11'	2.5 5.0 10.0
VNG	Lyndhurst, Australia S 38° 00' E 145° 02'	4.5 7.5 12.0
WWV	Fort Collins, Colorado, USA N 40° 41' W 105° 02'	2.5 5.0 10.0 15.0 20.0
WWVH	Maui, Hawaii, USA N 20° 46' W 156° 28'	2.5 5.0 10.0 15.0
ZUO	Olifantsfontein, South Africa S 25° 58' E 28° 04'	5.0
ZUO	Johannesburg, South Africa S 26° 11' E 28° 04'	10.0

D-4. Global Octants

Global octants are indicated by bold N-S, E-W lines and octant identifications. Determine the section location on the map and extract the appropriate octant number.

E-5. Climatic Regions

The seven climatic regions of the Northern Hemisphere are indicated and identified by the large black numbers 1 through 7.

APPENDIX E. CONVERSION TABLES

F-1. Angular Measurement

	Full Circle	3/4 Circle	Half Circle	1/4 Circle
Mils	6400	4800	3200	1600
Degrees	360	270	180	90
Grads	400	300	200	100
Radians	2π	$\frac{3\pi}{2}$	π	$\frac{\pi}{2}$

Decimal Degrees to Mils	Mils = Degrees/0.05625
Decimal Degrees to Grads	Grads = Degrees/0.9
Decimal Degrees to Radians	Radians = Degrees x (exact) $\frac{\pi}{180}$ (Pi) Rads = Degrees x 0.174532777
Mils to Decimal Degrees	Degrees = Mils x 0.05625
Mils to Grads	Grads + Mils/16
Grads to Mils	Mils = Grads x 16
Grads to Decimal Degrees	Degrees = Grads x 0.9
Radians to Decimal Degrees	Degrees = Rads x $\frac{180}{\pi \text{ (Pi)}}$

Mils to Degrees, Minutes, Seconds

Step 1: Mils x 0.05625 = Decimal Degrees
Number of Seconds
Step 2: 60 x Number to Right of Decimal
= Decimal Minutes
Step 3: 60 x Number to Right of Decimal
= Seconds

Example: Convert 2198.876 Mils
Step 1: 2198.876 x 0.05625 = 123.686775°
Step 2: 60 x 0.686775 = 41.2065'

Step 3: 60 x 0.2065 = 12.39"
2198.876 Mils = 123° 41' 12.39"

Degrees, Minutes, Seconds to Mils

Step 1: (Minutes x 60) + Seconds =

Step 2: (Number of Seconds/3600) +
Degrees = Decimal Degrees
Step 3: Decimal Degrees/0.05625 = Mils

Example: Convert 123° 41' 12.39"
Step 1: (41' x 60) + 12.39" = 2472.39"
Step 2: (2472.39"/3600) + 123° =
123.686775°
Step 3: 123.686775/0.05625 = 2198.876 Mils
123° 41' 12.39" = 2198.876 Mils

Vertical Angle (Mils)
VA = Vertical Interval/Range in Km x 1.0186

F-2. Linear Measurement

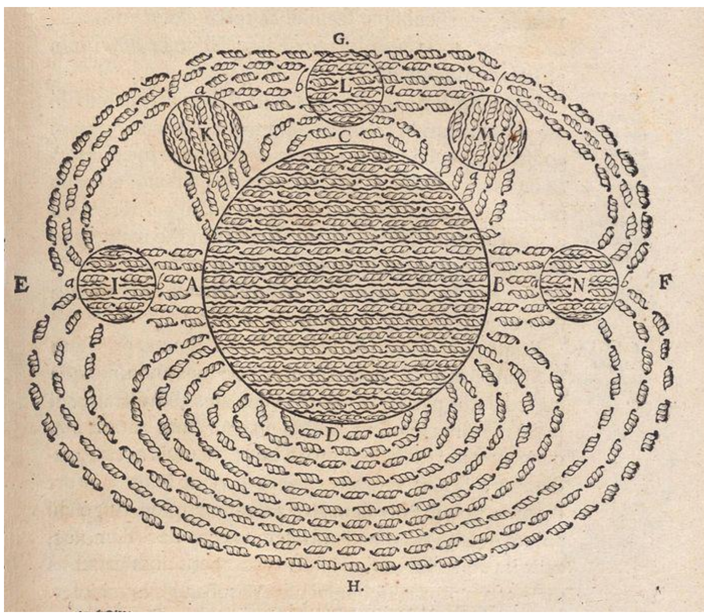
From	To	Equation
Meters	Feet (International)	FT = M/0.3048 exact
	Feet (US Survey)	FT = M/0.30480060960
	Feet (British Ordnance)	FT = M/0.304800756
	Feet (Indian old)	FT = M/0/30479842
	Feet (Survey of India)	FT = M/0.3047996
	Yards (International)	YDS = M x 1.093613
	Statute Miles	SM I = M/1609.344 exact
	Nautical Miles	NM I = M/1852 exact
Feet (International)	Meters	M = FT x 0.348 exact
	Nautical Miles	NM I = FT/6076.1033333
Feet (US Survey)	Meters	M = FT x 0.30480060960
	Meters	M = FT x 1200/3937 exact
	Statute Miles	SM I = FT/5280 exact
	Nautical Miles	NM I = FT/6076.1033333
Feet (Great Britain in Ordnance Survey)	Meters	M = FT x 0.304800756
*Feet (Indian Old)	Meters	M = FT x 0.30479842
Feet (Survey of India)	Meters	M = FT x 0.3047996
Statute Miles	Kilometers	KM = M I /0.6213712
	Statute Miles	M I = KM x 0.6213712

*Used by US and Great Britain for surveys in India and border nations

APPENDIX F. WORLD MAGNETIC MODEL (WMM) FIXED

SENSOR SECTION
TARGET ACQUISITION BRANCH, MARDET, FT SILL OK

MAGNETIC DECLINATION



1644 Depiction of the Earth’s Magnetic Field by Rene Descartes

MAGNETIC DECLINATION, GRID CONVERGENCE, GRID MAGNETIC ANGLE AND THEIR RELATIONSHIP IN A DECLINATION DIAGRAM

F-1. Introduction

a. Purpose**.** The purpose of this text is to provide basic understanding of how the three north orientations relate to each other and how they are used to develop information used by artillery personnel. From this, they should have the basic knowledge to create a declination diagram for any area of the world; further, they should be able to determine up to date Grid-Magnetic Angles and Declinations for orienting magnetic compasses to Grid North and orienting Meteorological Theodolites to True North.

b. Scope.

(1) This text discusses the relationship between the three north orientations normally used by artillerymen. It assumes that certain knowledge of Grids, Projections, computations, and other applications exist. The programs discussed in this text are not the only programs available for the development of the information discussed, but are the most widely accepted.

(2) Many of the subjects discussed in this text are discussed in more detail in other manuals, specifically MCTP 3-10E, *Artillery Operations*.

(3) This text will only discuss the relationship of the UTM Grid with True and Magnetic North. When the terms: Grid System, Grid Azimuth, Grid Convergence, etc., are used, the term Grid relates to the UTM Grid System.

F-2. North Orientations

a. True North**.**

(1) Definition**.** True North is the positive direction of an arc-line that is parallel to the Earth's rotational axis and is perpendicular to the equator at the equator. It is distinguished by any meridian of longitude in a direction toward the North Pole of the Earth. In other words, it is the direction from anywhere on the Earth to the North Pole along a meridian of longitude.

(2) Convergence**.** The meridians of longitude connect or converge at each pole at the Earth's rotational axis. The angle formed between any two meridians of longitude at the pole is called convergence of longitude or simply convergence (Figure G-1**)**.

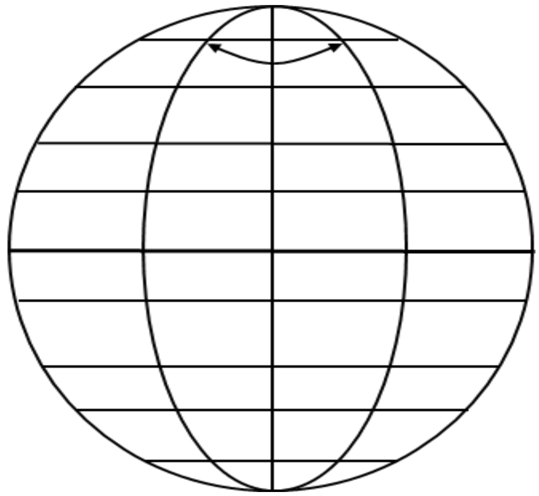


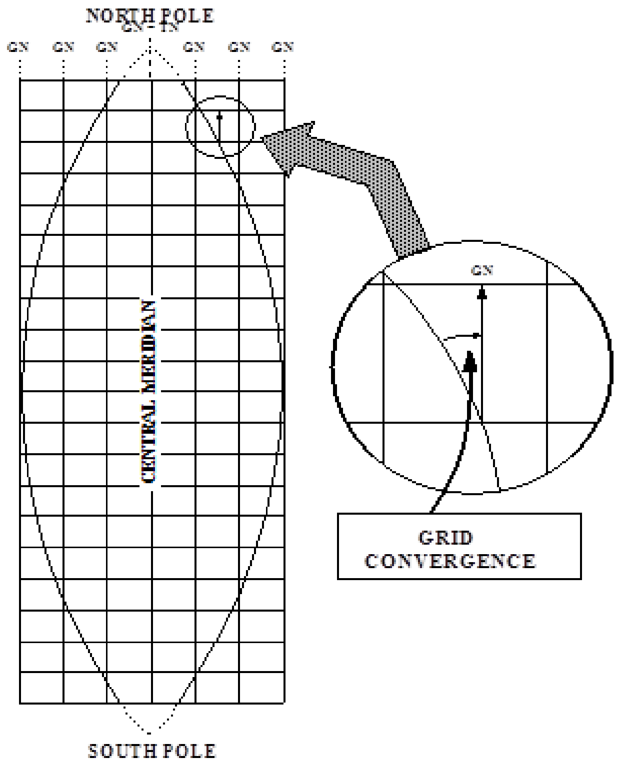
Figure F-1. Convergence

b. Grid North.

(1) Definition**.** Grid North is the direction of a line that is parallel to a specified meridian of a grid zone. For the UTM Grid System, Grid North is the direction of a line that is parallel to the Central Meridian of one of the 60 UTM Grid Zones.

(2) Grid Convergence**.** As an observer moves east or west from the Central Meridian of a UTM Grid Zone, the angle between the direction of Grid North and the observer's meridian of longitude increases. This angle is called the Grid Convergence. Basically, Grid Convergence is the angle from the convergence of True North and Grid North. At any point along the Central Meridian of a UTM Grid Zone, the Grid Convergence is zero (Figure F-2).

(3) Direction of Grid Convergence**.** In the northern hemisphere, Grid Convergence is considered negative east of the Central Meridian and positive west of the Central Meridian. In the southern hemisphere, Grid Convergence is considered positive east of the Central Meridian and negative west of the Central Meridian (Figure F- 3).



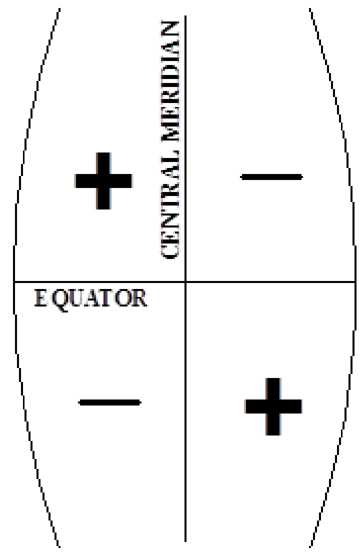


Figure F-2. Grid Convergence

Figure F-3. Direction of Grid Convergence.

c. Magnetic North.

(1) Definition. Magnetic North is the direction from the observer to the Earth's North Magnetic Pole.

(2) Declination**.** Declination is the angle formed by the convergence of the observer's meridian and a line in the direction of magnetic north and is measured East or West of True North.

(3) Grid Magnetic Angle**.** The G-M angle is that angle formed by the convergence of the direction of Grid North at the observer's meridian and a line in the direction of Magnetic North.

F-3. The Earth's Magnetic Field

a. Magnetic Field Composition. The Earth's magnetic field, as measured by a magnetic sensor on or above the Earth's surface, is actually a composite of several magnetic fields generated by a variety of sources (Figure F-4). These fields are superimposed on each other and through inductive processes interact with each other. The most important of these geomagnetic fields are:

(1) The Earth's main magnetic field generated in the conducting, fluid outer core;

(2) The crustal field generated in Earth's crust and upper mantle;

(3) The combined disturbance field from electrical currents flowing in the upper atmosphere and magnetosphere, which induce electrical currents in the sea and ground.

(4) The effects of solar wind flowing around and beyond Earth's magnetic shield.

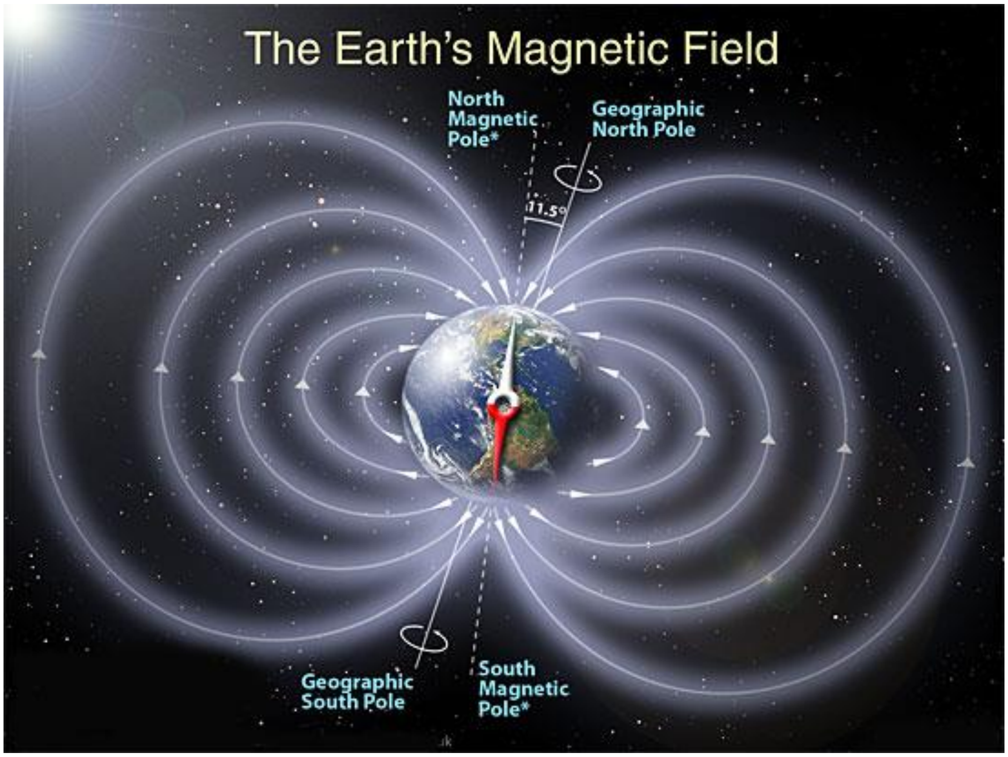


Figure F-4. Earth's Main Magnetic Field

b. Main Magnetic Field. The main magnetic field of the earth is generated by the dynamo action in the hot, liquid outer core. Above the Earth's surface, nearly dipolar field lines are oriented outwards in the southern and inwards in the northern hemisphere. The Earth's main magnetic field dominates the other generated magnetic fields, accounting for over 95% of the field strength at the Earth's surface. Secular variation is the slow change in time of the main magnetic field. The World Magnetic Model (WMM) software discussed later in this text represents only the main geomagnetic field (Figure F-4).

c. Observed Magnetic Field. The observed magnetic field is a sum of contributions of the main field (varying in both time and space), the crustal field (varies spatially, but considered constant in time for the time-scales of the WMM), and the disturbance fields (varying in space and rapidly in time Figure F-5).

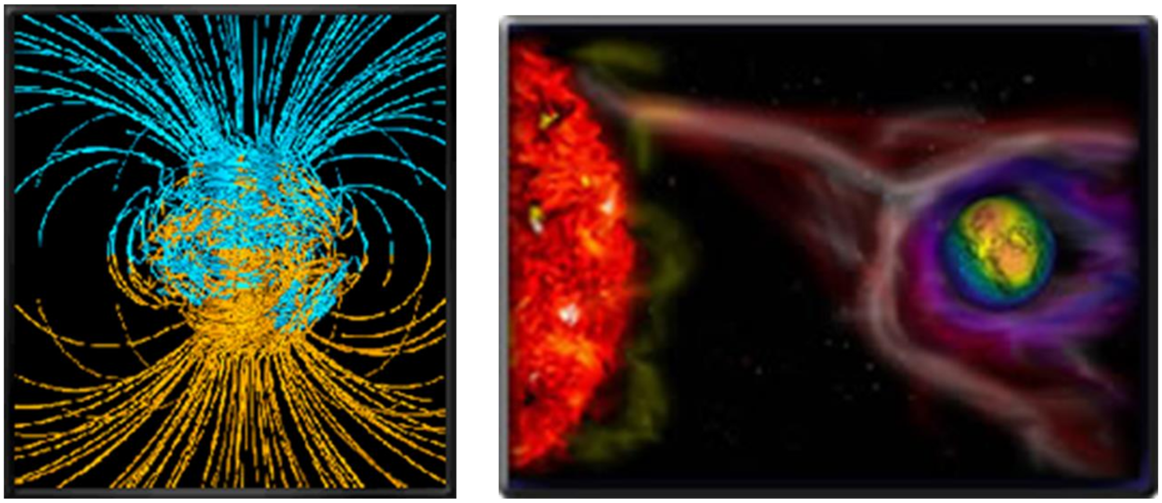


Figure F-5. Combination of Magnetic Fields Generating Observed Magnetic Field.

d. Solar Winds**.** The solar wind is a stream of charged particles, mostly high energy electrons and protons, ejected from the upper atmosphere of the sun. The stream of particles varies in temperature and speed with the passage of time. These particles are able to escape the sun's gravity, in part because of the high temperature of the corona, but also because of high kinetic energy that particles gain through a process that is not yet well understood. Figure F-6 illustrates the solar wind flowing around and beyond Earth's magnetic shield. This shield, the magnetosphere, is bullet-shaped, with a nose that lies about 64,000 kilometers (just over 39,768 miles) toward the Sun.

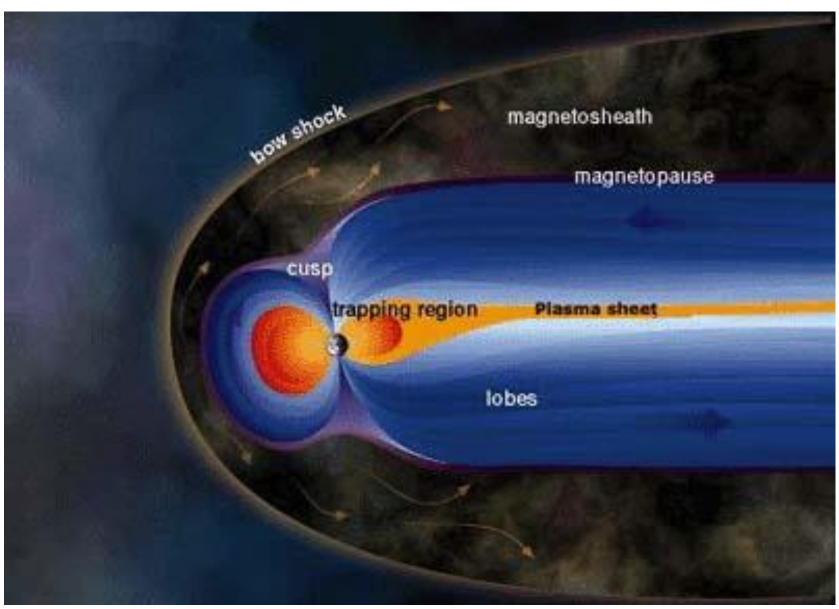


Figure F-6. Effects of Solar Winds

(1) Magnetosheath and Magnetopause. The outer layer of the Magnetosphere is the magnetosheath; it is a transition layer where interplanetary space meets Earth's "suit of armor." The magnetosheath is just outside the boundary of the magnetopause that lies toward the Sun at approximately 10 Earth radii (65,000 kilometers or 40,000

miles). The magnetopause marks the point where the Earth's geomagnetic field "pauses," or ceases for the most part, to extend further outward. Here the Earth's magnetic field is so weak that the pressure of the particles that escape Earth's gravity just equal the pressure within the solar wind.

(2) Effects of Solar Wind. As the solar wind bow shocks around our planet, it pushes Earth's magnetic field and "squashes" the field lines that face the Sun. At the same time, the solar wind plasma also exerts a drag, called a "tangential drag," that causes some of these field lines to be stretched into what appears to be a long tail, called the magnetotail. This "tail," which looks very much like a comet's tail, may extend to more than 6,400,000 kilometers (over 3,976,776 miles). It is divided into two lobes by a sheet of plasma, which ranges in temperature from 6,000 to 35,100 degrees kelvin (10,340 to 62,720 degrees Fahrenheit).

(a) Within the magnetosphere the hot solar wind plasma (ionized gas), which originated in the solar corona, mixes with the ionospheric plasma that moves up Earth's geomagnetic fields lines. This plasma is cool, in contrast to that of the solar wind. The movement of cool ionospheric plasma upward along these magnetic lines of force is usually termed the "polar wind" (just as the term "solar wind" describes the magnetic forces from the Sun).

(b) Over the polar regions of both the Sun and the Earth, the magnetic lines of force extend almost radially (from the center) outward into the solar wind and the magnetosphere, respectively. Because charged particles are not stopped from traveling along magnetic lines of force, they form magnetic natural channels for the outward flow of plasma from these bodies.

(c) While the magnetosphere deflects most of the Sun's plasma, some charged particles do leak through the magnetopause and become trapped. They also enter the magnetosphere through the funnel-like openings called "cusps" over the north and south magnetic poles. Then geomagnetic storms and sub storms occur. Such solar storms would have a devastating impact on our planet if we were not shielded by this magnetic field.

e. Geomagnetic Storms. A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a disturbance in space weather. Associated with solar coronal mass ejections (CMEs), coronal holes, or solar flares, a geomagnetic storm is caused by a solar wind shock wave which typically strikes the Earth's magnetic field 24 to 36 hours after the event. This only happens if the shock wave travels in a direction toward Earth. The solar wind pressure on the magnetosphere will increase or decrease depending on the Sun's activity. These solar wind pressure changes modify the electric currents in the ionosphere. Magnetic storms usually last 24 to 48 hours, but some may last for many days.

(1) Coronal Mass Ejections. A CME is an ejection of material from the solar corona (Figure F-7 page F-8). The ejected material is a plasma consisting primarily of

electrons and protons (in addition to small quantities of heavier elements such as helium, oxygen, and iron), plus the entraining coronal magnetic field. When the ejection reaches the Earth as an interplanetary CME, it may disrupt the Earth's magnetosphere, compressing it on the day side and extending the night-side tail. When the magnetosphere reconnects on the night side, it creates trillions of watts of power which is directed back toward the Earth's upper atmosphere. This process can cause particularly strong aurora also known as the Northern Lights, or aurora borealis (in the Northern Hemisphere), and the Southern Lights, or aurora australis (in the Southern Hemisphere). Coronal mass ejection events, along with solar flares, can disrupt radio transmissions, cause power outages (blackouts), and cause damage to satellites and electrical transmission lines.

(2) Solar Flares. A solar flare is a large explosion in the Sun's atmosphere that can release as much as 6×10^{25} joules of energy (Figure F-7). The term is also used to refer to similar phenomena in other stars, where the more accurate term stellar flare applies. Solar flares affect all layers of the solar atmosphere, heating plasma to tens of millions of kelvins and accelerating electrons, protons, and heavier ions to near the speed of light. They produce radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays. Most flares occur in active regions around sunspots, where intense magnetic fields penetrate the photosphere to link the corona to the solar interior. Flares are powered by the sudden (timescales of minutes to tens of minutes) release of magnetic energy stored in the corona. If a solar flare is exceptionally powerful, it can cause coronal mass ejections. X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications.

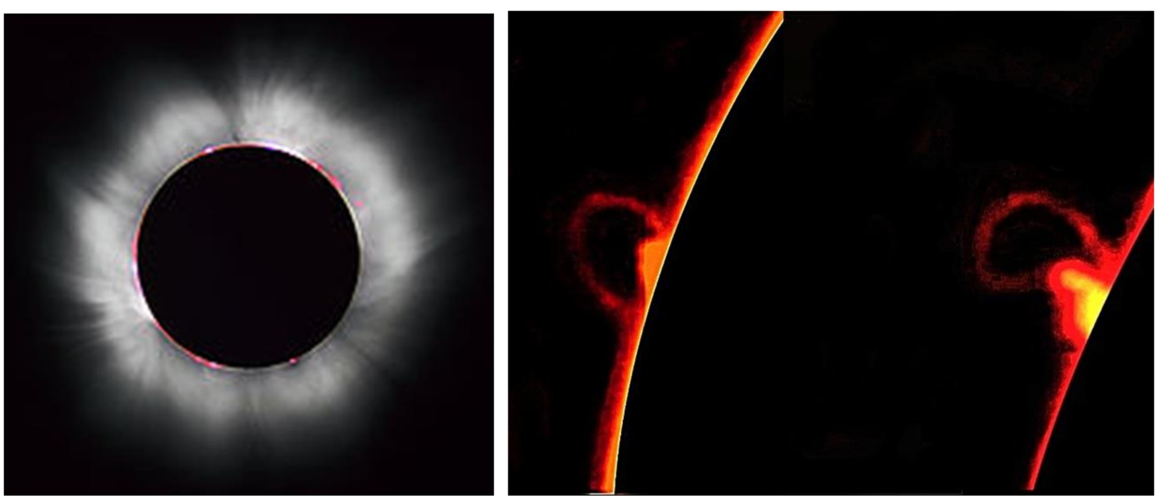


Figure F-7. Solar Corona Viewed During a Solar Eclipse and Solar Flares.

f. Developing a Model. To create an accurate main field model, you need data with good global coverage and as low a noise level as possible. The Danish Ørsted and German CHAMP satellite data sets satisfy these requirements. Both satellites provide high quality vector and scalar data at all latitudes and longitudes, but not during all time periods needed for modeling. These satellite data were augmented with ground observatory hourly mean data, which were available almost continuously over the period of interest, although with poorer spatial coverage. The observatory data provide valuable constraints on the time variations of the geomagnetic field. Used together, satellite and observatory data provide an exceptional quality data set for modeling the behavior of the main magnetic field in space and time.

F-4. World Magnetic Model 2010

a. Description.

(1) The WMM 2010 is the current standard model used for the computation of magnetic declination and other magnetic values by the US Department of Defense, the U.K. Ministry of Defense, the North Atlantic Treaty Organization, and the International Hydrographic Organization. It was produced by the US National Geophysical Data Center and the British Geological Survey with funding provided by the US National Geospatial-Intelligence Agency and the British Defense Geographic Imagery and Intelligence Agency.

(2) World Magnetic Models are developed for five year periods. The current WMM will expire on 31 December 2019. Some software applications using the WMM2010 extend the use of the model until December 31, 2015 with a limited decrease in accuracy.

b. Accuracy.

(1) On land, spatial anomalies are produced by mountain ranges, ore deposits, ground struck by lightning, geological faults, and cultural features such as trains, planes, tanks, railroad tracks, power lines, etc. The corresponding deviations are usually smaller at sea, and decrease with increasing altitude of an aircraft or spacecraft. In ocean areas, these anomalies occur most frequently along continental margins, near seamounts, and near ocean ridges, trenches, and fault zones, particularly those of volcanic origin. Ships and submarines are also sources of magnetic anomalies in the ocean.

(2) However, from a global main field perspective, the declination (D), inclination (I), and grid variation RMS errors of WMM2010 are estimated to be less than 1.0° at the Earth’s surface over the entire 5-year life span of the model. Also, the RMS errors at the Earth’s surface horizontal intensity (H), the vertical component (Z), and the total intensity (F) of WMM2010 are estimated to be well below 200 nanoTesla (nT), over the entire 5-year life of the model. Thus, the WMM2010 meets and exceeds the accuracy requirements detailed in MIL-W-89500 (Defense Mapping Agency, 1993) for the entire life span of the model.

(3) The crustal contributions could be included in an extended model, expanded to high degrees, as is common for modern gravity field models, such as EGM96 (Lemoine et al., 1998). Since the crustal field is almost constant in time, it can be inferred

from all available marine, aeromagnetic, and high resolution CHAMP and future SWARM satellite data, measured at all times. However, this extended model would differ significantly in format from the current WMM, requiring changes in supporting software.

(4) The WMM is a model of the Earth's main magnetic field, that portion of the field generated by the Earth's core. The accuracy of this model over a specific point is not discernible as there is no means to determine local magnetic attraction at that point without lengthy field gravitational measurements; however, this model will produce the most accurate data available to the field users for most applications.

c. Use of the WMM**.** For the purposes of the Field Artillery, this program can be used to determine magnetic declinations (Magnetic to True), Grid-Magnetic Angles (GM Angles), and annual changes. This data then can be used to develop declination diagrams for any point in time during the life of that model.

F-5. WMM 2010 Software.

a. Software to compute declination values can be downloaded from the following website: **http://www.ngdc.noaa.gov/geomag/models.shtml**

b. A description of the model, the modeling methods, and test values are published in National Oceanic and Atmospheric Administration Technical Report: The US/UK World Magnetic Model for 2010-2015. This can also be downloaded from the website listed above.

F-6. Computations Using the WMM 2005 Software

a. Software**.**

(1) WMM 2010 software works on all Windows based operating systems including Vista.

(2) The WMM2010 software is accessed by double clicking the WMM.exe file or the on the icon created when creating a shortcut for that file.

(3) After opening the software, the screen below will appear on the desktop (Figure G-8).

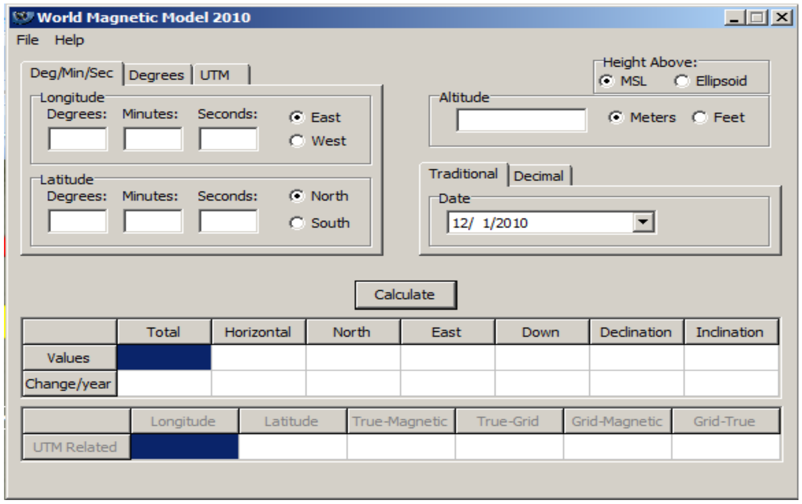


Figure F-8. 2005 Software Computations

b. Input Values.

(1) Position. The operator has the option to enter the location in either geographic positions or UTM Grid. The following formats are available for data entry:

(a) Degrees/Minutes/Seconds (Deg/Min/Sec). Enter longitude and latitude in degrees/minutes/seconds in separate windows, all positive values. The operator will select north/south or east/west buttons to indicate hemispheres.

(b) Degrees. Enter the longitude and latitude in decimal degrees. Western and southern hemispheres are entered with a negative sign.

(c) UTM. Enter the zone (1-60) of the UTM system. The operator may select the UTM Grid zone from a drop down window or by highlighting the zone and typing the zone in the window. Select northern or southern hemisphere button. Enter UTM easting and northing.

(2) UTM Zone Overlap. The program allows for limited computations in adjacent zones. Allowable Easting and Northing entries are -500000 < Easting < 1500000 and -500000 < Northing < 10500000. These allowable entries are in most cases excessive and allow a larger overlap than do mapping products.

(3) Equator Overlap. The operator can choose North or South. Limited equator overlap is allowed, but normally, the selection of "North" is for points above the Equator, and the selection of "South" is for points below the Equator. The selection of "North" dictates that the Equator is assigned 0 meters as its Northing, and the selection of "South" dictates that the Equator is assigned 10,000,000 meters as its Northing.

(4) Altitude. The operator has the option to enter the elevation or height above ellipsoid by choosing MSL or Ellipsoid and entering the altitude in meters or feet, and

indicates which by selecting a button.

(5) Date. For WMM2010, the operator can enter a date between January 1, 2010 and December 31, 2015 using one of the formats provided:

(a) Traditional format. Enter day, month, and year or use the drop down calendar.

(b) Decimal. Enter the date as the year number with a decimal fraction. For example, July 1, 2010 would be entered as 2010.5.

c. Output Components.

(1) Dependent on the input values, different output values will be computed.

(2) Whether inputting geographic positions or UTM coordinates, the following seven magnetic components are computed: (Figure F-9 page F-13).

(a) Total (F). The total intensity of the magnetic force. The intensity (or strength) of the entire magnetic field at a given location and time. Geometrically, it is the length of the magnetic field vector. In some applications, the Total field intensity is identified with an “F.”

(b) Horizontal (H). The intensity of the component of the magnetic field that is tangent to the Earth's surface at a given point.

(c) North (X). The portion of the magnetic field which is directed horizontally northward. A southward directed field would have a negative value for the North component.

(d) East (Y). The portion of the magnetic field which is directed horizontally eastward. A westward directed magnetic field would have a negative value for the East component.

(e) Down (Z). The portion of the magnetic field that is directed perpendicular to the Earth's surface at a given location. Positive values point into the earth.

(f) Declination. Geomagnetic Declination or Magnetic Variation. The angular difference between true North and magnetic North. The rotation is from true North to magnetic North with the clockwise sense reported positively. For instance, if the declination at a certain point was -10°, then the north-seeking needle of a compass at that location would actually align 10° West of true North (10° counterclockwise from true North). True North would be 10° East of the same needle.

(g) Inclination. The angle between the magnetic field vector and the horizontal plane at that point. The inclination is positive when the magnetic field points downward into the earth and negative when it points upward. The Earth's magnetic field lines emerge from the southern half of the earth and re-enter in the northern half. Several features of the Earth's field vary in a predictable way across the surface of the globe and might, in principle, be used in assessing geographic position. For example, at each location on the Earth, the field lines intersect the Earth's surface at a specific angle of inclination. Near the equator, the field lines are approximately parallel to the Earth's surface; the inclination angle in this region is said to be 0 degrees. As one travels north from the equator, however, the field lines become progressively steeper. At the magnetic pole, the field lines are directed almost straight down into the Earth and the inclination is said to be 90 degrees. Thus, inclination angle varies with latitude.

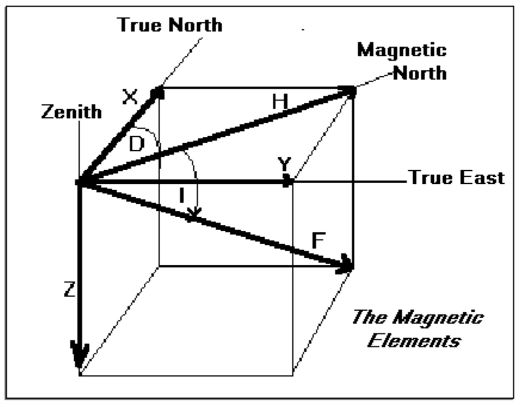


Figure F-9. Output Components

d. Annual change in each of these magnetic components is also displayed. The annual change is computed by subtracting the main field values for the desired input date from main field values one year later. The output units are displayed using the abbreviations nT, deg (degrees) and min (minutes) per year.

e. If UTM coordinates are input, the program will also provide the following output data:

(1) Longitude. The longitude corresponding to the entered UTM location.

(2) Latitude. The latitude corresponding to the entered UTM location.

(3) True-Magnetic. Same as Declination. Shown again for comparison purposes.

(4) True-Grid. The angle, positive for clockwise, from true North to grid North.

(5) Grid-Magnetic. The angle, positive for clockwise, from grid North to magnetic North.

(6) Grid-True. The angle, positive for clockwise from grid North to true North. It is the negative of the True-Grid angle.

F-7. Sample Computations Using the WMM 2010 Software

a. Deg/Min/Sec Input.

(1) Figure F-10 (page F-14) provides an example of using the Deg/Min/Sec input option.

(2) The example below will compute data for the Cap Serrat Training Area in Tunisia.

Latitude: 37º 06’ 02” N   Longitude: 9º 20’ 25” E   Elevation: 100 meters

Date: 1 July 2010

(3) Open the WMM 2010 software; input the Longitude and Latitude, Elevation, and Date.

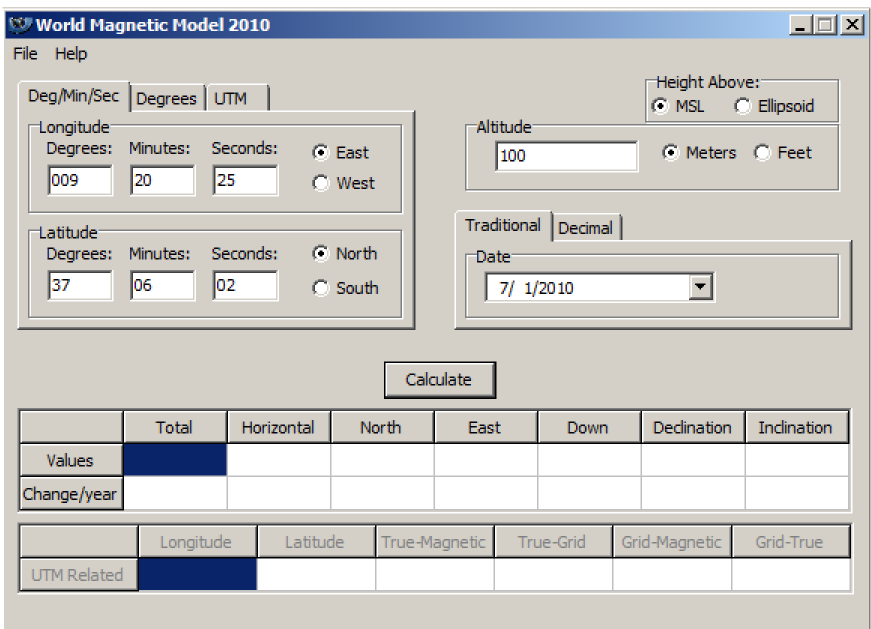


Figure F-10. WMM Software

(4) Select Calculate.

(5) The program computes and displays the results for the requested location and date (Figure F-11).

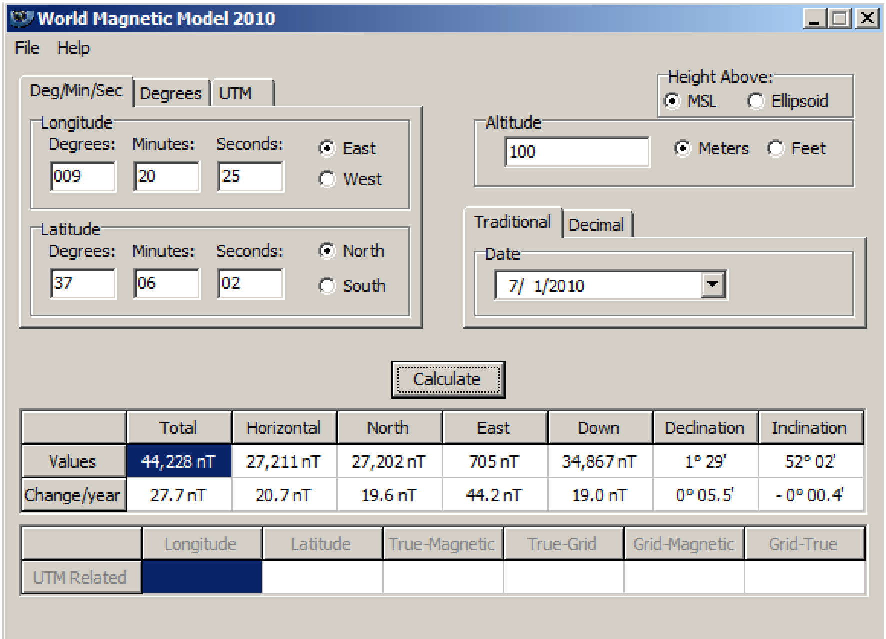


Figure F-11. Calculated Results

b. UTM Input**.**

(1) Figure F-12 will use the UTM input option.

(2) The example below will compute data for the Cap Serrat Training Area in Tunisia.

Grid zone: 32 Easting: 530237 Northing: 4106082 Elevation: 100 meters

(3) Open the WMM 2010 software; input the UTM Grid Zone, UTM Easting and Northing, Elevation, and Date.

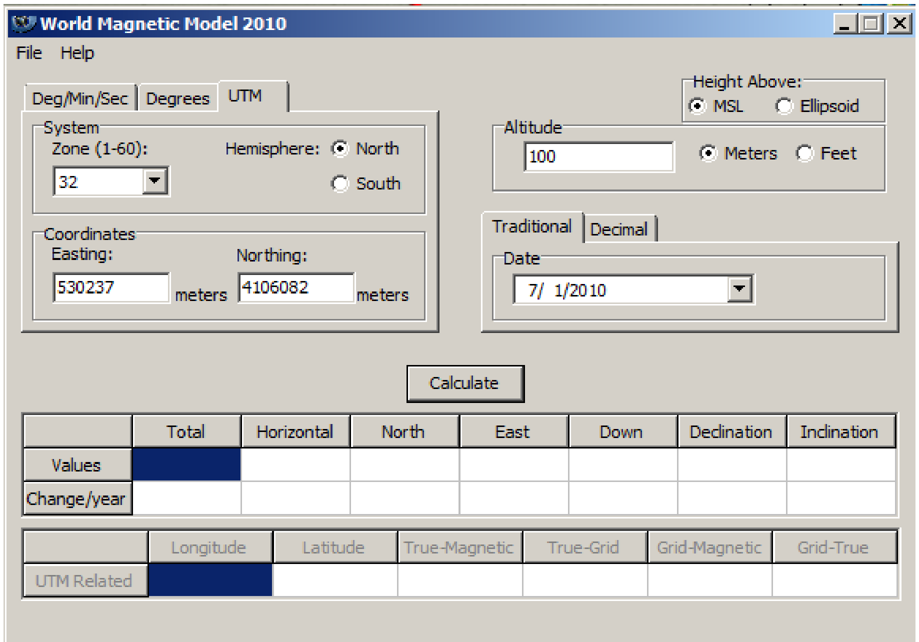


Figure F-12. UTM Input

(4) Select Calculate.

(5) The program computes and displays the results for the requested location and date.

(6) Note when using UTM coordinates, Latitude and Longitude are computed (Figure F-13).

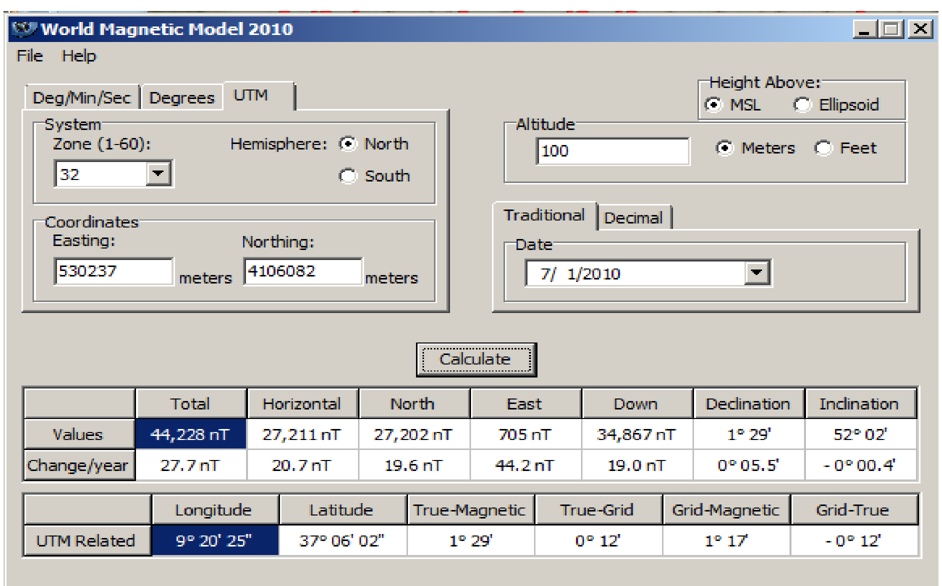


Figure F-13. Calculated Results

G-8. Printing the Output Data

a. Output data cannot be simply printed from this software. However, it can be cut and pasted to a Microsoft Word ™ document.

b. The following procedures can be used to create a printable output.

(1) Right Click any of the Values, Change/Year, or UTM Related windows.

(2) A window will open with two options: Copy and Select All.

(3) Click on Select All, all the fields in that row will highlight.

(4) Click on Copy, the contents of that row will copy to the clipboard.

(5) Each window must be copied separately.

c. The pasted product may require some editing for font and structure. Below is the edited output file for the UTM example above.

CAP SERRAT, TUNISIA
July 1, 2010

Results For

EASTING: 530237
NORTHING: 4106082
ALTITUDE: 100.00 METERS
DATE: 2005.5

OUTPUT

MAIN FIELD COMPONENTS		**ANNUAL CHANGE**	
TI= 44228	nT	TI = 27.7	nT/yr
HI = 27211	nT	HI = 20.7	nT/yr
X = 27202	nT	X = 19.6	nT/yr
Y = 705	nT	Y = 44.2	nT/yr
Z = 34867	nT	Z = 19.0	nT/yr
DEC = 1° 29’ EAST		DEC = 0° 05.5 MIN/yr EAST	
DIP = 52° 02’ DEG UP		DIP = 0° 00.4’ MIN/yr DOWN	
Legend:			
DEC: declination		HI: Height of instrument	

UTM GRID COORDINATE RELATED

TRUE-MAGNETIC	1° 29’
TRUE-GRID	0° 12’
GRID-MAGNETIC	1° 17’
GRID-TRUE	-0° 12’

F-9. Declination Diagrams and Orientation Data

a. Build a Declination Diagram. A Declination Diagram can be built with the information output from the WMM 2010 Software and the survey software with the AN/PYG-1. The Declination Diagram must show the three north directions: True, Magnetic, and UTM Grid North. It should also show the three angles developed by the relationship between the three north directions: UTM Grid Convergence, Declination, and G-M Angle. Knowing any two of these three angular measurements will produce the third.

b. Building a Declination Diagram**.** The Declination Diagram is built in a series of steps based on the computations of UTM Grid Convergence, Declination, and G-M Angle. These steps are detailed in the following paragraphs using the Cap Serrat, Tunisia example from earlier.

(1) Scale the UTM easting and northing from the center of the area of operations as accurately as possible. Scale the elevation to the nearest 100 meters. If there is a known station or a DAGR available, use data provided from those sources.

Grid zone: 32 Easting: 530237 Northing: 4106082 Elevation: 100 meters

(2) Using the BUCS, BUCS-R, or other accepted survey program, computes UTM Grid Convergence (True to Grid).

Grid zone: 32 Grid Convergence = -3.649 mils

(3) Compute Declination with the WMM 2010 Software. For this example, use the Cap Serrat Tunisia data from above.

(4) Convert the WMM 2010 data to mils. (See Cap Serrat, Tunisia output above)

c. Seven Components. Of the seven Main Field Components and seven Annual Change Components produced by the WMM 2010 Software, the declination (Declination True to Magnetic) and Annual Change to declination outputs are the components used to develop products for the field artillery. The Declination is output in degrees and minutes East (+) or West (-) of True North. The Annual Change in Declination is output in decimal minutes per year and will be either positive or negative.

d. Converting Declination from Degrees to Mils.

(1) The Declination can be converted from degrees and minutes to mils by converting the degrees and minutes to degrees; then dividing the declination by 0.05625.

(2) In the example, the Declination is 1º 29’ East. To convert that to mils, first convert the minutes to decimal degrees and add that value to the whole degrees:

29/60 = 0.483° + 1° = 1.483° , Then divide 1.483 by 0.05625; 1.483º/0.05625 = 26.364 mils

e. Converting Annual Chang in Declination to Mils.

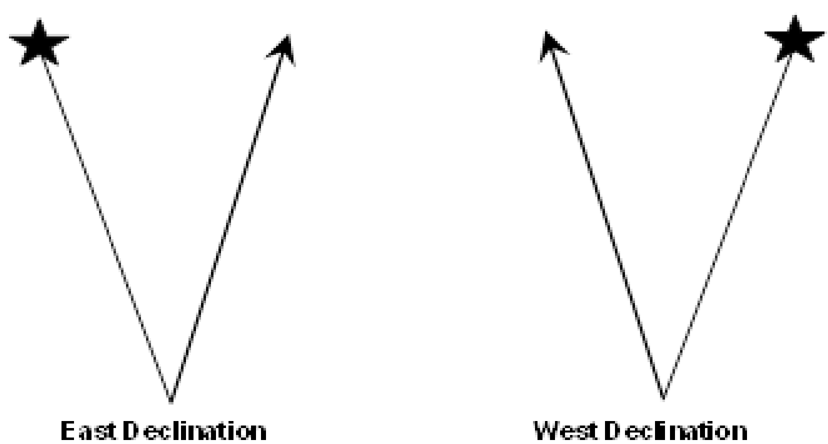
(1) Annual Change in Declination must first be converted to decimal degrees then converted to mils. Decimal minutes are converted to decimal degrees by dividing the decimal minutes by 60. Then divide the decimal degrees by 0.05625 as with the Declination above.

(2) In the example, the Annual Change in Declination is 5.5 min/yr. To convert that to decimal degrees, divide the decimal minutes by 60. Then divide the answer by 0.05625.

5.5/60 = 0.092 degrees/yr, then 0.092º/0.05625 = 1.636 mils/yr

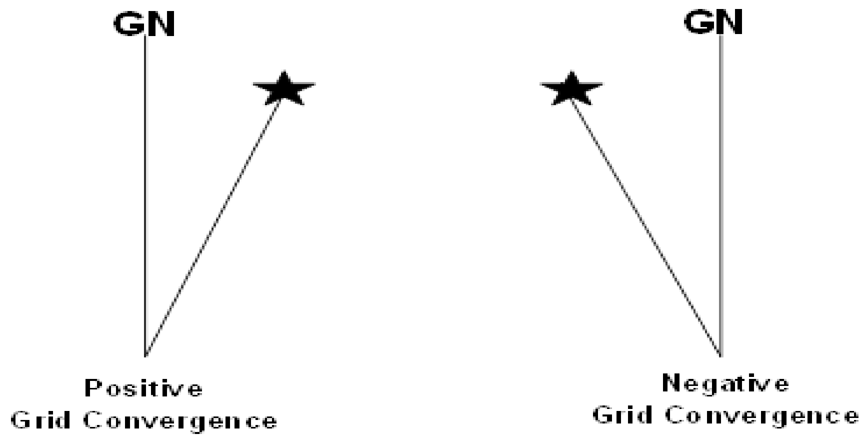
(3) Draw a straight line on a piece of paper and label it with a star to designate True North. This is the base reference for any declination diagram.

(4) Plot the computed Declination from Steps 3 and 4 by drawing a straight line from the bottom of the True North line in the direction of the Declination. Label this line with an arrow to designate Magnetic North. If the value of the computed Declination is east, plot the arrow on the right side of the True North line. If the value of the computed Declination is west, plot the arrow on the left side of the True North line.



For the example, the Declination was east. Draw the Magnetic North Line right of True North.

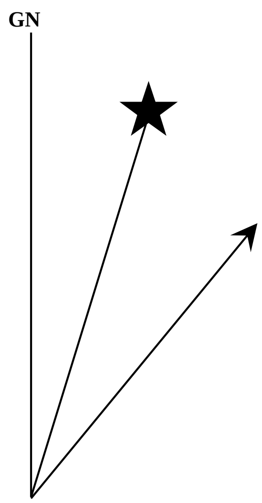
(5) Plot the computed UTM Grid Convergence from step 2. If the value of the computed UTM Grid Convergence is positive, plot the Grid North line to the left of True North. If the value of the computed UTM Grid Convergence is negative, plot the Grid North line to the right of True North.



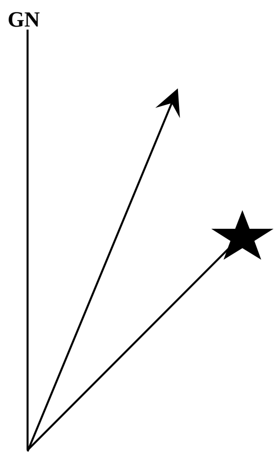
For the example, the UTM Grid Convergence was negative. Draw the Grid North line right of True North.

(6) Rotate the diagram so that Grid North is oriented vertically on the page.

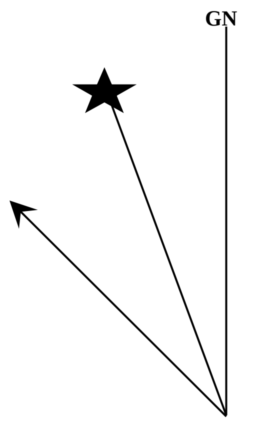
f. Six Possible Declination Diagrams**.** The following are the six possible declination diagrams and the procedures to convert between Grid and Magnetic North.



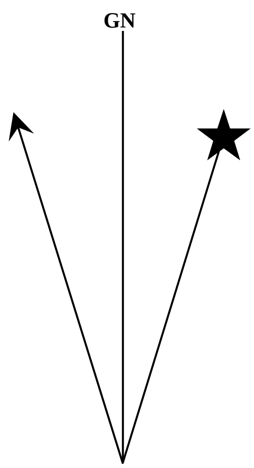
To convert a Magnetic azimuth to a Grid azimuth, add the G-M Angle.
To convert a Grid azimuth to a Magnetic azimuth, subtract the G-M Angle.



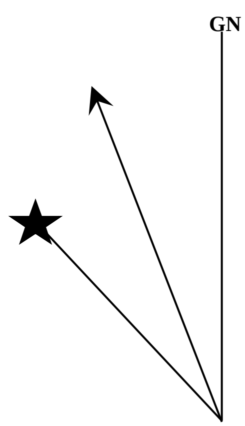
To convert a Magnetic azimuth to a Grid azimuth, add the G-M Angle.
To convert a Grid azimuth to a Magnetic azimuth, subtract the G-M Angle.



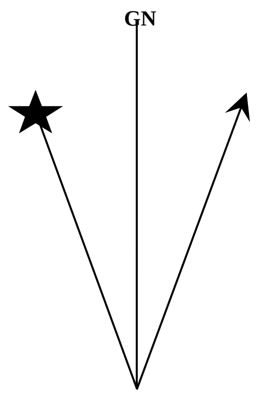
To convert a Magnetic azimuth to a Grid azimuth, add the G-M Angle.
To convert a Grid azimuth to a Magnetic azimuth, subtract the G-M Angle.



To convert a Magnetic azimuth to a Grid azimuth, subtract the G-M Angle.
To convert a Grid azimuth to a Magnetic azimuth, add the G-M Angle.

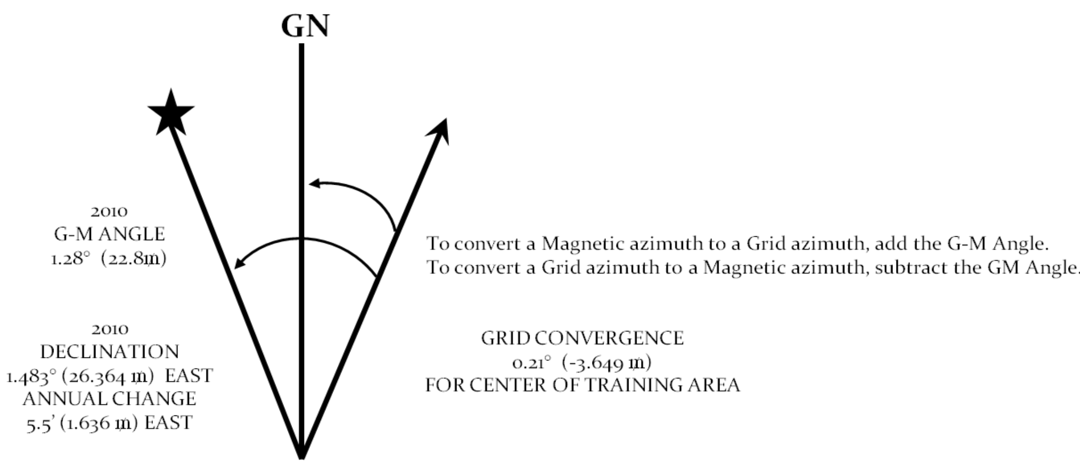


To convert a Magnetic azimuth to a Grid azimuth, subtract the G-M Angle. To convert a Grid azimuth to a Magnetic azimuth, add the GM Angle.



To convert a Magnetic azimuth to a Grid azimuth, add the G-M Angle. To convert a Grid azimuth to a Magnetic azimuth, subtract the GM Angle.

g. Final Declination Diagram. Using the information in steps (b) 1,2,3,4 and (e) 3,4,5,6 and the six possible diagrams, build the declination diagram for the training area. The figure below shows the final declination diagram for the Cap Serrat Tunisia example.



F-10. Orientation Data

a. Determining Orientation Data.

(1) General. Orientation data for different instruments can be developed by using the G-M Angles determined with the Declination Diagrams above and the declinations determined with the WMM2010 Software.

(2) Grid Declination for the M2A2 Aiming Circle. Using the Declination Diagram developed above; the artilleryman can determine the Grid Declination Constant to be used to orient the M2A2 Aiming Circle when a Declination Station is not available.

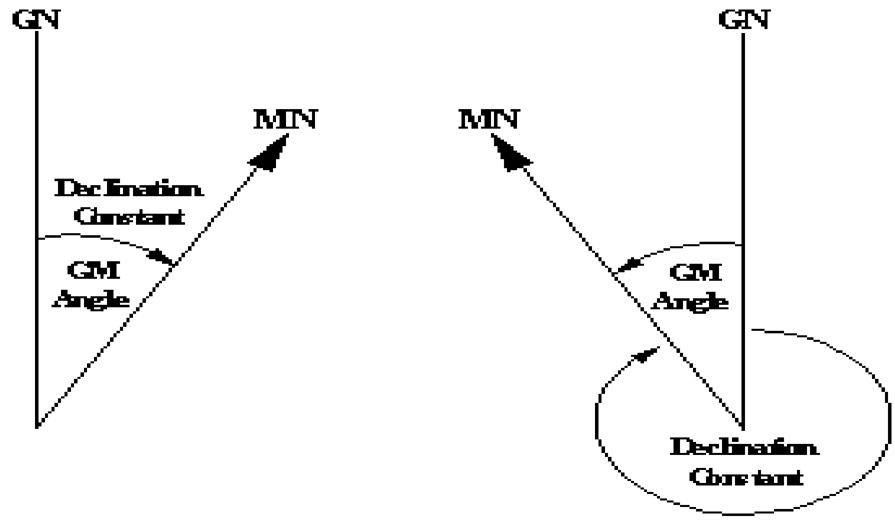


Figure F-14. Grid Declination and G-M Angles

(a) If Magnetic North is east of Grid North, the Grid Declination Constant is equal to the G-M Angle.

(b) If Magnetic North is west of Grid North, the Grid Declination Constant is equal to 6400 mils minus the G-M Angle.

(c) Example: when no declination station is available, use 0022.8 mils as the Grid Declination.

b. Declination for Meteorological Theodolite**.** Meteorological Theodolites are oriented to True North; however, the math is performed very much the same way as with an aiming circle.

(1) If Magnetic North is east of True North, the Declination Constant is equal to the Declination.

(2) If Magnetic North is west of True North, the Declination Constant is equal to 360º minus the Declination.

(3) Example: when no declination station is available, use 001.48º as Declination Constant.

APPENDIX G. GLOSSARY

Section I. ACRONYMS AND ABBREVIATIONS

2-D .... two-dimensional
3-D .... three-dimensional
2DRMS .... 2-deviations root mean square
3DRMS .... 3-deviations root mean square

AFATDS .... Advanced Field Artillery Tactical Data System
AFWA .... Air Force Weather Agency
AO .... area of operations
AR .... accuracy ratio
AZ .... azimuth
AZMK .... azimuth mark

°C / C .... Celsius
C/A .... coarse/acquisition
CBRN .... chemical biological radiological nuclear
cE .... easting coordinate correction
CEP .... circular error probable
CME .... coronal mass ejection
cN .... northing coordinate correction
COC .... combat operations center
CONUS .... continental United States
CORR .... corrected, correction
COP .... chief of party
COS .... cosine
CP .... command post
CPC .... command post computer
CVd .... crypto variable key
CVW .... crypto variable weekly
CW .... continuous wave

DAGR .... Defense Advanced Global Positioning System Receiver
dE .... difference easting
dH .... difference in elevation
DIST .... distance
dN .... difference northing
DOD .... Department of Defense
DOP .... dilution of precision

E .... easting
EGM .... Earth gravity model
eAZ .... azimuth error
eE .... error easting

eH .... elevation error
eN .... error northing
EOL .... end of the orienting line

°F .... Fahrenheit
FDC .... fire direction center
FGCS .... Federal Geodetic Control Subcommittee
FOB .... forward operating base
FOMET .... fallout meteorological

GALWEM .... global air-land weather exploitation model
GAT .... Greenwich apparent time
GBS .... Global Broadcast Service
GCE .... ground combat element
GCFS .... ground counter fire sensor
GDOP .... geometric dilution of precision
GHA .... Greenwich hour angle
GIC .... geospatial information center
GK .... Gauss-Kruger
G-M .... grid magnetic
GMR .... Global Broadcast Service mission request
GMT .... Greenwich mean time
GPS .... Global Positioning System
GPS-S .... Global Positioning System-survey
GRS .... Geodetic Reference System
GUV .... group unique variable

H .... height, elevation
H .... ellipsoid height, h = h+n
HAE .... height above ellipsoid or geodetic height
HORZ .... horizontal

IPADS-G .... improved position and azimuth determining system-Global Positioning System
IPB .... intelligence preparation of the battlespace
IR .... infrared

K .... Kelvin
km .... kilometer

L1 .... link 1
L2 .... link 2
LHA .... local hour angle
LMT .... local mean time
LOS .... line of sight

m .... meter

MAGTF........ Marine air-ground task force
MCPP........ Marine Corps planning process
MCRP ....Marine Corps reference publication
MEAN........ average
MEB........Marine expeditionary brigade
MET .... meteorology
METCM........meteorology computer message
METT-T........ mission, enemy, terrain and weather, troops and support available-time available
MGRS .... military grid reference system
MHz ....megahertz
MMIM........ modeled meteorological information manager
MM5 ....mesoscale model (fifth generation)
MN........mean
MSL ....mean sea level

N........northing
NAD........ North American datum
NAV Data ....navigation data
NAVSTAR........navigation, satellite, timing and ranging
NIMA........National Imagery and Mapping Agency
nT .... nanotesla
NWP........numerical weather prediction

O........side opposite the angle when calculating for cosine
OP .... observation post
OPORD........operation order
OPT........operational planning team
OS .... orienting station

P .... precise
PDOP .... position dilution of precision
PE........probable error
PGM........ precision-guided munition
PiBal........ pilot balloon
PPS........precise positioning service
PRC........pseudo-range correction
PRN........ pseudo-random noise
PZS Triangle ....astronomic triangle

R........reverse
RCDR........ recorder
RE ....radial error
READ........reading
RECIP ....reciprocal
RF........ radio frequency
RMS ....root mean square

RP....registration point
RPDA....ruggedized personal data assistant
RSO....rectified skew orthomorphic
RTK....real time kinematic

S....standard
S-2....intelligence officer/intelligence office
S-3....operations and training officer/operations and training office
SA....selective availability
SCP....survey control point
SHELREP....shell report
SIN....sine
SINCGARS....single-channel ground and airborne radio system
SOP....standing operating procedure
SP....sensor post
SPS....standard positioning service
STA....station
STANAG....standardization agreement (NATO)
SUBT....subtended

T....telescope
tan....tangent
TAP....target acquisition platoon
TGT....target
TIP....target in position
TM....transverse mercator
TPC....target processing center
TTL....total traverse length

UERE....user equivalent range error
UPS....universal polar stereographic
UTM....universal transverse mercator

VERT....vertical

WeRM....mil relation formula
WGS....world geodetic system
WMM....World Magnetic Model

ZULU....time zone indicator for Universal Time

Section II. DEFINITIONS

Absolute Positioning - The unique ability of a GPS receiver to produce positional values without the reference of another receiver.

Accelerometer - A device which measures acceleration. The output is double integrated to determine a change in distance.

Accuracy – (1) How close a measurement or a group of measurements are in relation to a standard or true value. **(2)** The degree of conformity with a standard, or the degree of perfection attained in a measurement. Accuracy relates to the quality of a result and is distinguished from precision which relates to the quality of the operation by which the result is obtained.

Accuracy Ratio - In artillery survey, it is the ratio between the radial error in closure and the total traverse length of a survey. It is usually expressed as a fraction with a numerator of 1.

Adjustment -The determination and application of corrections to observations for the purpose of reducing errors or removing internal inconsistencies in derived results. The term may refer to mathematical procedures or to corrections applied to instruments used in making observations.

Air Mass - An extensive body of air within which the conditions of temperature and moisture in a horizontal plane are essentially uniform.

Air Pressure - The weight of the air per unit of volume.

Alidade - The part of a surveying instrument which consists of a sighting device with index and reading and recording accessories.

Altitude – (1) The altitude of a celestial body is the arc of its vertical circle measured from the observer's horizon to the body, or it is the vertical angle at the observer's position between the horizon and the body. **(2)** The vertical distance between a point and a reference surface; usually the topography.

Ambiguity - The unknown number of whole carrier wavelengths between a satellite and a receiver. Also called cycle ambiguity.

Anemometer - The general name for instruments designed to measure the speed (or force) of the wind.

Angle - The arc of a circle formed by the intersection of two lines at the center of the circle.

Arbitrary Grid - Any reference system developed for use where no grid is available or practical, or where military security for the reference is desired.

Auto-reflection - A method of creating a line which is perpendicular to a reflective porro prism by projecting the image of a theodolite telescope onto the porro prism, then back to the telescope.

Azimuth - The horizontal angle measured clockwise between a reference direction and the line to an observed or designated point.

Azimuth, Geodetic - The angle between the geodetic meridian and the tangent to the geodetic line at the observer, measured in the plane perpendicular to the ellipsoidal, normal of the observer, preferably clockwise from north. A geodetic azimuth can be referred to as a true azimuth.

Azimuth, Grid - The horizontal direction of any line measured clockwise from grid north.

Azimuth Magnetic - The horizontal direction of any line measured clockwise from magnetic north.

Azimuth, Plane - The angle measured in a clockwise direction between grid north and a line on a grid.

Azimuth, True -The horizontal direction of any line measured clockwise from true north.

Back Azimuth - (1) In a plane rectangular coordinate system, like universal transverse mercator grid, the back azimuth differs from an azimuth by 180° (3200 mils). The azimuth and back azimuth form a straight line. **(2)** In geodetic survey, the azimuth and back azimuth do not differ by 180° because of convergence of the meridians. If the azimuth of point B from point A is given on a reference ellipsoid, then the back azimuth is the azimuth of point A from point B.

Ballistic Temperature - An assumed temperature that would have the same total effect on a projectile during its flight as the varying temperatures actually encountered; reported as a percent of standard.

Bandwidth - A measure of the width of the frequency spectrum of a signal expressed in hertz.

Barometer - An instrument for measuring atmospheric pressure.

Baroswitch - A pressure-operated switching device used in a radiosonde.

Baseline - The resultant three dimensional vectors, V, between any two stations from which simultaneous GPS data have been collected and processed. Generally given in Earth-centered Cartesian coordinates where: $V = \Delta x, \Delta y, \Delta z$.

Bearing - The direction of a line as measured from the north-south axis (X-axis) of a two dimensional system.

Binary Code - A system used in communications where selected strings of 0's and 1's are assigned definite meanings.

Broadcast Ephemeris - The ephemeris broadcast by the GPS satellites.

Calibration - The act of determining certain specific measurements in an instrument or device by comparison with a standard, for use in correction or compensating for non-standard errors.

Carrier - A high frequency radio wave having at least one characteristic (frequency, amplitude, or phase) which may be varied by modulation from an accepted value. In general, the carrier wavelength is much shorter than the wavelengths of the codes.

Carrier Frequency - The frequency of the un-modulated fundamental output of a radio transmitter.

Carrier Phase - The phase measurement of the carrier wave, converted from a percentage to millimeters.

Cartesian Coordinates - A coordinate system in which locations of points in space are expressed by reference to three mutually perpendicular planes, called coordinate planes. The three planes intersect in three straight lines called coordinate axes. The system is referred to as geocentric Cartesian coordinates when it defines the position of a point with respect to the center of mass of the Earth. See X-axis, Y-axis, and Z-axis.

Celestial Coordinates - The coordinates used to locate a celestial body by various systems. The coordinates considered in artillery are declination and right ascension.

Celestial Equator - The great circle on the celestial sphere whose plane is perpendicular to the axis of rotation of the Earth.

Celestial Horizon - That circle on the celestial sphere formed by the intersection of the celestial sphere and a plane through the center of the Earth and perpendicular to the zenith-nadir line.

Celestial Sphere - The imaginary sphere of infinite radius concentric with the Earth, on which all celestial bodies except the Earth are imagined to be projected. Astronomic surveying establishes that the celestial sphere and all bodies on the sphere rotate around the Earth from east to west.

Central Meridian – (1) The line of longitude at the center of a map projection. Generally, the basis for constructing the projection. **(2)** The longitude of origin at the center of each six-degree zone of the universal transverse mercator grid system. **(3)** The longitude of the center of a time zone.

Channel - GPS receiver hardware and software which allows the receiver to track the signal from one satellite at one of the two carrier frequencies. An eight-channel dual frequency receiver actually tracks sixteen channels.

Chip - The minimum transition time interval for individual bits of either a 0 or a 1 in a binary pulse code, usually transmitted in a pseudo-random sequence.

Circular Error - An accuracy figure representing the stated percentage of probability that any point expressed as a function of two linear components (e.g., horizontal position) will be within the given figure. Commonly used figures are **CEP** (50%), **CE** 1 (39.35%), **CE** (90%).

Circumpolar - Revolving about the elevated pole without setting. A celestial body is circumpolar when its polar distance is approximately equal to, or less than, the latitude of the observer.

Clock Bias - The difference between a clock’s indicated time and true Universal Time.

Clockwise Angle - The horizontal angle measured on a clockwise rotation scale. The alidade does not necessarily have to turn clockwise to measure a clockwise angle. For example, the horizontal scale of an S7 will measure the same angle between two stations no matter what direction the alidade is turned.

Coaltitude - The compliment of altitude, or 90° minus the altitude. The term has significance only when used in connection with altitude measured from the celestial horizon, when it is synonymous with zenith distance.

Code Receiver - An instrument that does require knowledge of the P or C/A code to complete its measurements. This type of receiver will record the broadcast ephemeris.

Coincidence – (1) In the measurement of angles with a theodolite, the instant at which two diametrically opposed index marks on the circle are in perfect optical alignment and appear to form a continuous line across the dividing line of the circle. **(2)** A prismatic arrangement common to leveling instruments and older theodolites wherein one-half of opposite ends of the leveling bubble are brought into view in a single image. Coincidence is achieved when two halves of the bubble ends match.

Colatitude - The side of the PZS triangle from the zenith to the pole. The complement of latitude, or 90° minus the latitude.

Conformal Map Projection - A map projection on which the shape of any small area of the surface mapped is preserved unchanged, and all angles around any point are correctly represented. Also called an orthomorphic map projection.

Conic Map Projection, Secant - A map projection produced by projecting the geographic meridians and parallels of a reference ellipsoid onto a cone which is secant to the surface of the ellipsoid. The points of secancy are usually two parallels of latitude. Also called a conic map projection with two standard parallels. (An example is the Lambert Conformal Projection.)

Contour - Imaginary lines in which all points on each line have the same elevation. Used to depict the terrain of the ground onto the flat surface of a map.

Contour Interval - The difference in elevation (dH) between two adjacent contour lines. This interval is usually listed below the bar graph in the marginal data of a map.

Contour Line - A line on a map in which all points on the line have the same elevation.

Control Segment - One of three GPS segments. The control segment is made up of monitoring and control stations that ensure the accuracy of the GPS satellite orbits and operation of their atomic clocks. There are currently five stations in the control segment.

Convergence - The angular difference between two meridians at the intersection of two lines that are tangent to the meridians at the same parallel of latitude. Usually called convergence of the meridians.

Coordinates - Linear or angular quantities that designate the position of a point in a given frame of reference. This term is usually referenced to three dimensional positioning systems such as Cartesian coordinates or Geodetic coordinates. The term has also been used to describe the position of a point located on a two dimensional grid system such as universal transverse mercator or UPS.

Cursor - An indicator on a computer.

Cycle Ambiguity - See Ambiguity.

Cycle Slip - A discontinuity in measured carrier beat phase resulting in a temporary loss of lock in the carrier tracking loop of a GPS receiver.

Datum (geodetic) – **(1)** A reference surface consisting of five quantities: the latitude and longitude of an initial point, the azimuth of a line from that point, and the parameters of the reference ellipsoid. **(2)** The mathematical model of the Earth used to calculate the coordinates on any map. Different nations use different datum for printing coordinates on their maps.

Datum, Horizontal - Also called a geodetic datum. A horizontal datum is generally defined by at least five quantities relating to position, azimuth, gravity models, and a reference ellipsoid. It fixes a reference ellipsoid to a specific orientation with respect to the surface of the geoid.

Datum Point - Any reference point of known or assumed coordinates from which calculations or measurements may be taken.

Datum Transformation - The systematic elimination of discrepancies between adjoining or overlapping triangulation networks from different datums by moving the origins, rotating, and stretching the networks to fit together.

Datum Vertical - A level surface to which elevations are referred, usually mean sea level. Sometimes referred to as an altitude datum.

Declination – (1) The angular distance from the celestial equator to a celestial body measured along the hour circle of the celestial body. Declination is positive when the body is north of the celestial equator and negative when south. Declination roughly corresponds to astronomic latitude on the Earth. **(2)** Often used as a shortened term for magnetic declination, although this use is technically incorrect.

Declination, Grid - The angular difference between magnetic north and grid north.

Declination, Magnetic - The angular difference between magnetic and true north.

Deflection of the Vertical - The angular difference between the upward direction of the plumb line (the vertical), and the perpendicular (normal) to the reference ellipsoid. This difference seldom exceeds 30” except in mountainous areas.

Density - The mass per unit volume, measured in grams per cubic meter.

Deviation - A departures from accepted policies or standards. Ballistic densities and temperatures are reported as deviations from the standards that were used to develop the weapons firing tables.

Differencing - A technique used in baseline processing to resolve the integer cycle ambiguity, and to reduce a number of error sources including oscillator variations and atmospheric and orbital modeling errors. This technique “differences” the measurement of the carrier beat phase across time, frequency, receivers, satellites, or any combination of these. The three most utilized differencing techniques are: **Single Difference -** between receivers is the instantaneous difference in the complete carrier beat phase measurements made at two receivers simultaneously tracking the same signal. **Double Difference -** between receivers and satellites is found by differencing the single difference for one satellite with the single difference for another satellite where both single differences are from the same epoch. **Triple Difference -** between receivers, between satellites, and between epochs (time) is the difference between a double difference at one epoch and the same double difference at the following epoch.

Differential Positioning - The determination of the position of a station relative to a reference station when GPS receivers at each station are simultaneously tracking the same signals.

Dilution of Precision - A measure of the geometric contribution to the uncertainty of a position fix. The more specific terms are given below, also called **DOP**.**(1) GDOP -** Geometric dilution of precision is the measurement accuracy in 3D position and time. **(2) PDOP -** Position dilution of precision is the measurement accuracy in 3D position. **(3) HDOP -** Horizontal dilution of precision is the measurement accuracy 2D horizontal position. **(4) VDOP -** Vertical dilution of precision is the measurement accuracy as standard deviation of vertical height. **(5) RDOP -** Relative dilution of precision is a measurement of the quality of baseline reductions.

Distance - The spatial separation of two points, measured by the length of a line joining them.

Distance Angle - An angle in a triangle opposite a side used as a base in the solution of the triangle, or a side whose length is to be computed.

Distance, Horizontal - The distance measured on a horizontal plane. Horizontal distance refers primarily to taped distances or to distances reduced to horizontal through computations.

Distance Slope - A straight-line distance between two points of unequal elevation. A slope distance is usually derived by electronic means and must be reduced to horizontal distance for use in artillery survey computations.

Doppler Shift - The apparent change in frequency of a received signal due to the rate of change of the distance between the transmitter and receiver.

Domain - A square geographic area with a center point selected by the system operator.

Downwind - The direction toward which the wind is blowing (with the wind).

Dry-Bulb Temperature - The temperature measured by the dry bulb of a thermometer; ambient air temperature.

Dynamic Positioning - See kinematic positioning.

Earth-Centered Ellipsoid - A reference ellipsoid whose geometric center coincides with the Earth's center of gravity and whose semi-minor axis coincides with the Earth's rotational axis.

Earth-Fixed Coordinate System - Any coordinate system in which the axes are stationary with respect to the Earth.

Easting - The eastward (left to right) reading of grid values. This term is used with two dimensional coordinate systems.

Eccentricity - The ratio of the distance from the center of an ellipse to its focus on the semi-major axis.

Ecliptic - The great circle formed by the intersection of the plane of the Earth's orbit around the sun and the celestial sphere.

Elevation - Vertical distance from a datum, usually mean sea level, to a point on the Earth's surface. More exactly, it is the distance between a point on the Earth's surface and the geoid, measured on a line perpendicular to the geoid. Elevation should not be confused with altitude which refers to points above the Earth's surface. Elevation is sometimes referred to as Orthometric height.

Elevation Angle - Elevation angle is the angle between the horizon and objects above the horizon measured along the arc which passes through the zenith and the object in question.

Ellipsoid - A surface whose plane sections (cross sections) are all ellipses or circles, or the solid enclosed by such a surface. The terms ellipsoid and spheroid are used interchangeably. See also reference ellipsoid.

Ellipsoid Height - The distance between a point on the Earth's surface and the reference ellipsoid, measured along a line which is perpendicular to the ellipsoid. The ellipsoid height is positive if the point is outside of the reference ellipsoid, also called geodetic height.

Epoch - A period of time or a date selected as a reference for a measurement.

Equator - The great circle on the Earth midway between the poles and in a plane perpendicular to the Earth's axis of rotation. It is the line of zero latitude.

Equatorial Plane - A plane which includes all the points located at the equator.

Equipotential Surface - A surface having the same potential of gravity at every point.

Error - The difference between an observed or computed value of a quantity and the ideal or true value of that quantity. An error is generally classified as one of three types: a blunder which can be identified and corrected, a systematic error which must be compensated for, and a random error which cannot be identified or compensated for.

Error of Closure – (1) The amount by which a quantity obtained by a series of related measurements differs from the true or fixed value of the same quantity. **(2)** (azimuth) The amount by which two values of the same azimuth line, derived by different surveys or other means, fails to be equal. This is usually termed azimuth error. **(3)** (traverse) The amount by which the value of the position of a traverse station, as obtained by computation through a traverse, fails to agree with another value of the same station as determined by a different set of observations or procedures. Usually called radial error, also called traverse error, position error, or horizontal error. **(4)** (triangulation) The amount by which the sum of the three interior angles of a triangle differ from 180° (3200 mils). **(5)** (horizon) The amount by which the sum of two or more adjacently measured horizontal angles around one point fails to equal 360° (6400 mils). Measurement of the last horizontal angle completes a circle and is called closing the horizon.

Fallout - Fallout is the precipitation to earth of particulate matter from a nuclear cloud; also applied to the particulate matter itself.

Flattening - The ratio of the difference between the equatorial and polar radii of the earth to its equatorial radius also called ellipticity.

Free Lift - Refers to the net upward force required for a balloon to rise at a given rate. Free lift corresponds to the specific balloon (sounding or pilot balloon) being used and is a portion of total lift.

Frequency Band - Range of frequencies in a region of the electromagnetic spectrum.

Fronts - A transition zone between air masses of different densities and temperatures.

Fundamental Frequency - The GPS fundamental frequency, F, is 10.23 megahertz (MHz). The carrier frequencies are:

L1 = 154 * F = 1575.42 MHz
L2 = 120 * F = 1227.60 MHz

Gauss-Kruger Projection - The same as the transverse mercator projection with the cylinder of projection placed tangent to the reference ellipsoid.

Geocentric - Relative to the Earth or geoid as a center, measured from the center of the Earth.

Geodesy - The science which deals with the determination of the size and figure of the Earth. It also deals with determining the external gravitational field of the Earth, the internal structure of the Earth, and derives three dimensional positions for points above, at, and below the surface of the Earth.

Geodetic Control - A system of horizontal and/or vertical control stations that have been established and adjusted by geodetic methods and in which the size and shape of the Earth have been considered in position computations.

Geodetic Coordinates - The quantities of latitude, longitude, and ellipsoid height, which define the position of a point on the Earth's surface with respect to a reference ellipsoid.

Geodetic Height - See ellipsoid height.

Geodetic Latitude - The angle between the plane of the equator and the normal to the ellipsoid through the computation point.

Geodetic Longitude- The angle between the plane of the geodetic meridian and the plane of the prime meridian. A geodetic longitude can be measured by the angle at the pole of rotation of the reference ellipsoid between the local and initial meridians, or by the arc of the geodetic equator intercepted by those meridians.

Geodetic Meridian - A line on a reference ellipsoid which has the same geodetic longitude at every point.

Geographic Coordinates - The quantities of latitude and longitude which define the position of a point on the surface of the Earth with respect to the reference ellipsoid.

Geoid - The equipotential surface in the gravity field of the Earth which coincides with the undisturbed mean sea level extended continuously through the continents. The direction of gravity is perpendicular to the geoid at every point. The geoid is the surface of reference for astronomic observations and for geodetic leveling.

Geoid Separation - The distance between the geoid and the reference ellipsoid measured along a line that is perpendicular to the ellipsoid. The distance is positive if the geoid is outside (above) the ellipsoid. Also called geoid height or undulation of the geoid.

Graticule - A network of lines representing the Earth's parallels of latitude and meridians of longitude.

Great Circle - A great circle is a circle, the plane of which passes through the center of a sphere or ellipsoid.

Greenwich Mean Time - Mean solar time at the meridian of Greenwich, England, used as a basis for standard time throughout the world also called GMT.

Greenwich Meridian - The meridian of longitude through Greenwich, England; serving as the reference for Greenwich time, in contrast with local meridians. It is accepted, almost universally, as the prime meridian or the origin of measuring longitude.

Greenwich Time - Time based upon the Greenwich meridian as reference, as contrasted with that based upon a local or zone meridian. Greenwich Time is referred to as Zulu Time.

Grid - Two sets of parallel lines intersecting at right angles and forming squares. When oriented with a map projection, the grid is used to determine grid coordinates.

Grid Convergence - The angular difference between the meridian of a point located within a plane grid system (such as universal transverse mercator grid) and a line which is parallel to the central meridian of that grid and passing through the point.

Grid Coordinates - Numbers and letters of a two dimensional coordinate system which designate a point on a gridded map, photograph, or chart.

Grid North - The northerly or zero direction of a grid oriented with a projection. Grid north in one grid system may not be the same direction as in another grid system.

Grid Zone - An arbitrary division of the Earth's surface designated for identification without reference to latitude or longitude.

Height - The vertical distance of an object or point above a reference plane.

Height of Instrument - The height of the center of the telescopic alidade above the ground or station mark.

Horizon - The horizon for any place on the surface of the Earth is the great circle formed on the celestial sphere by the extension of the plane of the observer's horizon. In general, the apparent or visible junction of Earth and sky as seen from any position.

Horizontal Angle - In artillery survey the angle formed by the intersection of the line between the occupied station and rear station and the line between the occupied station and the forward. This angle is measured from the rear station to the forward station.

Horizontal Control - A network of stations of known geographic or grid positions referred to a common horizontal datum.

Hour Angle - The time elapsed since the upper transit of a celestial body. It is the angle between the observer's meridian and the hour circle of the celestial body, measured positive westward from the meridian.

Hour Circle - Any great circle on the celestial sphere whose plane is perpendicular to the plane of the celestial equator.

Intersection - The procedure of determining the horizontal position of an unoccupied point by direction observations from two or more known positions.

Inversion - An increase of air temperature with increase in altitude (the ground being colder than the surrounding air). When an inversion exists, there are not convection currents and wind speed are below 5 knots. The atmosphere is stable and normally is considered the most favorable state for ground release of chemical agents.

Ionosphere - The region of the Earth's atmosphere between the stratosphere and the exosphere approximately 50 to 250 miles above the surface of the earth.

Ionospheric Refraction Delay - Delay in the propagation of the GPS signal caused by the signal traveling through the ionosphere.

Isobar - A line of constant pressure.

Isobaric - Means of equal or constant pressure.

Isotherm - A line of constant temperature.

Kestrel – Hand held wind and weather meter.

Lapse Rate - The rate at which temperature changes with altitude.

Latitude - The angular distance, for a specific spot on the surface of the Earth, from 0° to 90° north or south of the equator.

L-band - Radio frequency band from 390 MHz to 1550 MHz. The primary L-band signal radiated by each NAVSTAR satellite is L1 at 1575.42 MHz. The L1 beacon is modulated with the C/A and P-codes, and with the NAV message. The L2 signal is centered at 1227.50 MHz and is modulated with the P-code and NAV message.

Leveling - The operations of measuring vertical distances to determine elevations.

Local Datum - The point of reference for geodetic control used exclusively in a small area. Usually identified by a proper name.

Local Time - Time based on the local meridian as reference, as contrasted with time based upon a time zone meridian or the meridian of Greenwich.

Lock - The state of non-interruption in the reception of a radio signal.

Loran - A long-range radio navigation position fixing system using the time difference of reception of pulse type transmissions from two or more fixed positions.

Longitude - The angular distance, for a specific spot on the Earth, from 0° to 180° east or west of the Greenwich meridian, which is used by most nations as the prime or initial meridian.

Magnetic Declination - The angle between the magnetic and geographical meridians at any place, expressed in degrees east or west to indicate the direction of magnetic north from true north. In nautical and aeronautical navigation, the term magnetic variation is used instead of magnetic declination and the angle is termed variation of the compass or magnetic variation.

Magnetic North - The direction indicated by the north seeking pole of a freely suspended magnetic needle, influenced only by the Earth's magnetic field.

Magnitude - Relative brightness of a celestial body. In artillery survey, there are 73 (Sun not included) accepted survey stars. Sirius (star #25) is the brightest of those stars with a magnitude of -1.6; Octanis (star #69) is the dimmest of those stars with a magnitude of +3.7.

Map - A graphic representation of the Earth or a part of the Earth at an established scale, projected on a plane surface.

Map Projection - A systematic drawing of lines on a plane surface to represent parallels of latitude and meridians of longitude of the Earth or of a section of the earth. The type of map projection used is dependent upon the purpose of the map.

Map Scale - The ratio or fraction between the distance on a map or chart and the corresponding ground distance. Military maps are usually classified as one of three types: Large scale maps have a scale of 1:75,000 or larger, medium scale maps have a scale that is larger than 1:600,000 and smaller than 1:75,000, small scale maps have a scale of 1:600,000 or smaller. Standard scales for military maps are specified in STANAG 3677.

Map Sheet - An individual map or chart, usually part of a series.

Marginal Data - All explanatory information given in the margin of a map or chart which clarifies, defines, illustrates, and/or supplements the graphic portion of the map sheet. Marginal data requirements for military maps and charts are specified in STANAG 3676.

Mean Sea Level - The average height of the surface of the sea for all stages of the tide; used as a reference (datum) for elevations and closely resembles the geoid.

Mercator Map Projection - A conformal map projection of the cylindrical type. This projection depicts the equator as a straight line true to scale. The meridians of longitude are represented by evenly spaced parallel lines set perpendicular to the equator. The parallels of latitude are depicted as a set of lines placed perpendicular to the meridians and therefore parallel to the equator. Conformity is maintained by increasing the space between the parallels of latitude as they increase in distance from the equator.

Meridian - A north-south reference line, particularly a great circle, through the geographical poles of the Earth, from which longitudes and azimuths are determined.

Meteorological Datum Plane - The altitude of the meteorological measuring station from which all meteorological computations are based.

Meteorological Day - A 24-hour day divided into three periods - night, afternoon, and transition.

Meteorological Data - Measurements or observations of meteorological variables.

Meteorology - The science dealing with the earth's atmosphere and its phenomena, including weather and climate.

Military Grid Reference System - A system used to accurately identify the unique position of a point on the Earth’s surface. This system is designed for use with the universal transverse mercator and UPS grid systems.

Millibar - A unit of atmospheric pressure.

Multipath - A phenomenon similar to “ghosts” on a television screen; whereby GPS signals from a satellite arrive at an antenna after having traversed different paths. The signal traversing the longer path may have been reflected off one or more objects (i.e., the ground, water, building, etc.) and once received by the antenna will result in a larger pseudo-range estimate and increase the error. Multipath usually results in multipath error.

Nadir - That point where the extension of the plumb line beneath the observer intersects the celestial sphere.

National Geodetic Reference System - A system of common or relative survey control points throughout the United States and Puerto Rico as adjusted by the National Geodetic Survey.

Navigation Data - The 1500-bit navigation message broadcast by each satellite at 50 bps on both the L1 and L2 beacons. This message contains system time, clock correction parameters, ionospheric delay model parameters, and the satellite vehicle’s ephemeris and health. This information is used to process GPS signals and obtain user position and velocity. Can be referred to as the navigation message, satellite message, or the D-code.

NAVSTAR - Navigation satellite timing and ranging. NAVSTAR is the name given to GPS satellites, originally manufactured by Rockwell International.

Neat Lines - The lines that bound the body of a map; usually parallels and meridians, they can sometimes be conventional or arbitrary grid lines.

Normal - A straight line that is perpendicular to a surface or to another line.

Northing - A northward (bottom to top) reading of grid values on a map.

Oblate Ellipsoid - An ellipsoid whose shorter axis is the axis of rotation. All current reference ellipsoids are oblate.

Observations - Actual measurements of meteorological conditions, as opposed to predicted or interpolated values. Referred to as real-time meteorological observations.

Observer's Meridian - The great circle on the celestial sphere that passes through both celestial poles, and the observer's zenith.

Offset - The difference in distance and azimuth from a tracking point to the point of release of a sounding or pilot balloon.

Open Traverse - A traverse which begins from a station of known or assumed position, but does not end on such a station. This procedure allows no verification of fieldwork or starting control.

Orienting Line - A line of known azimuth between two points on the ground.

Orthometric Height - See elevation.

Parallax - The difference in altitude of a body as seen from the center of the Earth, and from a point on the surface of the Earth. There is no apparent parallax of the fixed stars, but that of the sun and planets is measurable. Parallax makes the body appear lower than it actually is; therefore, the correction is added.

Parallel - A circle on the surface of the Earth or ellipsoid, parallel to the equator, which connects all points of equal latitude.

Parameter - A quantity to which arbitrary values may be assigned, such a temperature, density, or pressure values.

Phase Measurement - A measurement expressed as a percentage of a portion of an entire wave (e.g., a sine wave). For example, a complete wavelength is 100%, one-half is 50%.

Pilot Balloon - A small balloon whose ascent is followed by a theodolite to obtain data for computing speed and direction of winds in the upper air.

Polar Distance - The side of the PZS triangle from the celestial north pole to the celestial body. The polar distance is determined by algebraically subtracting the declination of the body from 90° (1600 mils).

Polaris - The second magnitude star, Alpha, in the constellation Ursa Minor (Little Dipper). In artillery survey, it is the recommended star for astronomic observations. It is listed as star #10 and has a magnitude of 2.1. Polaris is called the North Star.

Porro Prism - A prism which has two reflecting surfaces at right angles to each other. It deviates the axis 180° and inverts the image in the plane in which the reflection takes place.

Precipitation - The form of water, either liquid or solid, that falls from the atmosphere, and which reaches the ground.

Precise Code (P-Code) - A sequence of pseudo- random binary biphase modulations on the GPS carriers L1 and L2 at a chipping rate of 10.23 MHz which repeats every 267 days. It is divided into 37 one-week segments, five of which are used by the ground segment and the other 32 are available for satellite vehicles. Therefore, each satellite vehicle has a unique one-week segment code which is a subset of the overall P(Y) code sequence.

Precise Ephemeris - The ephemeris computed after the transmission of the satellite signal and based on satellite tracking information. The broadcast ephemeris tells where the satellite is expected to be, and the precise ephemeris is where the satellite actually was.

Precise Positioning Service - Dynamic positioning of a single receiver based on the P-code. Currently, PPS is the most accurate dynamic positioning service offered with GPS. In general, a receiver can only be considered a PPS receiver if it can use the encrypted Y-code, and negate S/A also called **PPS**.

Precision - How close a group or sample of measurements are to each other. A group of measurements will have high precision and low accuracy if the measurements are close together yet not close to a standard or true measurement. High precision is indicated by a low standard deviation.

Pressure Gradient - The spacing between lines of constant pressure, or isobars.

Prime Meridian - The meridian of 0° longitude, used as the origin for measurement of longitude. Also called the Greenwich meridian.

Prime Vertical - The vertical circle that is perpendicular to the plane of the observer's meridian and intersects the celestial horizon at the points directly true east and west of the observer's meridian.

Projectile - Any object projected by exterior force and continuing in motion by its own inertia.

Projection - The extension of lines or planes to intersect a given surface; the transfer of a point from one surface to a corresponding position on another surface by graphical or analytical methods.

Pseudo-Random Noise - When used as a description of code, it indicates that the code has some random noise-like properties. Each GPS satellite has a unique PRN number assigned to it. Also called **PRN**.

Pseudo-Range - The time shift required to align a replica of a GPS code generated in the receiver with the code received from the satellite, scaled into distance by the speed of light. The time shift is the difference between the time of signal reception and the time of signal transmission where the reception is measured in the receiver time reference and the transmission is measured in the satellite time reference. Therefore, the pseudo-range contains several errors including satellite/receiver time offset and satellite ephemeris error.

Psychrometer - An instrument used for measuring atmospheric humidity that consists of a dry-bulb thermometer and a wet-bulb thermometer.

Radial Error - See error of closure, (3).

Random Error - Those errors not classified as blunders, systematic errors, or periodic errors. They are numerous, individually small, and each is as likely to be positive as negative.

Reference Ellipsoid - A mathematical figure used to closely approach the dimensions of the geoid in the section of the Earth's surface being considered.

Refraction - The refraction of a celestial body is the apparent displacement of the body caused by the bending of light rays passing through the Earth's gravitation, and layers of varying air density. The celestial body will appear higher than it actually is; therefore, the correction is subtracted.

Relative Humidity - The ratio of the actual vapor pressure of the air to the saturation vapor pressure, usually expressed in percent.

Resection—The determination of the horizontal position of a station by observed directions from that station to points with known positions.

Residual - A general term denoting a quantity remaining after some other quantity has been subtracted. For example, if the true value of a measurement is subtracted from the observed value, the difference can be called a residual; it is often referred to as an error.

Reticle - A system of wires, hairs, etched lines, or the like, placed normal to the axis of a telescope at its principle focus, by means of which the telescope is sighted on a target, or by means of which readings are made on some scale such as a leveling or stadia rod.

Revolution - The turning of a body about an exterior point or object. The Earth revolves around the sun on a 600 million mile orbit at a speed of about 18.5 miles per second.

Right Ascension - The arc on the celestial equator measured from the vernal equinox eastward to the hour circle of the body. It is measured in units of time from 0 to 24 hours. Right ascension roughly corresponds to longitude on Earth.

Root Mean Square - See Standard Deviation.

Rotation - The turning of a body on its axis. The body usually rotates around its north-south axis; the Earth rotates from west to east.

Scale Factor - A multiplier for reducing a distance from a map to the actual distance on the datum of the map. Scale factor is dependent on the map projection.

Secant - A line that intersects a geometric curve or surface at two or more points. For example, a cone that is secant to an ellipsoid, intersects the ellipsoid at two different parallels of latitude.

Selective Availability - The DOD policy of intentionally degrading the accuracy of the C/A-code.

Semi-Major Axis - One-half of the longest diameter of an ellipse.

Semi-Minor Axis - One-half of the shortest diameter of an ellipse.

Sidereal Time - Time determined by the stars. A sidereal day is 3 minutes and 56 seconds shorter than a 24-hour day.

Single Differencing - See differencing.

Solar Time - Time determined by the sun. A solar day is 24 hours in duration.

Solstice - The solstice occurs at two points on the ecliptic midway between each equinox. When the ecliptic is north of the celestial equator, the midpoint is called the summer solstice and occurs about 21 June. When the ecliptic is south of the celestial equator, the midpoint is called the winter solstice and occurs about 21 December. The solstice occurs when the Sun is at its greatest distance north or south of the equator.

Sounding - Upper-air meteorological data gathered by sensors and transmitted to a ground receiver by the radiosonde carried aloft by a balloon.

Sounding Balloon - A free unmanned balloon carrying a radiosonde to sound the upper air.

Space Segment - The portion of the GPS system with the major components in space; consists mainly of the satellites.

Spherical Coordinates - A coordinate system used to locate points on the celestial sphere. The two systems currently in use are the horizon and equator systems. Artillery surveyors use the equator system. The origin for this system is the vernal equinox and the celestial equator. See celestial coordinates.

Spheroid - See ellipsoid.

Spot Elevation - A point on a map or chart whose elevation is noted, usually not monumental.

Standard Ballistic Density - The density of the air as defined by the International Civil Aviation Organization standard atmosphere; density of 100 percent.

Standard Deviation – (1) The range of how close the measured values are from the arithmetic average. A low standard deviation indicates that the measurements or observations are close together. **(2)** The square root of the quantity obtained by dividing the sum of the squared errors by the number of errors minus one.

Standard Positioning Service - Positioning of a single receiver based on the C/A-code.

State Plane Coordinate System - The plane- rectangular coordinate systems established by the National Geodetic Survey, one for each state in the US, for use in defining positions of geodetic stations in terms of plane-rectangular (X, Y) coordinates.

Station Pressure - Surface pressure at the observing station; the atmospheric pressure computed for the level of the station elevation.

Surface Wind - The wind speed and direction as measured at the surface with an anemometer.

Survey - The act or operation of making measurements for determining the relative positions of points on, above, or beneath the Earth’s surface.

Switching Channel - A channel that is sequenced through a number of satellite signals at a rate that is slower than and asynchronous with the message data rate.

Systematic Error - See accumulative error.

Tangent - A line, curve, plane or other geometric figure that touches another geometric figure in only one point.

Theodolite - A precision instrument consisting of an alidade with a telescope. It is mounted on an accurately graduated circle and is equipped with necessary levels and reading devices. Sometimes the alidade includes a graduated vertical circle. Is used to measure azimuth and elevation angles.

Thermistor Temperature - The temperature measured by the temperature element (thermistor) on a radiosonde.

Time Zone - An area in all parts of which the same time is kept. In general, the world is divided into 24 time zones, each 15° wide and centered on a meridian whose longitude is evenly divisible by 15. In many areas of the world, political time zones are observed which means that the standard time zone has been expanded to cover the entire political boundary of the area.

Topographic Map - A map which presents the vertical position of features in measurable form as well as their horizontal positions.

Total Lift - The weight (grams) of the balloon with attachments that must be balanced by the gas volume in the inflated balloon for the balloon to rise at a desired rate of ascent.

Trajectory - The path of a projectile in the earth's atmosphere.

Traverse - A method of surveying in which distances and azimuths between stations are determined for use in the computations of the positions of the stations.

Triangulation - A method of surveying in which interior angles of single or adjacent triangles are measured to determine the position of stations located at the vertices of each triangle.

Trigonometric List - A list of essential information of accurately located survey control points, both horizontal and vertical. For military units, guidance for these listings is provided in STANAG 2210.

True North - The direction from an observer's position to the geographical North Pole. The north direction of any geographic meridian.

Undulation - The dips and swells that are the surface of the geoid.

Universal Time - Standard universally accepted time based on the Greenwich meridian.

Universal Transverse Mercator Grid - A military grid system based on the transverse mercator map projection. Applied to maps between the latitudes of 84° N and 80° S.

User Equivalent Range Error - A term for GPS measurement accuracy which represents the combined effects of ephemeris uncertainties, propagation errors, clock and timing errors, and receiver noise. A high UERE may indicate that S/A has been imposed on the satellite. Also called **UERE**.

User Segment - The portion of the GPS system that is directly interfaced by the user; mainly GPS receivers.

Vertical Dilution of Precision - See DOP.

Vector - See baseline.

Vernal Equinox - The imaginary point on the celestial sphere where the apparent annual path of the sun crosses the celestial equator moving from south to north. The point from which right ascension is measured.

Vertical - The line perpendicular to the geoid at any point. It is the direction of which the force of gravity acts.

Vertical Angle – (1) An angle in a vertical plane. **(2)** A vertical angle can be either the angle formed between the zenith and a line to a point (zenith distance) or the angle formed between the horizon and a line to a point (altitude). The zenith distance and altitude are complimentary angles. In artillery survey the second is used. Our instruments provide a zenith distance which we have termed the vertical reading. This reading is applied to 1600 mils (4800 mils in reverse mode) to compute the vertical angle.

Vertical Circle - Any great circle on the celestial sphere that passes through the observer's zenith-nadir.

Weather Information - Information concerning the state of the atmosphere, mainly with respect to its effects on the military; data and information concerned with forecasts, summaries, and climatology.

Weighing Off - A balloon inflation procedure when using an inflation shelter which involves inflating the balloon with attached weights in the inflation shelter until it just lifts off the ground and remains suspended in air.

Wind Chill - That part of the total cooling of a body caused by air motion.

World Geodetic System - One of several Earth- centered Earth-fixed ellipsoid/datum systems which positions its origin at the center of the Earth's mass. Designed by the DoD to replace local datums, WGS- 84 is the current system in use. Also called **WGS**.

X-axis – (1) In a system of plane rectangular coordinates, the x-axis is the line on which distances to the right or left (east or west) of the reference line are marked and measured. **(2)** In a three dimensional system (i.e., Cartesian coordinates) the x-axis is the line that lies perpendicular to the y-z plane and intersects that plane at its origin. An x-coordinate is the length of a line in the x-y plane that is parallel to the x-axis and measured from the y-z plane.

Y-axis – (1) In a system of plane rectangular coordinates, the y-axis is the line on which distances above or below (north or south) of a reference line are marked and measured. **(2)** In a three dimensional system (i.e., Cartesian coordinates) the y-axis is the line that lies perpendicular to the x-z plane and intersects that plane at its origin. A y-coordinate is the length of a line in the x-y plane that is parallel to the y- axis and measured from the x-z plane.

Z-axis - In a three dimensional coordinate system (i.e., Cartesian coordinates), the z-axis is the line that lies perpendicular to the x-y plane and intersects that plane at its origin. The z-axis coincides with the rotational axis of a reference ellipsoid. A z-coordinate is the length of a line that is parallel to the z-axis and is measured from the intersection of the x-coordinate and y-coordinate to a point on the surface of the Earth.

Zenith - The point where the extension of the plumb line overhead intersects the celestial sphere.

Zenith Distance - A vertical angle measured from the zenith to a point or object.

Zenith-Nadir - The zenith and nadir for any place on the surface of the Earth are two points where an extension of the observer's plumb line intersects the celestial sphere. The zenith is the point directly overhead, the nadir is the point directly below.

APPENDIX H. REFERENCES AND RELATED PUBLICATIONS

MARINE CORPS WARFIGHTING PUBLICATIONS (MCWP)

5-10	Marine Corps Planning Process

MARINE CORPS TACTICAL PUBLICATION (MCTP)

3-10E	Artillery Operations

MARINE CORPS REFERENCE PUBLICATIONS (MCRP)

3-10E.3 (FM 6-50)	Tactics, Techniques, and Procedures for Field Artillery Cannon Battery
3-10E.4	Tactics, Techniques, and Procedures for Field Artillery Manual Cannon Gunnery
3-10E.7	Tactics, Techniques, and Procedures for Field Artillery Target Acquisition

MARINE CORPS TECHNICAL/OPERATORS MANUALS

TM 11138A-OR	Operators Manual Ground Counter Fire Sensor
TM 11039A-OR/1&P	Improved Position and Azimuth Determining System (IPADS-G)
TM-09880-OR	DAGR Operator’s Pocket Guide
TM 09880-OI	Operator and Maintenance Manual Defense Advanced GPS Receiver (DAGR) Satellite Signals Navigation Set
TM 00476C-10/1	Operator and Field Maintenance Manual for Aiming Circle with Equipment M2A2

NATIONAL IMAGERY AND MAPPING AGENCY (NIMA)

DMA TM 8358.1	Datums, Ellipsoids, Grids, and Grid Reference Systems
NIMA TR 8350.2	Department of Defense (DOD) World Geodetic System 1984 (WGS 84), Definitions and Relationships with the Local Geodetic Systems
NIMA TR 8350.2 (Addendum)	Implementation of the World Geodetic System 1984 (WGS 84) Reference Frame G1150

FEDERAL GEODETIC CONTROL SUBCOMMITTEE MANUALS

Geometric Geodetic Accuracy Standards and Specifications

Standards and Specifications for Geodetic Control Networks

CRATER ANALYSIS AND REPORTING

Defense Intelligence Agency Projectile Fragment Identification Guide, DST-1160-G-029-85, with Change 1

STANDARDIZATION AGREEMENT (NATO) (STANAG)

2210	Digital Geodetic Data for List of Geodetic Data (TRIG LIST) and Position Information Graphic (PIG) Production
2211	Geodetic Datums, Projections, Grids and Grid References
3676	Marginal Information On Land Maps, Aeronautical Charts And Photomaps
3677	Standard Scales For Land Maps And Aeronautical Charts