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Marine Artillery Survey

United States Marine Corps
DEPARTMENT OF THE NAVY
Headquarters United States Marine Corps
Washington, DC 20380-0001

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???DATE???

FOREWORD

1. PURPOSE

Marine Corps Warfighting Publication (MCWP) 3-16.7, *Marine Artillery Survey*, provides the doctrinal foundation for and sets forth the techniques and procedures for employing Marine Corps survey assets and personnel on the modern battlefield.

2. SCOPE

This manual is intended as a training and field reference and as a study guide for all personnel involved in artillery survey operations. It is designed to cover a broad spectrum of survey issues ranging from general knowledge to survey equipment and survey planning. This manual does not replace the FM 6-2; however, it does supercede the FM 6-2 in cases of Marine specific organization, doctrine, and equipment.

3. SUPERSESSION

None.

4. CHANGES

Recommendations for improving this manual are invited from commands as well as from individuals. Forward suggestions using the User Suggestion Form format to :

Commanding Officer
Marine Corps Artillery Detachment
USAFAS
759 McNair Avenue
Ft. Sill, Oklahoma 73503-5600

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5. CERTIFICATION

Reviewed and approved this date.

BY DIRECTION OF THE COMMANDANT OF THE MARINE CORPS

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Commanding General
Marine Corps Combat Development Command
Quantico, Virginia

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MCWP 3-16.7

USER SUGGESTION FORM

From:

To: Commanding Officer, Marine Corps Artillery Detachment, USAFAS, 759 McNair Avenue, Ft. Sill, Oklahoma 73503-5600

Subj: RECOMMENDATIONS CONCERNING MCWP 3-16.7, *MARINE ARTILLERY SURVEY*

1. In accordance with the Forward to MCWP 3-16.7, which invites individuals to submit suggestions concerning this MCWP directly to the above addressee, the following unclassified recommendation is forwarded:

Page	Article/Paragraph	Line No.	Figure/Table No.

2. Proposed new verbatim text: (double-spaced; continue on additional pages as necessary.)

3. Justification/source: (Need not be double-spaced)

Note: Only one recommendation per page.

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RECORD OF CHANGES

Change No.	Date of Change	Date of Entry	Organization	Signature

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MARINE ARTILLERY SURVEY

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CHAPTER 1
MISSION, ORGANIZATION, AND DUTIES

The missions, responsibilities, and duties of the Marine artillery surveyor are as varied as those of the Marine Corps. In some cases, these missions, responsibilities, and duties are specified by Standard Operating Procedures (SOP). This chapter will provide guidance for the organization and operations of a survey section.

Section I
MISSION

1-1 Common Grid

a. General. The mission of the Marine artillery surveyor is to provide a common grid. This means that all fire support and targeting assets are oriented the same with respect to azimuth, position, and elevation, to a prescribed accuracy.

b. The establishment of a common grid is a command responsibility.

c. To provide a common grid is to provide data to the required accuracy which will permit:

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.

Delivery of surprised observed fires: Accurate and timely fires against enemy positions with no adjustment from targeting assets (i.e.. FOs, radar). If fires must be adjusted, the element of surprise is lost.

Delivery of effective unobserved fires: Effective and timely fires against enemy positions which are not observed (i.e. group and series targets, prep fires). Without survey, unobserved fires can only be effective if the target had been previously fired upon.

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.

Allow a firing unit to carry a registration forward to a new position: This is necessary when moving a battery from one primary position to another as well as when moving to an alternate or supplementary position. A common grid is also required between a firing position and an offset registration point.

d. Common grid does not apply only to the artillery, it must be established throughout the battlefield and constantly maintained for use by all fire support assets.

1-2 Components of a Common Grid

a. General. A common grid is the sum of all components of relative survey, as well as the geodetic system, coordinate system , and the projection/grid system of the operational area.

b. Geodetic System. A geodetic system consists of both a horizontal and vertical datum. In contingency terms, they may be referred to as operational datums. Operational datums must be listed in the operations order for any operation, whether a training exercise or an actual contingency.

1. **Operational Horizontal Datum.** The selection of an operational horizontal datum must be made at the highest possible level with the guidance of survey personnel. Because the US Navy and US Air Force operate solely in WGS-84, all joint operations must be conducted in that datum. Otherwise, the selection of the operational datum should made with consideration directed towards datums on available mapping products, programmed datums/ellipsoids in the fire support assets (i.e.. BCS, PADS, PLGR, IFSAS, etc.), and datum transformation capabilities of the units and equipment.

2. **Operational Vertical Datum.** The operational vertical datum, while not as important as the horizontal datum, must be considered and selected at the highest possible level; again, with the guidance of survey

personnel. This selection is very important to ground elements using GPS receivers. While most receivers can provide Mean Sea Level (MSL) data from the measured ellipsoid height, they do not have the ability to provide local vertical datums (i.e.. Mean Low Water, Panama Canal Lock Datum, etc.). Also, many mapping products are not produced using MSL. Mean Sea Level should be the selected vertical datum; however, if mapping products and local survey control are of a different reference, surveyors in the area must produce conversion constants for small regions in the operational area. The important thing is to ensure that all personnel, not just the artillery, are using the same reference for elevation.

c. Coordinate System. The coordinate system used is generally not a major concern in terms of common grid. Most fire support systems are programmed to operate in geographic coordinates or the UTM/UPS grid systems. Most military maps are produced in those systems. Several things must be known about the coordinate systems being used:

1. Geographic coordinates are the most commonly used coordinate system and several types of geographic systems exist. More importantly, the Greenwich Meridian is not the only reference for 0° longitude. For example, some systems reference the Paris Meridian as 0° longitude. If the Greenwich Meridian is not referenced as 0° longitude, then a grid system other than UTM or UPS must be used. In these cases, surveyors must produce UTM/UPS overlays to be reproduced for use by all personnel and fire support assets to ensure a common grid.

2. A grid system is applied to a map projection; a map projection is oriented on a reference ellipsoid by means of some three-dimensional coordinate system, usually geographic coordinates. Therefore, the coordinate system in some ways determines the projection and grid system used.

3. A horizontal datum can be fixed to the surface of the ellipsoid at a specific location and orientation. This location (datum point) is generally defined in terms of geographic coordinates.

d. Projection/Grid System. Most current fire support systems are designed to operate solely in the Transverse Mercator Projection with either geographic coordinates or the Universal Transverse Mercator (UTM) Grid System. Some can operate in the Polar Stereographic Projection with either geographic coordinates or the Universal Polar Stereographic (UPS) Grid System. In many areas, the mapping products will be produced in other projections or grids not available in fire support systems. (e.g., Tunisia is currently mapped in Lambert Projection with a Lambert type grid system.) The surveyor must produce overlays in a usable system, to ensure a common grid exists over the entire battlefield.

e. Relative (Common) Survey. Relative survey means that all points (stations) of concern are common or relative to each other. This can happen in several ways.

1. All stations surveyed in the same network, regardless of the survey methods used, are relative to specific points. Those points being the known control used to fix and adjust those networks.

2. Stations surveyed from other points which have already been listed as common are relative to those stations within that unit's specified level of accuracy. In other words, if a battalion survey section establishes a battery position (OS and EOL) from 4th order or higher common control, the battery position is common to the higher order control, but at a 5th order accuracy.

3. All stations surveyed from a point whose location was obtained by hasty methods (map spot, hasty resection) or from absolute methods (4000 MSGR, PLGR) are common to that point; however, they are not common to any local control.

4. Stations not already common to another network can be made common by adjustment, or by conversion to common control calculations (see Chapter 13).

5. In order for two stations to be considered common, they must meet the requirements of paragraphs b-e above. They must be referenced to the same datum/ ellipsoid, be developed from the same map projection, and the grid system and/or coordinate system must be the same between the points. Furthermore, they must either be from the same network or have been adjusted or converted to the same network.

1-3 Fundamentals of Survey Operations

The end product of all survey operations must be to ensure common survey is provided to supported units throughout the battlefield. The fundamentals of survey: Planning, Coordination, Fieldwork, and Computations, must lead to that end.

Chapter 1

Chapter 2 **Planning.** Survey planning begins with understanding the maneuver commander's intent and receiving the fire support coordinator's guidance. Then

thorough map and ground reconnaissance is conducted. During planning, full consideration is given to the commander's concept of operations, priorities, the tactical situation, survey control available, desired accuracy, number of installations, terrain, weather, personnel and time available. The commander is responsible for the establishment of a common grid and hence the accomplishment of the survey mission. Therefore, he must be kept informed. Aggressive survey planning that answers the questions who, what, where, when, why, and how is absolutely essential to mission success. Survey planning is discussed in Chapter 5.

Coordination. Coordination and planning originate at the Combat Operations Center (COC). The Survey Information Center (SIC) is the liaison with the topographic surveyors and non-artillery units requiring survey control. The coordination and planning effort at the COC is conducted by the highest echelon artillery survey officer in the area of operations. The survey plan is further coordinated with the next lower echelon survey officer and any survey officers with higher or adjacent commands as needed.

Fieldwork. Survey fieldwork is performed by the survey section using the methods and equipment necessary to extend common survey throughout the command's area of responsibility, as directed by the survey plan. Fieldwork must be started immediately upon receipt of the survey order, and be continuously and aggressively pursued until completion of the survey plan.

Computations. Survey computations and fieldwork are performed simultaneously. Computations are the use and calculations of all data needed to convert the fieldwork to usable positions, elevations, and azimuths. This includes computations of conventional surveys, updating and adjusting PADS data, calibrating kinematic GPS data, and adjusting static GPS data.

1-4 Echelons of Survey

a. General. The authorized level of survey for a survey section is driven solely by the section's mission. Three echelons of artillery survey exist: regimental, battalion, and battery. Three accuracy levels also exist: fourth, fifth, and hasty.

b. Regimental Survey.

1. The primary mission of regimental surveyors is to ensure a common grid over the division area. This includes establishing initial control, recovery of existing control, and conversion to common control over stations not in the division network. The artillery regiment's survey section is the division's survey asset.

2. The regimental survey section will normally perform fourth order surveys. In some cases they will be required to establish fifth order survey control for units not already covered by a battalion survey section or for units attached to the regiment.

3. The regimental survey section is responsible to establish permanent survey control markers when necessary.

4. A Survey Information Center is established and maintained by the regimental survey section, in order to provide required data for lower echelon survey sections to conduct their survey missions.

c. Battalion Survey.

1. The primary mission of battalion surveyors is to ensure common control over the artillery battalion's area of operations. This includes providing control to all units organic or attached to the battalion. In some cases, the battalion survey section may be tasked to provide control to units requiring survey who are not attached to the battalion, but are operating within the battalion's area. Due to their wide ranging and independent operating nature the battalion survey section is also the artillery battalion's reconnaissance element.

2. The battalion survey section will normally perform fifth order surveys. When a battalion is operating independently from the artillery regiment, as with a Marine Expeditionary Force - Forward (MEF-Fwd), they may be required to establish some limited fourth order control based on the requirements of the system being surveyed. Normally the battalion survey mission requires a more timely response than is afforded with fourth order work. If a regimental survey section is included in a follow-on force, all fourth order work performed by the battalion must be provided to the regimental section for inclusion in their network.

3. The battalion survey section will not establish permanent survey control unless it is absolutely essential to the mission.

d. Battery Survey.

1. The primary mission of the battery's surveyors is

to provide survey control inside the battery position when higher echelon survey is not already available or to carry control from one battery position to another. This second position could be used as an alternate/ supplemental position or for split battery operations.

2. The battery's surveyors will only perform hasty surveys. These surveys should eventually be upgraded by higher echelon surveyors when mission requirements permit.

1-5 Survey Accuracy Levels

a. General. Three accuracy levels exist for artillery surveyors. Figure 1-1 shows survey accuracy levels as designated by the National Geodetic Survey (NGS) and the National Imagery and Mapping Agency (NIMA) as well as the three artillery levels.

b. Geodetic Control Surveys. 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 Sub-committee (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.

c. Artillery Survey.

1. **Relative Position Accuracy.** A relative accuracy value (Accuracy Ratio) can be determined to show the position accuracy for a survey network. Accuracy ratio (AR) is the ratio between the position error and the total length of a survey. It shows the survey length necessary to produce 1 meter of position error in a given survey and is expressed as a fraction with 1 as the numerator and the survey length producing that error as the denominator. Required accuracy ratios for artillery surveys are described below.

a. **Fourth Order.** Fourth order survey is considered accurate to 1 meter error for every 3000 meters surveyed (1/3000).

b. **Fifth Order.** Fifth order survey is considered accurate to 1 meter error for every 1000 meters surveyed (1/1000).

c. **Hasty Survey.** Hasty survey is considered accurate to 1 meter error for every 500 meters surveyed.

2. **Relative Azimuth Accuracy (4th order).**

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

b. An azimuth of a line in a 4th order survey that, from its point of origin at a 4th order astronomic azimuth or higher order direction, has depreciated in accuracy by a probable error value of 0.030 mils per main scheme angle (using a T-2E); or the azimuth of a line computed between two 4th order or higher survey control points is considered accurate to 4th order standards. The computed azimuth is considered accurate to 0.300 mils.

3. **Relative Azimuth Accuracy (5th order).**

a. Fifth order astronomic azimuths are established by astronomic observations, the probable error of which does not exceed 0.12 mils. The considered accuracy is 0.300 mils

b. An azimuth of a line in a 5th order survey that, from its point of origin at a 5th order astronomic azimuth or higher order direction, has depreciated in accuracy by a probable error value of 0.030 mils per main scheme angle (using a T-2E); or the azimuth of a line computed between two 4th order or higher survey control points is considered accurate to 5th order standards. **A 5th order azimuth cannot be obtained by computations between a 5th order point and a point of equal or higher order.**

c. Probable Error Values. For some systems or survey methods (i.e.. PADS, GPS), probable error values are used to describe the accuracy. These values are generally used to express absolute accuracy; however, depending on the system and the survey method, they can be used to describe a relative (common) accuracy.

1. These values may be given in terms of Circular Error Probable (CEP), Probable Error (PE), or various standard deviation values (i.e.. 2DRMS, 3 sigma, etc.). These probable error values are described in paragraph 4-9 (Absolute GPS Accuracy).

2. These values are expressed in terms of percentage of probability or confidence that the position given is located within a line, circle, or sphere of a given size.

Figure 1-1 Distance Accuracy an Accuracy Ratio Standards

3. PE and CEP are derived from the positive standard deviation of the measurement (sigma-σ) as follows:

a. PE = 0.6745σ

b. CEP = 1.1774σ

c. CEP = 1.7456 PEσ

1-6 Survey Requirements

a. General.

1. Fire support systems do not all have the same survey requirements. Position, elevation, and azimuth requirements are listed in STANAG 2934, AArty P-1, Chapter 11.

2. Figure 1-2 shows the required survey accuracy listed by these agreements for the US. Other nations in these agreements have, in some cases, more stringent requirements; therefore, if your mission includes providing survey support to units of an allied nation, the survey requirements for that nation must be known.

3. Figure 1-2 lists the Remotely Piloted Vehicle (RPV) and the AN/TMQ-41 (MMS) as To Be Determined. Survey requirements for these systems have not been added to the listed STANAG as of the dates listed for the agreements in App D.; therefore, the following standards should be used until the agreements are updated.

a. Remotely Piloted Vehicles (RPV)/ Unmanned Aerial Vehicle (UAV). The only survey requirements listed for an RPV/UAV are for the Phoenix GDT as agreed upon by Great Britain. The azimuth accuracy listed is 0.3 mils; however, because the PADS does not meet that specification (see paragraph 7-4), 0.4 mils will be considered as sufficient for RPV/UAV orientation. The listed position and elevation accuracy agreed upon by Great Britain will also be used by Marine surveyors until a US specification is made. The listed accuracy is; Position: 10 meter (PE), 17.5 meters (CEP); Elevation 10 meters (PE).

b. AN/TMQ-41 (MMS). Until specifications are listed for the MMS, the accuracy listed for the AN/TMQ-31 (MDS) will be used.

Figure 1-2 STANAG Survey Requirements

b. Required Survey Formats. The format of the survey data provided depends on the type of position being surveyed. The following is a list of required survey data formats for different positions:

1. **Firing Position.**

a. An artillery firing position requires the establishment of an Orienting Station (OS) and the End of the Orienting Line (EOL). The orienting line <u>must</u> be main scheme of the survey.

b. 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.

2. **Multiple Launch Rocket System (MLRS).** The survey requirement for the MRLS is the operational datum and ellipsoid, UTM Easting and Northing of initialization and update points, as well as the elevation (meters) of those points.

3. **Fire Finder Radar.**

a. An artillery radar position requires the establishment of an Orienting Station (OS) and the End of the Orienting Line (EOL).

b. 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.

4. **Meteorological Measuring System (MMS).**

a. For Radio Directional Finder (RDF) operations, an MMS position requires the establishment of an Orienting Station (OS) and the End of the Orienting Line (EOL). For NAVAID or GPS sonde operations, only the OS is required.

b. The required survey data for an MMS position is the operational datum and ellipsoid, Latitude and Longitude (decimal degrees expressed to 0.1°) of the OS, elevation (meters) of the OS, true azimuth in decimal degrees expressed to 0.1° from the OS to the EOL.

5. **Unmanned Aerial Vehicle (UAV).**

a. An RPV/UAV position requires the establishment of a Tracking Control Unit (TCU) and a Beacon.

b. The required survey data for an RPV/UAV position is the operational datum and ellipsoid, UTM Easting and Northing of the TCU, elevation (meters) of the TCU, and the UTM grid azimuth (mils) from the TCU to the Beacon.

6. **Declination Station.**

a. The survey requirement for a declination station is the operational datum and ellipsoid, UTM Easting and Northing (accurate for map spot) and a UTM grid azimuth (expressed to 0.1 mils) to at least two azimuth marks in different quadrants.

b. The true azimuth in decimal degrees expressed to 0.1° should be provided for declination of the met theodolites.

7. **Observation Posts (OP).** The survey requirement for an observation post 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.

8. **Registration Point (RP).**

a. The survey requirement for a registration point 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.

b. The azimuth should be from the OP designated as O1 for the target survey; however, the tactical situation may deem it necessary to perform the registration from an OP other than O1.

c. Ideally, the RP should fall within the 800 mil fan of the registering battery's azimuth of fire.

9. **Targets.** The survey requirement for targets other than registration points is the operational datum and ellipsoid, UTM Easting and Northing expressed to 10 meters and elevation expressed to 10 meters.

Figure 1-2 STANAG Survey Requirements

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Section II
ORGANIZATION AND DUTIES

1-7 Survey Personnel

a. Regimental Survey Section. The regimental survey section, including the Survey Officer and Chief, consists of eighteen Marines. The Table of Organization divides the section into two conventional teams and two PADS teams. Figure 1-2 shows the breakdown of the section.

b. Battalion Survey Section. The battalion survey section, including the Survey Officer and Chief, consists of eleven Marines. The Table of Organization divides the section into one conventional team and two PADS teams. Figure 1-2 shows the breakdown of the section.

c. Survey Billets/Duties. Assignment of positions within the survey section should be administrative in nature. Versatility and adaptability are the keys; all members of the section must be familiar with, and able to perform all current survey methods regardless of the billet they hold. The Marines must further understand the advantages and disadvantages of all current survey methods. Thorough survey knowledge, individual initiative, and a belief that some form of survey is always possible must be the tenets of a successful survey section.

e. Survey Information Center. The regimental survey section is required to maintain an operational Survey Information Center (SIC). The T/O does not afford the additional Marines to fill these responsibilities; therefore, the billets for the SIC must be filled from the survey teams.

1-8 Duties Of Survey Personnel

a. Survey Officer. The Survey Officer fights the future battle, continually planning for the next phase of an operation. He must maintain situational awareness of the battle through close liaison with the S-3 and S-2, and by coordinating the current survey effort with the Survey Chief. The Survey Officer's specific duties include but are not limited to:

1. Advises the commander of the capabilities and limitations of the survey section.

2. Provide input to the Commander on datum and ellipsoid selection and options.

3. Recommends SOP to the Commander.

4. Coordinates, supervises, and inspects:

   a. Training of survey personnel.

   b. Preventive maintenance program for the survey equipment, communications assets,and vehicles.

   c. SIC if authorized at his echelon.

5. Formulates the survey plan after receiving orders from the S-3 and before conducting reconnaissance.

6. Issues survey orders and briefs the Survey Chief and Team Chiefs.

7. Conducts reconnaissance.

8. Coordinates survey operations with Survey Officers of higher, lower, and adjacent commands.

9. Advises and assists firing units and target acquisition sections in training for and conducting hasty survey operations.

b. Survey Chief. The Survey Chief fights the current battle by implementing the Survey Officer's plan. He will act as the direct link between the Survey Officer and the teams in the field. He will further keep the Survey Officer apprised of the current situation, and handle any immediate problems. The specific duties of the Survey Chief include, but are not limited to, the following:

1. Assist the Survey Officer.

2. Perform the duties of the Survey Officer in his absence.

3. Train the survey section in the performance of reconnaissance, communications, maintenance, and survey operations.

4. Act as the section's logistician.

5. Maintain liaison with the Survey Officer.

6. Perform other duties as directed.

c. Conventional Team Party) Chief. The duties of the Conventional Team chief include, but are not limited to, the following:

1. Train his survey party.

2. Inform/brief his party on the survey plan

3. Execute his portion of the survey plan.

4. Supervise and coordinate field operations of his survey team.

5. Maintain liaison with the Survey Officer/Chief.

6. Supervises and inspects preventive maintenance checks and services (PMCS) of section equipment, to include vehicles, communications equipment, weapons, and survey equipment.

7. Performs other duties as directed.

d. Survey Computer. The duties of the survey computer include, but are not limited to, the following:

1. Maintain the current required forms for the computation of surveys.

2. Perform independent computations during field operations with the current Survey Computer System .

3. Maintain the section's Survey Computer Systems including all accessories (e.g. printers, batteries, etc.).

4. Perform other duties as directed.

e. Instrument Operator. The duties of the instrument operator include, but are not limited to, the following:

1. Perform preventive maintenance checks and services (PMCS) on the team's survey instruments to include operator's adjustments.

2. Operate the instruments during field operations.

3. Read measured values to the recorder and verifies the recorded data when read back.

4. Familiarize himself with the fieldwork requirements for all survey methods.

5. Perform other duties as directed.

Regimental Survey Section

Survey Officer (CWO-4)
Survey Chief (GySgt)

2 Conventional Survey Teams c/o
- Team Chief (Sgt)
- Survey Man (Cpl) x 2
- Survey Man (LCpl)
- Survey Man (PFC) x 2

2 PADS Teams c/o
- Team Chief (Sgt)
- Survey Man/Driver (LCpl)

Battalion Survey Section

Survey Officer (WO-1)
Survey Chief (GySgt)

1 Conventional Survey Team c/o
- Team Chief (Sgt)
- Survey Man (Cpl)
- Survey Man (LCpl)
- Survey Man (PFC) x 2

2 PADS Teams c/o
- Team Chief (Sgt)
- Survey Man/Driver (LCpl

Figure 1-3 Survey Section Organization

f. Recorder/Computer. The duties of the Recorder/Computer include, but are not limited to, the following:

1. Perform the duties of the Team Chief in his absence.

2. Maintain the Field Recorder's Notebook for all surveys performed by his team.

3. Neatly and legibly record measurements and survey data in accordance with this text and local SOP.

4. Check and mean measurements determined by the instrument operator.

5. Provide required field data to the computers.

6. Familiarize himself with the fieldwork requirements for all survey methods.

7. Perform other duties as required.

g. PADS Operator (PADS Team Chief): The duties of the PADS operator (PADS Team Chief) include, but are not limited to, the following:

1. Execute his portion of the survey plan.

2. Maintain liaison with the Survey Officer/Chief during field operations.

3. Supervise and inspect preventive maintenance checks and services (PMCS) of section equipment, to include vehicles, communications equipment, weapons, and survey equipment.

4. Operate and maintains the PADS.

5. Monitor the PADS control and display unit (CDU), fault indicators, and status indicators during operation.

6. Set up and operate the T-2E theodolite during autoreflection operations.

7. Brief the assistant PADS operator on the survey mission and requirements.

8. Perform other duties as directed.

h. Assistant PADS Operator: The duties of the Assistant PADS operator include, but are not limited to, the following:

1. Operate and maintain the PADS vehicle.

2. Install, operate, and maintain the communications equipment.

3. Maneuver vehicle for auto-reflection or plumb bob positioning over an SCP or points to be established under the direction of the PADS operator.

4. Record PADS data and maintain the field recorder's notebook .

5. Set up range poles and establish survey stations as directed by the PADS operator.

6. Perform the duties of the PADS operator in his absence, and other duties as directed.

1-9 Survey Equipment

a. General. Survey equipment is generally classified according to its use. The five categories of artillery survey equipment are:

Inertial Measurement Systems
Angle Measuring
Distance Measuring
GPS Systems
Computation Equipment

The quantity of each item is set in the survey set SL-3, the unit T/E, and is dependent upon the echelon of survey.

b. Position and Azimuth Determining System (PADS) AN/USQ-70. The PADS is an inertial measuring system capable of meeting most artillery survey specifications. It is usually vehicle mounted but can be used in airborne operations. PADS is the primary means of providing survey control in the artillery battalion. It also provides sufficient accuracy for many applications of the surveyors at the artillery regiment.

c. T-2E Theodolite. The T-2E is the angle measuring system for Marine artillery surveyors. It is used by both battalion, and regimental artillery surveyors for conventional surveys as well as operations with the PADS (autoreflection).

d. DI3000 Distomat. The DI3000 is the distance measuring system for Marine artillery surveyors. It is used by both battalion, and regimental artillery surveyors for conventional surveys.

e. 4000 MSGR (GPS-S). The Trimble 4000 MSGR is the survey grade GPS receiver system used by Marine artillery surveyors. Regimental level surveyors will use the system to establish networks using static and kinematic methods; battalion level surveyors will primarily use kinematic methods.

f. Survey Computer Systems. Several systems are available for computing surveys and for determining data necessary for computing surveys. The HP 71B (BUCS), and the HP 200LX (HCS) are the current systems used by the Marine Corps.

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CHAPTER 2
BASIC GEODESY

The Marine artillery surveyor is primarily concerned with viewing small portions of the Earth's surface as a plane. However, farther reaching weapon systems, larger theaters of operation, Global Positioning Systems, and the advent of the World Geodetic System 1984 have all increased the need for the Marine artillery surveyor to have a basic knowledge of Geodesy that will enable him to evaluate and establish survey and mapping data as well as increase his ability to select and identify datum and ellipsoid options.

Section I
THE GEOID

2-1 The Geoid

The **GEOID** is defined as "the equipotential surface in the gravity field of the Earth which coincides with the undisturbed mean sea level extended through the continents." In other words, the geoid is the zero reference for elevation; it is a closed surface of equal gravitational force. The geoid is perpendicular to the direction of gravity, and closely approximates Mean Sea Level (MSL) and the extension of MSL through the landmasses of the Earth.

2-2 Shape of the Geoid

The geoid is affected by variances in the density, type, and amount of landmass that pushes up through the water or lie below it, causing dips and swells. It can be pictured as an ellipsoid with irregular dips and swells over its entire surface; thus conforming to an equal force of gravity over that surface. The dips and swells are called undulations. (See figure 2-1.)

Figure 2-1 Undulation

2-3 Use of the Geoid

a. 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 in a theodolite is centered when it lies parallel with the geoid, which establishes a horizontal reference at a specific location.

b. The geoid provides a common reference for elevations. The point at which the surface of the geoid intersects a land mass is generally referred to as Approximate Mean Sea Level (MSL).

Figure 2-2 Elevation

c. Elevation is the distance between a point on the Earth's surface and the geoid, measured along a line that is 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 Mean Sea Level height. Elevation is labeled

"H". (See Figure 2-2.)

2-4 Ellipsoids

An **ELLIPSOID** is defined as "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, which 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; this is referred to as an oblate ellipsoid. The terms **ellipsoid** and **spheroid** are considered interchangeable. This text will use the term ellipsoid unless the mathematical figure of a spheroid is necessary. (See Figure 2-3.)

Figure 2-3 Ellipsoid

2-5 Defining Parameters of an Ellipsoid

a. An ellipsoid is generally defined in terms of three parameters, or dimensions, which provide the size and ellipticity of the ellipsoid. Tables A-1a and A-1b list the defining parameters for 42 ellipsoids.

1. **Semi-major Axis:** The semi-major axis of an ellipsoid 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. The semi-major axis is labeled "a". (See Figure 2-4.)

2. **Semi-minor Axis:** The semi-minor axis of an ellipsoid 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. The semi-minor axis is labeled "b". (See Figure 2-4.)

3. **Flattening:** The flattening of an ellipsoid is the ratio of the difference between the equatorial and polar radii (semi-major and semi-minor axis) to the equatorial radius (semi-major axis) and is labeled "f". It is more commonly expressed as the inverse of flattening **(1/f)**. Flattening can also be called ellipticity.

Figure 2-4 Defining Parameters

b. There are other defining parameters for ellipsoids which are discussed in detail in DMA TM 8358.1 and DMA TR 8350.2. These parameters include Earth gravity information, angular velocity, and eccentricity; an understanding of these parameters is not necessary for artillery surveyors and will not be discussed in this text.

c. Computing Ellipsoid Parameters

In many cases, all three defining parameters discussed in paragraphs 2-5 a1, 2, and 3 above will not be available. The user can compute the third parameter from two known parameters using the formulas below.

1. To compute the semi-minor axis (b) use the formula **b=a (1-f)**.

Example: GRS-80 ellipsoid

Step 1: determine f. 1/f = 298.257222101 so
f = 0.00335281068118

Step 2: determine b. b=a (1-f)
a = 6378137 (1 - 0.00335281068118)
b = 6356752.31414

***** NIMA published value for b is 6356752.3141.

2. To compute flattening (1/f) use the formula **f=(a-b)/a**.

Example: GRS-80 ellipsoid

Step 1: determine f. f = (a - b) / a
f = (6378137 - 6356752.3141) / 6378137
f = 0.00335281068751

Step 2: determine 1/f.
Flattening = 1 / 0.00335281068751
1/f = 298.257221538

***** NIMA published value for 1/f is 298.257222101.

3. These computations may provide a quantity that is slightly different than the accepted NIMA parameters. This is generally due to rounding and is considered insignificant for many geodetic applications and for all artillery survey applications.

2-6 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 itself. Since that is not the case, an ellipsoid is defined, and then fixed to a specific location (usually located on the surface of the geoid) and orientation which makes it closely resemble the surface of the geoid; this is accomplished by establishing a Horizontal Datum which is discussed in detail in Section 3 of this chapter. Once an ellipsoid is fixed by a specific datum it is referred to as a **Reference Ellipsoid.**

b. Reference ellipsoids can be either local in extent or global. If the ellipsoid resembles only a small region of the geoid, and it is fixed to a point on the surface of the Earth, it is local. 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 can be considered global and is considered an **Earth-centered Earth-fixed** (ECEF) ellipsoid. (See Figures 2-5 and 2-6.)

Figure 2-5 Local Reference Ellipsoid

Figure 2-6 ECEF Ellipsoid

2-7 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 considered positive when the geoid lies outside the ellipsoid and negative when the geoid lies inside the ellipsoid. Geoid separation is labeled "N" and can also be called Geoidal Height or Undulation of the Geoid. (See Figure 2-7.)

Figure 2-7 Geoid Separation

2-8 Ellipsoid Height

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. (See Figure 2-8.)

Figure 2-8 Ellipsoid Height

2-9 h, H, and N Relationship

The relationship between ellipsoid height (h), elevation (H), and geoid separation is shown in the formula: h H+N. (See Figure 2-9.)

surface of "0" elevation and can also be called Altitude Datums.

Figure 2-9 Relationship between h, H, and N.

Section III
DATUMS

2-10 Datums

A **DATUM** is defined as "any numerical or geometrical quantity, or set of such quantities, which may serve as a reference or base for other quantities." Surveyors generally consider two types of datums: **Vertical** and **Horizontal**. When the term datum is used by itself, it is usually referring to a horizontal datum.

2-11 Geodetic Systems

a. 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.

b. Horizontal and vertical 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; while vertical positions are defined by the geoid referenced to the Mean Sea Level Datum.

2-12 Vertical Datums

a. A **Vertical Datum** is a level surface or arbitrary level to which elevations are referred. Usually, the geoid (Mean Sea Level) is that surface; however, other vertical datums may include: Mean Low Level, the level at which the atmospheric pressure is 29.92 inches of mercury (1013.2 mbs), or an arbitrary starting elevation. Vertical datums are usually defined as a

b. Since it is impossible to determine exactly where the geoid intersects a landmass, it is impossible to use the geoid itself as the actual vertical datum. Historically, tide gauge measurements were averaged over nineteen years to establish a local mean sea level. These Mean Sea Level datums are very close to the geoid but not exactly. For this reason, level lines ran from tide gauge marks in different regions do not connect exactly at the same elevation. In the United States, the National Geodetic Vertical Datum (NGVD) of 1929 replaced the Mean Sea Level 1929 and has since been updated to the North American Vertical Datum (NAVD) 1988. This new vertical datum, which is based on tide gauge measurements and precise geodetic leveling, has extended a "common" vertical network to most of the continental U.S. 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.

c. Because of the uncertainty between local Mean Sea Level Datums and the geoid, and because the exact relationships between those datums is unknown; all elevations should be considered to be referenced to the Mean Sea Level Datum for the purpose of shifting between vertical datums.

2-13 Horizontal Datums (Geodetic Datums)

a. General. A **Horizontal Datum** is a set of quantities, which fix an ellipsoid to a specific position

and orientation. The point at which the ellipsoid is fixed is called the Datum Point. There are two types of datums to be considered: Surface fixed and Geocentric.

b. Surface Fixed Horizontal Datum.

1. A surface fixed horizontal datum is a set of quantities relating to a specific point on the surface of the Earth, which 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 of surface datums are: NAD 27, Tokyo, and ARC 1950. (See Figure 2-10.)

2. A surface 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. This type of 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. In many cases, the same ellipsoid, fixed to a different location and orientation, is used.

Figure 2-10 Surface Fixed Ellipsoid

c. Geocentric Horizontal Datum

1. A geocentric horizontal datum is one, which specifies that the center of the reference ellipsoid be placed at the center of mass of the Earth. This point at the center mass of the Earth is also the datum point. Examples of geocentric datums are the World Geodetic Systems. (See Figure 2-11.)

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

3. Geocentric datums generally cover a large area of the world and in some cases are global in extent. The geoid separation remains relatively small for the entire region covered by the datum. The World Geodetic Systems (WGS) developed by the Defense Mapping Agency are all global coverage datums; WGS 84 being the newest and most accurate. A World Geodetic System offers the basic geometric figure of the earth (ellipsoid) as well as an associated gravity model (geoid). Because of this, the geoid separation remains relatively small over the entire system (generally less than 102 meters within WGS 84).

Figure 2-11 Earth-centered Earth-fixed Ellipsoid

2-14 Multiple Datum Problems

a. Over 1000 different datums exist. Practically every island or island group in the Pacific Ocean has its own datum; many areas of the world are covered by multiple datums. This causes the most concern for surveyors who must decide which datum to use, and then 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.

b. The WGS was developed to create a global system, which could be used to alleviate many of these problems. The National Imagery and Mapping Agency (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 in which mapping and charting products will reference GRS-80 as the ellipsoid and NAD 83 as the datum.

2-15 Datum to Datum Shifts

a. All datums are defined relative to WGS-84. For this reason, transformations between datums are performed from and to WGS-84. In other words, when converting from Local Datum 1 to Local Datum 2 you must first transform Datum 1 to the WGS-84 and then transform

the WGS-84 datum to Datum 2.

b. 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 local datum coordinates.

c. Several methods of datum transformation are available, a few are listed below.

1. **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 used come from differences in the local and WGS 84 Cartesian coordinates; 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 STANAG 2211 for some applications in Europe and England. It is considered more accurate than the five-parameter model. (See Figure 2-12.)

Figure 2-12 Origin Shift Parameters

2. **Five Parameter Model:** this model considers only the relative sizes of the ellipsoids and the offset differences in their origins. The five parameters used in this model are the difference in the semi-major axes (Δa), 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 the computation of the Standard Molodensky Equations and is considered accurate to 5-10 meters. (See Figure 2-12.)

3. **WGS 72 to WGS 84:** Formulas transforming between these two geocentric datums were created when WGS 84 was developed. The equations are more accurate than the Seven and Five Parameter Models. These formulas are listed on page Appendix A-44 Note 3 and discussed in detail in DMA TR 8350.2. Care must be taken when using these formulas to determine the source of the WGS 72 coordinates. **If the WGS 72 coordinates were transformed from original local datum coordinates, then a direct local datum to WGS 84 transformation will be more accurate.**

4. NAD 83 to WGS 84:

a. For most applications, these two datums are considered the same. The Geodetic Reference System 1980 (GRS- 80) is the reference ellipsoid for NAD 83. It was developed prior to the WGS 84 system and was a factor in the necessity to upgrade WGS 72. When developing WGS 84, three of the system's four defining parameters were made identical to the parameters used for the GRS 80; the only difference being the gravity model.

b. For our purposes, the two datums are considered identical in all areas covered by NAD 83 with the exception of the Aleutian Islands and Hawaii. A datum transformation is necessary in those two areas; origin shift parameters are provided in Appendix A.

5. Multiple Regression Equations (MRE): MREs 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 1-3 meters.

6. Lateral Shift Method: When transforming between datums referenced to the same ellipsoid, a constant shift ($\Delta\phi$,$\Delta\lambda$) can be determined which 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, and then applied to stations that need to be transformed. This procedure will produce accurate data for the entire island of Vieques, Puerto Rico.

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Meridian.

Section IV
COORDINATE SYSTEMS

2-16 General

The location of a point on the surface of the Earth is generally represented by coordinates. A coordinate system is a three dimensional 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 which are two dimensional and are usually related to a grid system as discussed in Chapter 3.

2-17 Cartesian Coordinates

a. Cartesian Coordinates identify the location of a unique three dimensional (*X, Y, Z*) position in space. The system consists of an origin, and three coordinate planes. (See Figure 2-13.)

1. **Origin:** The origin is the intersection point of the three coordinate planes and is located at the center of the reference ellipsoid. In cases where the origin is also located at the center mass of the Earth, the system is considered to be geocentric.

2. **Coordinate Planes:** The three mutually perpendicular coordinate planes intersect in three straight lines called coordinate axes. The axes intersect at right angles at the origin.

Z-Axis: 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.

X-Axis: 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.

Y-Axis: 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

Figure 2-13 Coordinate Planes

b. The position of a point on the surface of the Earth 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. The X, Y, and Z coordinates are discussed below: (See Figure 2-14.)

1. **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.

2. **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.

3. **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.

4. The coordinates of the origin are written 0,0,0.

Figure 2-14 Cartesian Coordinates

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2-18 Geographic Coordinates

a. Geographic coordinates are any three dimensional coordinate system which 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, which can describe both geodetic and astronomic positions. (See Figure 2-15.)

Figure 2-15 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.

1. Latitude lines are called Parallels of Latitude. Latitude originates at the equator at 0°; and 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°). (See Figure 2-16.)

Figure 2-16 Parallels of Latitude

2. 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 "-" (i.e. 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. (See Figure 2-17.)

Figure 2-17 Meridians of Longitude

3. 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. (See Figure 2-18)

Figure 2-18 Graticule

c. Convergence. The inclination of two meridians towards 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. The convergence of the meridians at the equator is 0°. At the poles, the convergence is equal to 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. (See Figure 2-18.)

2-19 Geodetic Coordinates

a. Geodetic Coordinates are the quantities of latitude (ϕ), Longitude (λ), and ellipsoid height (h) which 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 (i.e.. WGS-84), the coordinates are termed **Geocentric 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, which passes through the point and is perpendicular to the reference ellipsoid. (See Figure 2-19.)

Figure 2-19 Geodetic Coordinates

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 (NGRS) in the United States.

2-20 Astronomic Coordinates

a. Astronomic coordinates are those values, which define the position of a point on the surface of the Earth or the geoid and reference the local direction of gravity. **Note: The term Astronomic Coordinates can also be used to refer to the location of a celestial body.** Astronomic positions are often used to establish and define horizontal datums. An ellipsoid is oriented in such a way that a line through a point which is perpendicular to the geoid (vertical) is also perpendicular to the ellipsoid (normal), and the geoid separation is generally zero at that point. At that point the geodetic and astronomic coordinates are the same.

b. The **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 is equal to 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. (See Figure 2-20.)

Figure 2-20 Astronomic Coordinates

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

2-21 Prime Meridian

a. General. The Prime Meridian is the meridian of longitude referenced as 0° for a particular geographic system. In most cases, the term Prime Meridian is the Greenwich Meridian; however, Figure 2-21 lists several systems using other meridians of longitude as the Prime Meridian for that system.

b. Converting to Greenwich. In any case where survey data is provided in a system not referencing the Greenwich Meridian as 0° longitude, applying the longitude offset to the survey data longitude can make a simple conversion. (See Figure 2-21.)

2-22 Angular Measurements

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

b. Centesimal System. The unit usually associated with a centesimal system is the grad (used extensively in Europe and North Africa).

1. A grad is defined as the hundredth part (1/100th) of a right angle. In this system, one grad equals one hundred minutes and one minute equals one hundred seconds.

2. Grads are notated by a superscript g (e.g., 12^{g}); centesimal minutes by a superscript c (e.g.,48^{c}); and centesimal second by a superscript cc (e.g., 27^{cc}). The entire number is notated together as in the following example: $12^{g}\,48^{c}\,27^{cc}$.

c. Sexagesimal System. The unit usually associated with a sexagesimal system is the degree.

1. A degree can be defined as the ninetieth part (1/90th) of a right angle. In this system, one degree equals sixty minutes and one minute equals sixty seconds.

2. Degrees are notated by the symbol ° (e.g., 24°); sexagesimal minutes by a ' (e.g., 38'); and sexagesimal seconds by a " (e.g., 02"). The entire number is notated together as in the following example: 24° 38' 02".

Figure 2-21 Astronomic Longitudes of Prime Meridians

2-23 Deflection of the Vertical

a. The deflection of the vertical at a point is the angular difference between the vertical (plumb line), which is perpendicular to the geoid, and a line through the point, which is perpendicular to the reference ellipsoid. This term can be more accurately referred to as the **Astro-geodetic Deflection of the Vertical**.
(See Figure 2-22.)

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 between 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

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CHAPTER 3
PROJECTIONS AND GRIDS

Portions of the world have been mapped by different nations since the earliest time of man's exploration of the Earth. These early maps were crude and inaccurate by our standards but sufficed for their intended purpose. As man's world grew and the need arose for maps covering larger areas with better accuracy, cartographers devised methods of projecting the Earth onto a surface, which could be flattened with little distortion in angles, distances, shapes, and sizes depending on the intended use of the map.

Section I
MAP PROJECTIONS

3-1 General

a. In general, a map projection is a method of representing a portion of the Earth's round surface on a flat surface. Because this procedure causes distortions of different types many different projections have been developed; each design dictated by the size of the area being mapped, the map scale, and the intended use of the maps. (See Tables 3-1, 2, and 3 at the end of this section.)

b. An ellipsoidal surface cannot be flattened onto a plane without distortions of such properties as distance, angle, direction, shape, and size. For example, an orange peel cannot be flattened onto a table without tearing; if the skin could be flattened and not tear, the areas farthest away from the center would stretch causing distortion. The same is true for a map projection.

c. Many types of map projections exist, each preserving certain properties and distorting others. Most projections are cylindrical, conical, or azimuthal; projecting an ellipsoid onto cylinders, cones, or plane surfaces. These surfaces may be tangent to the ellipsoid, or they may be secant. 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. (See Figure 3-1.)

d. One common characteristic applies to all US military maps; they are all based on a **conformal** projection. This means that the shape of any small area of the surface mapped is preserved unchanged. In other words, a conformal map projection is one that at any point, the scale is the same in any direction. Also, the angle between any two lines on the ellipsoid is the same when projected onto a plane.

Figure 3-1 Projection Types; tangent and secant

3-2 Prescribed Projections

a. The Transverse Mercator Projection is the preferred projection for all military mapping, but that projection is not necessarily the one used on all military maps.

b. The following is a list of projections that are prescribed for US military topographic maps and charts that display a military grid on a standard scale

1. Topographic maps at scales of 1: 500,000 or larger which lie between 80° South latitude and 84° North latitude are based on the Transverse Mercator Projection.

2. Topographic maps at scales of 1: 1,000,000, which lie between 80? South latitude and 84? North latitude, are based on the Lambert Conformal Conic Projection.

3. 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.

4. Maps at scales smaller than 1: 1,000,000 are based on the projection best suited for the intended use of the map.

c. Military maps of non-US areas produced by other nations may not always conform to the above standards. Also, US made maps of foreign areas may be based on other projections due to treaty agreements.

3-3 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 one. This 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.

3-4 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:

1. Small-scale: 1: 600,000 and smaller

2. Medium Scale: larger than 1: 600,000; smaller than 1: 75,000

3. Large Scale: 1: 75,000 and larger

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; in other words, 1/100,000 is a smaller number than 1/50,000. Standard scales for military maps are:

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

Figure 3-3 Mercator Projection Flattened onto a plane

3-5 Mercator projection

a. The **Mercator Projection** is a cylindrical projection in which 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. The cylinder is then opened and flattened 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, as the normal limits are from 80° N latitude to 80° S latitude. (See Figure 3-2 and 3-3.)

Figure 3-2 Mercator projection

b. As the distance from the equator increases, so does the amount of distortion; for example, 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 in some cases where the entire Earth must be displayed and relative positions of landmasses are more important than size and distance.

3-6 Transverse Mercator Projection

a. General. The **Transverse Mercator Projection** is a cylindrical conformal projection. It is based on a modified Mercator projection in that the cylinder is rotated (transverse) 90° so that the rotational axis of the ellipsoid is perpendicular to the axis of the cylinder. Generally, the Transverse Mercator Projection is considered as a cylinder, which 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. (See Figure 3-4.)

Figure 3-4 Transverse Mercator Projection

b. Area Distortion. When the Transverse Mercator Projection is used to project a portion of the ellipsoid onto the cylinder, the equator and the central meridian will appear as mutually perpendicular straight lines. A hemisphere will be distorted towards its outer edges. The shaded areas of Figure 3-5 show the varying distortion of two equivalent geographic areas on the same projection. Note that both areas encompass a region which is 20° by 20° and are both bounded by 20° and 40° N latitude; therefore, on the ellipsoid they are the same size. On the projected surface; however, 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 60 six-degree wide projection zones, each having a meridian of longitude as its Central Meridian. Each zone is projected between 84° 30' N latitude and 80° 30' S latitude. (See Figure 3-5 and 3-6.)

c. Secancy of the Ellipsoid. The cylinder used as the projection surface for the Transverse Mercator Projection is generally considered to be secant to the

Figure 3-5 Distortion within the Transverse Mercator Projection

ellipsoid as shown in Figure 3-4. This means that the cylinder intersects the ellipsoid in two places creating lines of secancy, which 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. (See Figure 3-6).

Figure 3-6 Secancy in a 6° Zone

d. Distortion of Lines. Figure 3-7 shows a cross section of an ellipsoid and a cylinder of projection, which is secant to the ellipsoid. Passing a plane through the ellipsoid at the equator makes the cross section. 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. Note that line BM'C is shorter than line BMC; this shows that any line which 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 which 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.

e. Scale Factor. For the Transverse Mercator 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. (See Figure 3-7 and Table 3-1.)

Figure 3-7 Line Distortion and Scale Factor in the Transverse Merca

Easting of Starting Station		Scale Factor
50		
49		
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

Table 3-1 TM Scale Factor By UTM Easting

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3-7 Gauss-Kruger Projection

a. General. The **Gauss-Kruger Projection** can be described as the Transverse Mercator Projection derived by mapping directly from an ellipsoid, which is *tangent* to the cylinder. It is a conformal projection with many similarities to the Transverse Mercator Projection. The tangent point is the meridian of longitude chosen as the Central Meridian for the projection. As with Transverse Mercator, the Gauss-Kruger Projection depicts 60 zones and area distortion is the same as described in paragraph 3-6b above. Many geodesists consider the Gauss-Kruger and Transverse Mercator Projections to be the same, except for scale factor. (See Figure 3-8.)

Figure 3-8 Gauss-Kruger Projection

Figure 3-9 Line Distortion and Scale Factor in the Gauss-Kruger Projec

a cylinder of projection, there is no distortion along that line. Figure 3-9 shows that all lines, which are 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, and M is the central meridian (tangent point).

c. Scale Factor. For the Gauss-Kruger 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.

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3-8 Polar Stereographic Projection

a. General. The **Polar Stereographic Projection** 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, which is developed by projecting a polar region onto a plane, which is either tangent to an ellipsoid at the pole or secant to the ellipsoid at a specific latitude. The plane is perpendicular to the polar axis of the projection is the opposite pole. In this projection, meridians are straight lines and parallels are concentric circles. (See Figure 3-10, 11, 12.)

Figure 3-10 Polar Stereographic Projection: Secant

Figure 3-11 Origin of Projection

b. Secancy of the Ellipsoid. 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 onto a plane. In order to reduce that distortion the plane is placed secant to the ellipsoid at approximately 81° 07' North and South Latitude. This establishes a circle in each zone which is common to the ellipsoid and the plane and has no distortion.

Figure 3-12 View of Secant Plane

c. Distortion of Lines. Figure 3-13 shows a cross-section of the ellipsoid and the secant plane made by passing a plane through a polar region of the ellipsoid. Line A'P'D' represents the plane of projection; line 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 81° 07') is longer than the same line when it is projected on the plane (BP is longer than BP'). Note also that a line on the ellipsoid which lies outside the circle (latitude less than 81° 07') is shorter than the same line when it is projected onto the plane (AB is shorter than A'B).

d. Scale Factor. The scale factor used with the Polar Stereographic Projection is Exact (1.000 or Unity) along the line of secancy (81° 07' Lat). It decreases to 0.994 at the pole and increases to 1.0016076 at 80° latitude. The scale factor reaches its maximum value of 1.0023916 at 79° 30' latitude. Scale factor is constant along any given parallel. (See Figure 3-13.)

Figure 3-13 Line Distortion and Scale Factor in the Polar Stereographic Projection

3-9 Overlapping Projections

a. General. 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 possible that a contingency may cross between these projections in one direction or the other. In order to reduce the amount of confusion caused by crossing the established limits of a projection, an overlap between the two projections is used.

b. Transverse Mercator. The Transverse Mercator Projection is normally considered to cover areas between 80° S latitude and 84° N latitude. However, this projection extends to 80° 30' S and 84° 30' N latitudes. The 30' extension is an overlap into the *Polar Stereographic Projection.*

c. Polar Stereographic. The Polar Stereographic Projection is normally considered to cover the polar regions south of 80° S latitude and north of 84° N latitude. However, this projection extends to 79° 30' S and 83° 30' N latitudes. The 30' extension is an overlap into the *Transverse Mercator Projection.*

3-10 Lambert Conformal Conic Projection

a. General. Lambert Conformal Conic Projections are the most widely used projections for civilian mapmakers and surveyors. Many nations use this projection for civil and military purposes in their country. The Lambert Conic Conformal Projection can be visualized as the projection of an ellipsoid onto a cone, which 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, which touches the ellipsoid at one parallel of latitude; a secant cone will intersect the ellipsoid at two parallels, called **Standard Parallels**.

This text will discuss the secant condition. (See Figure 3-14.)

Figure 3-14 Secant Condition of Lambert Conformal Conic Projection

b. Plane of Projection. When the cone of projection is flattened into a plane, meridians appear as straight lines radiating from a point beyond the mapped areas; parallels appear as arcs of concentric circles, which are centered at the point from which the meridians radiate.

None of the parallels appear in exactly the projected positions; they are mathematically adjusted to produce the property of conformality. This projection can also be called the **Lambert Conformal Orthomorphic Projection**. (See Figure 3-15.)

Figure 3-15 Cone Flattened onto a Plane

c. Secancy of the Ellipsoid. The mapmaker chooses the parallels of latitude on the ellipsoid, which are to be secant to the cone. The distance between the secant lines is based on the purpose and scale of the map. For example, a US Geological Survey (USGS) map depicting the 48 contiguous states will use 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); and for the National Atlas of Canada the secant lines are 49° N and 77° N (28° between secants). The standard parallels for USGS maps in the 7.5 and 15-minute series will vary from state to state, several states are separated into two or more zones with two or more sets of standard parallels. (See Figure 3-16.)

Figure 3-16 Oklahoma Lambert Projection; North and South Zones

d. Distortion. Since this is a conformal projection Mercator 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.

e. Scale Factor. 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 is dependent upon the distance between the standard parallels.

3-11 Oblique Mercator Projection

a. General. The Oblique Mercator Projection is actually many different projections using variations of the Transverse Mercator. All are cylindrical and conformal; however, instead of the cylinder being transverse 90° from the Mercator Projection, it is transverse at an angle, which places the long axis of the cylinder 90° from the long axis of the area being mapped. In other words, 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, and the lines of secancy vary between projections. Many Oblique Mercator Projections exist; however, only two will be discussed in this manual: the Laborde Projection and the West Malaysia Rectified Skew Orthomorphic (RSO) Projection.

b. Laborde Projection. This 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. West Malaysia Rectified Skew Orthomorphic (RSO) Projection. This 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, the following:

Alaska Zone 1 RSO
Borneo RSO
Great Lakes (4 Zones) RSO
Liberia RSO
Malaya (chain) RSO
Malaya (yard) RSO
Switzerland Oblique Mercator

3-12 New Zealand Map Grid Projection

The **New Zealand Map Grid Projection (NZMG)** 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 NZMG has no defined scale factor at the central meridian, scale factor ranges from 1.00023 to 0.00078 over the entire projection.

3-13 Cassini Projection

a. The **Cassini Projection** can be viewed outwardly as a Gauss-Kruger projection in that the cylinder is transverse 90° from the Mercator Projection and is also tangent to the ellipsoid at the central meridian of a zone. The Cassini Projection predates the Gauss-Kruger and Transverse Mercator Projections, and is made by treating all meridians as planes, which 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, which intersect the equator at right angles and curve toward the central meridian except for those meridians, which are located 90° from the central meridian. Those meridians appear as straight lines, which 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 and in many areas has been replaced by the Transverse Mercator Projection. This projection is sometimes referred to as the Cassini-Solder Projection.

b. Some of the local grids, which use the Cassini Projection and may still be available, are:

Cyprus Grid-superseded in 1967
English Grid-superseded in 1950
Irish Grid-superseded in 1976
Jahore Grid-superseded in 1967
Malay Grid-superseded in 1967
Palestine Civil-still in use

c. Position differences between Cassini grid systems and Transverse Mercator grid systems are slight. For example, northing is the same in the Palestine Cassini Civil Grid as it is in the Palestine Transverse Mercator Civil Grid. The easting difference between the two is zero at 20 Km from the central meridian and only 4.1 meters at 100 Km from the central meridian.

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Section II
GRID SYSTEMS

3-14 Grid Systems

a. General. A **grid system** is a two-dimensional 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 and northing) and for the computations relating to those coordinates to be made by ordinary methods of plane surveying.

b. Local and Universal Grids. Currently there are many grid systems in use. The majority of the "local" systems will eventually be converted to one of the universal grid systems, while some areas will continue to be mapped in a local system such as the British National Grid (BNG), the Irish Transverse Mercator Grid (ITMG), and the Madagascar Grid (MG). There are two universal grids used by the US military and its allies: **Universal Transverse Mercator (UTM)** and **Universal Polar Stereographic (UPS)**.

c.Grid Lines. 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 is dependent on the scale of the map and the type of grid system. Most systems use meters as a basis for grid line spacing; while others use yards or feet. Standard scale military maps generally adhere to the following: grid lines on large scale maps are spaced at 1000 meters, grid lines on medium scale maps at 1:250,000 are spaced at 10,000 meters. For scales smaller than 1:250,000, the grid lines may or may not be depicted, dependent on the purpose of the map.

d. Grid Line Values. The north-south lines in a grid system are called **Eastings** and increase in value from west to east. The east-west lines in a grid system are called **Northings** and their value increases 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 (e.g. equator); but it can have other references. The origin for the false easting and false northing are normally different lines or points.

3-15 Grid Convergence

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

3-16 Universal Transverse Mercator Grid

a. The **Universal Transverse Mercator (UTM) Grid System** is referenced to the Transverse Mercator Projection. The ellipsoid is divided into 60 grid zones, each 6° wide, extending from 84° N latitude to 80° S latitude. The zones are numbered from 1 to 60, with zone 1 starting at 180°- 174° W longitude, zone 2 at 174° W - 168° W longitude, continuing east to zone 60 at 174° E - 180° longitude. The Prime Meridian (0° longitude) separates zones 30 and 31. (See Figure 3-17.)

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 Transverse Mercator 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 you are operating in the northern hemisphere the northing of the equator is 0 meters and increases north, if you are in the southern hemisphere the northing of the equator is 10,000,000 meters and decreases south. Grid lines that run north

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Figure 3-17 UTM/UPS Grid Zones and Grid Zone Designators

and south are easting lines; these lines are parallel to the central meridian of the grid zone. Grid lines that run east and west are northing lines; these lines are parallel to the equator. (See Figure 3-18.)

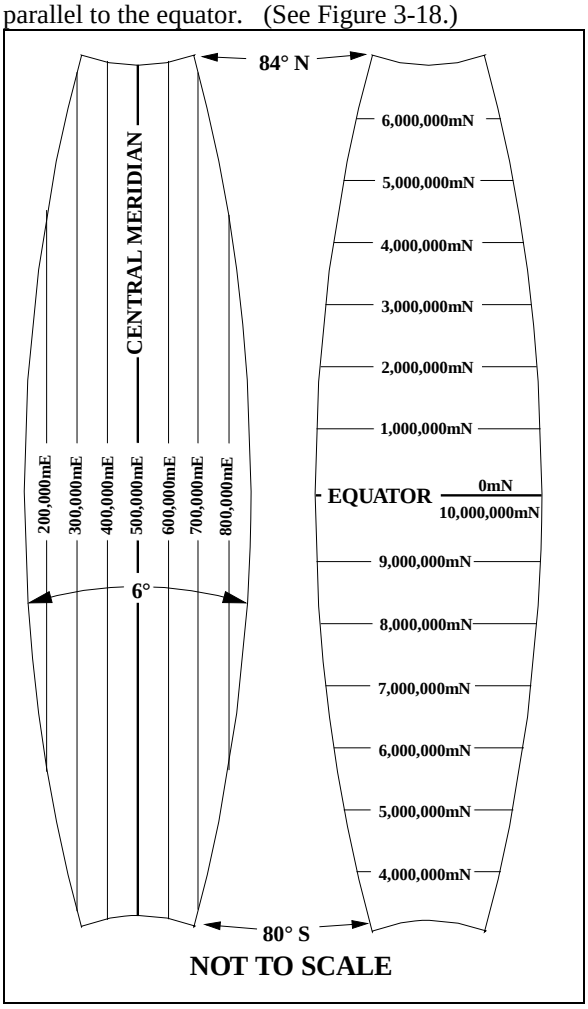

Figure 3-18 UTM Easting and Northing

d. Grid Convergence.

1. **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 5th 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. (See Figure 3-19.)

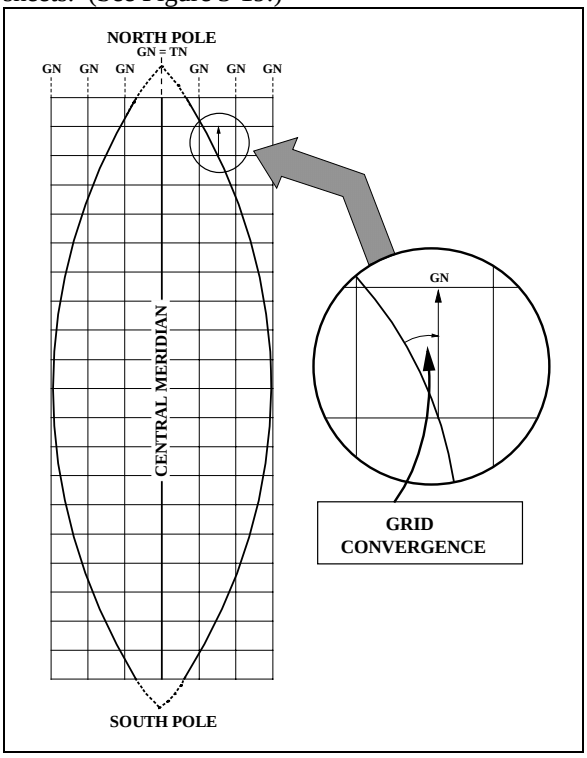

Figure 3-19 UTM Grid Convergence

2. In the northern hemisphere, grid convergence is considered negative east of the central meridian and positive west. In the southern hemisphere, grid convergence is considered to be positive east of the central meridian and negative west. The direction (+, -) and the value of the grid convergence is 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. (See Figure 3-20.)

Figure 3-20 Sign of Grid Convergence

Figure 3-21 Non-Standard UTM Grid Zones

e. Non-standard Zones. 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, so user defined options or work around methods must be used in those areas. Figure 3-21 depicts the non-standard portions of the respective grid zones.

f. UTM Grid Coordinates.

1. The Easting and Northing values of a point in the UTM grid system are called **Grid Coordinates**. The easting will consist of six digits before the decimal point. The only exception to this is positions which 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. The northing will generally have 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 is dependent on the order of survey and the accuracy needed. An example of a UTM grid coordinate is 6 39127.84 - 38 25411.24.

2. 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.

3-17 Universal Polar Stereographic Grid

a. The **Universal Polar Stereographic (UPS) Grid System** is referenced to the Polar Stereographic Projection. It is used to map the polar regions of the earth north of 84° N latitude and south of 80° S latitude.

b. Each polar region is a grid zone. The two zones are not numbered as in the UTM system; they are merely referred to as the **North and South grid zone**. The origin for each UPS grid zone is the pole (North or South). The grid is oriented by placing the

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Figure 3-22 UPS North and South Grid Zones

east-west axis of the grid in coincidence with the 90°W and 90°E meridians and the north-south axis of the grid in coincidence with the 0° and 180° meridians. (See Figure 3-17.)

c. The location of any point on a UPS grid can be designated by coordinates by giving its distance east-west (easting) of the 0° and 180° meridians or north-south (northing) of the 90°W and 90°E meridians. A value of 2,000,000 meters is assigned to the meridians for both easting and northing. The easting value increases from two million meters toward the eastern hemisphere and decreases toward the western hemisphere in both grid zones. The northing value in the North grid zone increases from two million meters in the direction of the International Dateline (180° longitude) and decreases in the direction of the Prime Meridian (0° longitude). In the South grid zone, the northing value increases from two million meters in the direction of the Prime Meridian and decreases in the direction of the International Dateline. (See Figure 3-22.)

d. Grid Convergence.

1. In the North zone, grid north is the direction toward the North Pole along the 0° meridian and the direction away from the North Pole along the 180° meridian. In the South zone, grid north is the direction toward the South Pole along the 180° meridian and the direction away from the South Pole along the 0° meridian. For any points not on the 0° and 180° meridians, grid north is the northern direction of a line through the point which is parallel to those meridians.

2. All meridians of longitude are straight lines radiating from the center of the grid (North and South zone). These lines are true north-south lines; therefore, the direction of true north at a point is the same as the longitude at that point.

3. As with the UTM system, **grid convergence** is the angle from a true north line to a grid north line. Grid north is the same as true north along the 0° meridian. Grid north is in the opposite direction of true north along the 180° meridian. Grid convergence increases east and west of 0° to 180°. The value of grid convergence at any point in the UPS system is equal to the longitude of that point and is expressed as an angular measure east or west as measured from true north. (See Figure 3-23.)

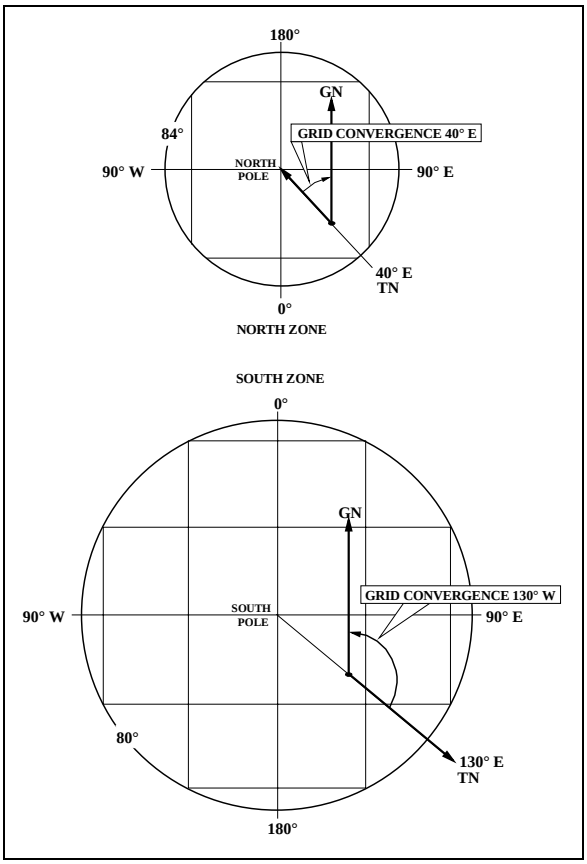

Figure 3-23 UPS Grid Convergence

e. UPS Grid Coordinates. In the UPS grid system, both eastings and northings will consist of seven digits before the decimal point. The first two digits (1,100,000 meters) can be separated from the next five by a space. The number of digits following the decimal point is dependent upon the order of survey and the accuracy needed. An example of a UPS grid coordinate is 17 81256.41 - 26 41416.82.

3-18 UTM/UPS Overlap

a. General. As with the Transverse Mercator and Polar Stereographic Projections, the UTM and UPS systems provide for a one degree overlap; each system continuing into the other for 30 minutes.

b. UTM/UPS. The standard limits of the UTM and UPS grid systems are at 84° N and 80° S latitude. A 30-minute overlap extends the UTM to 84° 30' N and 80° 30' S latitude. The UPS is extended 30 minutes to 83° 30' N and 79° 30' S latitude.

3-19 Gauss-Kruger Grid

a. The **Gauss-Kruger (GK) Grid System** is referenced to the Gauss-Kruger (Transverse Mercator - tangent) projection. 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

b. The GK grid has many similarities to the UTM grid.

1. Each GK grid zone is 6° wide and they are numbered from 1 to 60. The zones start at the Prime Meridian (0° longitude) instead of the International Dateline (180° longitude). This difference offsets the grid zone numbers by 30; therefore, UTM grid zone 6 is the same as GK grid zone 36.

2. The central meridian of each GK grid zone is the same as the central meridian of each UTM grid zone.

3. The north and south limits of the GK grid have not been rigidly defined but it is generally accepted that the limits are similar to those of the UTM grid system.

4. Grid convergence is the same for a GK grid coordinate as it is for the corresponding UTM coordinate.

c. The origin for coordinates is the same in the GK system as the UTM system, the false value applied to the equator is the same in both systems, but the easting is slightly different. The false value applied to the central meridian is 500,000, like UTM, with the grid zone number added to the millions place. For example, the easting value of the central meridian in GK grid zone 6 is 6,500,000 meters.

d. GK Grid Coordinates. A GK grid coordinate is expressed with the northing written before the easting. The northing is written with seven digits before the decimal point with and may have a space between the first two and the next five digits. The easting is written with the grid zone first, then with six digits before the decimal point. A space can be placed between the 100,000-meter place and the next five digits. An example of a GK grid coordinate in zone 5 is: 38 25411.24 - 56 39127.84. (This example uses the same numbers as the example for a UTM coordinate, para 3-13,f,1.)

3-20 Converting from GK to UTM

a. General. Simply applying the UTM scale factor to the GK grid can perform conversions from the GK grid to the UTM grid. The UTM and GK grids are both referenced to the same projection (the Transverse Mercator Projection and Gauss-Kruger Projection can be considered the same), the only difference being that the UTM grid is oriented to a secant cylinder while the GK grid is oriented to a tangent cylinder. Since both grid systems use the same central meridians in each zone, and since the false values applied to the origins for easting and northing are basically the same, the only major difference to be considered is the scale factor. The Gauss-Kruger Projection has a scale factor of 1.00 (exact or unity) at the central meridian of each zone, while the scale factor for the central meridian in each Transverse Mercator Projection zone is 0.9996.

b. Procedures. To convert a GK grid coordinate to a UTM grid coordinate, use the following steps:

EASTING

Step 1: Drop the GK grid zone from the millions place.

Step 2: Subtract 500,000 meters from the GK easting. (If the point is west of the central meridian, the result will be a negative number.)

Step 3: Multiply the result in Step 2 by 0.9996.

Step 4: Add 500,000 meters to the result of Step 3.

Step 5: Determine UTM grid zone by adding or subtracting 30 from the GK grid zone. (The result must be between 1 and 60 inclusive.)

NORTHING

(NORTH OF EQUATOR)

Step 1: Multiply the GK northing by 0.9996.

(SOUTH OF EQUATOR)

Step 1: Subtract 10,000,000 meters from the GK northing. (The result will be negative.)

Step 2: Multiply the result of Step 1 by 0.9996.

Step 3: Add 10,000,000 meters to the result of Step 2.

**** NOTE ** The** resulting easting and northing coordinates will be referenced to the UTM grid system in the same ellipsoid and datum as the GK coordinates.

3-21. Unique Coordinates

a. UTM, GK and UPS grid coordinates are **not** unique. Any UTM grid coordinates can be plotted in each of the 60 grid zones; additionally 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° N and S latitudes will plot in each of the two UPS grid zones.

b. To make UTM and UPS grid coordinates unique, the grid zone and grid zone designator should accompany them.

3-22 Military Grid Reference System

a. General. 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.

b. Grid Zone Designator. A grid zone designator is a one-letter code 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. (See Figure 3-17.)

1. **UTM.** Each of the 60 UTM grid zones are divided into 20 grid zone designators, each designator representing an 8° portion of the grid zone except the northernmost representing 12°. The 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) which specifies a 6° by 12° area.

2. **UPS.** Both UPS zones (North and South) are divided into two grid zone designations separated by the 0° and 180° meridians. In the north zone, the designator Y covers the western hemisphere, Z covers the eastern hemisphere. In the south zone, designator A covers the western hemisphere, B the eastern hemisphere. Since numbers are not used to identify the UPS grid zones, a UPS grid MGRS coordinate will begin with the grid zone designator.

c. 100,000 Meter Square Identifier. Each UTM/UPS grid zone is divided into 100,000-meter squares. These 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 is dependent on the reference ellipsoid. This text will discuss 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.
(See Figure 3-24.)

1. **UTM.**

a. 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" omitting "I" and "O". This alphabet is repeated every 18° eastward around the earth.

b. The second (linear) letter of the 100,000 meter square identification is lettered from "A" to "V", omitting "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

Figure 3-24 Military Grid Reference System: 100,00 meter Square Identification Lettering Convention For the UTM Grid, WGS 84/GRS 80 Ellipsoids.

"A" along the equator; in even numbered grid zones the second letter is "F" along the equator.

c. 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. It can be seen from this example that unique coordinates can be established for every position within the UTM grid using the MGRS.

2. **UPS.** 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. 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. (See Figure 3-25.)

a. **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" with "M", "N", "O", "V", and "W" omitted.

b. **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" with "D", "E", "I", "M", "N" and "O" omitted.

c. 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" with "I" and "O" omitted.

d. MGRS Grid Coordinates.

1. The easting and northing coordinates used with the MGRS are the same as the grid coordinates used with UTM/UPS with the following modifications:

a. For UTM grid MGRS 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.

b. For UPS grid MGRS 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.

2. The entire MGRS grid coordinate is written as one entity without parenthesis, dashes, or decimals.

Examples:

3Q	indicates location within a 6° x 8°
3QXV	indicates location to within 100,000m
3QXV41	indicates location to within 10,000m
3QXV4312	indicates location to within 1,000m
3QXV432123	indicates location to within 100m
3QXV43211234	indicates location to within 10m
3QXY4321012345	indicates location to within 1m

3-23 Non-Standard Grids

a. General. Many grid systems were developed by individual nations which cover only that nation or a region surrounding that nation. In most cases, no direct relationship exists between local grid systems; the same as no direct relationship exists between the state plane grid systems of the US states.

b. Names. Non-Standard grids are generally named for the nation or region they cover and will normally contain the term Grid, Zone, or Belt (i.e. Ceylon Belt, Madagascar Grid, and India Zone I).

1. A **Grid** covers a relatively small area. Its limits consist of combinations of meridians, parallels, rhumb lines, or grid lines.

2. A **Zone** is usually wide in longitude and narrow in latitude. Its limits consist of meridians and parallels.

3. A **Belt** is usually wide in latitude and narrow in longitude.

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Figure 3-25 100,000 Meter Square Identification: UPS Grid, International Ellipsoid

3-24 World Geodetic Reference System

The **World Geodetic Reference System** (GEOREF) is an alphanumeric system for reporting

positions based on geodetic coordinates. It is a worldwide position reference system that can be used with any map or chart graduated in latitude and longitude, regardless of the map projection. The primary use of the GEOREF is for inter-service and inter-allied positioning and reporting of aircraft and air targets.

3-25 User-Defined Grid Systems

a. When operating in an area that is mapped in a grid system other than UTM and UPS, it may become 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; however, if the option is available, the following information is necessary:

Operational Ellipsoid
Ellipsoid Parameters (a, b, 1/ *f)*
Scale Factor (at the origin) for the projection
Latitude of the origin
Longitude of the origin
Unit (i.e. meters, feet, yards, chains, rods)
False easting of the origin
False northing of the origin

b. Figure 3-26 lists the needed information for several common non-standard grids as published in Table 6 of DMA TM 8358.1.

c. Figure 3-27 lists the needed information for several common non-standard grids *not* published in DMA TM 8358.1.

Figure 3-26 Specifications for Secondary Grids listed in Table 6 DMA TM 8358.1

Figure 3-27 Specifications for Secondary Grids *not* listed in Table 6 DMA TM 8358.1

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CHAPTER 4
GLOBAL POSITIONING SYSTEM

The NAVSTAR (**NAV**igation **S**atellite **T**iming **A**nd **R**anging) GPS (**G**lobal **P**ositioning **S**ystem) is a space-based navigation and timing system operated and maintained by the Department of Defense. It continuously provides accurate, all-weather, 3-dimensional (3D) position, velocity and time over the entire world. To make full use of the user equipment available for this system, a general knowledge of GPS operational theory is necessary.

Section I
CONFIGURATION, SIGNALS, AND CODE

4-1 System Configuration. The NAVSTAR GPS is configured into three distinct segments; each one very much dependent upon the other. (See Figure 4-1.)

a. Space Segment. Originally, the complete Space Segment was to consist of 24 Block II satellites (Block I satellites were considered developmental, Block IIR (Replacement) satellites are being developed to provide system operations through the year 2025). Currently, more than 24 satellites are in orbit. The satellites 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 altitude of 10,898 miles. The satellites move continuously through their orbit in the same direction as the Earth's rotation. They orbit the earth twice in 23h 56m 04.091s solar time or one 24 hour sidereal day.

b. Control Segment. The Control Segment consists of five unmanned monitor/tracking stations located in Hawaii, Colorado, Ascension Island, Diego Garcia, and Kwajalein. The tracking stations use special receivers to track each satellite individually. The information obtained from tracking the satellites is used in

Figure 4-1 System Configuration; Space, Control, and User Segments.

controlling the satellites and predicting their orbits. Three of the stations (Ascension Island, Diego Garcia, and Kwajalein) are used for transmitting information back to the satellites. All data collected at the tracking stations is transmitted to the Master Control Center, 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 Center is also responsible for the daily management and control of the satellites and the overall Control Segment.

c. User Segment. The User Segment consists of any one with a GPS receiver. Both military and civilian personnel, including the enemy, use these receivers. Methods used by DoD to deny the enemy of high accuracy or even to deny him use of the GPS signals are discussed later in this section.

4-2 Satellite Signals

a. Carrier Frequencies. Each GPS satellite broadcasts signals on two spread-spectrum radio frequencies (RF). These are termed carrier frequencies 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), which is multiplied by a factor, which produces the actual carrier frequency. (See Figure 4-5.)

1. **L1-RF.** Multiplying the fundamental frequency by 154 generates the Link 1 RF (L1) carrier frequency. It is centered at 1575.42 (MHz) and has a bandwidth of 20.46 MHz. In other words, the majority of the intensity of the signal lies at 1575.42 MHz (± 10.23 MHz). The wavelength of the L1 signal is 19 centimeters. (See Figures 4-2 and 4-5.)

2. **L2-RF.** Multiplying the fundamental frequency by 120 generates the Link 2 RF (L2) carrier frequency. It is centered at 1227.60 MHz and has a bandwidth of 20.46 MHz. In other words, the majority of the intensity of the signal lies at 1227.60 MHz (± 10.23 MHz). The wavelength of the L2 signal is 24 centimeters. (See Figures 4-3 and 4-5).

b. Data Sequences. Each GPS satellite develops several binary data sequences transmitted from the GPS control segment. These sequences include the Coarse/ Acquisition Code (C/A-Code), the Precise Code (P-Code), and the Navigation Data Message.

1. **Coarse Acquisition Code.** The Coarse/ Acquisition Code (C/A Code) is sometimes referred to as the Standard Code (S-Code). It has also been called the Clear Access or Civilian Access Code. All GPS satellites on the L-1 carrier wave broadcast it. The transmission of the data sequence is centered at 1575.42 MHz (L-1 Frequency). It is modulated at ± 1.023 MHz providing a bandwidth of 2.046 MHz. The code contains a sequence of 1,023 pseudo-random binary biphase modulations on the GPS carrier at a chipping rate of 1.023 MHz, thus having a repetition period of 1 ms. The C/A-code is a 300 meter measurement wave. (See Figures 4-2, 4-4, and 4-5.)

2. **Precise code.**

a. **General.** The Precise Code (P-Code) is sometimes referred to as the Protected Code. All GPS satellites on both the L-1 and L-2 carrier broadcast it. The transmission of the data sequence is centered at 1575.42 MHz on the L-1 carrier and at 1227.60 MHz on the L-2 carrier. It is modulated at ±10.23 MHz on both 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. (See Figures 4-2, 4-3, 4-4, and 4-5.)

Figure 4-2 L-1 Carrier Frequency

Figure 4-3 L-2 Carrier Frequency

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

b. **P-Code Repetition.** The overall P-Code is a mathematically derived binary sequence that is 267 days (approximately 37 weeks) long. It is broken into one-week segments for operational use. Five of these one-week segments are reserved for the GPS control segment. The other 32 segments are available for satellite vehicles (SVs). Therefore, each SV has a unique one-week segment code, which is a subset of the overall P-Code sequence. For this reason, it is generally accepted that the P-Code repeats every week.

Figure 4-5 GPS Signal Data Flow

3. **Navigation Data Message.**

a. **General.** The navigation data message (NAV data) is a 1500 bit navigation message broadcast on either L-1 and L-2 carriers at a rate of 50 bits per second (bps) or 50 Hz. The NAV data message 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 can be referred to as the D-Code.

b. **Broadcast Format.** The Navigation Data Message is a separate binary data sequence in the satellite; however, the navigation data message 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 with the P-Code to formulate 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 are the codes 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.

4-3 Ephemeris and Almanac Data

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.

a. Broadcast Ephemeris. The broadcast ephemerides are actually predicted satellite positions transmitted as part of the NAV Data message. Any receiver capable of acquiring the C/A or P-Code can acquire the ephemerides in real time. The Master Control Station using past tracking data provided from the five tracking stations computes the broadcast ephemerides. The new orbital parameters are then transmitted back to the satellites once every 24 hours for subsequent transmission to the user segment.

b. Precise Ephemeris. The precise ephemerides are computed from actual tracking data, post-processed to obtain more accurate satellite positions. These ephemerides are available at a later date and are more accurate than broadcast ephemerides because they are based on actual tracking data and not predicted data.

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Section II
SYSTEM SAFEGUARDS AND ERROR SOURCES

4-4 Selective Availability (SA)

a. Purpose. When the concept of GPS was initially developed, it was planned that the Precise Code would be reserved for military use, while the less accurate C/A Code would be authorized for use by anyone. During initial testing of the system it was discovered that while the P-Code measurements provided the expected 10-20 meter accuracy, and the C/A Code provided accuracy as high as 20 meters; much better than the expected 100 meters. The Department of Defense, 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 was the outcome.

b. Methods. SA is a method used by the U.S. Department of Defense (DoD) 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. **Dither.** To alter or manipulate 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 pseudorange.

2. **Epsilon.** To alter the orbital parameters (satellite position) which are broadcast in the Almanac portion of the navigation data message. Position error is then created because the receiver is positioned based on the satellite location.

c. Accuracy Levels. The level of accuracy achieved by a GPS receiver is now dependent on whether or not the receiver is equipped with an encryption device, which allows the receiver to accept, and store crypto variables referred to as a key. This key allows the receiver to decrypt SA correction data, which is transmitted in the NAV Data message. This key also allows the receiver to utilize the encrypted P-Code. The two accuracy levels are the Precise Positioning Service and the Standard Positioning Service.

Precise Positioning Service (PPS). 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 (SEP).

Standard Positioning Service (SPS). 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.

4-5 Anti- Spoofing (AS)

Anti-Spoofing (AS) 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.

4-6 Cryptovariables

a. General. As stated before, cryptovariables are necessary for a GPS receiver to access the Precise Positioning Service, allowing the receiver to correct for errors caused by SA and AS. It is unauthorized to use a military GPS receiver without a valid crypto fill.

b. Key Materials and Loading Formats. There are three types of key materials available for use with a GPS receiver: Operational Key Material, Maintenance Key Material, and Simulator Key Material. There are also three different formats for key loading.

1. **Operational Key Material.**

a. Two operational cryptographic keys, **Group Unique Variable (GUV) key** and **Crypto- Variable Weekly (CVW) key**, are available for issue to a GPS user. Both the GUV and the CVW keys can be used by a receiver to obtain a daily key (CVd). All Operational Keys are classified CONFIDENTIAL and are marked CRYPTO.

b. The Group Unique Variable (GUV) key is an annual key. It is a Key Encryption Key (KEK), which is used to decrypt 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 daily 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.

c. The Crypto-Variable Weekly (CVW) key is sometimes referred to as the Crypto key Weekly (CKW). It is a Key Production Key (KPK), which is used to automatically generate daily keys within the user equipment. Obtaining the daily key from a satellite downlink is not necessary for receivers loaded with a CVW key; therefore, a user with a CVW key will begin 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.

d. Both the GUV key and the CVW key will produce the same Daily Crypto-Variable (CVd) key. Once the receiver determines the current working CVd, processing navigational data may commence and the effects of SA and AS 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 AS.

2. **Maintenance Key Material.** A maintenance key is available to users for troubleshooting the GPS user equipment. The maintenance key does not allow a user to gain access to the daily encryption key. Maintenance keys are unclassified and may be re-used until they are physically unusable.

3. **Simulator Key Material.** A simulator key is available to users for testing receivers. Both 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 re-used until they are physically unusable.

4. **Key Loading Formats.** GPS keying materials are provided in three different formats to accommodate various methods of key loading. The **eight-level punched tape format** is used in common COMSEC fill devices such as the KOI-18 General Purpose Tape Reader, the KYK-13 Electronic Transfer Device (capable of loading multiple keys) used in conjunction with the KOI-18, and the AN/CYZ-10 Data Transfer Device (DTD) also used in conjunction with the KOI-18. The **hexadecimal printed format** is used with a GPS data loader or an equivalent NSA approved key loader device. The **decimal printed format** is used with the GPS control display unit. Both the decimal and hexadecimal key formats are commonly referred to as key lists.

c. User Equipment Security. Because of the security classification of the CVW key and GUV key, GPS receivers designed specifically for military use 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.

4-7 GPS Error Sources

a. General. 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 referred to as a biased range or "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 AS). In addition to these major errors, 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 for. The following paragraphs discuss these errors as they associate with GPS positioning and navigation. Most of these errors

are eliminated or their effects significantly reduced when GPS is used in a differential mode because the same errors are common to both receivers during simultaneously observed sessions.

b. Ephemeris Errors and Orbit Perturbations. Satellite ephemeris errors are errors in the prediction of the satellite position, which are then transmitted to the user in the navigation data message. Ephemeris errors are satellite dependent and very difficult to predict and compensate for. This is because the many forces acting on the predicted orbit of a satellite are difficult to measure directly.

c. Clock Error. 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 is equal to the possible error due to clock bias as shown below:

$$R_E = T_O \text{ x } c$$

When R_E is the Range Error due to clock bias
T_O is the Time Offset
C is the speed of light (299,792,458 m/s).

For example, if the time offset is 1 microsecond (10^{-6}) then the RE =10^{-6} x 299,792,458 = 299.8 meters.

d. Ionospheric Delays. GPS signals are electro-magnetic signals, which are dispersed non-linearly 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 because the dispersion and refraction of the signal results in an error in the GPS range value. Ionospheric range effects are frequency dependent; in other words the L1 and L2 frequencies are affected differently even though they follow the same path through the ionosphere.

1. The error effect of ionospheric refraction on the GPS range value is dependent on sunspot activity, time of day, and satellite geometry. Periods of high sunspot activity will 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 nighttime 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 ionospheric 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. Single frequency receivers used in the absolute and differential positioning modes normally rely on an ionospheric model of the typical ionosphere. The use of these models can remove a significant amount of the ionospheric delay.

e. Tropospheric Delays. GPS signals are not dispersed by the troposphere; however, they are refracted. The tropospheric conditions causing this refraction of the signal can be modeled by measuring the dry and wet components.

1. The dry component can be modeled easily through measurement of the surface pressure using the following equation:

$$D_C = (2.27 \text{ x } 0.001) \text{ x } P_O$$

When D_C is the dry term range contribution in ze
P_O is the surface pressure in millibars

For example, if the surface pressure is 765 Mb then the dry term range error is (2.27 x 0.001) x 765 = 1.73655 or 1.7 meters.

2. The wet component cannot be so easily modeled. This is because the wet component is approximated by not only the surface conditions, but by the atmospheric conditions along the entire path of the GPS signal. These conditions include water vapor content, temperature, altitude, and the angle of the signal path above the horizon.

f. Multipath. Multipath is a positioning error caused by the signal arriving at the receiver from more than one path. Generally, this is due to the receiver being located near a reflective surface such as a metal building or structure. Newer antenna designs have some 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 of time can also reduce the effects of multipath.

g. Receiver Noise. This error source includes a variety of errors associated with the receiver's ability to measure a finite time difference. These include signal processing and filtering, clock/signal synchronization

and correlation methods, receiver resolution, signal noise, and electronic interference. Most of these errors cannot be modeled or accounted for.

4-8 User Equivalent Range Error (UERE)

User Equivalent Range Error (UERE) can be referred to as the total budgeted error caused by the error sources listed above. Many of these error sources can be reduced through planning or the use of L1/L2 antennas. The use of differential techniques can even eliminate some of these sources of error. Figure 4-6 lists these errors and biases by associating them with their source segment. The error values in this figure do not include the effects of S/A.

4-9 Absolute GPS Accuracy

a. General. Absolute positions are those, which are 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 is largely dependent upon which code (C/A or P(Y)) is being used to determine the position. This range accuracy (i.e., UERE), when coupled with the geometrical relationships of the satellites, result in a 3-dimensional confidence ellipsoid, which depicts uncertainties in all three coordinates. Since the satellites are constantly moving, the geometry constantly changes; therefore, GPS accuracy is time/position dependent.

Figure 4-6 User Equivalent Range Error

b. Root Mean Square (RMS) Error Measures.

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

2. Figure 4-7 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 4-7 Error Ellipse at 2-σ RMS

c. Probable Error Measures.

1. In two-dimensional (2D) horizontal positioning, a Circular Error Probable (CEP) statistic is most commonly used, especially in military targeting. CEP refers to the radius of a circle with a 50% probability of position confidence. In other words, a measured or calculated position will fall inside a circle of some radius at least 50% of the time.

2. Three-dimensional (3D) GPS accuracy is most commonly expressed as a Spherical Error Probable (SEP). This value represents the radius of a sphere with a 50% confidence level or probability. It is important to understand that this sphere only approximates an actual 3D error ellipsoid that represents the uncertainties in the geocentric coordinate system.

d. Dilution of Precision (DOP). Dilution of Precision 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 that are observed and used in the final solution, the better the solution. Since DOP can be used as a measure of geometric strength, it can also be used to determine which satellites a receiver can use to determine the most accurate position.

1. **Satellite Geometry and DOP.** 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 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 Dilution of Precision. 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 and the Dilution of Precision would be small.

2. **Geometric Dilution of Precision (GDOP).** The main form of DOP used in measuring absolute accuracy is the Geometric Dilution Of Precision (GDOP). GDOP is the measure of accuracy of three-dimensional position and time. GDOP is related to actual range error by stating that the actual range error is equal to GDOP multiplied by the UERE.

3. **Position Dilution of Precision (PDOP).** PDOP is the measure of the accuracy in 3D position only.

a. PDOP values are generally developed from satellite ephemerides prior to the conduct of survey operations. When this is done, the surveyor can more adequately plan sessions and occupations for his equipment.

b. 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). In other words, 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.

c. 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.

4. **Horizontal Dilution of Precision (HDOP).** HDOP is a measurement of the accuracy in 2D horizontal position. It is significant in evaluating surveys intended for horizontal control. Basically, HDOP 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. HDOP values lower than 3 indicate the best geometry.

5. **Vertical Dilution of Precision (VDOP).** VDOP is a measurement of the accuracy in standard deviation () in vertical height. Mathematically, it is the (Sigma Up) divided by UERE (around 6 meters with P(Y)-code and 12 meters with C/A-code). A VDOP value lower than 3 indicates a strong vertical component in the geometry.

6. **Time Dilution of Precision (TDOP).** TDOP is the measurement of the accuracy of the time determined by the GPS receiver.

Section III
GPS Measurements

4-10 GPS Reference System

The GPS satellites reference their own position to the WGS 84 coordinate system. This system is based on the WGS 84 ellipsoid. The Earth rotates on an axis, but that axis is not constant, it "wobbles" much like a spinning top. In order to fix the Earth in time and space for the development of the WGS 84 ellipsoid, the Conventional Terrestrial Pole of 1984 (CTP 84) was chosen. In other words, the position of the Earth's polar axis at 1984.0 as defined by the Bureau International De l'Heure (BIH) 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.

4-11 Code Phase Measurements

a. General. The primary purpose of Code Phase measurements is to determine approximate ranges from satellites to the GPS receiver, which will 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 that is determined by the GPS receiver is referred to as a **Pseudo-range**.
(See Figure 4-8.)

b. Pseudo-random Noise (PRN) Code. The PRN-code is a binary data string of digital ones and zeros, which 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). (See Figure 4-8.)

Figure 4-8 Psuedo-range

Figure 4-9 Carrier Modulated by PRN

c. Time Delay. 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, which 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. (See Figure 4-10.)

Figure 4-10 Time Delay of a GPS Signal

d. Satellite Ranging.

1. 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 following formula:

$$\text{Pseudo-range} = \Delta t \times \text{speed of light}$$

This procedure can be simultaneously performed on many satellites. The number of satellites is dependent on the receiver being used, or more specifically, how many channels are available in the receiver.

Figure 4-11 Ranging One Satellite

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 is equal to the pseudo-range with the satellite at the center of the sphere. (See Figure 4-11.)

3. When the second satellite is acquired, the same ranging technique is used creating a second sphere. The intersection of the two spheres is a circle; the receiver is located somewhere along the edge of that circle. (See Figure 4-12.)

Figure 4-12 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 be capable of providing a two dimensional position.

Figure 4-13 Ranging Three Satellites

5. In order to achieve a three-dimensional position, at least four satellites must be ranged. This fourth satellite will provide the necessary timing data needed for the receiver to resolve timing errors in the system.

4-12 Carrier Phase Measurements

a. General. The primary purpose of Carrier Phase measurements is to determine ranges from satellites to receivers, which will allow the receiver to position itself. Usually these positions are processed relative to another receiver position and are referred to as differential positions. The ranges to the satellites are pseudoranges, as in code phase; however, this method of ranging requires the solution of the integer ambiguity of the signal. In other words, the determination of this distance requires that the number of whole carrier wavelengths be known.

b. Integer Ambiguity. The whole number of wavelengths between the satellite and the receiver is known as integer ambiguity or cycle ambiguity. Since we know the L1 carrier wavelength is 19 cm long and L2 is 24 cm long, and since most carrier phase receivers can determine the partial wavelength to an accuracy around 2 mm; the pseudorange 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 (Beat) Phase. Carrier phase GPS receivers contain an internal oscillator, which 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. Continuous Carrier Phase.

1. 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.

2. If the satellite signal is interrupted (see Cycle Slips below), the continuous carrier phase is reset. It is set to the next fractional wave measurement (carrier phase observable) immediately following the break.

e. Cycle Slips. A cycle slip is the interruption or break in the continuous carrier wave.

1. 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.

2. 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 be caused by burst jamming signals. In most cases, reconnaissance, line of site clearing, and planning can eliminate many sources of cycle slips.

4-13 Differencing

a. General. Differencing is a method used by the processors to solve for the first estimation of a baseline solution and remove measurement errors. There are three different processing modes: Single Differences, Double Differences, and Triple Differences.

b. Single Differences.

1. Between Receivers. 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, and 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. (See Figure 4-14.)

Figure 4-14 Single Differences Between Receivers

2. **Between Satellites.** Differencing measurements acquired by one receiver observing two satellites at a particular point in time or epoch can form a single difference. Single differences between satellites reduce most receiver dependent errors. (See Figure 4-15.)

Figure 4-15 Single Differences Between Satellites

c. Double Differences (Between Satellites and Receivers). Differencing two single differences forms a double difference. 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. (See Figure 4-16.)

Figure 4-16 Double Differencing

d. Triple Differences (Between Satellites, Receivers, and Time).

1. A triple difference is determined by combining two double differences over time. In other words, 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. (See Figure 4-17.)

Figure 4-17 Triple Differencing

2. Triple differences are often used to find cycle slips. A cycle slip, in the single differencing mode, causes the receiver to recompute 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.

4-14 Baseline Solutions

a. General. A baseline solution (vector) is a straight line defined by its 3-dimensional (ΔX, ΔY, ΔZ) values

when one end of the vector is the origin and the other end is the point containing those relative values.

1. 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**.

2. If we can determine the integer ambiguity, we can multiply that value by the wavelength (19cm - L1, 24 cm - 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.

b. Float Solution. Since we have determined an initial estimate of the baseline vector, we can place that value in the formula:

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

Whereas: $\Delta X, \Delta Y, \Delta Z$ is the baseline vector,
N is the integer ambiguity,
λ is the wavelength,
ϕ 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 a whole integer for the processor to determine if the ambiguity is 500 or 501; therefore, it cannot set the value to a whole integer.

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

c. Fixed Solution. 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 iteration (the last computation of whole integer values) can be determined as follows:

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

4. With a single frequency receiver, this is the best solution that can be determined; it is sometimes referred to as a **double-difference fixed solution**.

5. With a dual-frequency receiver, it is possible to combine carrier phase observables to create other fixed solutions.

a. **Widelane Fixed Solution.** A widelane 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.

b. **Narrowlane Fixed Solution.** The narrowlane carrier phase is generated when the processor combines the carrier phase observables (L1+L2). The effective wavelength of the narrowlane carrier phase is 10.7 cm. This combination is very effective for canceling out ionospheric errors.

c. **Ionospheric Free Fixed Solution.** 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.

4-15 GPS Survey Methods

a. Absolute Positioning.

1. Absolute positioning is a GPS survey method, which involves the use of a single passive receiver (e.g. AN/PSN-11 PLGR, AN/PSN-13 4000 MSGR). The term absolute does not refer to a specific accuracy, but to the fact that 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 relative (common) to any other station and the accuracy of this position is dependent on many different error sources as well as the user's level of authorization (PPS or SPS).

2. The receiver collects data from multiple satellites and will use this data to determine position, velocity, and timing information. The position is generally determined from code phase measurements; however, some receivers are capable of using carrier phase measurements to determine absolute positions.

b. Differential (Relative) Positioning.

1. General.

a. Differential positioning is a GPS survey method, which requires that at least two receivers collect data from at least 4 common satellites simultaneously to compute a vector between the two receivers. The vector is then fixed at one end to a point and the other end is the relative position.

b. Usually, one of the receivers will be 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 either in the office or by the receiver in the field, also dependent on the differential technique used.

c. Much of the accuracy achieved from this method of GPS survey is due to the use of common satellites and common epochs (a specific point of time selected for a GPS measurement). Figure 4-6 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. In other words, 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. Therefore, 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 a reasonable length (25-30 Km), the tropospheric and ionospheric errors are basically the same; in other words, the 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; however, the use of an L1/L2 antenna will decrease this error.

2. Code Phase Differential Positioning. 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.

a. 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, let’s say 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 +2 meters. A pseudo-range correction 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 (common) position; thus the distance between the two points will be relatively accurate (0.5-10 meters) even when the absolute positions are not.

b. Code phase differential positioning has its primary applications in real-time navigation where relative accuracy as low as 10 meters is acceptable. Also, some engineering survey applications can tolerate this accuracy. This would not be acceptable for geodetic applications, and does not meet artillery specifications.

3. **Carrier Phase Differential Positioning.** 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.

4-16 GPS Survey Techniques

a. General. When GPS receivers are used for surveying purposes, it is generally accepted that the survey will be performed using carrier phase differential (relative) survey methods. Differential survey is usually divided into two techniques: Static and Kinematic. The following paragraphs provide a basic explanation of these techniques. The MSGR Job Aid provides more in depth discussion of these techniques as they apply to the Trimble 4000 MSGR (AN/GSN-13).

b. Static Survey. Static surveys provide the most accurate results. In this technique, receivers must remain stationary (static) for a period of time dependent on the type of static survey performed. Two types of static survey are generally considered: Static and Fast Static. Both types require extensive planning and post-processing. Static survey allows for extremely accurate networking of survey control. Due to the planning, fieldwork, and post-processing requirements, artillery surveyors whose mission is to provide fourth order control should only use this technique.

c. Kinematic Survey. Kinematic surveys provide accuracy results sufficient for most artillery survey missions (4th and 5th order), but do not provide the same networking capabilities as static techniques. Two types of kinematic surveys are generally considered: Stop-and-Go and Continuous. Stop-and-Go surveys can be post-processed in the office PCs or in the field by the receivers using Real Time Kinematic (RTK) and Real Time Kinematic/On the Fly (RTK/OTF) procedures. Kinematic survey techniques require that one receiver remains static while another receiver acts as a "rover", moving along a route or from station to station collecting data.

4-17 Vulnerabilities/Survivability

The GPS design process required consideration of certain system vulnerabilities. These vulnerabilities are generally grouped by the GPS segment they threaten.

a. Space Segment.

1. **Anti-satellite Weapons (ASAT).**

a. The height of the GPS satellites (10,898 miles) is outside the range of current Anti-satellite 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 Km apart in each orbital plane and the control segment manages the system so that no two satellites will orbit within 8,100 Km 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 ASAT would be detected early enough in the three-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 ten minutes or longer in the L-band. This detonation would disturb the atmosphere and the ionosphere with subsequent effects on propagation; also the effects of radiation could incapacitate the functioning of the erasable read only memories (EROMS) and random access memories (RAMS) of these systems if the blast is sufficiently close. For the GPS satellites, there exists built-in protection against the electromagnetic pulse (EMP) caused by nuclear detonations and there is a capability to restore their erased memories through the control segment.

c. Two other factors exist that add an unplanned edge of survivability against ASAT. The first is the Russian GLONASS system. The GLONASS system orbits at an altitude close to the GPS orbit. A nuclear assault against GPS would have the same effect on GLONASS. The second unplanned factor is the increased use of GPS by former Eastern Block nations including the former Soviet Union.

2. **Lasers**. Since the introduction of the Strategic Defense Initiative (SDI), lasers have become a planned vulnerability to orbiting satellites. Limited laser hardening of the satellites enhances survivability of GPS against laser technology. Additionally, a space-based laser at low altitudes would be an extremely heavy device to launch. The tracking and targeting of a GPS satellite is extremely difficult due to its relatively small size and its orbital rate (14,500 Km/hr). Technology is available for a high power ground based laser to target and have a limited effect on GPS satellites.

3. **Replenishment**. 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 nine or more satellites, still providing 3D coverage a full 12 hours and 2D coverage more than 20 hours.

b. Control Segment. This is considered by many to be the most vulnerable segment of GPS. The Master Control Station, located in Colorado Springs Colorado, is very well protected being collocated with several military bases; however, the tracking stations do not have this advantage. All the stations are susceptible to espionage and natural disasters, but the 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 8 hours. Next generation satellites are planned to provide a cross-link ranging capability, which will allow satellites to communicate with each other, making the offshore tracking stations redundant. Jamming of the control segment between the tracking stations and the Master Control Station is a real possibility; however, all four tracking stations would have to jam simultaneously to be effective.

c. User Segment.

1. Only two major vulnerabilities exist with the user segment, key security and jamming. Key security is discussed below. Jamming is considered so important that it will be discussed separately as its own topic.

2. **Cryptographic Key Security.** 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.

4-18 Jamming in GPS

a. Types of Jammers. There are several types of jamming that can be used against GPS receivers. Only four will be discussed:

1. Spoofing (Deception Jamming)
2. Continuous Wave (CW) Jamming
3. Wide Band Jamming
4. Pulse/Amplitude Modulated Jamming

1. **Spoofing.** Spoofing is classified as the enemy's attempts to duplicate or imitate GPS signals.

a. 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. Also, the enemy must know which satellites are being tracked as well as the position and velocity of the receiver to be able to create a false signal that will have the correct Doppler shift. Once false lock is established, the spoofer can perturb the duplicated navigation signals to cause navigation errors.

b. When GPS anti-spoofing protection is enabled, spoofers cannot autonomously generate the signals needed to deceive the receiver looking for the encrypted P-code. This technique transforms the P-code by cryptographic means. The resultant bit stream is a cipher 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. For this reason, the C/A-code is very susceptible to deception jamming.

2. **Continuous Wave (CW) Jamming.** A CW jammer, or Spot Jammer, will concentrate its jamming power in a very narrow band around the L1 or L2 carrier. In the GPS receiver the jamming power will be spread out according to the receiver "processing gain" using the modulated C/A- or P-code. After this spreading occurs, only a small portion of the jamming power will enter the tracking loops of the receiver. Consequently, a CW (Spot) jammer needs to be very powerful in order to effectively jam a GPS receiver.

3. **Wide Band Jamming.** A Wide Band Jammer needs a sufficiently wide spectrum in order to cover the frequency band of the GPS signals. In most cases, wide band jamming is performed in either a sweeping mode or a quasi-random noise (barrage) mode. In a sweeping mode, the jammer carrier is moved rapidly and possibly randomly through the band to be jammed. In the case of "barrage" jamming; however, the spectral power density is low compared with spot jamming.

4. **Pulse/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 and 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.

b. Jamming Effects on Code Acquisition. Three modes of acquiring the GPS signal will be considered: C/A-code acquisition, P(Y)-code acquisition, and P(Y)-code reacquisition.

1. **C/A-code Acquisition.** The GPS user is at a severe disadvantage when having to use C/A-code acquisition in a hostile region. Current technology receivers have only a limited tolerance to jamming during C/A-code acquisition (usually around 25 dB). Although only 1023 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 predetection bandwidth in order to acquire the C/A- code at the expense of reduced jamming tolerance (J/S). The C/A-code is widely disseminated, so a smart jammer can broadcast a false signal and lock up the receiver with very low power. Tests have indicated that a very modest one watt noise jammer can prevent a receiver from acquiring the GPS signal using the C/A-code out to a range of 85 Km. 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; therefore, the receiver's jamming tolerance would be on the order of 0 dB, a one watt spoofer could deny C/A-code acquisition past 1000 Km or to the jammer's horizon.

2. **P(Y)-code Acquisition.** 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 dB 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 J/S level in excess of 35 dB. However, because the P(Y)-code is so long, (approximately 6×10^{12} chips) much time or more correlators operating in parallel are needed for the two-dimensional 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.

3. **P(Y)-code Reacquisition.** 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 J/S tolerance (in excess of 50 dB dependent on the receiver).

c. Anti-jam Capabilities of GPS. GPS vulnerability to jamming can never be completely eliminated. With constantly improving techniques and technology, higher power outputs by the enemy jammers are required to deny access to GPS signals.

1. **Line of Sight Limitations.** The GPS satellites broadcast in the Ultra-High Frequency (UHF) domain. UHF 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, obviously, are not so restricted. A smart user will position his GPS receiver as to limit the effects of a line-of-sight jammer. Defilade areas, which still allow open skies for satellite signals, can be used. Handheld receivers can be placed in a "cathole" or the user can simply turn his 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.

2. **Inherent Receiver Anti-jam Capabilities.**

a. The satellite signal is a continuous wave 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.

b. To be able 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 (SNR or C/N). 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. Dependent on the power output of the jammer, the SNR may be too high for the receiver to filter out enough noise to determine data.

3. Many other Anti-jam capabilities exist for GPS. Among them, Inertial Navigation System (INS) integration with GPS and high cost antennas. Both 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.

4-19 Additional Considerations.

1. In addition to the previously stated limitations and possibilities for jamming; the Surveyor must be aware of the ambient conditions of the GPS satellites and their surrounding environment.

2. Solar flares, occurring in 11-year cycles, send great fountains of electromagnetic energy and radiation deep into space, causing interference in GPS signals.

3. Meteor showers, such as the Leonid event, occur close to the Earth, and could potentially damage satellites in the GPS constellation.

4. The GPS satellites are hardened against such possibilities, but they are not invulnerable.

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CHAPTER 5
SURVEY PLANNING

Survey planning is initiated at the maneuver commander's level, and is conducted at all levels down to the survey team chief. Planning is affected by many factors ranging from the commander's guidance, to unit SOP, to the individual surveyor's ability. This chapter will discuss these factors as well as provide options and guidance for the formulation of a realistic and timely survey plans.

Section I
THE PLANNING CHAIN

5-1 The Operation Order/Plan

a. The commander initiates the requirements for survey planning when he issues guidance in the form of an operation order or plan. He does so by stating his intent, scheme of maneuver, the rate of movement, the anticipated enemy threat, and the critical phases of battle.

b. The operation order is issued in the five-paragraph order format, and may be a short oral order or, a very large written text. This order will be the basis for any other order produced during the operation. As situations change the base document will remain the same, only the paragraphs with changes will be reissued in the form of a Frag Order. The Op Order will *not* contain SOP information.

5-2 The Artillery Fire Plan

a. The Artillery Fire Plan is part of the Maneuver Commander's operation order based on the fire support plan, and contains information necessary for understanding how the artillery will be used to support the maneuver element.

b. The Artillery Fire Plan follows the five-paragraph order format and is Tab B to Appendix 19 (Fire Support) to Annex C (Operations). Some of the essential elements of the artillery fire plan necessary for survey planning are listed below:

1. Allocation of all artillery assets.

2. Projected changes to the allocation of artillery assets based on tactical contingencies in the operation order.

3. The artillery Commander's concept of Artillery support. (Paragraph 3b of the Artillery Fire Plan.)

4. Priorities of survey. (Paragraph 3d [Coordinating Instructions] of the Artillery Fire Plan.)

5. Locations of command posts. (Paragraph 5 of the Artillery Fire Plan.)

6. Artillery targets. (Encl. 1 of the Artillery Fire Plan.) This may consist of a target list worksheet and scheduling worksheet. A target list is also included in the fire support plan that includes all targets, not just artillery targets. This list may be needed for planning target surveys for non-artillery targets.

7. Initial positions and planned movement of firing units to support the fire support plan. (Encl. 2 of the Artillery Fire Plan; an overlay may be included.) This enclosure lists initial position areas assigned to artillery units and their firing capabilities. Unit boundaries and range fans are depicted on the overlay.

8. Artillery target overlay. (Encl. 3 of the Artillery Fire Plan.) The overlay includes artillery targets, fire support coordination measures, and unit boundaries.

9. Observation and Target Acquisition Plan. (Encl. 5 of the Artillery Fire Plan.) This enclosure contains information concerning battlefield observation. It outlines mission statements for the collection of specific information, reporting requirements, positioning, and sectors of coverage of the artillery's target acquisition assets (e.g., FOs, OPs, radar, air observers, and UAV/RPVs).

5-3 The Survey Plan/Frag Order

a. General. The survey plan is written in the five-paragraph order format. The survey plan is contained in Enclosure 6 of the Artillery Fire Plan, which is Tab B to Appendix 19 (Fire Support) of Annex C (Operations) of the Operation Order/Plan. The five paragraphs in the survey plan will not duplicate the higher level planning documents. Only information necessary for the survey teams to complete their mission is included.

b. Five-Paragraph Order. The five-paragraph order, as it pertains to a survey plan, is written as follows:

1. **Situation.** This paragraph consists of the general situation as it pertains to survey operations to be conducted.

Enemy. Intelligence information regarding the enemy situation as it affects survey (routes, weapons, etc.).

Friendly. The friendly (higher, lower, and adjacent units) situation as it effects survey.

Attachments and Detachments. Units who can provide support to the survey mission (i.e., security, maintenance, etc.), or that are attached to the section.

2. **Mission.** This paragraph is a clear, concise statement of what must be accomplished.

3. **Execution.** This paragraph consists of several subparagraphs that answer the questions; who, what, where, and when. It will further establish priority of work, and the preferred survey methods to be used.

a. **Concept of Operation.** This subparagraph describes the survey methods to be used.

b., c., d... **Specific Instructions For Each Party.** These subparagraphs contain specific instructions each team needs in order to accomplish its portion of the survey mission. Survey control to be used by this team, general locations (6-place grids) for required control, and information which deviates from SOP are listed in these subparagraphs.

e. **Coordinating Instructions.** The last subparagraph contains instructions and/or information common to two or more parties. (timelines, rally points, etc.)

4. **Administration And Logistics.** This paragraph contains information necessary to insure service support is adequate for the mission. Information concerning rations, ammunition, aid stations, handling of prisoners, etc. will be addressed in this paragraph.

5. **Command And Signal.** This paragraph contains information such as the location of the survey officer, survey chief, chain of command, frequencies, call signs, medevac procedures, and communications between survey teams.

c. Frag Order. Once the operation, or a particular phase of an operation begins, the situation changes and occurrences develop which will affect the way fire support assets are deployed on the battlefield. When this happens, the survey officer must issue a survey frag order, and will only issue paragraphs two and three of the five-paragraph order. If however, the other paragraphs have changed, the survey officer may decide to issue the portion of those paragraphs that have changed.

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Section II
SURVEY PLANNING

5-4 Survey Planning And Common Grid

a. The survey plan is contained in Enclosure 6 to TAB B(Artillery Fire Plan), to APPENDIX 19 (Fire Support) to ANNEX C (Operations). This enclosure is titled Survey/Met Plan and is inclusive of both the survey and the meteorological plans of the unit. This chapter will discuss the survey plan only.

b. Survey planning is initiated with the operation order. Information drawn from SOP, the operation order, the fire support plan, and the artillery fire plan, is used to generate the survey plan. The survey plan must provide for a common grid. If this is not possible, the plan must provide for conversion to a common grid as soon as possible.

c. The survey plan must be simple, flexible, and adaptable to the chaotic and rapidly changing environment of the battlefield. Additionally it must provide required control, provide checks, and be timely.

d. Ultimately the survey plan will result in an order issued to the survey section. Execution of this order will ensure accurate and timely fires are delivered, and help alleviate any lapse in fire support to the maneuver commander.

5-5 Conduct Of Planning

a. Survey planning is conducted at all levels at the same time. Coordination between higher, lower, and adjacent survey 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.

b. To begin survey planning the Survey Officer must have a thorough understanding of the Commander's intent, and concept of operations. This understanding will allow him to prioritize which surveys should be conducted first, and what time constraints he has for completion. He can then consider all the other factors that will impact the survey plan.

c. Coordination with the Commander's staff, primarily the S-3 and S-2, in developing the survey plan is paramount.

1. The Survey Officer will generally receive the Commander's guidance through the S-3. He can provide the Survey Officer with operational information that will affect the Survey plan. Furthermore, the S-3 must be kept informed of all survey related problems that will affect the firing units and fire support assets.

2. The S-2 can make available mapping, charting, and geodesy products as well as friendly and enemy situations for the area of operations. He may also request information be obtained during the course of survey operations with regard to routes of march, road conditions, terrain conditions, volume of refugees, etc.

5-6 Factors Affecting the Survey Plan

a. In formulating the survey plan, the Survey Officer must make an estimate of the situation. METT-TSL provides the framework for that estimate. (Mission/Enemy/Terrain & Weather/Troops-Time/ Space/Logistics) METT-TSL considerations include, but are not limited to;

1. **MISSION:** 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 environment the surveyors will be operating in, (i.e., defensive, offensive, high intensity, low intensity, etc.). Rules of Engagement, fire support coordination measures, and boundaries, may hinder survey operations by restricting survey methods, or access to Survey Control Points.

2. **ENEMY:** The enemy situation has a tremendous influence on survey operations. The disposition of enemy troops may interfere

with, or limit, the movement and capabilities of survey personnel. Restrictions on communications, such as radio silence, and jamming, can greatly reduce a survey team's effectiveness. The ability of the enemy to degrade survey operations by denying terrain or routes of march is a prime consideration. Marine surveyors must be able to readily identify enemy vehicles, and positions they may encounter, and be trained to call for and adjust fires on those targets. The survey section must be equipped, and trained to take immediate action in response to the type of enemy force they may encounter. (e.g., regular troops, militia, guerrillas, etc.) Enemy air capabilities are also of importance due to the vulnerability of survey teams. Lengthy initialization times with PADS, or occupying traverse and GPS stations leave the surveyors exposed to air attack and observation.

3. **TERRAIN and WEATHER:** Terrain and weather encountered will be a primary factor in determining which method of survey to use, and**,** to some extent, the priority of installations to be surveyed first. The survey planner must be familiar with the influence of terrain and weather on survey operations. Adverse weather conditions greatly reduce the capability of the survey teams. Fog, rain, snow, or dust can make observation through optical instruments virtually impossible. Extreme heat or cold decrease efficiency, and increase the time needed to complete survey. 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.

4. **TROOPS AND FIRE SUPPORT:** The 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. The availability and condition of surveying equipment may further dictate what methods can be used, and the time required. Availability of fire support is largely dependent upon the tactical mission of the artillery unit (i.e.. DS, GS, GSR, R). For the most part the survey section must rely on it's own organic weapons due in large part to the independent nature of survey operations, and because the majority of survey operations will be conducted behind the FLOT.

5. **TIME:** 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 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.

6. **SPACE:** For the survey planner space is restricted to his operational area, within his unit's boundaries. Available survey control may only exist outside these boundaries thus requiring additional coordination and planning. Possibly the terrain within a unit' s proposed boundary may not be suitable for them to occupy.

7. **LOGISTICS:** Availability of logistical support must be considered in all planning. The survey section has a wide array of equipment that may need servicing or repair. Regardless of the survey method used surveyors are heavily reliant 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 POL are just some of the supply issues that must be addressed.

b. The elements of METT-TSL are all interrelated and must be considered together. It is a dynamic framework, *not* a checklist. Some other factors may have an effect on a survey plan but are not necessarily covered in METT-TSL, i.e.. refugees, political/diplomatic agreements, etc.

c. In addition to evaluating the factors of METT-TSL, the survey officer must also understand the characteristics of the different survey methods, their advantages and disadvantages, and their impact on mission accomplishment.

Position And Azimuth Determining System (PADS). The PADS is a vital survey asset. The speed at which PADS can provide survey data is it's primary advantage. The following considerations must be made when planning survey operations including PADS.

1. Is existing control accessible with a military vehicle? If not, is existing control within 16 meters of a location that will allow autoreflection?

2. Is the area of operations between 75° N and 75° S latitudes? (PADS operational limits)

3. Planning Times. The following vehicle speeds and system times should be used for planning with PADS operations:

Cross-country: 10 KPH
Unimproved Roads: 25 KPH
Improved Roads: 50 KPH
30-day Bias: 2-3 hours
Initialization: 30-45 min
Update/Mark: 5 min
Autoreflection: 15 min
Mission Time: Unlimited

4. Is existing common control available within 55 kilometers of the planned update point that can be used for future updates?

5. Does the PADS support the operational ellipsoid in the operation order? If not, is user-defined data available?

6. Does the PADS meet the accuracy requirements for the unit being supported?

Traverse. Traverse is the preferred *conventional* method of survey. The following considerations must be made when planning survey operations including Traverse.

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 between 84° N and 80° S latitudes? (This is the UTM north and south limits. Most survey computers used by artillery surveyors will only compute traverses in UTM.) If not, does the section have the capability to perform manual computations?

3. Planning Times. The following vehicle speeds and planning times should be used for planning with traverse operations:

Cross-country: 10 KPH
Unimproved Roads: 25 KPH
Improved Roads: 50 KPH
Distances Traversed: 1-20 KPH (Line of sight dependent)
LOS Clearing:Jungle: 100 meters per hour
Forest: 1 KPH

Many different considerations come in to play with planning a traverse on a timeline.

a. How far is existing control from the area requiring survey?
b. How much line of sight cutting is required? Is engineer equipment (chain saws, weed-eaters, bulldozers, etc.) available to help cut line of sight?

c. Is the control accessible by military vehicles or does equipment have to be carried into the area?

d. What is the required accuracy?

4. What means of communications between team members is available? (radio, panel marker, hand and arm signals, etc.)

5. Will traverse provide a timely enough response to the need for survey data?

Intersection. This is the primary method of survey used to determine target locations. Considerations for intersection include visibility, the accessibility and availability of control (OPs), azimuth marks, and communications between teams. Intersection can also be used to provide update and initialization points for PADS, or to locate other critical points other than targets.

Astronomic Observations. When weather conditions allow the observations of celestial bodies, the Artillery Astro Method is the primary means used to determine an azimuth. (The firing battery's primary method of astronomic observation is Hasty Astro.) The following considerations must be made when planning survey operations that include astronomic observations.

1. Do weather conditions allow observations of celestial bodies?

2. Do celestial bodies fall inside of allowable observation windows, relative to time and position of the body?

3. What is the required accuracy?

4. Is accurate time available?

Real Time Kinematic (RTK) On The Fly (OTF) GPS Survey. RTK/OTF is the newest method available to Marine artillery surveyors. Accuracy achieved by this method is well above that necessary for most artillery survey missions and this is the

fastest method available to provide survey data. The following considerations must be made when planning survey operations including RTK/OTF.

1. Is existing control available or will the base station be operated in the absolute mode? If control is available, is enough control of adequate accuracy available to be used as calibration points?

2. Are enough communications assets available to provide each GPS team with a voice radio and an additional SINGARS radio for digital communications between the receivers?

3. Have communications lines of sight been verified in the areas requiring control? If not, has a map reconnaissance shown that communications lines of sight are clear?

4. Are alternate sites available for the base station when communications are not available or the tactical situation forces evacuation of the original position?

5. What is the required accuracy?

6. Is electronic line of sight to the satellites available? If not, is engineer equipment (chain saws, weed eaters, bulldozers, etc.) available to help cut electronic line of sight.

7. Are planned base receiver sites within 10 kilometers of installations requiring survey? If not, are supplemental positions available?

8. What are the enemy radio direction finding assets?

Static / Rapid Static GPS Survey. Static / Rapid Static survey is the most accurate method available to Marine artillery surveyors. Static GPS methods provide geodetic level accuracy and are used establish high order survey networks. The following considerations must be made when planning survey operations including Static methods.

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?

3. If no control is available, can absolute stations be established distant enough (at least 50 kilometers) from each other to allow for adjustment of GPS measurements?

5-7 Environment

a. General. Survey operations must continue regardless of environmental factors such as climate and terrain. The types of environmental conditions that will be encountered must be considered in survey planning.

b. Arctic Areas and Cold Weather Conditions. Arctic areas and cold weather conditions provide the surveyor with unique problems that must be overcome if the surveyor is to provide adequate survey control to the supported units. For the most part, arctic regions provide the same problems as cold weather conditions anywhere else. When committing survey teams to field operations in extreme cold, the effects of ice movement, snowfall, prevailing wind, light refraction, and other peculiarities must be considered. Cold weather operations are discussed in great detail in FM 31-70 and FM 31-71.

1. While the warmer seasons can provide the advantage of better visibility, personal comfort, and fewer equipment malfunctions, cold seasons can provide the advantages of reduced transportation difficulties in river, lake, and tundra regions. Survey control can be extended easily along riverbanks, over large bodies of water, or over the relatively level, treeless plains of the arctic tundra.

2. Equipment malfunctions increase in cold weather conditions.

a. The PADS operates without performance degradation at temperature extremes as low as -50°F (-45°C). Initialization will take longer when the temperature drops below -5°F (-20°C) or when wind blows into the IMU heat exchanger. The heat exchanger exhaust can be covered by a blanket or field jacket to help reduce heat loss. The vehicle heater should be used along with windbreaks to maintain an operational temperature for the PADS. PADS batteries should be stored in a warm place (above -20°F) when not being used.

b. Another planning concern when using PADS is that it is limited to operations between 75° north and south latitudes. Operations in arctic regions may force the use of GPS and conventional surveys.

c. The HCS can be stored without batteries, or risk of damage in temperatures as low as -4°F; however, the HCS will not operate in temperatures below 32°F, and any stored data will be lost at temperatures of –32° F or lower. The HCS must be maintained inside the user's field jacket, against the body in cold weather conditions.

d. Optical equipment must be acclimatized prior to 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 in which they will be used.

3. Personnel must be trained in the use of cold weather equipment and cold weather field expedients.

4. Existing survey control in arctic regions is sparse to say the least. Locating existing control in arctic regions and cold weather conditions will take longer than in warm weather conditions. This is due in part to a lack of reference points to help identify or witness the stations as well as the need to dig through snow and ice to find it. Surveyors must understand that a pick and shovel can cause severe damage to a survey control point and that care must be taken when digging for control.

c. Desert Areas. A very large percentage of the world is covered by desert. Operations in desert regions are a common occurrence and these regions provide for there own unique obstacles for surveyors. While the open terrain and normally clear skies allow for long lines of sight and an abundance of celestial bodies for observation, other problems do exist.

1. The effects of wind blown sand and heat on equipment forces the surveyors to include those factors in the planning process.

a. The PADS operates without performance degradation at temperature extremes as high as 125°F (50°C). It may be stored at temperatures as high as 160°F without damage. Sand and dust will clog the PADS air vents and cause the PADS to quickly overheat. Covering the PADS to protect it from sand will have the same effect as the sand itself. Post operation maintenance including blowing the air vents clean is more important in desert regions than in any other environment.

b. Optical equipment must be shaded during leveling and protected from sand when not in use. Leveling vials increase about 2 graduations past true center in temperatures above 100°F and at temperatures reaching 120°F, leveling may be impossible. The most obvious obstacle to survey operations with optical equipment is heat waves. Eyestrain is more prevalent and instrument operator changes are more frequent. Observing long distances may not be possible. At those temperature extremes, survey operations using optical equipment should be avoided.

c. The HCS can be stored without batteries, or risk of damage in temperatures as high as 140°F, but will not operate in temperatures above 122°F. Any stored data will be lost at temperatures above 122° F. Additionally damage may occur to the LCD at 90% humidity with temperatures of 104° F or higher.

2. Personnel must be trained in desert operations. Noise and light discipline are more important in desert regions than other environments. Personnel should be trained in desert survival techniques since the time necessary to acclimatize is not normally available.

3. 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.

d. Jungle Areas. Jungle areas provide obstacles to surveyors such as heat, humidity, and a lack of adequate mapping products. Line of sight is a major concern in jungle regions, even for GPS operations, depending on the type of canopy.

1. Heat will effect the equipment in much the same manner as described for desert regions; however, the influence of 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.

3. Existing control will usually be located on mountaintops. This may preclude the use of PADS with those stations. Optical line of sight is a major problem for conventional teams, as is electronic line of sight for GPS teams.

e. Urban Areas. Survey in built-up or urban areas is restricted by line of sight, communications, the enemy situation, and accuracy.

1. PADS operations in urban areas may be the preferred method due to line of sight restrictions. Communications are also restricted due to the limited range of FM radios in built-up areas.

2. The tactical situation has a strong influence on survey operations in urban areas. The enemy can be well hidden in sewers, ladder wells, windows, on rooftops, etc. Enemy obstacles (i.e., mines, barricades, etc.) may deny the use of certain terrain or routes needed for the extension of survey through or around a built-up area.

3. Survey accuracy requirements in built-up areas may be increased due to the presence of the local populace. This is especially true when performing target surveys inside those areas.

4. Locations of installations are a concern in urban areas. OPs may have to be placed on rooftops, firing positions in airports, parks, or riverbeds. Reconnaissance and planning are essential for proper use of survey assets in urban areas.

5-8 Mapping, Charting, Geodesy

a. UTM Boundaries. The UTM grid system is bounded in the north at 84° N latitude and in the south at 80° south latitude. Beyond those boundaries, the UPS grid system is used with some overlap between the two systems. These systems are explained in detail in Chapter 3, Section II. Many fire support assets and survey computational devices do not provide for computations outside of the UTM system.

b. Nonstandard UTM Zones. These zones are found in the areas around Norway and Svalgard. Maps in those regions are made using the nonstandard zones; however, many fire support and survey systems do not recognize these zones.

c. Non-UTM Systems. Many areas of the world are mapped in systems other than UTM. Chapter 3 discusses some of the projection and grid systems that may be encountered. The surveyors may be required to develop UTM overlays of these areas. Also, existing control will be established in these systems; conversions to UTM will be required.

d. In many cases, mapping products and existing control will be of a different ellipsoid and datum combination than is prescribed in the operation order. Marine surveyors may be required to perform datum-to-datum transformations from the local datum to the operational datum as well as develop overlays and provide insight to datum problems and transformation accuracy. Chapter 2 discusses ellipsoids and datum's.

5-9 Steps In Survey Planning

a. The steps for generating the survey plan/order can be found in the acronym BAMCIS.

BEGIN THE PLANNING:

1. Review the Commander's intent, scheme of maneuver, and the Artillery Fire Support Plan. This information is used in conjunction 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.

2. Enclosures 1 and 4 of the Artillery fire Support Plan describe targeting information and timelines for planned Artillery fires. These are used along with guidance from the Commander and S-3 to determine time requirements for providing survey support.

3. Priorities can also be established at this time, as to which installations or control will be surveyed first.

4. A warning order should be issued to the survey chief and party chiefs to allow for preparation of personnel and equipment to conduct the reconnaissance.

5. 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 recon and mentally walk through the tentative plan to ensure it will meet all requirements.

ARRANGE RECONNAISSANCE:

1. Once the tentative plan is formulated a thorough ground reconnaissance made. (If the time and tactical situation permits.)

2. The survey chief ensures the required personnel and equipment are prepared to conduct the reconnaissance.

3. The route of march, with check points, and a brief itinerary should be provided to the 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 recon.

4. 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.

5. Additional security requirements should also be requested through the battalion.

MAKE THE RECONNAISSANCE:
1. Only those Marines essential to accomplish the recon should accompany the survey officer. Limits should also be placed on the amount of equipment taken as well.

2. During the recon mission the survey officer should:

a. Verify map data
b. Determine validity of his plan
c. Assess trafficability of routes
d. Assess condition of terrain
e. Note weather conditions
f. Note changes to any intelligence information received from the S-2
g. Make any changes necessary

COMPLETE THE PLAN:
1. Upon returning from the reconnaissance the Survey officer finalizes his plan. The survey order is written and briefed to the S-3. If time permits the survey plan is added to the Artillery Fire Support Plan. The S-2 is also briefed on any changes to the intelligence information he provided previously.

ISSUE THE ORDER:
1. The survey officer issues the survey order to the entire section in the form of a 5 Paragraph Order. The order may be written or oral. (If given orally certain information should be provided to the survey teams separately, i.e. strip maps, trig lists.)

2. The order should be simple, direct, and thorough. All the information required to complete the mission should be given to
allow for action in the absence of further orders. The order should describe what needs to be accomplished, and when. Priorities and accuracy are stated along with the methods to be used. Once the 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.

3. Use of a terrain model and/or a map during the brief is of great importance for the Marines to visualize the mission and what is expected of them.

4. Time should be provided at the *end* of the brief for any questions that may arise. This ensures a thorough understanding of the mission.

5. Any acceptable deviations from current SOP should be specifically noted.

SUPERVISE:
1. Once the survey order has been issued, and the teams begin their portions of the plan , the Survey chief supervises conduct of the mission while the survey officer begins the planning process all over again, and coordinates with the S-3 concerning future operations.

2. As the current mission progresses and the situation changes, subsequent orders will be issued in the form of a FRAG. (The only required information being paragraphs 2 and 3, [Mission, and Execution] of the 5 paragraph order.) The survey chief must maintain close liaison with the survey officer and add to his situational awareness.

5-10 Survey Sketch

a. General. A survey sketch must reflect the survey order, and should be provided to the survey teams to ensure their portion of the survey mission is understood. This sketch should be as detailed as possible without hindering the flexibility and adaptability of the survey plan. The following items should be included in all sketches:

1. The sketch should be drawn to scale. Use a large-scale map or plotting chart for surveys covering large areas or to enlarge small surveys.

2. The sketch must be self-explanatory.

3. The sketch must show all known and required control. General locations (6-digit grids) can be used for required installations.

4. All points must be labeled.

5. A north arrow will be drawn for orientation purposes if a map is not used for the sketch.

6. Routes which must be taken for security purposes and restricted areas (i.e., hazards, obstacles, etc.) should be included on the sketch.

b. PADS Operations. For PADS operations, a detailed sketch is not always necessary. In many cases a strip map or route overlay that includes known and required control may suffice.

c. Real Time Kinematic/On The Fly (RTK/OTF). A sketch for an RTK/OTF roving team will be prepared in much the same way as that for a PADS team.

d. Static GPS Survey. A sketch for a static GPS network must include all stations in the network, not just the stations planned for that team. It will include prescribed routes and in some cases may include pre-planned observation times. Because of the large area covered by a static network, this sketch will generally be performed on the map sheet.

e. Conventional Survey. A sketch for a conventional survey must be more detailed than that for a PADS team. Other than the information listed above, the sketch should also include the following:

1. Show all traverse stations.

2. Show all horizontal angles, drawn from the rear station to the forward station.

3. Starting and closing azimuths will be shown as a dashed line with an arrow pointing towards the azimuth mark.

f. Security Of Survey Sketches. The survey sketch includes a large amount of information that can be useful to the enemy. For this reason, the sketch must not be compromised; it must be destroyed if a serious threat of capture exists.

DRAFT

CHAPTER 6
POSITION AZIMUTH DETERMINING SYSTEM

The Position and Azimuth Determining System (PADS) is an asset in both Battalion and Regimental Survey Sections. Because the capabilities of the PADS, with respect to accuracy and mobility, it has become the battalion survey section's primary means of establishing artillery survey control.

Section I
SYSTEM CONFIGURATION

6-1 System Description

The **Position and Azimuth Determining System (PADS)** is a self contained inertial surveying system capable of rapidly determining accurate position, elevation, and azimuth when used during ground or airborne survey operations. It can be used in conjunction with or apart from other assets available to the survey section, such as conventional assets and GPS receivers.

6-2 PADS Vehicles

a. The PADS can be mounted in any military vehicle as long as the correct lever arm information (plumb bob position) is known. The current version of PADS software (V. 4) is programmed with seven lever arms for six vehicles and also has the capability of storing up to three non-defined vehicles. Any vehicle used with the PADS must have an available 24 volt system.

b. The following ground and air vehicles are programmed in the PADS with the their corresponding lever arm:

1. **High-Mobility Multipurpose Wheeled Vehicle- HMMWV** with the plumb bob mounted at the drivers door. The PADS cue for this lever arm is HUM.

2. **M151** ¼ ton utility vehicle **(Jeep)** with two lever arms. The first is located at the pintle hook with a PADS cue of M151; the second lever arm is the PADS plumb bob arm with a cue of PLMB.

3. **Commercial Utility Cargo Vehicle - CUCV** with the plumb bob mounted at the vehicles pintle hook. The PADS cue is CUCV.

4. **Small Unit Support Vehicle - SUSV** with the plumb bob mounted on a drivers side mount. The PADS cue for this lever arm is SUSV.

5. **UH-1 helicopter**. When mounted in the UH-1 **(Huey)**, the PADS plumb bob arm is used with a PADS cue of UH-1.

6. **OH-58 Light Observation Helicopter**. As with the Huey, the plumb bob arm is used; the PADS cue is OH-58.

c. The PADS can be transferred from a ground vehicle to a Blackhawk (UH-60) equipped with an AC to DC converter.

6-3 Capabilities and Limitations

a. Capabilities. PADS can perform surveys faster than a conventional survey party. It can provide coordinates, azimuth, and elevation to any point located either where the vehicle can be placed or within 16 meters of the PADS. The PADS requires less personnel than a conventional survey party and requires less time for recon and planning. It can provide data that meets the accuracy requirements of most artillery systems, and can provide accurate azimuth when coordinates have been assumed.

b. Limitations. The PADS limitations are mostly software driven. Current PADS use a Solid State memory with Version 4 software.

1. PADS with Version 4 software has a continuous mission time and no longer requires the system be updated once every seven hours or within a

55 Km radius of the last update.

2. PADS is limited to surveying between the latitudes of 75° N and 75° S.

3. PADS is limited to operations between -150 meters to 4500 meters in elevation.

4. Ambient temperature limits for operations are from -50° F to 125° F.

5. PADS power requirements dictate that the vehicle's electrical system include at least a 100 AMP alternator (200 Amp preferable).

6. PADS requires an initialization/alignment time of 30 to 45 minutes.

7. PADS with V.4 software limited to 12 programmed ellipsoids and 2 user defined options.

8. PADS with V.4 software can only store 50 positions as update and mark stations.

6-4 Accuracy

a. General. The accuracy obtained from the PADS is dependent upon the **Zero-Velocity Corrections** used during the survey mission. Zero- Velocity Corrections (Z-Vel) are performed automatically by the PADS during all marks and updates; they must be performed by the operator at other times en route between stations. This operation allows the PADS to correct itself based on the large amount of data it has collected while moving from one position to another. A 10 minute Z-Vel is sufficient for most artillery survey operations. For some missions; however, a 5 minute Z-Vel is required. Examples of those missions include Q-37 radar sites and declination stations. Procedures for performing a Zero-Velocity Correction and for changing the time for Z-Vels are discussed in Section II.

b. Accuracy of Survey Operations (10 Minute Zero-velocity Corrections)

	Latitude	
	0°-65° N/S	65°-75° N/S
Horiz. Position (CEP)	7.0 m.	10.0 m.
Vert. Position (PE)	3.0 m.	3.0 m.
Azimuth (PE)	0.4 mils	0.6 mils

c. Accuracies of Survey Operations (5 Minute Zero-Velocity Corrections)

	Latitude	
	0°-65° N/S	65°-75° N/S
Horiz. Position (CEP)	4.0 m.	7.0 m.
Vert. Position (PE)	2.0 m.	2.0 m.
Azimuth (PE)	0.4 mils	0.6 mils

6-5 Major Components

a. General. The PADS is contained in two sections; the Primary and Secondary pallets. When unpacked for the first time, the system will contain these pallets plus the mounting base (subfloor). If the PADS is to be installed into a HMMWV, CUCV, or a SUSV, a separate installation kit is required.

b. Primary Pallet (Mounting Base). The Primary Pallet is named for the metal framed housing in which the components are mounted to. The Primary Pallet has four major components.

1. **Inertial Measurement Unit (IMU).** The IMU contains two gyroscopes, three accelerometer sensors, and the associated electronics necessary to maintain the survey coordinate frame and measure distances traveled to each coordinate axis. The accelerometers sense the movement and the gyroscopes give the accelerometers a reference point that detects actual movement. (See Figure 6-1.)

a. A **Gyroscope** is a spinning wheel that tends to keep a fixed orientation in space. It also is designed to act as a gyrocompass which finds true north by sensing the Earth's rotation. The PADS uses the two gyroscopes to give the accelerometers a reference point. One gyroscope is oriented to true north while the other is aligned horizontal and orthogonal (perpendicular) to the spin axis of the other gyroscope. This allows the PADS to provide a three dimensional reference point to the accelerometers.

b. An **Accelerometer** measures acceleration which is the time rate of velocity. If a car is going 50 miles per hour and accelerates to 70 miles per hour, the actual acceleration time rate is 20 miles per hour. PADS uses three accelerometers: one to measure acceleration in the North-South direction, one to measure acceleration in an East-West direction, and

one to measure the acceleration vertically.

Figure 6-1 Inertial Measurement Unit (IMU)

2. **Computer.** The computer consists of a general purpose digital computer and interface circuitry. It processes IMU data, computes survey data, and provides system control functions. The computer receives three signals from the accelerometers: Acceleration North-South, East-West, and acceleration in the vertical position. These signals are integrated with time to produce the velocity signals. The velocity signals are once again integrated with respect to time to produce the distance traveled in each cardinal and vertical direction. The computer also produces error signals that are used for calculations for Earth rotation rates and for keeping the gyroscopes level during survey operations. (See Figure 6-2.)

3. **Control and Display Unit (CDU).** The CDU is the operator's interface with the PADS. It is a keyboard and an alphanumeric display for operator entry and display of survey data and system commands. The CDU is the input/output device for the systems computer, and is the only portion of the PADS that must be accessible during a survey mission. (See Figure 6-3.)

4. **Power Supply.** The Power Supply receives unregulated power from the vehicle or the PADS batteries and sends power out to the PADS other components. It supplies, controls, and regulates the amperage to the IMU, CDU, and Computer, and charges the PADS auxiliary batteries. The computer also has a power supply. It receives the input power from the PADS Power Supply and regulates the amperage necessary for the computer.(See Figure 6-4.)

Figure 6-2 PADS Computer

Figure 6-3 Control and Display Unit (CDU)

Figure 6-4 PADS Power Supply

c. Secondary Pallet. The secondary pallet consists of the battery box. The battery box contains two 12-volt DC batteries hooked in series to provide 24 volts for back-up power. It also can be used to continue survey operations while the PADS is transferred between a ground vehicle and a helicopter. It provides additional power for initialization and back-up power in the event that vehicle power fails. It is also a transport case that houses cables, tools, small hardware, spare lamps, modules, reference manuals, etc. (See Figure 6-5.)

Figure 6-5 Secondary Pallet (Battery Box)

6-6 Operator Controls

a. CDU. Most of the operator controls are on the CDU. The CDU has an alpha numeric display that displays commands and input/output data. It also has a keyboard and display for status/fault indicators. Status indicators usually appear as orange/yellow lights, the DS2 fault indicator shows white.

1. **Status Indicators.** The status indicators are located on the top half of the CDU display. These are lights that prompt the operator to perform a task or to indicate a possible malfunction or problem. (See Figure 6-6.)

a. **COMP.** Indicates possible computer failure.

b. **IMU.** Indicates possible IMU failure.

c. **BATT.** A steady BATT may indicate one of several problems: the vehicle or PADS battery is not connected, the PADS battery is being discharged, or one of the PS circuit breakers are off. A flashing BATT indicates the input voltage is too low and the PADS may turn itself off unless the problem is corrected.

d. **ATTN.** Indicates operator error.

e. **STOP.** A flashing STOP alerts the operator to stop for zero-velocity corrections. A steady STOP alerts the operator to remain stopped.

f. **GO.** A flashing GO advises the operator that the vehicle can be moved. A steady GO indicates the vehicle has been moved since the last zero-velocity correction.

g. **CHRG.** Indicates PADS batteries are charging.

h. **ADZ.** Indicates entry and display of position data are in the adjacent UTM grid zone.

i. **MON.** CDU displays user requested data. (in the monitor table)

j. **UPDT.** Indicates the system is ready to accept update data.

Figure 6-6 CDU Status Indicators

k. **CAL.** Lights during initialization and 30 day bias. Lighting during an update indicates the operator entered incorrect data or the system is out of calibration.

l. **MARK.** Indicates the system is recording marked survey data.

m. **Z-VEL.** Indicates that the PADS is performing a zero-velocity correction.

n. **ENT.** Indicates computer is ready to accept data from the keyboard.

2. **Operator Commands.** The CDU keyboard allows the operator to enter system commands and data.

a. **STOP.** Starts zero-velocity correction, lights STOP indicator, turns off audible alarm (IF ALARM IS ON), and will illuminate the ATTN status indicator, if pressed while vehicle is moving.

b. **MARK.** Initiates position mark procedures. Lights MARK indicator. Pressing MARK twice cancels a position-mark procedure.

c. **UPDT.** Initiates position and/or elevation update procedure. Lights UPDT indicator. Pressing UPDT twice cancels an update procedure.

d. **ON/OFF.** If the system is off, pressing ON/OFF applies power. If the system is on, pressing ON/OFF causes the CDU to display commands for shutdown procedures.

e. **LAMP.** Tests all CDU status indicators, alphanumeric display lamps, and system fault indicators. When held down varies lamp intensity and sounds DS3 ALARM.

f. **MON.** Selects the monitor mode. Lights MON status indicator.

g. **ADZ.** Directs the system to enter or display the adjacent UTM grid zone. Lights the ADZ indicator.

h. **SPH.** Allows the entry and display of spheroid (ellipsoid) options. Also allows the option for performing a 30-day bias or for entering geographic coordinates.

i. **TIME.** During 30-day bias, initialization and zero-velocity corrections, displays elapsed time since turned on. When the vehicle is in motion, it displays time to the next zero-velocity correction. Silences ALARM DS3 for 30 seconds.

j. **ID.** When pressed, followed by an ID number, followed by ENT, cues PADS to provide mark data for the ID number entered. ID, 0, ENT indicates current data display. Pressing ID twice selects position, azimuth, and elevation (PAE) display.

k. **DIST.** Allows entry and display of the distance between the porro prism and a theodolite for an optical position mark. Displays the distance between points on a two position azimuth mark.

l. **<.** Allows entry and display of a horizontal angle measured by a theodolite.

m. **E.** Allows entry and display of the UTM grid zone and easting.

n. **N.** Allows entry and display of a northing coordinate; when pressed twice, it indicates southern hemisphere by displaying "S". Only during the initial entry of data may the change in selection of hemisphere from northern to southern be made.

o. **EL.** Allows entry and display of elevation.

p. **GAZ/TAZ.** Displays grid azimuth. When pressed twice, displays true azimuth, clear or enter (TA C-E). Operator may display true azimuth by pressing ENT. If CLR is pressed, grid azimuth is displayed.

q. **1,2,3,4,5,6,7,8,9,0.** Enters numerical data as selected.

r. **+2, -8.** When elevation has been selected for entry of data, the first pressing of the 2 or 8 will enter a + or -, respectively; thereafter, the 2 and 8 revert to normal number functions. Advances (+) and decreases (-) through ID and monitor numbers.

s. **ENT.** Causes displayed data (or function) to be entered into the computer (or executed).

t. **CLR.** Clears display and mode selection.

3. **DS Alerts.** The CDU has two DS alerts to indicate that a specific task needs to be performed or

that a malfunction has occurred. (See Figure 7-3.)

a. **ALARM DS3.** Warns the operator to stop for a zero-velocity correction or may sound if there is excessive motion during initialization.

b**. Fault indicator DS2.** Indicates the CDU is functioning (black) or malfunctioning (white).

b. Power Supply. Operator controls that are located on the Power Supply are as follows:

1. **Circuit Breakers.**

a. **CB1.** Controls battery power from the PADS Battery Box to the Power Supply.

b. **CB2.** Controls vehicle power from the prime mover to the Power Supply.

2. **DS Fault Indicators.**

a. **DS1.** The BATT FAIL fault indicator DS1 turns from black to white when the PADS batteries do not have sufficient power to maintain standalone system operations.

b. **DS2.** The PS FAIL fault indicator DS2 indicates whether the Power Supply is functioning (black) or malfunctioning (white).

3. **M1.** The elapsed time indicator displays the total Power Supply operating time.

c. Computer. Operator controls on the Computer are:

1. **M1.** The elapsed time indicator displays the total computer operating time.

2. **DS1.** The fault indicator DS1 indicates whether the computer is functioning (black) or malfunctioning (white).

d. IMU. Operator controls on the IMU are:

1. **M1.** The elapsed time indicator displays the total IMU operating time.

2. **Porro Prism Controls.** (See Figure 6-7.)

a. **Porro Prism.** Used to align the theodolite to the IMU during optical measurements (offset).

b. **Level Adjustment Knob.** Used to level the porro prism.

c. **Level Vial.** Indicates the level of the porro prism.

d. **Stadia Scale.** Used with the theodolite stadia lines to indicate the distance between the porro prism and the theodolite to the nearest 0.1 meter.

3. Plumb Bob Arm Assembly. Used with the plumb bob for plumb bob marks and updates. When mounted in a vehicle that uses the standard plumb bob position (M151, OH-58).

Figure 6-7 Porro Prism Components

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Section II
PADS OPERATIONS

6-7 Recording PADS Field Notes.

a. PADS survey data is recorded in the current version of the field recorder's notebook. As with all field notes, the first page of the recorder's book is the index. The heading and column titles for normal PADS missions will be filled out as described below. (See Figure 6-10.)

1. The **designation** block should be filled in with PADS SURVEY as the method of survey being conducted.

2. The **date** block will be filled in with the date the field work was performed.

3. The heading of the following page will include the PADS serial number (taken from the primary pallet), ellipsoid, and datum. At the right side of that page, list the names of the operator and assistant operator and the interval that zero-velocity corrections were made.

4. The column titles under the heading will be labeled (from left to right) as follows:

a. Column 1: STA; to identify the update or marked stations.

b. Column 2: ID #; to identify the storage position in the PADS computer for update and marked positions.

Figure 6-10 PADS Recording Procedures

PADS Version 4 can store 50 positions, Core Memory systems loaded with Version 3 can store 30 positions.

c. Column 3: PAE; to identify the operation performed at each position.

d. Column 4: U/A; to identify unadjusted and adjusted data.

e. Columns 5 & 6: EASTING; to identify the UTM grid zone and UTM easting of the position.

f. Columns 7 & 8: NORTHING, to identify the UTM northing of the position.

g. Column 9: EL; to identify the elevation of the position.

h. Column 10: GRID AZ; to identify the UTM grid azimuth between two marked points or to an optically sighted azimuth mark. **PADS with Version 4 software will adjust the azimuth, only the unadjusted azimuth should be used.** If the azimuth recorded is a true azimuth, then the word TRUE will be recorded in the block with the azimuth.

i. Column 11: DIST; to identify the distance (in meters) between two marked stations or to identify the distance measured by an autoreflection.

j. Column 12: REM: to identify any system malfunctions, magnetic azimuth checks, etc.

Figure 6-11 PADS Recording Procedures for Optical Azimuth Method

b. Recording the information obtained from the optical azimuth method is performed in the same manner as recording a one-position horizontal angle. Other measurements such as distances to azimuth marks and vertical angles may be obtained, and an entry in the remarks section made concerning those measurements. The offset distance between the theodolite and the PADS porro prism will be recorded on the page of the recorders book with the PADS mission. Figure 6-11 shows an example of this procedure.

6-8 PADS Mission Procedures

a. General. PADS mission procedures are explained in detail in Marine Corps TM 08837A-12/1A (Army TM 5-6675-308-12), and they are outlined in Appendix F of this publication. The procedures outlined in Appendix F are for PADS V.4 software and reflect the procedures provided in the above listed TM with Changes #3 and #4. All PADS mission procedures must begin with pre-operation checks and services as outlined in the TM and in Appendix F.

b. 30-Day Azimuth Gyro Bias.

1. The 30-Day Azimuth Gyro Bias is no longer required as a normal part of scheduled maintenance on the PADS. PADS Version 4 solid state circuitry is able to conduct azimuth gyro alignment during normal initialization. It may become necessary to perform this procedure as part of regular operations as indicated in the troubleshooting section of the TM.

2. It should be done while plumb over a fourth order or higher survey control point but may be done using a GPS position if need be. This operation cannot be performed with a theodolite.

3. The PADS must be level to ±5°. Once the 30-Day Azimuth Gyro Bias has begun the vehicle cannot be disturbed for any reason. This procedure will last anywhere from 2½ to 3 hours and the PADS will align its way through 18 modes. Once the PADS reaches mode 18, the GO light will flash, informing the operator it can be moved.

4. A PADS which has just completed the 30-Day Azimuth Gyro Bias does not have to go through the initialization process.

c. Initialization.

1. Initialization procedures must be performed every time the PADS is going to be used to provide survey control. This procedure aligns the gyros for use during the mission. The initialization does not take a space as an ID # in the PADS memory.

2. The PADS must be within 100 meters of the initialization site. Elevation should be within 10 meters. Initialization can be done using a GPS position when no survey control is available. This procedure cannot be performed with a theodolite.

3. The PADS should be level to ±5°. The PADS can be initialized on slopes greater than 5°, but with a possible decrease in alignment accuracy. LEVEL will display on the CDU at which time the operator should shut down the PADS, wait two minutes, move to a more level position, and reinitialize. If this is not possible, the PADS will continue to initialize until it reaches mode 8 at which time LEVEL will go off and the GO light will flash.

4. Once the PADS is turned on it must not be moved for at least one minute or damage to the system may result. The system can be moved after one minute without damaging the system; however, the IMU and ATTN indicators will light and the system may have to go through a 30-Day Azimuth Gyro Bias to realign the gyros. The vehicle should be faced into the wind, and allowed to set without moving for approximately 30 to 45 minutes. Once the PADS reaches mode 8, the GO indicator will flash informing the operator it can be moved.

d. Updating.

1. This procedure is performed to tell the PADS exactly where it is. It must be performed prior to marking a position; if adjusted data is needed it must be performed after marking positions . All updates are stored as ID #s in the PADS memory.

2. Updating the PADS should be done while plumb over a fourth order or higher survey control point; however, a GPS position can be used to update if no survey control is available. The PADS will not adjust stations that were marked before or after a GPS update. In other words, if you update over a survey control point, mark stations, then update with a GPS position; the stations marked between the two updates will not be updated.

3. The PADS can be updated with the programmed lever arm or with a theodolite (auto-reflection). If autoreflection is used, the PADS must be within 16 meters of the station.

4. The position and elevation can be updated together or separately depending on what survey data is available. Azimuth cannot be updated.

e. Mark

1. This procedure is used to obtain the position and elevation of a point (i.e. OS, EOL, OP, etc.). It can also be used to obtain an azimuth between two marked stations (Two- Position Mark) or between a marked station and an offset station (Optical Azimuth Method). All marked positions are stored as ID #s in the PADS memory.

2. When performing a Two-Position Mark, the first position mark is performed exactly the same as a regular mark, with either the PADS lever arm or with the theodolite; the second position *must* be marked with the PADS vehicle. The PADS will not allow the second position to be marked with a theodolite. The distance between the two stations must be between 100 and 1000 meters, otherwise an error (E) will appear in the PAE portion of the mark.

f. Zero-Velocity Correction.

1. Zero-Velocity Corrections (Z-Vels) are necessary for accurate computation of survey data. The PADS automatically performs Z-Vels during a 30-Day Bias, Initialization, and during all marks and updates. The operator must perform all Z-Vels during the mission between stations.

2. The PADS will cue the operator 30 seconds prior to the scheduled Z-Vel by flashing the STOP and GO status indicators and by sounding alarm DS3. The driver must stop the vehicle, place the transmission in neutral, set the parking brake, and release the foot brake. Once the vehicle is completely stopped, the operator must press the STOP key to start the Z-Vel. The PADS will flash GO when the Z-Vel is complete. Failure to perform the scheduled Z-Vel will degrade the accuracy of the survey data.

3. The operator can change the scheduled Z-Vel by performing the following keystrokes:
5 min: MON, ID, 4, 6, ENT, MON, 5, 0, ENT
10 min: MON, ID, 4, 6, ENT, MON, 1, 0, 0, ENT
The PADS defaults to the last Z-Vel time entered.

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6-9 PAE Codes

a. Each time a station is marked or the PADS is updated, that station occupies one of 50 ID #s stored in the Mark portion of the PADS memory. Part of that ID # is the PAE, which is an acronym meaning Position, Azimuth, and Elevation. The PAE tells the operator the method used to mark or update and whether or not that procedure was performed without error.

b. A separate code is assigned to each part of the PAE. These codes will be displayed on the CDU after the mark is completed or after the update is accepted by the PADS. The display will appear on the CDU as follows: ID # PAE XYZ where X represents the code assigned to Position, Y to Azimuth, and Z to Elevation. The three codes can be all the same, all different, or any combination of the following codes:

U: indicates that the position and/or elevation has been updated using a plumb-bob or a theodolite over a control point.

g: indicates that the position and/or elevation has been updated using GPS only.

d: indicates that the position and/or elevation has been updated using Differential GPS.

1: indicates that a theodolite was used to mark position, azimuth, and/or elevation.

2: indicates that a plumb bob was used to mark position, azimuth, and/or elevation.

E: indicates that an error may exist in position, azimuth, and/or elevation.

-: indicates that position, azimuth, and/or elevation has not been updated or was not marked.

c. A" g" or a "d" associated with the numbers 1 or 2 (e.g., g1, g2, d1, d2) may appear in one of the PAE positions. This indicates that a mark has been affected by using a GPS or Differential GPS (Diff. GPS) method. A "g" or "d" with a 1 indicates a GPS or Diff. GPS association with a theodolite mark; a "g" or "d" with a 2 indicates an association with a plumb bob mark.

d. The following are examples of PAE readings:

PAE U-U	Position and elevation were updated.
PAE U--	Position only was updated.
PAE --U	Elevation only was updated.
PAE g-g	Position and elevation were updated using GPS only.
PAE g--	Position only was updated by GPS.
PAE d-d	Position and elevation were updated with Differential GPS.
PAE d--	Position only was updated with Differential GPS.
PAE --d	Elevation only was updated with Differential GPS.
PAE 1-1	Position and elevation were marked using a theodolite.
PAE 111	Position, azimuth, and elevation were marked using a theodolite. Azimuth obtained by optical azimuth method.
PAE 2-2	Position and elevation were marked with a plumb bob.
PAE 222	Position, azimuth, and elevation were marked with a plumb bob. Azimuth obtained by a two-position mark.
PAE 2E2	Position and elevation were marked; however, the azimuth may be in error. Normally occurs when the distance between two stations in a two-position mark is less than 100 meters or too much time was used to travel between the stations.
PAE g1-g1	GPS influenced position and elevation mark with a theodolite. This will occur when the last update was performed with a GPS position.

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PAE g2-2	GPS influenced position from a plumb bob mark with a standard Control elevation mark. This may occur if the last position update was performed with GPS and the elevation was updated separately over a survey control point.

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CHAPTER 7
CONVENTIONAL EQUIPMENT

Marine Surveyors have many assets at their disposal for the completion of their mission. From high tech GPS systems to low-tech 30-meter steel tapes, the surveyor must maintain a certain level of proficiency with all his equipment. This chapter discusses the surveyor's conventional assets: the T-2E, DI-3000, and Precise Target Set.

Section I
T-2E Theodolite

7-1 Description

a. The T2-E Theodolite is a lightweight, compact, dust proof optical reading instrument equipped with a fixed reticle. It is a directional-type instrument used to measure horizontal angles and vertical readings.

b. The interior scales (circles), read by means of a built-in optical system, are graduated in mils, and can be read directly to 0.001 mils. The circles are illuminated by sunlight or by a built-in wiring system producing artificial light. All parts of the instrument that can be damaged by dust or moisture are enclosed.

7-2 Components

The T-2E is generally divided into three parts: the Tribrach, the Lower Part, and the Alidade. (See Figures 7-2 and 7-3.)

a. Tribrach. The most commonly used tribrach for the T-2E is the GDF-22. This is also the tribrach used with the Target Set. (See Figure 7-1.)

The GDF-22 will mount on all tripods with a standard 5/8 inch fixing screw. It has three leveling knobs, a fish-eye level, and an optical plummet. It also has a swivel-locking knob used to attach the Lower Part to the tribrach.

b. Lower Part. The Lower Part of the theodolite contains the centering flange, which attaches to the tribrach. It also contains the standing axis system, the horizontal circle, the circle setting knob, the horizontal mirror, and the cable plug-in for use with artificial light. The main purpose of the Lower Part is to provide a fixed rotational axis around the standing axis system for the alidade. The standing axis system consists of the axis sleeve, which is rigidly connected to the centering flange and the axis stem, which is screwed fast to the alidade.

c. Alidade. The alidade is the upper part of the theodolite, which contains the telescope, reading microscope, and the majority of the T-2E operator controls. The operator controls are as follows:

1. **Horizontal Locking Clamp:** fixes the alidade to the lower part so that the alidade cannot be rotated except by the Horizontal Drive Screw.

2. **Horizontal Drive Screw:** rotates the alidade for fine adjustments in pointing.

3. **Vertical Locking Clamp:** fixes the tilting axis of the telescope so that it cannot be rotated except by the Vertical Drive Screw.

4. **Vertical Drive Screw:** rotates the tilting axis of the telescope for fine adjustments in pointing.

Figure 7-1 GDF-22 Tribrach

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Section II
DI 3000 Distomat

7-25 Description

a. The DI 3000 is a timed-pulse electronic distance-measuring device. The time needed for a pulse of infrared light to travel to the reflector and back is measured. Depending on the measuring mode, the displayed result will be the mean of hundreds or even thousands of such measurements.

b. The laser is listed as a Class 1 laser product meaning it is completely harmless. The DI 3000 weighs 1.7 kg (3.7 lb) and can be operated between -20° CS to 50° C.

7-26 Range and Accuracy

a. Range. The maximum range of the DI 3000 is dependent upon atmospheric conditions and prism configuration. Poor atmospheric conditions such as haze or bright sunlight will decrease its maximum ranges. Figure 8-23 shows the typical ranges that can be expected with different target configurations and different atmospheric conditions using Wild (Leica) circular prisms.

Figure 7-23 Typical Ranges

b. Accuracy. The accuracy of the displayed distances is dependent on the operating mode of the DI 3000. Standard deviation is listed at 3-5 mm +1 ppm for all operating modes except the tracking mode; in this case it is 10 mm +1 ppm. One ppm (parts per million) is equal to 1 mm per km measured. This all means that with a distance of 10,000 meters in the normal mode, the standard deviation will be equal to 13-15 mm.

7-27 Power Sources

a. Types of Power Sources. The DI 3000 requires a 12v DC power source. Several sources of power are available to Marine Surveyors.

1. **GEB 70.**

a. The GEB 70 is a 2Ah, 12v DC, Nickel-cadmium, rechargeable battery. When fully charged it can provide sufficient power to measure about 2000 distances. The GEB 70 has a clip on its side to allow it to be hung on a tripod leg. It contains a 2.5A fuse located on its bottom to prevent damage to the battery and Distomat. A 5-pin cable (GEV 52) is used to connect the GEB 70 to the DI 3000. (See Figure 7-23.)

Figure 7-23 GEB 70 NiCad Battery

Figure 7-24 GEB 70 Discharge Rate

b. The GEB 70 NiCad battery has a non-

constant discharge rate. In other words, the battery discharges quickly between power indicators 9 to 7 and between indicators 3 to 1. It discharges slowly between power indicators 7 to 3. The power indicators are displayed on the DI 3000 Control Panel. When the battery voltage drops below 11.0V (power indicator 1), the Distomat will not measure a distance and error message 12 appears on the display. (See Figure 7-24.)

2. **GEV 51.** The GEV 51 is the cable used to connect the DI 3000 to a 12v vehicle battery. One end has alligator clips for the battery terminals; the other end has a black box containing a 2.5A fuse with two spares. The black box also has a 5-pin connection for the GEV 52 power cable.

b. GKL-12 Battery Charger.

1. The GKL-12 battery charger is capable of recharging two GEB 70 NiCad batteries at a time. It will generally take 14 hours to recharge a completely discharged battery. The GKL-12 plugs into a standard AC outlet and may be set for either 115 or 220 volts. When the batteries are connected, a red light illuminates on the charger. If this light does not illuminate, then either the cables are not connected properly, no power is going to the charger, or the fuse in the batteries have blown.

2. The GKL-12 has a built-in overload protection timer. With a battery connected, press the red button to start a 14-hour charge. If there is a break in the AC main supply, the timer restarts automatically. At the end of the charging period, it automatically switches off the power supply.

7-28 Mounting the DI 3000 to a T-2E

a. Modification of the T-2E. Before the DI 3000 can be mounted on a T-2E, the user must ensure that the theodolite has been properly modified. The modification includes adding an adapter plate to the reverse side of the telescope, adding a tension pin on the standard of the theodolite, and changing the spring in the vertical drive. (See Figure 7-26.)

b. Mount the Distomat. The DI 3000 is mounted to the T-2E in the following manner:

1. Setup and plumb the tripod as described in paragraph 8-5.
2. Mount the theodolite on the tripod as described in paragraph 8-6.

3. Remove the carrying handle and lens cap from the theodolite. Place the telescope in the reverse position.

4. Attach the GEB 70 battery to the tripod leg taking care not to disturb the plumb and level of the tripod.

5. Holding the DI 3000 by the carrying handle, press the two spring levers at the keyboard end together with the other hand. (See Figure 7-25.)

Figure 7-25 DI 3000 Bottom View

Figure 7-26 T-2E Modification for DI 3000

6. Place the DI 3000 over the telescope, aligning the tension pin on the standard between the balancing springs on the Distomat. Lower the Distomat so that the holes in the base plate are aligned to the posts on the telescopes adapter plate. Release the two spring levers. Check to ensure the DI 3000 is properly seated. (See Figures 7-25 and 7-26.)

7. Connect the large end of the GEV 52 cable to the GEB 70 battery or to the GEV 51 12v cable by aligning

the red dots on the connectors. Connect the small end of the GEV 52 cable to the DI 3000 by aligning the red dots on the connectors.

8. Remove the lens covers from the front of the Distomat and place them in the instrument case. Close the instrument case and place it out of the way of the instrument operator.

9. Plumb and level the theodolite as described in paragraph 8-7.

Figure 8-27 DI 3000 Mounted on T-2E

7-29 DI 3000 Control Panel

a. General. All operations with the DI 3000 will be performed using the Control panel. The DI 3000 Control Panel includes the signal strength indicator, the LCD display, and the keyboard. (See Figure 7-27.)

Figure 8-27 DI 3000 Control Panel

b. Signal Strength Indicator. The signal strength indicator is located at the upper right corner of the control panel. When a signal is received from a prism set the indicator will illuminate in red. When a weak signal is received, the indicator illuminates to the left; when a strong signal is received, the indicator illuminates to the right; and if no return signal is received, the indicator will not illuminate.

c. LCD Display. The DI 3000 is equipped with a 7 digit LCD that can be illuminated. The full distance is always displayed as well as symbols indicating operating modes and functions.

d. Keyboard. The keyboard of the DI 3000 is the operator's interface with the Distomat. The keys can have several functions as indicated by the colors on the keypad. Key functions colored white are main commands, key functions colored green are display settings, and key functions colored orange are set and store parameters. The DI 3000 will beep with each keystroke unless that keystroke is out of sequence, illogical, or if the Distomat is carrying out an operation. (See Figure 7-29.)

Figure 7-29 DI 3000 Keyboard

7-30 Operating the DI 3000

a. On/Off. To turn on the DI 3000, press the **ON/OFF** button. The LCD will display the stored ppm and prism constant. To turn off the DI 3000, press the **ON/OFF** button. By default, the DI 3000 will switch off automatically 10 minutes after the last keystroke, except in the tracking mode.

b. Display Illumination. The DI 3000 display field is illuminated from the back. To illuminate the display press the lamp button. Pressing the same button turns off illumination.

c. Test Mode and Battery Power Indicator. To display the LCD test and the battery power indicator, press and hold down the TEST button. The display check will appear while the TEST button is pressed, when it is released the battery power indicator will display the battery voltage in terms of a value from 1 to 9. The DI 3000 will send out a signal to the prism set, the signal strength indicator will illuminate and a tone

will sound. The **STOP** button will cancel the tone. Press any command key to exit the test mode.

d. CE, RUN, +/-. The **CE** key will allow the operator to exit from a command with the current setting retained. While inputting data the **CE** button will clear the entry one figure at a time until **RUN** is touched. **RUN** completes entries and commands. Once **RUN** is touched, settings are made and their values are stored. When entering values that require a negative press the +/- key.

e. STOP. Use the **STOP** key to halt a command or function as follows:

1. Stop tracking in the track mode.
2. Stop the repeat mode.
3. Stop a normal measurement. This is necessary if the beam is interrupted by an object and the measurement cannot be completed.
4. Stops the tone in the test mode.

7-31 DI 3000 System Settings

a. Prism Constant (mm).

1. The DI 3000 determines the distance to the center of the reflective surface of the prism. The position of this surface is offset differently depending upon the type of prism being used. If the measured distance is to be correct, the prism constant for the type of prism must be stored in the DI 3000. The prism constant must be entered in millimeters. The following settings should be used:

   a. 0 mm for Wild circular prisms.
   b. -35 mm for Wild rectangular prisms.
   c. When using non-Wild prisms, determine the prism constant by measuring or accurately kno

2. To store the prism constant:

   a. Press **SET**, **mm**
   b. Enter the millimeter value
   c. Press **RUN**

b. Units.

1. The DI 3000 can be set to measure either meters or feet. The unit of measurement that has been stored will be used until it is changed, even if turned off and then on again. An **F** will appear in front of the ppm value on the display if feet are stored as the unit of measure.

2. To set units to either meters or feet:

   a. Press **SET**, **MODE**
   b. Enter **41**
   c. Press **RUN**
   d. Enter 0 for meters, 1 for feet
   e. Press **RUN**

c. Decimal Fix.

1. The number of digits displayed after the decimal point in a measured distance can be set from 0 to 4. This setting will remain in the DI 3000 until changed. The displayed distances are as follows (n = number of digits after the decimal point):

n = 0	1m	1 ft
n = 1	0.1m	0.1 ft
n = 2	0.01m	0.01 ft
n = 3	0.001m	0.001 ft
n = 4	0.0001m	0.0001 ft

2. To set the number of digits after the decimal:

   a. Press **SET**, **FIX**
   b. Enter **n**. See above.
   c. Press **RUN**

7-32 Scale Correction (ppm)

a. General. The scale correction in parts per million (ppm) is used to apply proportionate corrections to a measured distance. The corrections are necessary to delete the effects of atmospheric conditions, reduction to sea level, and correction for projection scale factor. The effects of atmospheric conditions are discussed in this paragraph. The effects of sea level reduction and projection scale factor are necessary for in most survey computer systems, and should not be used with the DI3000. Reduction to sea level and projection scale factor corrections are discussed in paragraph 9-3.

b. Atmospheric Conditions. Atmospheric conditions affect the speed of the infrared light, which, in turn, affect the time required for that light to travel to the prism and back. Therefore, the time used to compute the distance is in error, and a ppm compensates for this. The conditions used to determine ppm corrections are temperature, barometric pressure, and humidity.

1. **Temperature and Pressure.** Temperature and pressure are generally considered together to produce a scale correction. The DI 3000 Operators Manual has a

chart for figuring a ppm from temperature and pressure. The DI 3000 allows the operator to enter that ppm or, it can compute a ppm from a user entered pressure and temperature. It is preferable to allow the Distomat to compute the ppm. Pressure must be entered in millibars; temperature must be entered in ° Celsius. Both methods are explained below.

a. To store the scale correction (ppm):

1. Press **SET**, **ppm**
2. Enter the ppm value
3. Press **RUN**

b. To enter and store pressure and temperature:

1. Press **SET**, **p/t**
2. Enter the pressure (550 mb to 1050 mb)
3. Press **RUN**
4. Enter the temperature (-99 to +99 ° C)
5. Press **RUN**

2. **Relative Humidity.** The influence of humidity on infrared light is very small. It needs only to be considered in hot regions, and if the most precise distance measurements are needed. The humidity value stored in the DI 3000 defaults to 60% when turned on. This default value is sufficient for all artillery survey applications. The atmospheric correction in ppm is calculated in the DI 3000 using the entered temperature, pressure, and humidity values. If the default value of 60% humidity is accepted, the error in the calculated atmospheric correction will never exceed 2 ppm (2 mm per km) at 50° C; it will never exceed 0.5 ppm at (0.5 mm per km) at 20° C.

a. To enter the relative humidity:

1. Press **SET, MODE**
2. Enter **45**
3. Press **RUN**
4. Enter the humidity value in %
5. Press **RUN**

b. The DI 3000 does not store the humidity value when turned off; the default value of 60% is reset at turn-on and the ppm displayed is recomputed using the default value.

7-33 Distance Measurement

a. General. Once the DI 3000 has been mounted on the T-2E, and the theodolite is properly plumb and level; the operator must sight on the target as described in paragraph 7-9. To measure distances press **ON.** Enter the scale correction as described in paragraph 7-28. Press **TEST.** If the Signal Strength Indicator displays a sufficient return signal, the operator can measure the distance using one of four operating modes. If the return signal strength is not sufficient to measure a distance, correct the parallelism of the Distomat (see paragraph 7-30).

b. Operating Modes. The DI 3000 has four modes for measuring distances:

1. **Normal (DIST) mode.** This mode takes 3.5 seconds and has a standard deviation of 3 - 5 mm + 1 ppm. To use this mode press **DIST**. The DI 3000 measures the distance and displays it. If the operator uses this mode, several distances must be measured and meaned. At least three distances must be measured.

2. **Rapid (DI) mode.** This mode takes 0.8 seconds and has a standard deviation of 5 mm + 1 ppm. To use this mode press **DI**. The DI 3000 measures the distance and displays it. If the operator uses this mode, several distances must be measured and meaned. At least three distances must be measured. The primary differences between this mode and the normal mode are the listed accuracy. This mode can also be used when heat-shimmer conditions prevent the user from measuring long distances with the normal and repeat modes; this is because the rapid mode requires only short bursts of return signal to measure a distance.

3. **Tracking (TRK) mode.** This mode takes 0.8 seconds for the initial measurement followed by updates every 0.3 seconds and has a standard deviation of 10 mm + 1 ppm. To use this mode press **TRK**. This mode sends a constant signal and continuously displays a new distance. It will mostly be used with stake out measurements but can be used during parallelism adjustments. This mode can drain the batteries if not monitored because the automatic shut-off is disabled while tracking.

4. Repeat (DIL) mode. This mode takes 3.5 seconds for the initial measurement and repeats automatically. The display in the repeat mode alternates between the cumulative mean of all measurements on one display and the number of measurements taken **(n)** and the standard deviation **(s)** in mm of a single measurement on the next display. To use this mode press **DIL**. With this mode, the instrument operator monitors the standard deviation as

it falls and then levels out. Once the standard deviation levels out, press **STOP**. The cumulative mean of all distances is displayed. If the number of measurements and the standard deviation needs to be viewed press **DSP, ns**.

c. Beam Interruptions. Interruptions in the beam of infrared light will not affect the result. If the beam is interrupted, the display shows from 1 to 6 bars. The bars indicate how far the measurement has progressed:

1 bar = start of measurement
6 bars = end of measurement.

Short interruptions can be caused by air turbulence. Thus, long distance measurements may take slightly longer in heat-shimmer conditions. In the normal, rapid, and repeat modes the measurement terminates automatically if the beam is interrupted for 30 seconds. In the tracking mode the tracking sequence starts again with an initial 0.8 second-measurement if the beam is interrupted for 0.5 seconds.

7-34 Parallelism: DI 3000 to Telescope

a. General. The infrared beam of the DI 3000 and the line of sight of the T-2E telescope should be parallel. The return signal strength will then be strongest when a proper pointing is made at a target. If parallelism is not correctly adjusted, the return signal strength will be weak or there will be no signal at all. (See Figure 7-30.)

b. Prism-Target Distance. Parallelism is normally adjusted at the Distomat; however, the prism-target distance must be set for the type of theodolite. Prism-target distance is the distance from the center of the prism (GPR1) to the center of the optical sight on the target reflector (GRZ3). This distance must be set so that it is equal to the distance between the center of the objective lenses of the DI 3000 and the center of the telescope's objective lens. Prism-target distance is set in the following manner: (See Figure 7-31)

Figure 7-30 Parallelism

Figure 7-31 Prism-Target Distance

1. Using a jeweler's screwdriver, drive the grub screw in the stem of the prism holder (GPH3Z) into the stem.

2. Slide the two stems of the prism holder into the target reflector so that the grub screw is aligned with the 87 mm hole labeled for the T-2 theodolite.

3. Using the jeweler's screwdriver, draw the grub screw out of the stem enough to keep the prism holder fixed in place in the target reflector.

c. Checking Parallelism. Parallelism should be checked prior to starting a survey; however, the adjustment can be made anytime. To check the parallelism, perform the following steps:

1. Set up the DI 3000 as described in paragraph 8-24. Set up a target at least 200 meters away with a clear line of sight.

2. Make a pointing on the target reflector as described in paragraph 7-9.

3. Press **ON, TEST**. If the signal strength indicator illuminates to the right of center, no adjustment is necessary. If the indicator illuminates to the left of center or not at all a parallelism adjustment is necessary.

d. Adjusting Parallelism. If the procedures described above indicate that a parallelism adjustment is necessary, perform the following steps:

1. Ensure the telescope of the T-2E is properly pointed

on the target.

2. Press **TEST**.

3. View the optical sight located on the bottom right side of the DI 3000. Using the hex key, turn the horizontal and vertical adjustment screws to bring the white cross onto the prism. The signal strength indicator should illuminate towards the right and an audible tone will be heard. (See Figure 7-32.)

Figure 7-32 Adjusting Parallelism

3. Viewing the signal strength indicator, adjust the horizontal and vertical adjustment screws until the strongest return signal is achieved. Press **STOP**.

4. Press **OFF**.

5. Press **ON, TEST**. The signal strength indicator should illuminate to the right and the audible tone should sound. Press **STOP, OFF**.

7-35 Care of the DI 3000

a. Cleaning.

1. Clean the objective lenses and display with lens paper. If necessary, moisten a cotton ball or swab with ether or pure alcohol. Never use liquids such as benzene, oil, or water. Do not touch the objective lenses with your fingers.

2. Wipe paintwork clean. If necessary, use a cloth dampened with water. Never use liquids such as benzene or oil.

3. Wipe a wet instrument carefully with a dry, lint-free cloth. Let the instrument dry completely before placing it back in the case. Never store a wet instrument in its case.

4. Keep the container clean, inside and out. Keep the inside dry. If water gets into the container, wipe it and leave it open to dry completely.

5. Wipe cables clean with a damp cloth. If a connection or a cable plug becomes dirty, wash it in spirit and allow it to dry.

b. Storage and Transport.

1. The instrument should not be stored inside the shipping case, remove the instrument from the case so that air can flow around it. This helps to prevent mildew and fungus in the case and instrument. Store the instrument in a low humidity, dust proof area.

2. The DI 3000 is shipped and transported in the foam rubber padded transportation cases.

c. Adjustments and Calibration.

1. Test the DI 3000 on a regular basis. Parallelism is the only authorized operator adjustment for this instrument. It is suggested, but not necessary, that each DI 3000 be paired with a T-2E.

2. Calibration and repairs for the DI 3000 Distomat will be conducted through the Survey Instrument Calibration Program (SICP).

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Figure 7-2 T-2E Components

5. **Circle Selector Knob:** allows the operator to change his view from the horizontal circle to the

vertical circle.

6. **Micrometer Knob:** used to bring the horizontal and vertical scales into coincidence.

7. **Automatic Index Button:** pressing this button checks the functioning of the automatic index. This check ensures that any residual error in leveling will be eliminated.

7-3 Telescope

a. The telescope of the T-2E provides an erect (upright) view of the target. Rotating the eyepiece focuses the reticle pattern; rotating the silver focusing sleeve focuses the target. The reticle pattern is a 1 to 100-scale stadia pattern for optical distance measurements. (See Figures 7-4 and 7-5.)

Figure 7-4 T-2E Focusing Sleeve and Eyepiece

Figure 7-5 T-2E Reticle Pattern

b. The eyepiece can be removed by rotating the bayonet ring counter-clockwise so that another eyepiece can be installed. The standard T-2E eyepiece has a 30X lens. Optional eyepieces include the 40X FOK53 and the 18X FOK 117.

c. When using artificial illumination, the lever under the optical sight can be pushed toward the objective lens (front) to illuminate the reticle.

7-4 T-2E Accessories

a. The accessories for the T-2E are carried and stored in the plastic transportation case for the theodolite. The accessories include the following:

5. User Manual
6. Eyepiece Assembly: consisting of a carrying case
7. a GMZ2 elbow microscope, and a GFZ1 elbow telescope.
8. GOF4 black sun filter.
9. Jeweler's screwdriver: with two adjusting pins and two standard screwdriver blades.
10. Plastic Wet Weather instrument cover.
11. GSP-1 Roelofs Prism, w/ case.
12. Illumination Kit consisting of two GEB-58 plug-in lamps, one GEV-34 cable, and one GEB-63 battery box.

7-5 Setting Up the Tripod GST-20

The GST-20 Tripod is the primary tripod used with conventional survey equipment in the Marine Corps. Set up the tripod as discussed below.

1. Upend the tripod, place the tripod head on the toe of your boot, and unbuckle the restraining strap.

2. Loosen the leg clamp thumbscrews and extend the tripod legs to the desired length. Tighten the leg clamp thumbscrews sufficiently to maintain the weight of a T-2E and DI-3000. Do not force the thumbscrews.

3. Spread the legs and place the tripod over the occupied station with one leg bisecting the angle(s) to be measured. Set up the tripod head so that the telescope will be at a convenient height for the operator. Rough level the tripod.

4. Insert the bayonet of the plumb bob into the instrument fixing screw. The plumb bob should hang about 1 inch above the station. Center the tripod over the station to within approximately 1" of plumb.

5. Firmly embed the tripod legs in the ground. The plumb bob should now be within 0.5 inches laterally of

center of the station. The tripod head must approximate level once the legs are embedded in the ground.

6. Remove the tripod head cover. Fix the cover to the side of the tripod and lightly wipe your hand over the tripod head to remove any sand or dirt.

7-6 Mount the T-2E on the Tripod

Mount the T-2E onto the tripod as discussed below:

1. Open the theodolite's transportation case.

2. Grasp the theodolite by the right standard (the right standard will be facing up in the transportation case) and lift the theodolite from the transportation case. Place the free hand underneath the tribrach. **The operator will maintain a hold on the instrument with at least one hand until the T-2E is securely tightened to the tripod.**

3. Carefully place the theodolite on top of the tripod. Keeping one hand on the instrument, attach the T-2E to the tripod head by screwing the fixing screw snugly into the base of the tribrach.

4. Replace the cover on the transportation case to keep dust and moisture from entering the case. Move the case away from the tripod to provide a working area for the instrument operator.

7-7 Plumb and Level the T-2E

Plumb and level the T-2E as discussed below:

1. Loosen the fixing screw slightly and carefully slide the instrument on the tripod head to center the point of the plumb bob exactly over the station.

2. With one hand on the theodolite, tighten the fixing screw. **Excessive tightening of the fixing screw will bend the tripod's slotted arm and damage the tripod head.** Be sure the point of the plumb bob remains centered over the station. Remove the plumb bob and return it to its case.

3. Loosen the horizontal clamping screw, and rotate the alidade until the axis of the plate level is parallel to any two of the three leveling screw knobs. Grasp the leveling screw knobs between the thumb and forefinger of each hand. Turn the knobs simultaneously so the thumbs of both hands move either toward each other or away from each other. This movement tightens one screw as it loosens the other. **The bubble always moves in the same direction as the left thumb.** Center the bubble by using these two leveling screw knobs. This is the first position. (See Figure 7-6.)

Figure 7-6 1st and 3rd Leveling Position

4. Rotate the alidade clockwise 1600 mils. This second position places the axis of the tubular level at a right angle to the first position. Using the third leveling screw knob only, center the bubble. (See Figure 7-7.)

Figure 7-7 2nd and 4th Leveling Position

5. Rotate the alidade clockwise 1600 mils so that it is 3200 mils from the first position. Level the instrument using the same two leveling screws as were used in the first position. This is the third position.

6. Rotate the alidade clockwise 1600 mils so that it is 3200 mils from the second position. Level the instrument using the same single leveling screw that was used in the second position, this is the fourth position.

7. Repeat Steps 5 and 6 above until the bubble remains centered in both positions.

8. Rotate the alidade to the first position. If the bubble remains centered in this position, rotate the alidade to the second position. If the bubble remains centered in this position, rotate the alidade throughout 6,400 mils. If the bubble remains centered the instrument is level.

9. If the bubble does not remain centered during the procedures in Step 8 but does remain within one graduation, level the instrument by bringing the bubble halfway back towards the centered position. If the bubble continues to move more than one graduation, the vial level should be adjusted using the procedures outlined in paragraph 7-17 of this chapter.

10. After the instrument is level, check the optical plumb to ensure that the instrument is centered exactly over the station. If it is not, center the instrument over the station by loosening the fixing screw on the tripod and shifting the instrument on the tripod head. Check the level of the instrument. If necessary, repeat the leveling process, and again check the optical plumb. Repeat this process until the instrument is both level and centered over the station. The optical plumb must be in proper adjustment; if not, the plumb bob may be a more accurate method of plumbing the instrument. See paragraph 7-19 of this chapter for procedures for testing and adjusting the optical plumb.

7-8 Eliminating Parallax and Adjusting Focus

a. Before using the theodolite to measure angles, the reticle parallax must be eliminated and the telescope brought into focus. Eliminate parallax by bringing the focus of the eyepiece and the focus of the objective lens to the plane of the reticle (cross lines). To do this, point the telescope toward the sky or a uniformly light surface. Rotate the knurled ring of the eyepiece until the reticle pattern is sharp, distinct lines. When doing this, focus your eyes on the crosshairs and not on the sky. Next, point the telescope toward a well-defined distant point. While focusing on the crosshairs, bring the distant point into a clear, sharp image by rotating the focusing sleeve on the telescope.

b. To check for parallax, use the horizontal drive screw to center the vertical crosshair on the point. Move your eye horizontally back and forth across the eyepiece; if parallax is eliminated, the crosshair will remain fixed on the object as you move your eye. If parallax is not eliminated, the crosshair will appear to move back and forth across the object. To eliminate any remaining parallax, change the focus of the eyepiece slightly to bring the cross lines into sharper focus and refocus the telescope accordingly until there is no apparent motion.

7-9 Pointing with the T-2E

a. Once the parallax has been eliminated and the instrument is in focus, the instrument operator is ready to make pointing on targets. These procedures are the same for all pointings; however, the placement of the crosshairs is dependent on the type of target.

1. **Range Pole.** For pointing on a range pole, the standard rule is to make the pointing centered on the lowest visible point. In cases where the range pole is too close to the theodolite to judge the center, the operator can point to the left side of the range pole with the telescope in the direct mode and the right side in the reverse mode. The mean between the direct and reverse will produce an angle measured from the center of the range pole but will usually not meet the 0.150 mil specification between direct and reverse readings. (See Figure 7-8.)

Figure 7-8 Pointing on a Range Pole

2. **Target Plate.** When making pointing on the target plate (GZT1) of a target set, the instrument operator should center the crosshairs so that the vertical line is centered up and down in the thin white extension of the small triangles and the horizontal line is centered left and right in the thin extension of the large white triangle. (See Figure 7-9.)

Figure 7-9 Pointing on a Tgt Plate (GZT1)

3. **Target Reflector.** For pointing to a target reflector (GRZ3) with either a single or triple prism holder (GPH1Z or GPH3Z) the instrument operator should center the crosshair below the optical sight of the target reflector at the intersection of the three yellow triangles. The target reflector must be correctly oriented towards the theodolite to ensure an accurate sighting. (See Figure 7-10.)

Figure 7-10 Pointing on a Tgt Reflector

4. **Eleven Prism Holder (GPH11).** When making pointing to an eleven-prism holder, the instrument operator should center the crosshairs on the center prism. Since this prism configuration is not to be used for distances under 500 meters, parallelism with the DI3000 (see section 2) is not affected. If the target lamp (GEB72) is being used, it should be placed in the center portal and will be used to make pointings. (See Figure 7-11.)

Figure 7-11 Pointing on an Eleven-Prism Holder

b. To make a pointing on a target, unlock the horizontal and vertical clamp and point the telescope towards the target. Roughly align the telescope on the target with the optical sight. Lock the horizontal and vertical clamps. Using the horizontal and vertical drive screws, center the cross lines on the target as described in paragraph 7-9a above. **The last turn of the horizontal and vertical drive screws should always be clockwise; against the spring.**

7-10 Reading The Scales

a. A system of lenses and prisms permits the observer to see small sections of either the horizontal or vertical circles. The circles are viewed through the circle-reading microscope eyepiece located beside the telescope. The observer selects the circle to be viewed by turning the circle-selector knob located on the right standard. The field of view of the circle-reading microscope contains three small windows. When the red line on the circle-selector knob is horizontal, the three windows will be yellow and horizontal readings are taken. When the red line on the circle selector knob is vertical, the three windows will be white and vertical readings are taken. (See Figure 7-12.)

Figure 8-12 View of the T-2E Scales

1. **Upper Window.** This window is sometimes referred to as the coincidence scale. When viewing this window, two images of graduation lines of diametrically opposite parts of the circle are seen. The two images move in opposite directions and appear to be separated by a fine line. The interval between graduations on each circle is 2 mils; however, coincidence between the circles occurs every 1 mil.

2. **Central Window.** The central window has two scales: the main scale and the base scale. The **Main Scale** is located in the upper portion of the central window. It is made up of sets of three digit numbers representing tens of mils. In other words, 0 mils appears as 000; 10 mils as 001; 450 mils as 045; and 6390 mils as 639. Each three-digit number is centered above a triangular index, which is used to read the base scale. The **Base Scale** is located in the bottom portion of the central window. It consists of a stationary scale numbered 9 through 0, from left to right. Each number represents its value in mils.

3. **Bottom Window.** This window is called the micrometer scale. It is graduated clockwise from -0.006 mils to 1.006 mils in 0.001 mil increments. The scale is numbered every 0.010 mils. A stationary index line is set vertically across the center of the window.

b. Coincidence. Optical coincidence is obtained by aligning diametrically opposite graduations of a circle by turning the micrometer knob. The graduations of the circle (upper window) are brought into coincidence by making the graduations appear to form continuous lines across the dividing line. (See Figure 7-13.)
The following procedures are used to bring the scales into coincidence:

1. Rotate the micrometer knob forward (clockwise), then back (counter-clockwise) through its complete range of motion. Looking into the microscope, view only the upper window.

2. Rotate the micrometer knob until the graduations in the top and bottom circles form single continuous vertical lines across the thin horizontal line of the upper window.

Figure 7-13 Sample Circle Reading

c. Circle Readings. Once the operator has sighted on the target and brought the scales into coincidence, he is ready to announce circle readings. This is done by reading the central and lower windows from top to bottom. The procedures for reading the scales are the same for both horizontal and vertical readings. The following procedures for reading the scales use Figure 7-13 as an example.

1. Viewing the central window, only one triangular index in the main scale will be over the base scale. Announce the three digits above that index, and then announce the digit in the base scale directly under the index. Figure 7-13 shows 481 from the main scale and 2 from the base scale.

2. Viewing the bottom window, read the two digits directly to the left of the index line. Then determine the value of the graduation closest to the index line. Announce the three digits together preceded by the word "point" to designate the position of the decimal. Figure 8-13 shows 156 in the bottom window. When the index line appears to be centered between two graduations, the instrument operator should read the even number.

3. The circle reading should be announced in individual digits to ensure proper-r recording; in other

words, the reading from Figure 7-13 will be announced as "four, eight, one, two, point, one, five, six."

7-11 Setting the Horizontal Circle

The horizontal circle of the T-2E cannot be fixed; therefore, prior to setting the circle, a pointing at a target must be made and the horizontal clamp locked. Generally, there are two situations which would require the instrument operator to set the horizontal circle; establishing an initial circle setting and orienting the telescope along a line of known azimuth.

a. Initial Circle Setting. An initial circle setting is used during the process of measuring a horizontal angle. It provides a buffer for both operator pointing errors and horizontal collimation error. An initial circle setting is established on the horizontal circle by performing the following steps:

1. Make a pointing on the rear station. Ensure the circle-selector knob is set for the horizontal circle.

2. Using the micrometer knob, set 0.150 mils on the micrometer scale (bottom window).

3. Rotate the circle setting knob so that the triangular index located under the 000 number of the main scale is directly over the 0 on the base scale.

4. Using the circle setting knob, bring the upper window into coincidence, ensure that the reading in the central window is still 0 mils. Close the cap over the circle setting knob.

5. Rotate the micrometer knob forward (clockwise), and then back (counter-clockwise) through its complete range of motion. Looking into the microscope, view only the upper window.

6. Using the micrometer knob, bring the upper window into coincidence.

7. Read the horizontal circle. The reading should be within ±0.100 mils of 0.150.

b. Orienting the Scale. The horizontal circle of the T-2E can be set so that the circle reading will correspond to a known azimuth to a target or station. With this method, the azimuth to any point on which the telescope is oriented can be read directly from the horizontal circle. The following procedures can be used to orient the horizontal circle:

1. Make a pointing on the station that lies along the known azimuth. Ensure the circle-selector knob is set for the horizontal circle.

2. Using the micrometer knob, set the decimal mils value of the known azimuth on the micrometer scale (bottom window). For example, if the known azimuth is 2176.987 mils; the operator will set 0.987 on the micrometer scale.

3. Rotate the circle-setting knob so that the triangular index located under the tens of mils value of the known azimuth in the main scale is directly over the ones value on the base scale. Again, if the known azimuth is 2176.987 mils; the operator will place the triangular index under 217 in the main scale over the 6 in the base scale.

4. Using the circle setting knob, bring the upper window into coincidence, ensure that the reading in the central and bottom windows is still equal to the known azimuth. Close the cap over the circle setting knob.

7-12 Horizontal Angles

a. Position Angle. The horizontal circle of the T-2E is a clockwise scale; therefore, all horizontal readings from this instrument are said to be clockwise horizontal angles. This should not be confused with the rotational direction of the alidade. The alidade should be rotated clockwise in the direct mode and counter-clockwise in the reverse mode. The procedures for measuring a horizontal angle are discussed below.

1. With the telescope in the direct mode, point to the rear station. Set the circle-selector knob for the horizontal circle. Set the initial circle setting and announce it to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

2. Rotate the alidade clockwise to the forward station. Make a pointing at the forward station and announce the circle reading to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

3. Plunge the telescope to the reverse mode and make a pointing at the forward station. Announce the circle reading to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

4. With the telescope in the reverse mode, rotate the

alidade counter-clockwise to the rear station. Make a pointing at the rear station and announce the reading to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

5. Steps 1 through 4 above constitute one direct and one reverse pointing on each station; this is referred to as a one-position angle.

b. Multiple Angles. When it is necessary to measure the angle to more than one station, make a pointing on the rear station with the telescope in the direct mode and then on each station around the horizon in a clockwise direction. After obtaining a circle reading on the last station, plunge the telescope and make a pointing at each station in a counterclockwise direction; starting with the last forward station and ending with the rear station. One set of direct and reverse pointings on all of the observed stations constitutes one position. This procedure is called measuring a multiple angle.

c. Circle Closure. The direct and reverse circle readings at each station should differ by 3200 mils, ± 0.150 mils.

1. If the difference between direct and reverse readings is constant over several pointings, it can be assumed that the error is in the horizontal collimation of the instrument. Procedures for adjusting this error are discussed in paragraph 7-20.

2. If the difference is not relatively constant, the error is a mixture of collimation error and operator error. In this case, the instrument should *not* be adjusted until constant errors are measured.

d. Two-Position Angle. In artillery survey, one-position angles are normally measured. It may be become necessary to measure a two-position angle.

1. This method measures the same angle twice and uses the mean of the two measurements. The first position angle is measured as described in paragraph 7-13a. The second position angle is measured in the same manner except that the initial pointing at the rear station is performed in the reverse mode and the horizontal circle is set to 4800.150 mils, ± 0.100, for an initial circle setting.

2. When two positions angles are observed, the two measured angles cannot differ by more than 0.050 mils. If they do differ by more than 0.050 mils, the angles must be rejected and remeasured.

7-13 Vertical Angles

a. General. The T-2E does not measure vertical angles directly. The vertical circle places 0 mils at the zenith; therefore, the vertical circle readings are zenith angles, or in artillery, **vertical readings**. (See Figure 7-14.)

Figure 7-14 Vertical Readings/Angles

1. To convert a vertical reading to a vertical angle, the recorder must determine the angular difference between the horizon and the line of sight. The horizon being 1600 mils in the direct mode and 4800 mils in the reverse mode; the line of sight being the vertical reading (zenith angle).

2. The vertical angle is considered positive if the line of sight is above the horizon (vertical readings less than 1600 mils and greater than 4800 mils). It is considered negative when the line of sight is below the horizon (vertical readings greater than 1600 mils and less than 4800 mils).

b. Vertical Index. The T-2E has an automatic vertical index. The functioning of the automatic index is checked as part of each vertical reading. To check the automatic index, press the black index button located on the left standard. **The operator must press and release the button; holding it in will eventually compress the spring and cause the automatic index to malfunction.** When the operator presses the index button, he must be viewing the upper window in the microscope.

If the instrument is properly leveled, the graduation lines on the vertical circle will swing away from each other and then settle back smoothly to their original position. This verifies that the automatic index is functioning properly. If the graduation lines do not settle back smoothly to their original position, but jerk to a stop; the instrument must be releveled or turned in for maintenance.

c. Determining Vertical Readings. To determine vertical readings perform the following steps:

1. Make a pointing on the target in the direct mode. Set the circle-selector knob for the vertical circle.

2. While viewing the upper window in the microscope, press the index button to check the automatic index.

3. Viewing only the upper window, bring the scale into coincidence using the micrometer knob.

4. Announce the circle reading to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

5. Plunge the telescope to the reverse mode and make a pointing at the target.

6. While viewing the upper window in the microscope, press the index button to check the automatic index.

7. Viewing only the upper window, bring the scale into coincidence using the micrometer knob.

8. Announce the circle reading to the recorder. When the recorder reads this back the operator must be looking into the microscope to verify the reading.

d. The procedures described above are the same whether the pointing is made to a forward station or to a rear station.

e. Once the recorder has determined the vertical angles from the vertical readings, the direct and reverse vertical angles at each station should be the same, ± 0.150 mils.

f. If the difference between direct and reverse readings is constant over several pointings, it can be assumed that the error is in the vertical collimation of the instrument. Procedures for adjusting this error are discussed in paragraph 7-21. If the difference is not relatively constant, the error is a mixture of collimation error and operator error; in this case, the instrument should *not* be adjusted until constant errors are measured.

7-14 Reciprocal Vertical Angles

a. A **Reciprocal Vertical Angle** is the mean of two vertical angles measured in opposite directions along the same leg. The sign of the reciprocal vertical angle is the same as the sign of the vertical angle measured from the occupied station to the forward station.

b. The purpose of measuring a reciprocal vertical angle is to diminish the effects of refraction and earth curvature.

1. Refraction is the bending and slowing of light as it passes through the Earth's atmosphere. The angle of refraction is affected by temperature and pressure. It is preferable to measure the reciprocal vertical angles through similar atmospheric conditions; therefore, the time span between measuring reciprocal vertical angles should be as short as possible.

2. The effects of curvature of the earth are minimal at distances less than 1000 meters and corrections are not used in manual computations. Reciprocal vertical angles completely negate the effects of Earth curvature. For this reason, it is a requirement to measure reciprocal vertical angles for all legs of a survey longer than 1000 meters in both fourth and fifth order surveys.

c. Most computers and software for computing surveys will prompt reciprocal vertical angles. If you tell the computer that reciprocal vertical angles were not measured, the computer will apply an Earth curvature correction to the distance. If reciprocal vertical angles were measured, the computer will not apply those corrections.

7-15 Observation and Tracking Procedures for Sun and Stars (Arty Astro)

a. General. 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 pinpricks of light even through the telescope, and offer a more defined target than the large fiery mass of the Sun.

b. Observation for Stars. When observing a star to determine astronomic azimuth the most difficult part is locating the desired celestial body. Choosing an appropriate star for your situation is discussed in Chapter 8. The theodolite is set up as described previously, and 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 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. Once the stars direction and rate of movement are determined tracking may begin. The instrument operator will announce "Tracking". The recorder begins keeping time while the instrument operator repeatedly announces "tacking" until he has the celestial body centered in the crosshairs of the telescope, at which time he announces "TIP" (meaning Target In Position.) Immediately at TIP, the recorder must note and record the time of observation. The instrument operator then reads the horizontal circle reading to the recorder, who reads it back. Three *direct* readings are taken in this manner, and only then, after the third direct reading, will the instrument operator plunge the scope and take three reverse readings using the same procedures, as required.

c. Observation for Sun. When observing the Sun to determine azimuth the theodolite is set up as described previously, and 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. The filter should be inspected 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. 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 will announce "Tracking" repeatedly until the moment the Sun appears to be in the center of the reticle, at which time he will announce "TIP". The time is immediately noted and recorded in the recorder's book. The instrument operator then reads the horizontal circle reading to the recorder, who reads it back. Three *direct* readings are taken in this manner, and only then, after the third direct reading, will the instrument operator plunge the scope and take three reverse readings using the same procedures, if required.

d. Direct and Reverse readings. When determining azimuth by the Arty Astro method Reverse readings are required for fourth order azimuths only. Bearing this in mind, three direct readings may be taken consecutively, and as stated above, the telescope is plunged and the three reverse readings are taken.

e. Recording and Meaning Astronomic Observations.

The methods for recording and meaning astronomic observations are covered in Chapter 8.

7-16 March Order the T-2E

The procedure for march ordering the T-2E theodolite is discussed below.

1. Open the transportation case and place it near the tripod.

2. Place the black cap over the objective lens of the telescope. Place the telescope in a vertical position with the objective lens down, and lock the vertical clamp.

3. Replace any parts of the T-2E that were taken off during operation (e.g., mirrors, carrying handle).

4. Ensure the mirrors and circle-setting knob cover are closed.

5. Center the leveling screws on the triibrach.

6. Rotate the alidade so that the red line on the right standard is aligned with the red line on the Lower Part. Lock the horizontal clamp.

7. Hold the theodolite by its right standard and unscrew the tribrach from the fixing screw. Lift the theodolite from the tripod and secure it in the transportation case.

8. Replace the tripod head cover, collapse the tripod legs, and strap the legs together. Make sure the legs are securely tightened.

7-17 Tests and Adjustments

a. The T-2E theodolite must be kept in correct adjustment if accurate results are to be obtained. There are five operator tests and adjustments of the T-2E theodolite. When a test indicates that an adjustment is necessary, the operator makes the adjustment and retests the instrument for accuracy before making the next test in sequence. The instrument operator must make these tests and adjustments in the following sequence:

1. Plate Level

2. Circular Bubble

3. Optical Plumb

4. Horizontal Collimation

5. Vertical Index

b. The five operator tests and adjustments of the theodolite are made with the instrument mounted on its tripod. The instrument is set up in the shade, on firm ground, with the head of the tripod as level as possible. The theodolite should be protected from the wind.

7-18 Plate Level Test and Adjustment

a. Purpose. The purpose of the plate level adjustment is to align the vertical axis of the theodolite to a line, which is perpendicular to the geoid when the bubble of the plate level is centered in its vial.

b. Test. The test for the T-2E plate level is the same as the leveling procedures described in paragraph 7-7.

c. Adjustment.

Adjust the T-2E plate level as described below:

1. Unlock the horizontal clamp and rotate the alidade until the axis of the plate level is parallel with any two leveling screws. Center the bubble using those two screws.

2. Rotate the alidade clockwise through 1600 mils and center the bubble with the third leveling screw.

3. Rotate the alidade through 3200 mils. Noting the position of the bubble, use the third leveling screw to bring the bubble halfway back to its centered position.

4. Using an adjusting pin provided in the jeweler's screwdriver, carefully turn the adjustment screw until the bubble is centered. The adjustment screw is located inside a small aperture at the bottom of the left standard. (See Figure 7-15.)

Figure 7-15 Plate Level Adjustment Pin

5. Repeat these steps until the bubble remains centered within one graduation for all positions of the alidade.

7-19 Circular Bubble Test and Adjustment

a. Purpose. The purpose of the circular bubble adjustment is to ensure that the vertical axis of the tribrach is aligned with the vertical axis of the theodolite. This is very important when taking the T-2E off the tribrach and replacing it with a target carrier.

b. Test. The test for the tribrach circular bubble is simply to level the T-2E plate level to within one graduation of center. The circular bubble must then be centered or it must be adjusted.

c. Adjustment. On the GDF22 tribrach, two capstan screws are accessible via the side slits under the circular bubble. As either screw is loosened, the bubble runs towards it; as it is tightened the bubble runs away. Adjust the circular bubble as described below: (See Figure 7-16.)

Figure 7-16 Circular Bubble Adjustment

1. Using an adjusting pin provided in the jeweler's screwdriver, turn one of the two capstan screws until the bubble is located on a line between the center of the circle and the other screw.

2. Turn the other screw until the bubble is centered in the circle.

3. Repeat if necessary. Do not turn the screws anymore than is necessary for the adjustment.

7-20 Optical Plumb Test and Adjustment

a. Purpose. The purpose of the optical plumb adjustment is to make the vertical axis of the GDF22 tribrach pass through the station mark when the theodolite (or target carrier) is properly leveled and plumbed.

b. Test. The test for the optical plumb requires that a theodolite or a target carrier be mounted in the GDF22 tribrach. This is because leveling must be precise to test the optical plummet. The plate level of the theodolite or target carrier must have been already adjusted to perform this test. Use the following steps to test the optical plumb:

1. Set up and fine level the theodolite on a level tripod. Attach a plumb bob to the fixing screw.

2. Place a piece of paper or tape on the ground under the plumb bob. Using a fine tip pen, mark the plumb point on the paper. Rotate the plumb bob's bayonet plug and mark several positions through 6400 mils. Determine the center position of all the marks.

3. Remove the plumb bob. The tribrach should be optically plumbed over the mark located in the center of the plumb bob marks; if not, the optical plumb needs to be adjusted.

c. Adjustment. The optical plumb has two adjusting screws located on the optical plumb arm under the tribrach. Both screws must be turned simultaneously in the directions indicated in Figure 7-17. To adjust the optical plumb, follow the procedures below:

1. Look through the optical plumb.

2. Using two jeweler's screwdrivers turn the adjustment screws in the direction indicated in figure 7-17, in small increments, until the optical plumb is centered over the mark.

Figure 7-17 Optical Plumb Adjustment Screws

7-21 Horizontal Collimation Test And Adjustment

a. Purpose. The purpose of the horizontal collimation adjustment is to make the line of sight perpendicular to the tilting axis of the telescope.

b. Test. Test the horizontal collimation as described below.

1. Select a well-defined point at least 100 meters from and at about the same elevation as the instrument.

2. With the telescope in the direct position, center the vertical crosshair on the target and read the horizontal circle reading to the recorder. For example, assume your direct reading is 0000.202 mils.

3. Plunge the telescope to the reverse position and take a reverse reading to the same point. For example, assume the reverse reading is 3,200.802 mils.

4. The difference between the direct and reverse readings should be exactly 3,200 mils. Assuming no operator error is present the discrepancy between the actual difference in the two readings and 3,200 mils is the apparent horizontal collimation error, or twice the actual horizontal collimation error. If the apparent horizontal collimation error exceeds the specified standard (0000.150 mils for the T-2E), the operator should perform the horizontal collimation adjustment.

c. Adjustment. The horizontal collimation is adjusted as small as possible at the factory but cannot be completely eliminated by adjustment.

The error is; however, completely eliminated by meaning the observations on a point with the telescope in both the direct and reverse positions. For this reason, adjustments of the horizontal collimation should only be made when absolutely necessary; another reason is that if the adjustment screws are not set correctly, too loose or too tight, the instrument will not maintain the

adjustment. Adjust the horizontal collimation error as discussed below:

1. With the telescope on the point in the reverse position, set the mean value of the direct and reverse pointing (from example = 3200.502) on the micrometer scale by using the coincidence knob.

2. Bring the main scale into coincidence by using the horizontal tangent screw. This moves the vertical cross line of the telescope off the point by the amount of the actual horizontal collimation error.

3. Using the adjusting pins in the jewelers screwdriver, the operator must align the vertical cross line back on the point by lateral movement of the reticle within the telescope. The T-2E has two pull-action capstan adjusting screws arranged horizontally and on opposite sides of the telescope. To align the vertical crosshair, loosen one screw and tighten the opposite one an equal amount. The crosshair will move laterally toward the screw that you tighten. Do not try to make the entire adjustment in one step. Loosen and tighten the opposite screws in small amounts. Proceed in this manner until the crosshair is aligned on the station. **Ensure that the capstan screws are rotated equal amounts; otherwise the reticle will be either too loose or too tight and will not remain in adjustment.** (See Figure 7-18.)

.

Figure 7-18 Capstan Adjustment Screws

4. Perform the horizontal collimation test again; make additional adjustments as necessary until the difference between the direct and reverse pointing is less than 0.150 mils

7-22 Vertical Collimation (Index Error) Test And Adjustment

a. Purpose. The purpose of the vertical collimation adjustment is to make the line of sight perpendicular to the zenith when the vertical circle reads 1600 mils with the telescope in the direct position or 4800 mils with the telescope in the reverse position.

b. Test. To test for index error, perform the following steps:

1. Select a well-defined point at least 100 meters from the instrument at approximately the same elevation.

2. With the telescope in the direct position, give the recorder a direct vertical circle reading to the point.

3. Plunge the telescope to the reverse position and give the recorder a reverse vertical circle reading to the same point.

4. The sum of the direct and reverse readings should equal 6400 mils. Any difference between the sum of the two readings and 6,400 mils is the apparent vertical collimation error, or twice the actual error. If the difference exceeds 0.150 mils the vertical index should be adjusted.

c. Adjustment. The index error is adjusted as small as possible at the factory but cannot be completely eliminated by adjustment. Meaning the observations on a point with the telescope in both the direct and reverse positions eliminates the error. For this reason, adjustments of the horizontal collimation should only be made when absolutely necessary. Adjust the index error as discussed below:

1. With the telescope in the reverse position and accurately sighted on the selected point, use the micrometer knob to set the fractional part of the corrected reading on the micrometer scale. This will bring the scale out of coincidence. To determine the corrected reading, see the examples in Figure 7-19.

Direct Reading:	1609.812	1598.216
Reverse Reading:	4790.715	4801.208
SUM=	6400.527	6399.424
Apparent Error:	+0.527	-0.576
Actual Error:	+0.264	-0.288
Correction:	-0.264	+0.288
Corrected Reading:	4790.451	4801.496

Figure 7-19 Computing the Corrected Reading

2. Using the wide tip in the jeweler's screwdriver, open the Index Cover located beside the vertical drive screw to show the index adjustment screw. Turn the index adjustment screw until coincidence is obtained in the upper window of the scales. Close the Index Cover. (See Figure 7-20.)

3. Perform the test again and make additional adjustments as necessary until the sum of the direct and reverse pointing is within 0.150 mils of 6400.

7-23 Artificial Illumination

a. The T-2E theodolite is equipped for artificial illumination by way of a coaxial socket located on the Lower Part of the theodolite and an illumination kit. Both the horizontal and vertical circle can be illuminated as well as the reticle.

Figure 7-20 Index Cover and Adjustment Screw

b. All components of the illumination kit are stored in the GEB-63 battery box. The battery box has three socket holes along its bottom edge. The largest of these socket holes is for a cable connected to an external power source (i.e. GEB70 battery, 12v vehicle power). The other two holes are for instrument illumination. The battery box also has an ON/OFF switch located on its side. (See Figure 7-21.)

c. The illumination kit is powered primarily by a 9v battery. Under normal conditions a new 9v battery will last up to 20 hours. The ON/OFF switch should be placed in the OFF position when power is not needed to prevent undue discharge and increase battery life. The 9v battery should be removed for storage. A cable is available to provide external power from a GEB-70 NiCad battery.

d. Two GEB-58 plug-in lamps are used to supply the illumination. These lamps plug in to the mirror sockets when the mirrors are removed. Each GEB-58 lamp has a rheostat knob, which can be rotated to adjust the illumination brightness. They also contain high-performance light emitting diodes (LED), which ensure a uniform illumination of the circles and the field of view.

e. The illumination kit is attached in the following manner (see Figure 7-22):

1. Prior to leveling the T-2E, remove the mirrors and plug in the GEB-58 lamps. The mirrors should be placed in the T-2E transportation case until replaced on the theodolite. Hang the battery box on a tripod leg.

2. One end of the GEV-34 cable is then plugged into the coaxial socket on the Lower Part; the other end is plugged into one of the two small socket holes at the bottom of the battery box. Both ends of the cable are the same.

3. Attach external power if necessary.

4. Place the ON/OFF switch in the ON position.

5. Adjust the illumination brightness with the rheostat knobs on the plug-in lamps.

Figure 7-21 GEB 63 with Accessories

Figure 7-22 T-2E with Artificial Illumination

7-24 Care Of the T-2E

a. Cleaning.

1. Clean all lenses, mirrors, and bubbles with lens paper. Do not touch the lenses with your fingers.

2. Wipe all paintwork with a dry, lint-free cloth. If necessary, moisten the cloth with ether or alcohol; never use oil, benzene, or water.

3. Carefully wipe a wet instrument with a lint-free cloth. Let a wet instrument dry completely before returning it to the case. Never store a wet instrument in its case.

4. Keep the case clean inside and out. The foam rubber inserts are removable for cleaning.

b. Temperature Equilibrium. When a large temperature difference exists between outside and storage temperatures, time must be allowed for the instrument to obtain temperature equilibrium. This is necessary if full use of the instruments measuring accuracy is to be obtained. As a general rule, the time needed to obtain equilibrium corresponds to the temperature difference in °C. In other words, if there is a 5°C difference between storage and outside temperatures, then 5 minutes should be allowed.

c. Storage and Transport.

1. The transportation case should not be used for storage of the T-2E. The theodolite should be stored outside the case so that air can flow around it. This helps to prevent mildew and fungus in both the T-2E and the case. The instrument should be stored in an area as close to outside temperatures as possible to decrease the effects of steaming of the optics and condensation inside the T-2E. A dehumidifier should be used in humid climates.

2. The T-2E is shipped and transported in the foam rubber padded transportation cases.

d. Adjustments and Calibration.

1. Test the T-2E on a regular basis. Adjustments should only be performed when actually necessary. A Test and Adjustment log is suggested to be maintained with the equipment records.

2. Calibration and repair for the T-2E theodolite will be conducted through the Survey Instrument Calibration Program (SICP).

DRAFT

Section III
PRECISE TARGET SET

7-36 Description

a. The Precise Target Set is a system that allows for forced centering over a station being used as a target for measuring angles, measuring distances, or both. It provides a rapid and accurate method of switching between target and theodolite and requires the tripod and tribrach to be setup only once.

b. The Precise Target Set, referred to as a target set, has a standard quick release mounting post. It will hold the target plate, prism holders, or the MSGR 4000 (GPS-S) antenna with a quick release adapter. It has night lighting capability and is virtually waterproof.

7-37 Components

The target set is comprised of a tribrach, target carrier, target plate, illumination kit, and shipping case.

a. Tribrach. The tribrach for the target set is the GDF-22. This is also the tribrach used with the T-2E (see Section I). The GDF-22 will mount on all tripods with a standard 5/8 inch fixing screw. It has three leveling knobs, a fish-eye level, and an optical plummet. (See Figure 7-33.)

Figure 7-33 GDF-22 Tribach

b. Target Carrier (GZR2). There are two types of target sets: simple and precise. The difference is the target carrier. The GZR2 Target Carrier is used with the Precise Target Set. It has a plate level for precise leveling up; therefore, when properly adjusted and level, and when mounted in a tribrach with a properly adjusted optical plummet, the target can be centered over the ground point to within 0.5 mm. The GZR2 Target Carrier is designed for use with the T-2E Theodolite. It is placed in the tribrach and is locked in place by
turning the swivel locking knob on the side of the tribrach. (See Figure 7-34.)

c. Target Plate (GZT1). The target plate is fitted onto the target carrier by pressing the release button on the bottom side of the plate. It has a black and white target grid, which creates reference marks for horizontal and vertical pointing. When fitted on the GZR2 carrier, the horizontal pointing marks of the target plate are the same height above the tribrach base as the T-2E tilting axis. The vertical pointing mark is aligned with the plumb line when the carrier and tribrach are properly adjusted and leveled. The target is generally observable in daylight at distances of over 1 km. For longer distances, the GZT2 large target plate can be fitted onto the GZT1 target. The large target plate is not a component of the target set, but it is a component of the Survey Set. The GZT2 target allows sightings as long as 8km in good visibility conditions.

Figure 7-34 Target Set with Target Plate

d. Illumination Kit. The illumination kit consists of a screw on reflector and a battery box. The battery box has an ON/OFF switch located on the back of the case and is powered by two AA batteries. The bulb is screwed into the front side of the case and an extra bulb is inside. The reflector is screwed onto the case over the bulb and slides over the backside of the target plate. (Used with the GZT1 Target only.)

Figure 7-35 Target Set with Illumination Kit

e. Target Set with Prism Holder. The target set can be used to hold the target plate GRZ3 with the triple prism holder GPH3Z; the prism holder has a release button similar to that of the target plate, GZT1, for mounting on the target carrier. When the prism holder is set for use with the T-2E theodolite, the horizontal pointing markers on the prism holder are the same height above the tribrach base as the T-2E tilting axis. (See Figure 7-36.)

Figure 7-36 Target Set with GRZ3 and GPH3Z

7-38 Setting Up the Tripod GST-20

The GST-20 Tripod is the primary tripod used with conventional survey equipment in the Marine Corps. Set up the tripod as discussed below.

1. Upend the tripod, place the tripod head on the toe of your boot, and unbuckle the restraining strap.

2. Loosen the leg clamp thumbscrews and extend the tripod legs to the desired length. Tighten the leg clamp thumbscrews sufficiently to maintain the weight of a T-2E and DI-3000. Do not force the thumbscrews.

3. Spread the legs and place the tripod over the occupied station with one leg bisecting the angle(s) to be measured. Set up the tripod head so that the target will be at a convenient height for the operator when the T-2E is placed on the tripod. Rough level the tripod.

4. Insert the bayonet of the plumb bob into the instrument fixing screw. The plumb bob should hang about 1 inch above the station. Center the tripod over the station to within approximately 1" of plumb.

5. Firmly embed the tripod legs in the ground. The plumb bob should now be within 0.5 inches laterally of center of the station. The tripod head must approximate level once the legs are embedded in the ground.

6. Remove the tripod head cover. Fix the cover to the side of the tripod and lightly wipe your hand over the tripod head to remove any sand or dirt.

7-39 Mount the Target Set

Mount the target set onto the tripod as discussed below:

1. Open the target set case.

2. Carefully place the tribrach on top of the tripod. Keeping one hand on the tribrach, attach the tribrach to the tripod head by screwing the fixing screw snugly into the base of the tribrach.

3. Ensure the swivel-locking knob is open; carefully place the target carrier into the tribrach. Rotate the swivel-locking knob clockwise one-half turn until the arrow is pointing down and the carrier is secure.

7-40 Plumb and Level the Target Set

Plumb and level the target set as discussed below:

1. Loosen the fixing screw slightly and carefully slide the target set on the tripod head to center the point of the plumb bob exactly over the station.

2. With one hand on the target set, tighten the fixing screw. **Excessive tightening of the fixing screw will bend the tripod's slotted arm and damage the tripod**

head. Be sure the point of the plumb bob remains centered over the station. Remove the plumb bob and return it to its case.

3. Rotate the target carrier until the axis of the plate level is parallel to any two of the three leveling screw knobs. Grasp the leveling screw knobs between the thumb and forefinger of each hand. Turn the knobs simultaneously so the thumbs of both hands move either toward each other or away from each other. This movement tightens one screw as it loosens the other. **The bubble always moves in the same direction as the left thumb.** Center the bubble by using these two leveling screw knobs. This is the first position. (See Figure 7-37.)

Figure 7-37 1st and 3rd Leveling Position

4. Rotate the target carrier clockwise 1600 mils. This second position places the axis of the plate level at a right angle to the first position. Using the third leveling screw knob only, center the bubble. (See Figure 7-38.)

5. Rotate the target carrier clockwise 1600 mils so that it is 3200 mils from the first position. Level the target set using the same two leveling screws as were used in the first position. This is the third position.

6. Rotate the target carrier clockwise 1600 mils so that it is 3200 mils from the second position. Level the target set using the same single leveling screw that was used in the second position, this is the fourth position.

7. Repeat Steps 5 and 6 above until the bubble remains centered in both positions.

Figure 7-38 2nd and 4th Leveling Position

8. Rotate the target carrier to the first position. If the bubble remains centered in this position, rotate the target carrier to the second position. If the bubble remains centered in this position, rotate the target carrier throughout 6,400 mils. If the bubble remains centered the instrument is level.

9. If the bubble does not remain centered during the procedures in Step 8 but does remain within one graduation, level the instrument by bringing the bubble halfway back towards the centered position. If the bubble continues to move more than one graduation, adjust the level vial as per procedures in paragraph 8-42 of this chapter.

10. After the instrument is level, check the optical plumb to ensure that the target set is centered exactly over the station. If it is not, center the instrument over the station by loosening the fixing screw on the tripod and shifting the target set on the tripod head. Check the level of the target set. If necessary, repeat the leveling process, and again check the optical plumb. Repeat this process until the target set is both level and centered over the station. The optical plumb must be in proper adjustment; if not, the plumb bob may be a more accurate method of plumbing the instrument. See paragraph 7-44 of this chapter for procedures for testing and adjusting the optical plumb.

7-41 Mount the Target Plate

a. Once the target set is plumbed and leveled, the target plate can be placed on the carrier.

1. If using a GZT1 target plate, depress the release button at the bottom-side of the target plate, and carefully place the target plate over the target carrier mounting post. Orient the target towards the station

which will be sighting on the target. Place the GZT2 large target plate or the Illumination Kit over the GZT1 target plate at this time.

2. If using the GRZ3 target plate with the GPH3Z triple prism holder, depress the release button at the bottom-side of the target plate and carefully place the target plate over the target carrier mounting post. Orient the target towards the station which will be sighting on the target using the optical sight on the target plate. If necessary, rotate the prisms vertically by loosening the screw knobs on the sides of the target plate and rotating the plate until the prisms are oriented towards the station. Tighten the screw knobs.

b. After placing the target plate on the target carrier, verify the target set plumb and level.

7-42 Tests and Adjustments

a. The Target Set must be kept in correct adjustment if accurate results are to be obtained. There are three operator tests and adjustments of the target set. When a test indicates that an adjustment is necessary, the operator makes the adjustment and retests the target set for accuracy before making the next test in sequence. The operator must make these tests and adjustments in the following sequence:

1. Plate Level
2. Circular Bubble
3. Optical Plumb

b. The three operator tests and adjustments of the target set are made with the set mounted on its tripod. The target set is set up in the shade on firm ground with the head of the tripod as level as possible. The target set should be protected from the wind.

7-43 Plate Level Test and Adjustment

a. Purpose. The purpose of the plate level adjustment is to align the vertical axis of the target carrier to a line, which is perpendicular to the geoid when the bubble of the plate level is centered in its vial.

b. Test. The test for the target carrier plate level is the same as the leveling procedures described in paragraph 8-36.

c. Adjustment.

Adjust the target carrier plate level as described below:

1. Rotate the target carrier until the axis of the plate level is parallel with any two leveling screws. Center the bubble using those two screws.

2. Rotate the target carrier clockwise through 1600 mils and center the bubble with the third leveling screw.

3. Rotate the target carrier through 3200 mils. Noting the position of the bubble, use the third leveling screw to bring the bubble halfway back to it's centered position.

4. Using an adjusting pin provided in the jewelers screwdriver with the T-2E theodolite, carefully turn the adjustment screw until the bubble is centered. The adjustment screw is located inside a small aperture at the base of the carrier.

5. Repeat these steps until the bubble remains centered within one graduation for all positions of the alidade.

7-44 Circular Bubble Test and Adjustment

a. Purpose. The purpose of the circular bubble adjustment is to ensure that the vertical axis of the tribrach is aligned with the vertical axis of the target carrier. This is very important when taking the target carrier off the tribrach and replacing it with a T2-E theodolite.

b. Test. The test for the tribrach circular bubble is simply to level the target carrier plate level to within one graduation of center. The circular bubble must then be centered or it must be adjusted.

c. Adjustment. On the GDF22 tribrach, two capstan screws are accessible via the side slits under the circular bubble. As either screw is loosened, the bubble runs towards it; as it is tightened the bubble runs away. Adjust the circular bubble as described below: (See Figure 7-16.)

1. Using an adjusting pin provided in the jewelers screwdriver with the T-2E theodolite, turn one of the two capstan screws until the bubble is located on a line between the center of the circle and the other screw.

2. Turn the other screw until the bubble is centered in the circle.

3. Repeat if necessary. Do not turn the screws anymore than is necessary for the adjustment.

7-45 Optical Plumb Test and Adjustment

a. Purpose. The purpose of the optical plumb adjustment is to make the vertical axis of the GDF22 tribrach pass through the station mark when the target carrier is properly leveled and plumbed.

b. Test. The test for the optical plumb requires that a target carrier be mounted in the GDF22 tribrach. This is because leveling must be precise to test the optical plummet. The plate level of the target carrier must have been already adjusted to
perform this test. Use the following steps to test the optical plumb:

1. Set up and fine level the target set on a level tripod. Attach a plumb bob to the fixing screw.

2. Place a piece of paper or tape on the ground under the plumb bob. Using a fine tip pen, mark the plumb point on the paper. Rotate the plumb bob's bayonet plug and mark several positions through 6400 mils. Determine the center position of all the marks.

3. Remove the plumb bob. The tribrach should be optically plumb over the mark located in the center of the plumb bob marks; if not, the optical plumb needs to be adjusted.

c. Adjustment. The optical plumb has two adjusting screws located on the optical plumb arm under the tribrach. Both screws must be turned simultaneously in the directions indicated in Figure 7-17. To adjust the optical plumb, follow the procedures below:

1. Look through the optical plumb.

2. Using two jewelers screwdrivers, turn the adjustment screws in the direction indicated in figure 7-17 until the optical plumb is centered over the mark.

7-46 Care of the Target Set

a. Cleaning.

1. Clean the plate level and circular bubble with lens paper. If necessary, moisten a cotton ball or swab with ether or pure alcohol. Never use liquids such as benzene, oil, or water.

2. Wipe paintwork clean. If necessary, use a cloth dampened with water. Never use liquids such as benzene

3. Wipe a wet instrument carefully with a dry, lint-free cloth. Let the instrument dry completely before placing it back in the case. Never store a wet instrument in its case.

4. Keep the case clean, inside and out. Keep the inside dry. If water gets into the case, wipe it and leave it open to dry completely.

b. Storage and Transport.

1. The target set should not be stored inside the shipping case, remove the instrument from the case so that air can flow around it. This helps to prevent mildew and fungus in the case and instrument. Store the instrument in a low humidity, dust proof area.

2. The target set is shipped and transported in the foam rubber padded transportation cases.

c. Adjustments and Calibration.

1. Test the target set on a regular basis. Adjustments made to a theodolite are useless if the target sets are not properly adjusted.

2. Calibration and repairs for the target set will be conducted through the Survey Instrument Calibration Program (SICP).

d. Changing the Batteries. To change the AA batteries in the illumination kit, unscrew the two screws on the backside of the battery box. Be careful not to pull the back off too far; a delicate cable inside the box only allows about one inch play.

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CHAPTER 8
ASTRONOMY FOR MARINE ARTILLERY

Marine artillery surveyors are required to provide an azimuth to the supported unit, or to determine a starting azimuth for conventional survey. If an azimuth is not provided in a Trig list, or cannot be computed, the surveyor can establish an azimuth by performing observations of celestial bodies.

Section I
BASIC ASTRONOMY

8-1 The Tilted Polar Axis and Movement of the Earth

a. The Earth's Tilted Axis. 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. (See Figure 8-1)

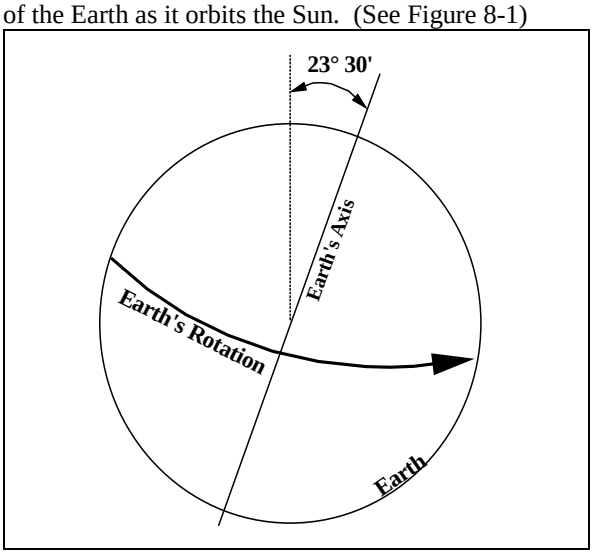

Figure 8-1 Earth's Rotational Axis

b. Movement of the Earth. The Earth and its motions are of primary interest to the artillery surveyor. These motions form a complex pattern, all of which affect the Earth's relationship to the stars and other planets.

1. **Precession.** The Earth's axis has a cone-shaped motion, or precession, making one turn in 25,800 solar years or, one platonic year (great year). This is caused by torque imposed on the Earth mostly by the Moon and Sun. It can be visualized as a spinning top; as the spinning slows, the top begins to wobble creating a cone-shaped motion in its rotating axis.

2. **Rotation.** The Earth makes one 360° rotation on its axis every 23h 56m 04.091s. The rotation is from west to east; therefore, because of revolution, the Earth must rotate more than 360° for the same point to face directly at the sun on subsequent days. (See Figure 8-1.)

3. **Revolution.** The Earth revolves around the Sun once every 365 days (approx.) 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.

4. Other types of motion affect the Earth. For instance, the north and south poles are not stationary; they vary through rough circles approximately 40 feet in diameter. Also, 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.

8-2 Celestial Sphere

a. General. For purposes of practical astronomy, we assume that the Earth is at the center of the Universe, and that everything else (i.e. Sun, stars, planets, etc.) falls on the surface of a sphere of infinite radius referred to as the **Celestial Sphere**. 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

(counterclockwise), so the apparent motion of celestial bodies is the opposite direction. (See Figure 8-2.)

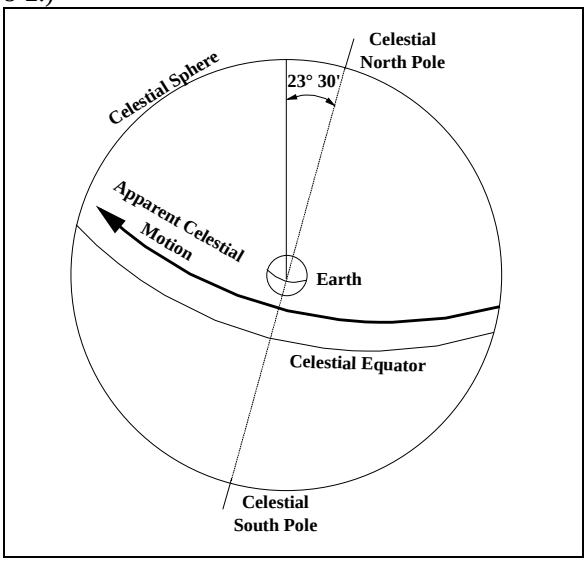

Figure 8-2 Celestial Sphere

b. Celestial Poles and Equator. The celestial sphere rotates around the stationary Earth on an axis that coincides with the polar axis of the Earth. The 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**. (See Figure 8-2.)

8-3 Celestial Coordinates

a. General. 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. In general, there are two systems of spherical coordinates: the horizon system and the equator system. For artillery survey methods, the equator system is used.

b. Great Circle/Hour Circle. 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. Observer's Meridian. 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 which 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. Zenith Position. 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. (See Figure 8-3.)

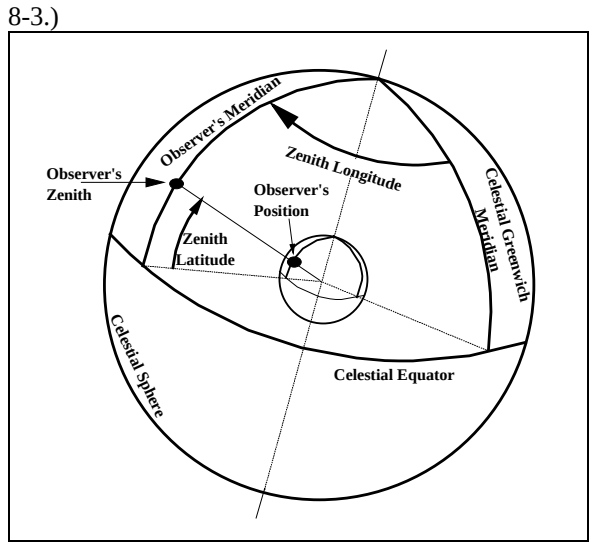

Figure 8-3 Zenith Position

e. Prime Vertical. 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. Star Position. The position of a star on the celestial sphere is defined in terms of Right Ascension and Declination.

1. **Right Ascension (RA).**

a. 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 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. (See Figure 8-4.)

b. Right Ascension (RA) is the arc distance eastward along the celestial equator measured from the vernal equinox to the hour circle of a celestial body. In most cases, RA 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. (See Figure 8-5.)

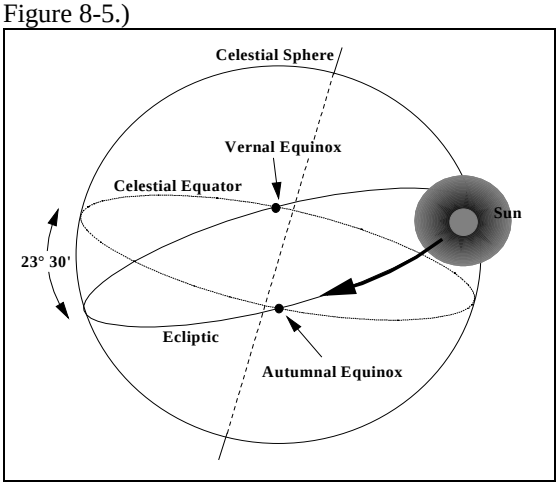

Figure 8-4 Ecliptic and Vernal Equinox

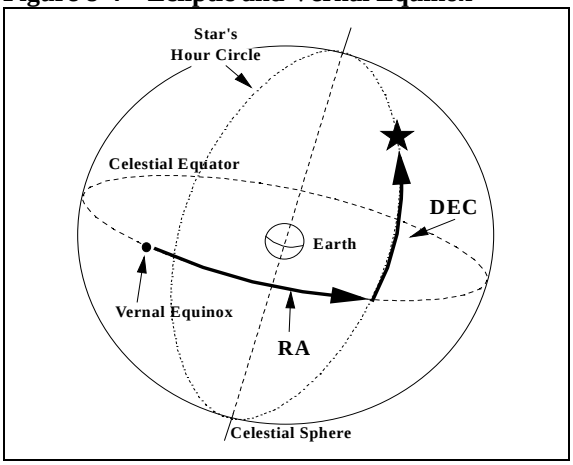

Figure 8-5 Right Ascension and Declination

2. **Declination (Dec).** 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. (See Figure 8-5.)

8-4 Astronomic Triangle (PZS Triangle)

a. General. The determination of an astronomic azimuth is dependent upon the solution of a spherical triangle located on the surface of the celestial sphere. This triangle is referred to as the PZS triangle. The method of astronomic observation determines the sides and vertices of the triangle to be solved.

b. Vertices. The PZS triangle has vertices at the celestial North **P**ole, at the observer's **Z**enith, and at the **S**tar (or Sun). These vertices are the intersections of great circles that include the triangle's sides. (See Figure 8-6.)

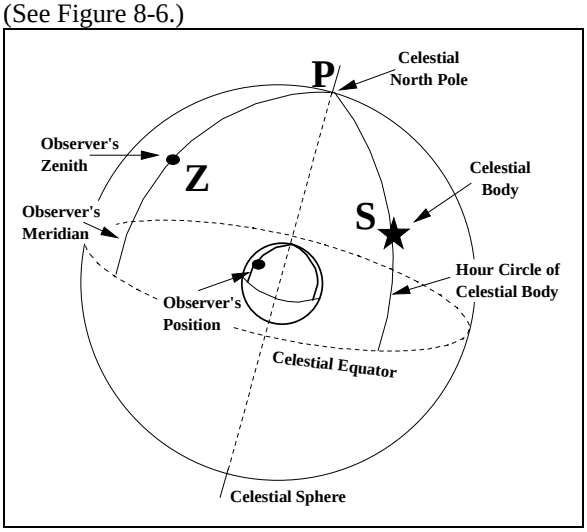

Figure 8-6 Vertices of the PZS Triangle

c. Sides. The sides of the PZS triangle are segments of great circles passing through any two of the vertices. Therefore, the 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.

1. **Polar Distance.** Polar distance 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.(See Figure 8-7.)

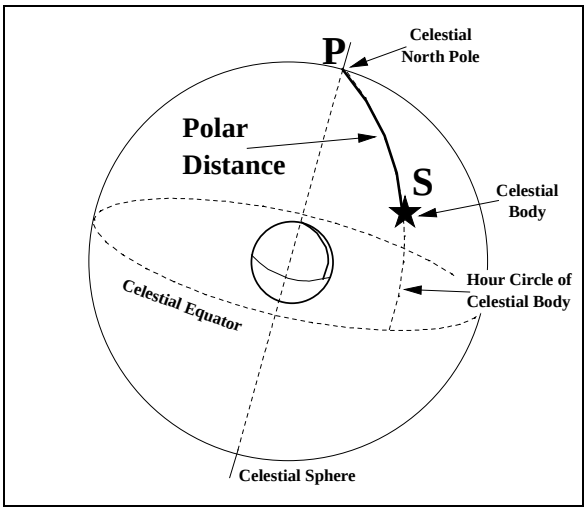

Figure 8-7 Polar Distance

2. **Coaltitude.** Coaltitude is the arc length of the side of the PZS triangle from the celestial body to the observer's zenith.

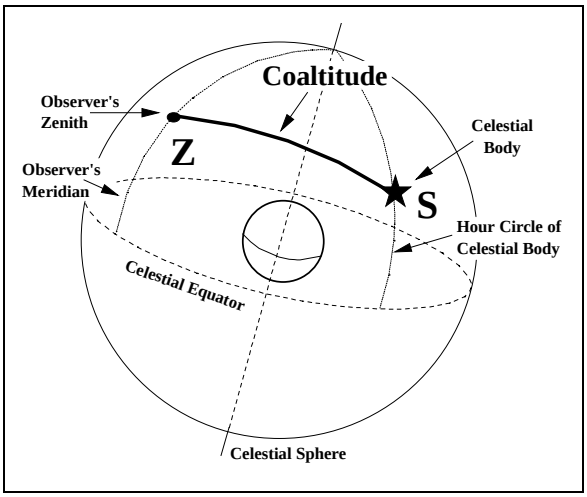

Figure 8-8 Coaltitude

a. **Observer's Horizon.** 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. See Figure 8-9.

b. **Determining Coaltitude.** Coaltitude is determined 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 can be referred to as the zenith angle of the celestial body. (See Figure 8-9.)

Figure 8-9 Determining Coaltitude

c. **Parallax.** Parallax 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 the 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. (See Figure 8-10.)

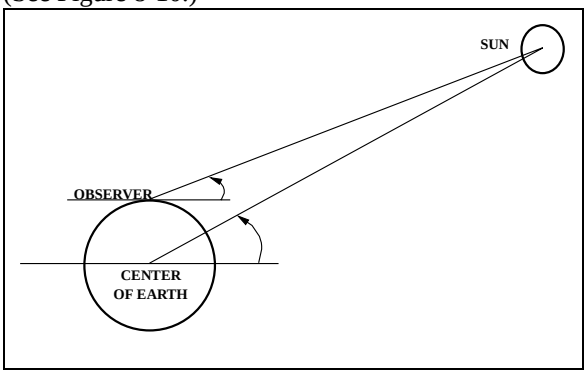

Figure 9-10 Parallax

d. **Refraction.** Refraction 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. (See Figure 8-11.)

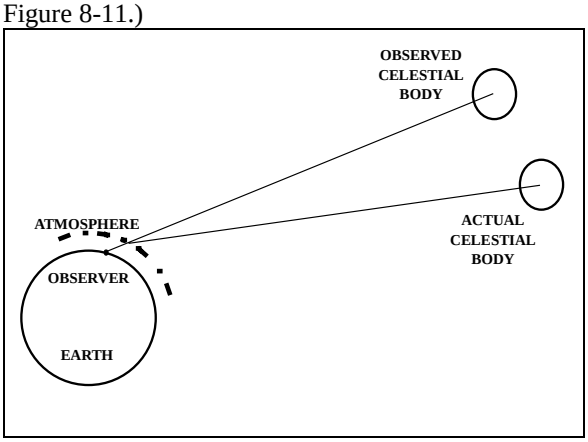

Figure 8-11 Refraction

3. **Colatitude.** Colatitude is a segment of an 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°. In other words, if the observer's latitude is north (+)

Figure 8-12 Colatitude

the Colatitude equals 90° minus the observer's latitude; if the observer's latitude is south (-), the Colatitude equals 90° plus the observer's latitude. (See Figure 8-12.)

d. Angles. 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. **Parallactic Angle.** 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. It is used in determining astronomic azimuths but is canceled out during the computations. (See Figure 8-13.)

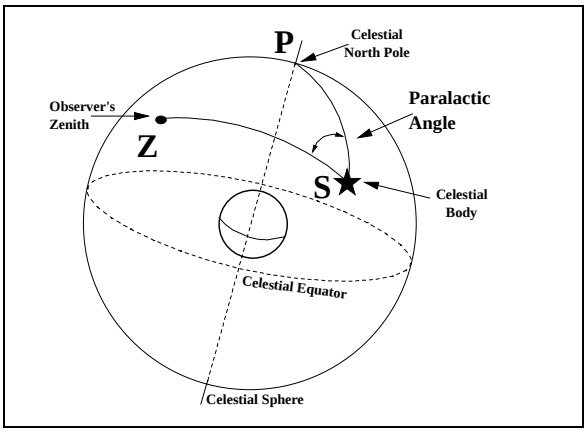

Figure 8-13 Parallactic Angle

2. **Hour Angle (Time Angle).** 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. It is sometimes referred to as the time 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. (See Figure 9-14.)

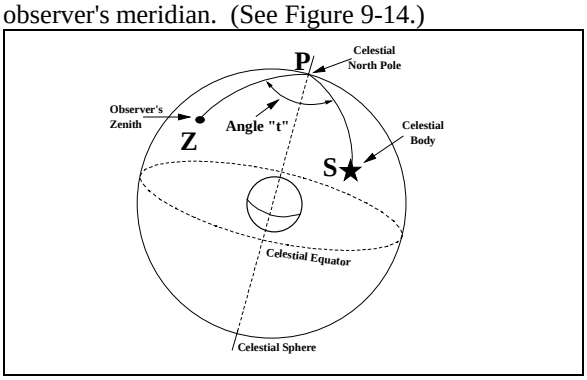

Figure 9-14 Hour Angle (Time Angle or Angle t")

3. **Azimuth Angle.** 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 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. (See Figure 8-15.)

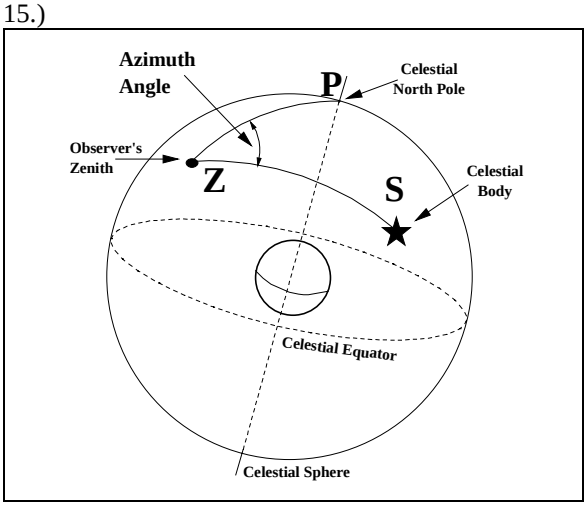

Figure 8-15 Azimuth Angle

e. 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 8-16 depicts the complete PZS triangle.

Figure 8-16 PZS Triangle

8-5 Time

a. General. 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. Time References. 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.

1. 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.

2. 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.

3. Figure 8-17 shows the relationship between solar time and sidereal time. 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 4 minutes longer than transits of the vernal equinox over the observer's meridian. In other words, one 24 hour sidereal day is equal to 23h 56m 04.091s of a solar day.

c. One apparent rotation of the celestial sphere is completed in a sidereal day; therefore, a star rises at nearly the same sidereal time throughout the year. On solar time it rises about 4 minutes earlier from night to night, or two hours earlier each month. Thus, at the same hour, day-by-day, the star moves slowly westward across the sky as the year lengthens.

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Figure 8-17 Relationship between Solar Time and Sidereal Time

8-6 Solar Time

a. General. 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.

b. Apparent Solar Time.

1. Time indicated by the position of the actual Sun is called Apparent Solar Time.

2. 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 (LAT) 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. (See Figure 8-18.)

3. 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. First, the movement of the Sun is along the ecliptic and not the celestial sphere, also because the rate of this movement is not uniform, and lastly because the Earth's orbit is elliptical and not circular. Thus, 25 December is 50 seconds longer than 13 September, and days in January average 15 seconds longer than days in July.

c. Mean Solar Time.

1. 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 with each hour consisting of 15° of arc, or longitude (360° x 24h = 15°/h). Solar noon occurs when the mean sun crosses the observer's meridian.

2. 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). (See Figure 8-18.)

d. Equation of Time. The difference between apparent solar time and mean solar time is called the Equation of Time. This value can vary from plus 16 minutes (mean sun slow) to minus 14 minutes (mean sun fast), depending on the season.

e. Solar Year. 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.

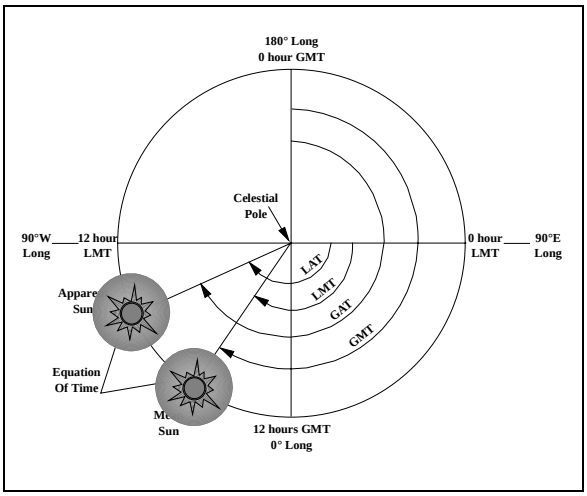

Figure 8-18 Concepts of Solar Time

8-7 Sidereal Time

a. General.

1. Sidereal time is based on the Earth's rotation with respect to the stars. A sidereal day is the amount of time necessary for two successive passes of the vernal equinox over a meridian of longitude. The sidereal day begins when the vernal equinox crosses the observer's meridian at the upper transit (sidereal Noon).

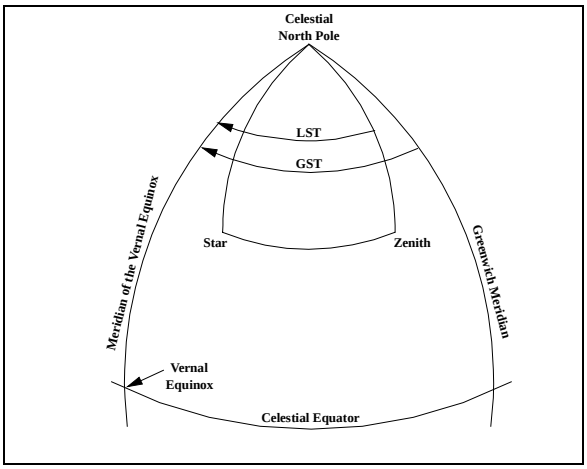

Figure 8-19 Concepts of Sidereal Time

2. Sidereal time for any point is the amount of time that has elapsed since the vernal equinox last passed the meridian at that point. Hence, Local Sidereal Time (LST) is the amount of time that has elapsed since the vernal equinox last passed the observer's meridian; Greenwich Sidereal Time (GST) is the amount of time that has elapsed since the vernal equinox last passed the Greenwich meridian. (See Figure 8-19.)

b. Sidereal Year. 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 21 September 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.

8-8 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. Each of the 24 time zones is designated by a letter A-Z (J omitted). (See Figure 8-23.)

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, where time is 1 hour later since the sun has already crossed 15° E longitude. Therefore, the difference in local time between two places equals the difference in longitude between the two places. (See Figures 8-20 and 8-23.)

c. 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. Therefore, the time zone including the Prime Meridian extends from 7.5° E longitude to 7.5° W longitude and 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 US. (See Figure 9-21.)

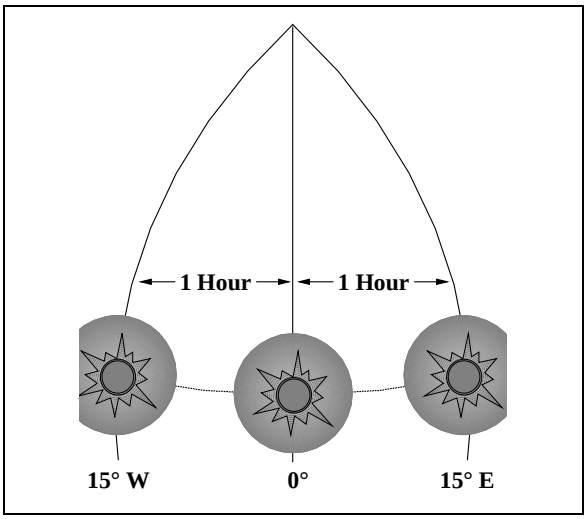

Figure 9-20 Time and Apparent Motion of the Sun

d. 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. For example, Ft Sill OK 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. Artillery surveyors use the term local mean time (LMT) in referring to standard time or local time in a referenced locale. In other words, the time used by the local inhabitants is local mean time, unless a non standard time is in use.

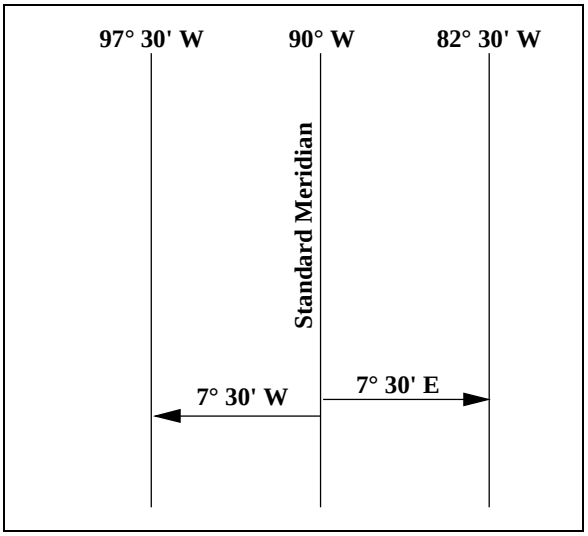

Figure 8-21 Time Zone Boundaries

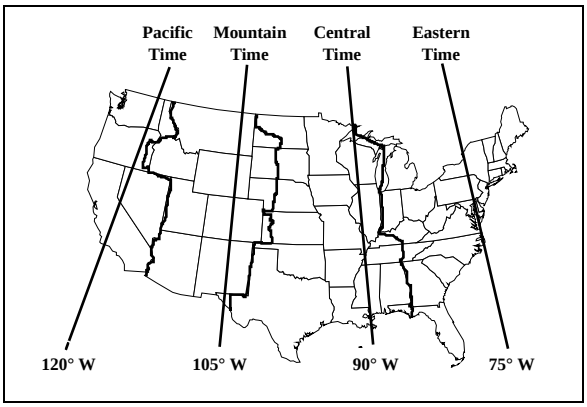

Figure 8-22 Political Time Zones in the US

e. 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.

Figure 8-23 Time Zone Letter Designations and Corrections; Local to Greenwich Mean Time

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Figure 9-24 World Time Zone Chart (Local to Greenwich)

Greenwich standard time (Zulu time), also known as Greenwich Mean 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. Therefore, since the observer's clock is usually set to standard (local) time, that time (LMT) must be converted to GMT. (See Figure 8-18.)

8-9 Daylight Savings Time

Daylight savings time is clock time advanced by 1 hour from standard time. Effective 1987, federal law required that daylight saving time be observed from the first Sunday in April until the last Sunday in October; however, individual states may exempt

themselves. During World War II, a double daylight saving time (2 hour advance) was observed nationwide and was called wartime.

8-10 Greenwich Mean Time (GMT)

a. Converting LMT to GMT. Local Mean Time can easily be converted to Greenwich Mean Time by applying a time zone correction. (See Figure 8-23.)

1. **Western Hemisphere.** If the observer is located in 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 of the observation. If this result is greater than 24 hours, subtract 24 hours and add 1 day to obtain the Greenwich time and date.

2. **Eastern Hemisphere.** If the observer is located in 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 of the observation.

b. Converting Greenwich Apparent Time (GAT) to GMT. When the Marine artillery surveyor makes observations on the Sun, he actually observes the apparent sun on the celestial sphere and not the mean sun on which his clock is based. Consequently, the surveyor must convert his Greenwich Apparent Time (GAT) to GMT. This correction is contained within the Arty Astro program and need not be determined manually. The correction is provided in Table 2 of the Army Ephemeris using the observation date as an entry argument. The resultant equation of time (see paragraph 8-6.d) for zero hours GMT (0h) and the daily change are used to determine a correction for the date and proportionate part of the day to be applied to the GMT of the observation.

8-11 Determining the Local Hour Angle (LHA) and Angle t

a. Determining Local Hour Angle (LHA).

1. 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 Greenwich apparent time (GAT). By simply adding 12 hours to, or subtracting it from, the GAT (the result cannot exceed 24 hours), the surveyor determines the value of the Greenwich hour angle (GHA). The Greenwich hour angle is the amount of time that has elapsed since the Sun last crossed the Greenwich upper meridian (upper transit).

2. To determine the Local Hour Angle in mils of arc, the GHA and the observer's longitude must be converted to mils of arc. If the observer is located in the western hemisphere, the LHA is determined by subtracting the observer's longitude (mils of arc) from the GHA in mils. If the observer is located in the eastern hemisphere, the LHA is determined by adding the observer's longitude (mils of arc) to the GHA in mils.

b. Determining Angle t. Angle t is the angle in the PZS triangle at the polar vertex. It is determined as discussed below:

1. If the local hour angle is greater than 3200 mils, angle t equals 6400 mils minus the LHA.

2. If the local hour angle is less than 3200 mils, angle t equals the LHA.

Section II
ASTRONOMIC MET

8-12 Methods of Determining Azimuth

a. General. The primary astronomic method Marine artillery surveyors will use is the Arty Astro Method. Arty Astro is based on the Hour Angle Method and can be used with the Sun or stars. With the advent of the PLGR, and SINCGARS, accurate time is now readily available to surveyors, making Arty Astro the preferred method. At the battery level the Hasty Astro Method of observation will be used, and is discussed in Chapter 11.

b. Arty Astro (Hour Angle) Method. In the Arty Astro Method, using two sides and the included angle

solves the azimuth angle of the PZS triangle. 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 (See Figure 8-25.):

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 local hour angle.

8-13 Arty Astro (Hour Angle) Method Sun

a. General. The Arty Astro Method may be used to determine azimuths from Sun observations. The Arty Astro Method does not require the measurement of a vertical angle or temperature and, the 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 is dependent on solving the local hour angle.

b. Position of the Sun. For the Sun to be suitable for use with the Arty Astro Method, it must not be within one 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 or with the card method.

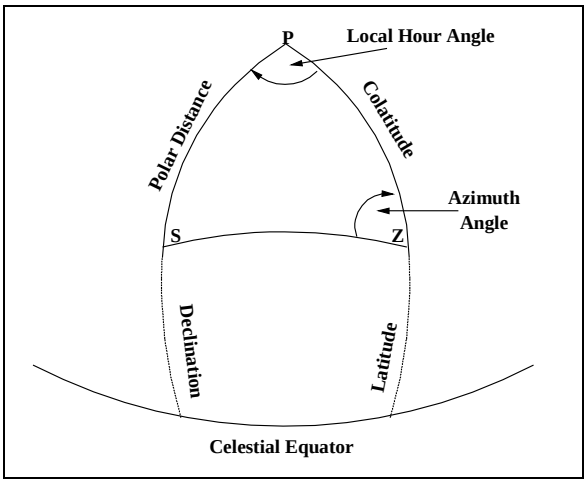

Figure 8-25 Solving the Arty Astro Method

c. Time. In the Arty Astro Method (Sun), time is critical to the accurate determination of the local hour angle. For this reason, time must be accurate to 1 second. Accurate time is available through radio time signals and GPS receivers (i.e. PLGR, MSGR, SINCGARS).

d. Solving the PZS Triangle. The formula for solving the PZS triangle has been arranged in a manner as to require only the determination of the local hour angle. 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.

1. The computation of the polar distance is not necessary since the formula uses the Sun's declination.

2. The computation of the Colatitude is not necessary since the formula uses the observer's latitude.

3. **Determination of Local Hour Angle (LHA).** For the hour angle solution, the element of the PZS triangle that is necessary is the local hour angle. This angle is determined by using the time of the observation. In general terms, the local hour angle is determined by converting the local mean time (watch time) to Greenwich mean time, to Greenwich apparent time, to Greenwich hour angle, and finally to the local hour angle. More specifically, this conversion can be performed as outlined below:

Local mean time
+time zone correction
=**Greenwich mean time**
±equation of time for 0h
±daily change for portion of day
=**Greenwich apparent time**
±12 hours
=**Greenwich hour angle**
±longitude
=**local hour angle**

Greenwich Mean Time (GMT). The 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 Greenwich mean time (Zulu Time) is obtained. This step can be skipped if the watch is set to Zulu time. (See Figure 8-26.)

Greenwich Apparent Time (GAT). Greenwich apparent time (GAT) is the time that has elapsed since the last passage of the apparent sun over the lower transit of the Greenwich meridian. GAT is obtained by applying the equation of time and the proportionate part of the daily change in the equation of time to the GMT.

Greenwich Hour Angle (GHA). The Greenwich hour angle (GHA) is the amount of time that has elapsed since the sun last crossed the Greenwich meridian; therefore, Greenwich apparent time is always ± 12 hours from the Greenwich hour angle. To determine the Greenwich hour angle, simply add or subtract 12 hours to or from the Greenwich apparent time, remembering that the result must be between 0 and 24 hours.

Local Hour Angle (LHA). The 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 used to determine the local hour angle depends on the hemisphere (east or west) of the observer. In the western hemisphere, both the longitude and the Greenwich hour angle are measured west from the Greenwich meridian; therefore, 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; therefore, the LHA in the eastern hemisphere is equal to the sum of the GHA and the longitude minus 360° (LHA = (GHA + Long.) - 360°).

4. 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:

$$\tan \tfrac{1}{2}(A + q) = \frac{\cos \tfrac{1}{2}(\text{Lat} - \text{Dec}) \cot \tfrac{1}{2} t}{\sin \tfrac{1}{2}(\text{Lat} + \text{Dec})}$$

$$\tan \tfrac{1}{2}(A - q) = \frac{\sin \tfrac{1}{2}(\text{Lat} - \text{Dec}) \cot \tfrac{1}{2} t}{\cos \tfrac{1}{2}(\text{Lat} + \text{Dec})}$$

Where: **A** is the astronomic azimuth (true) of the Sun measured east or west of the meridian.
q is the parallactic angle (cancels out in computations.
Lat is the latitude of the station.
Dec is the apparent declination of the sun
t is the local hour angle (less than 12h) of the sun.

e. Computations. Survey computer systems (i.e. HCS) contain the Arty Astro 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.

8-14 Arty Astro (Hour Angle) Method Star

a. General. The Arty Astro 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 or the Sun due to more accurate sighting. The preferred star for this method in the Northern Hemisphere is Polaris as it displays the least apparent motion being a circumpolar star. (In the Southern hemisphere the preferred star is Alpha Acrux.) The Arty Astro Method does not require the measurements of a vertical angle or a temperature and the 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 is dependent on solving the local hour angle.

b. Position of the Stars. 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. East west stars can be selected by using the star finder and star rate template. The 175-mil restriction minimizes the effects of refraction.

c. Time. In the Arty Astro Method (star), time is critical to the accurate determination of the local hour angle. For this reason, time must be accurate to 10

seconds for observations on Polaris and 1 second for observations on east-west stars. Accurate time is available through radio time signals and GPS receivers (i.e. PLGR, MSGR, SINCGARS).

d. Solving the PZS Triangle. The formula for solving the PZS triangle with star observations is the same as for the Sun. The only difference in the computations is that sidereal time is used to determine the local hour angle. In general terms, the local hour angle is determined by converting the local mean time (watch time) to Greenwich mean time, to Greenwich sidereal time, to Greenwich hour angle, and finally to the local hour angle; as outlined below:

Local mean time
+time zone correction
=**Greenwich mean time**
±sidereal time for 0h GMT
±correction for GMT
=**Greenwich sidereal time**
-right ascension of the star
=**Greenwich hour angle**
±longitude
=**local hour angle**

Greenwich Mean Time (GMT). The 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 (see Figure 9-20) the Greenwich mean time (Zulu Time) is obtained. This step can be skipped if the watch is set to Zulu time.

Greenwich Sidereal Time (GST). Greenwich sidereal time is the time elapsed since the vernal equinox last crossed the Greenwich meridian. GST is obtained by applying the sidereal time at 0h GMT (Army Ephemeris, Table 2) and the correction for GMT (Army Ephemeris, Table 4) to the Greenwich mean time.

Greenwich Hour Angle (GHA). The Greenwich hour angle is the time elapsed since the celestial body last crossed the Greenwich meridian. The GHA is obtained by subtracting the right ascension from the Greenwich sidereal time.

Local Hour Angle (LHA). The 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 used to determine the local hour angle depends on the hemisphere (east or west) of the observer. In the western hemisphere, both the longitude and the Greenwich hour angle are measured west from the Greenwich meridian; therefore, 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; therefore, the LHA in the eastern hemisphere is equal to the sum of the GHA and the longitude minus 360° (LHA = (GHA + Long.) - 360°).

e. Computations. Survey computer systems (i.e. HCS) contain the Arty Astro 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.

8-15 Azimuth Specifications

a. The arty astro method can be used to determine either fourth or fifth order azimuth. For Marine artillery surveyors, a T2-E theodolite 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 (both fourth and fifth order).

c. The considered accuracy for a fifth order astronomic azimuth is ±0.3 mils and ±0.15 mils for a fourth order azimuth.

8-16 Selection of Methods of Observation

a. General. The Marine artillery surveyor must consider several factors when selecting a method of observation. These considerations include the following:

1. Day or night, north or south latitude.

2. Accuracy of the watch time.

3. Positions of celestial bodies at specific times.

4. Degree of accuracy required.

5. Observer's position accuracy. This consideration is more important for the computation of UTM grid convergence (true azimuth to grid

azimuth) than for the actual observation computations.

6. The experience of the instrument operator

b. Procedures. Specific procedures to observe celestial bodies are outlined in Chapter 7 Section I.

Section III
STAR SELECTION AND IDENTIFICATION

8-17 General

a. There are important advantages to using stars rather than the sun as a source for astronomic azimuths. Since stars appear as pinpoints of light in the telescope they are easier to track. At least one of the 73 survey stars can be found in a position that will allow for astronomic observation, regardless of the observer's location or the time of night.

b. Polaris should always be used when it is visible. Polaris is the most desirable star to observe because it is usually easy to locate and because its slow apparent motion makes it easy to track. Because of weather conditions, ambient light, line of sight barriers, or the observer's latitude, Polaris may not always be available. In this case, an east-west star must be used. East-west stars must be selected based on their star rate and their position relative to the observer. A Star Finder and Identifier will aid in selecting and identifying usable east-west stars.

8-18 Polaris

a. 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 north celestial pole, it is visible throughout the night in most of the northern hemisphere. When the Polaris local hour angle is 0 or 12 hours, the star is said to be in its upper or lower culmination, respectively. When the Polaris local hour angle 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. (See Figure 8-27.)

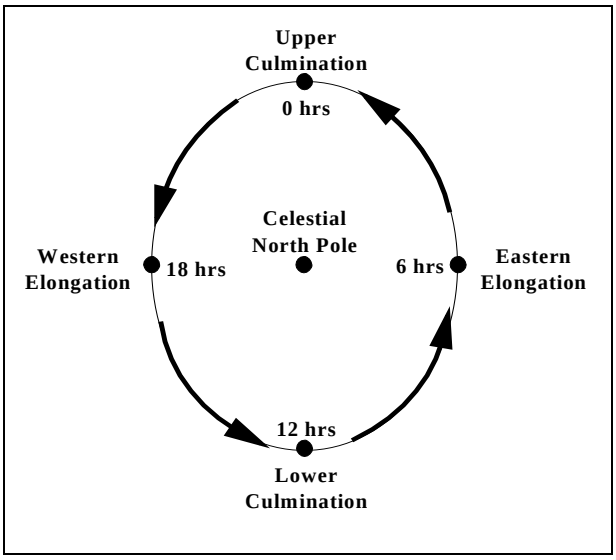

Figure 9-27 Orbit of Polaris

b. Identification of Polaris.

1. 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.

2. 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. (See Figure 8-28.)

3. 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. (See Figure 8-28.)

4. The vertical angle to the celestial North Pole is equal to the observer's latitude; therefore, the vertical angle to Polaris is approximately equal to observer's latitude.

Figure 8-28 Identification of Polaris

a. 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. (See Figure 8-29.)

b. 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 8-29). 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.

Figure 8-29 Relationship Between the Observer's Latitude and the Vertical Angle to the Celestial North Pole.

5. 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.

8-19 Star Rate

If Polaris is not visible, an east-west star may be observed. East-west stars should be selected according to their star rate.

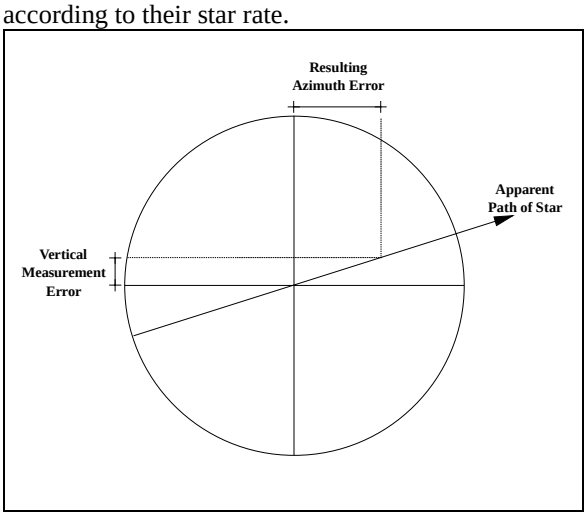

Figure 9-30 High Star Rate

a. The apparent motion of a celestial body has two measurable components: a horizontal motion (change in azimuth), and a vertical motion (change in altitude.) The star rate of the body is equal to the ratio between the two components. In other words, when a 1-mil error in the vertical angle causes an azimuth error of 3 mils, the star rate is 3. When observing a star that moves at a small angle relative to the horizon, a small error in vertical angle will result in a large error in azimuth. When observing a star that moves at a large angle relative to the horizon, an error in vertical angle will result in a smaller error in azimuth. (See figures 8-30 and 8-31.)

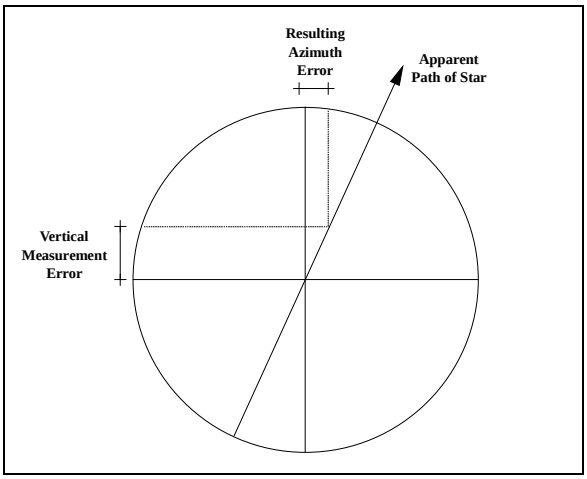

Figure 8-31 Low Star Rate

b. The star rate of a celestial body is largely dependent on the observer's latitude. Because vertical angles are not measured in the Arty Astro method, any east-west star can be observed. However, bodies with a low star rate also have a smaller apparent horizontal motion; therefore, those stars with a low star rate are preferred because they are easier to track. Even though Polaris has a high star rate in its culmination, its apparent motion is slow so it can be observed any time it is visible with the Arty Astro method. Stars below 175 mils in vertical angle, even those with a low star rate, must not be observed because of the increased effects of refraction.

c. Appendix E includes star rate charts that can be used to select stars based on their star rate. The chart used should be the one closest to the latitude of the user and will be the same latitude as the template of the star finder and identifier. The areas marked on the charts are as follows:

1. Block A: Star rates from 0 - 0.5. The dotted line represents a rate of zero. These are the most desirable stars.

2. Block B: Star rates from 0.5 - 1.0. These are the second most desirable.

3. Block C: Star rates from 1.0 - 3.0.

4. Block D: Star rates over 3.0. These stars can be used for Arty Astro in extreme cases.

5. Star rates above 60° altitude are not listed and stars located in that area should not be used.

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8-20 Star Finder and Identifier

a. General. The star finder and identifier is a device used to determine the approximate (±2°) azimuth and altitude of selected stars.

b. Base and Templates. The star finder and identifier consist of a base, ten templates, and a case.

1. **Base.** The base is a two-sided star chart. One side displays stars of the northern hemisphere, the other side the southern hemisphere. The center of each side represents the celestial pole, north or south dependent on the side of the base. The edge of the base is a circle graduated in half degrees and numbered counter- clockwise every five degrees. These graduations represent the local hour angle of the vernal equinox or the local sidereal time (LST).

2. **Templates.** The star finder and identifier include ten templates. One which is used to plot the Sun and planets (not used by artillery surveyors); and nine to identify stars and determine their position once the template is properly oriented. The nine templates are clear plastic that allow the user to view the stars displayed on the base. Each template is constructed for a specific latitude starting at 5° and increase in 10 degree increments to 85°. The templates are two sided, one side for north latitudes and the other side for south latitudes. The user selects a template that corresponds closest to his latitude. On each template is a series of concentric ellipses. Around the outer edge of these ellipses are two sets of numbers from 0° to 360°. The inner set of numbers, numbered clockwise, start at the top of the template and are readable for north latitudes. The outer set of numbers, also numbered clockwise, start at the bottom of the template and are readable for south latitudes. The 0° - 180° line represents the observer's meridian; the other numbers represent the azimuth from the celestial pole, north or south, to the line identified by those numbers. The templates display the observer's horizon as the outer ellipse. The center of the ellipses is the observer's zenith. The series of concentric ellipses represent the altitude in degrees above the horizon of the celestial body.

8-21 Orienting the Star Finder and Identifier.

The star finder and identifier is oriented by placing the arrow at the 0° - 180° line of the template over the local sidereal time (LST) on the outer edge of the base. Local sidereal time can be determined in several ways, each requiring the same information:

- Observation Date
- Observation Time
- Longitude of the Observer

a. DA Form 6-21. This manual computation form allows the user to determine the LST by means of simple mathematical computations and the extraction of several data from charts displayed on the back of the form.

b. Survey Computer Systems. Survey computer systems (HCS) will allow the user to compute the LST by means of input of the above data. For instructions on the operations of these systems, consult the user's manual for that equipment.

c. Haught Method. This is an easy field-expedient method of determining LST accurate to 1° and can be used for any time and location. The final result from these computations is the LST for 1900 hours on the date of observation. The time-arc relationship is then used to determine the LST for the actual observation time. The Haught Method is performed as follows:

1. Count the number of months this year prior to the current month. Multiply that number by 30.

2. Add the calendar day of the current month.

(If the Julian Date of the observation is known, use the Julian Date instead of steps 1 and 2.)

3. Add a constant of 24.

4. Determine the difference between the observer's longitude and the longitude of the time zone central meridian (CM). Add the difference if the observer is east longitude, subtract if the difference is west longitude.

5. If using daylight savings time (DST), subtract 15. In the US, DST is from the first Sunday in April to the last Sunday in October.

**The result is the LST for 1900 hours.

6. Determine the difference between 1900 and the time of observation. Add 15° for each hour after 1900 and 1° for each 4 minutes after the whole hour. If the observation time is prior to 1900, subtract the correction.

7. Sample. An astronomic observation will be made at 2230 on July 23. The observer's longitude is 98°.

Step 1:	# of full months x 30	180
Step 2:	Observation Date	23
Step 3:	Add 24	+24
		227
Step 4:	Offset from CM	-8
		219
Step 5:	Correction for DST	-15
LST for 1900 hours		**204**

Step 6: Observation time difference is 3h 30m.

3 x 15 = 45
30 / 4 = 7.5 +52.5

LST for 2230 on 23 July is 256.5

selection of a star by its star rate can be performed by plotting the position of selected stars on the star rate charts listed in Appendix E.

b. Determine the Position of a Star. Once the stars have been selected, the observer can either plot the azimuth and altitude to the celestial body from the template of the star finder and identifier or he can enter the star number (or name dependent on the system) of the celestial body into a survey computer system. Either method is adequate for locating the star in the telescope of a T-2E Theodolite.

c. Identification of stars other than Polaris is aided by the Star Cards and the World Star Chart included in Appendix E. The star cards display the stars in their constellations, and the star list provides the star number and magnitude.

Section IV
RECORDING ASTRONOMIC OBSERVATIONS

8-23 Recording Arty Astro Method Field Notes (5th order).

a. General. The procedures listed below for recording Arty Astro Method astronomic observations will be used for 5th order accuracy.

b. Heading and Column Titles. As with all field notes, the first page of the recorder's notebook is the index. The heading and column titles will be filled out as described below. (See Figure 8-32.)

1. The **designation** block should be filled in with ARTY ASTRO (Sun) or (Star) as the method of survey being conducted.

2. The **date** block must be filled in with the date the fieldwork was performed. This will be the date used in the computations.

Figure 8-32 Heading and Column Titles (5th Order Arty Astro)

a. General. A star should be selected for its star rate, or the rate of its apparent motion. There are however, other considerations depending on the method of astronomic observation used. Once the star finder and identifier is properly oriented,

include the weather description, T-2E serial number, Party Chief (COP) name, Instrument Operator (IO) name, and Recorder (RCDR) name.

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4. The column titles under the heading will be labeled (from left to right) as follows:

a. Column 1: **STA**; to identify the occupied, rear, and forward stations. The forward station star name will be listed.

b. Column 2: **T**; to identify the telescope mode, direct (D) or reverse (R).

c. Column 3 and 4: **TIME** (**h m s**); to designate 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.

d. Column 5: **HORZ;** to record horizontal readings to the azimuth mark and to the celestial body.

e. Columns 7-12: **REMARKS**; this side of the page will be used to record information pertinent to these observations. Entries are discussed in the following paragraph.

c. Remarks Entries. The remarks page includes both required entries and some optional information that may be needed by the computer or for future reference.
(See Figure 8-33.)

1. Required Entries. The remarks section will include the following information:

- Easting and Northing of the Occupied Station.
- UTM Grid Zone.
- Horizontal Datum/Ellipsoid.
- Source of the position information.
- Center, leading, or trailing edge if using the sun.
- Time Zone Letter (If using local time, an entry must be made indicating Daylight Savings or Standard Times).
- Sketch; as close to scale as possible.

2. Optional Entries. Optional entries can include, but are not restricted to, the following:

- Location of occupied and rear stations.
- Route to these locations from a known point.
- Changes to data in trig list concerning the stations.
- Weather phenomena not covered in header information.
- RCDR, IO, COP initial blocks
- Approx. azimuth to AzMk

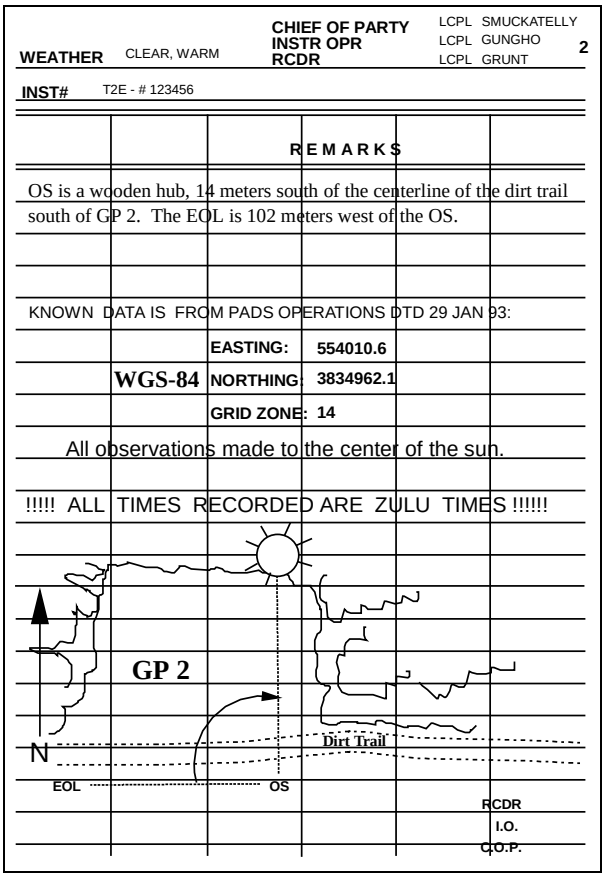

Figure 8-33 Remarks For Arty Astro

d. Recording Field Data.

1. Field data will be recorded in the columns and rows corresponding to the pointing. In other words, the initial circle setting is recorded in the horizontal angle column, in the rear station/direct reading row. (See Figure 8-34.)

2. The "T" (telescope) column will be filled out as shown in Figure 8-36. The rear station (AzMk) name will be recorded in the direct (D) 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, the star name must be recorded.

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DESIGNATION ARTILLERY ASTRO (SUN) DATE 4 DEC 19 90

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 8-34 Field Data (5th Order) For Arty Astro

3. When recording times, record the seconds, minutes, and then hours (24 hr format).

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

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

6. If the azimuth is being computed in the field using the computer's internal clock, the solution is part of the fieldwork and must therefore be included in the field recorder's book. The solution is recorded in column 6 in the row listing the occupied station and is circled. (See Figure 8-34.)

8-24 Recording Arty Astro Method Field Notes (4th order).

a. General. The procedures listed below for recording Arty Astro Method astronomic observations will be used for 4th order accuracy. In this method two sets of observations will be made; one with the telescope in the direct mode, the second in the reverse mode. This method will minimize the effects of small pointing errors on the observed stations.

b. Heading and Column Titles. As with all field notes, the first page of the recorder's notebook is the index. The heading and column titles will be filled out as described below. Note that except for the addition of column 6, MEAN, everything else is the same as 5th order recording. (See Figure 8-35.)

1. The **designation** block should be filled in with ARTY ASTRO (Sun) or (Star) as the method of survey being conducted.

2. The **date** block must be filled in with the date the fieldwork was performed. This will be the date used in the computations.

3. The heading of the right side of the page will be filled out the same as with traverse. This heading will include the weather description, T-2E serial number, Party Chief (COP) name, Instrument Operator (IO) name, and Recorder (RCDR) name.

4. The column titles under the heading will be labeled (from left to right) as follows:

a. Column 1: **STA**; to identify the occupied, rear, and forward stations. If the forward station is a star, the star name will be listed.

b. Column 2: **T**; to identify the telescope mode, direct (D) or reverse (R).

c. Column 3 and 4: **TIME (h m s)**; to designate 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.

d. Column 5: **HORZ;** to record horizontal readings to the azimuth mark and to the celestial body.

Figure 8-35 Heading and Column Titles (4th Order Arty Astro)

e. Column 6: **MEAN**; to record the solutions for the direct and reverse sets; and to record the mean solution of the sets.

f. Columns 7-12: **REMARKS**; this side of the page will be used to record information pertinent to these observations. Entries are discussed in the following paragraph.

c. Remarks Entries. The remarks page includes both required entries and some optional information that may be needed by the computer or for future reference. (See Figure 8-33.)

1. Required Entries. The remarks section will include the following information:

- Easting and Northing of the Occupied Station.
- UTM Grid Zone.
- Horizontal Datum/Ellipsoid.
- Source of the position information.
- Center, leading, trailing edge if using the Sun.
- Time Zone Letter (If using local time, an entry must be made indicating Daylight Savings or Standard Times).
- Sketch; as close to scale as possible.

2. Optional Entries. Optional entries can include, but are not restricted to, the following:

- Location of occupied and rear stations.
- Route to these locations from a known point.
- Changes to data in trig list concerning the stations.
- Weather phenomena not covered in header information.
- RCDR, IO, COP initial blocks
- Approx. azimuth to AzMk

d. Recording Field Data.

1. The first set in this method is recorded the same as the procedures listed for 5th order except that the solution is *not* circled, it is placed in parenthesis. (See Figure 8-36.)

2. The "T" (telescope) column will be filled out as shown in Figure 8-36. There will be three spaces between the last direct reading in the first set and the initial circle setting ("R" reverse reading) in the second set.

3. The second set is recorded as follows:

a. The rear station (AzMk) name will be recorded in the reverse (R) mode row in the second set. 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, the star name must be recorded.

b. When the fieldwork was completed for the first set, the instrument operator had a pointing on the rear station in the reverse mode. This was 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 mode and close the angle in the direct mode to complete the second set. (See Figure 9-37.)

b. When recording times, record the seconds, minutes, and then hours (24 hr format).

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

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

e. If the azimuth is being computed in the field using the computer's internal clock, the solution is part of the fieldwork and must therefore be included in the field recorder's book. The solution is recorded in column 6 (MEAN) in the row listing the occupied station and is placed in **parenthesis**. The azimuth

determined from the direct readings must equal the azimuth from the reverse readings, ± 0.150 mils. (See Figure 8-37.)

4. 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. (See Figure 8-37.)

DESIGNATION ARTILLERY ASTRO (SUN) DATE 4 DEC 19 90

STATION	T	TIME h	m	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 8-36 Field Data (4th Order) For Arty Astro

DESIGNATION ARTILLERY ASTRO (SUN) DATE 4 DEC 19 90

STATION	T	TIME h	m	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	2790.707	
	R	20	57	01	2793.403	

Figure 8-37 Field Data (4th Order) For Arty Astro

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CHAPTER 9
TRAVERSE

In survey, traverse is defined as the field operation of measuring the lengths and directions of a series of straight lines connecting a series of points on the Earth. Each of these straight lines is called a traverse leg and each point is called a traverse station (TS).

Section I
TRAVERSE METHODS

9-1 General

a. Traverse is a conventional survey method used to determine the position (UTM) and elevation of the stations occupied by a survey team as well as the azimuth between those stations. While traverse can be used for all accuracy levels of artillery survey: 4th, 5th, and hasty, in the chaotic and rapidly changing environment of the battlefield it may be too time consuming to perform at the battalion and battery level where accurate, timely direction is *the* most critical data needed to begin firing. The establishment of 4th Order horizontal control by Regimental surveyors is the most likely traverse operation to be conducted, when other methods (i.e., GPS, PADS) are not feasible. Only 4th and 5th order survey methods will be discussed in detail in this chapter, hasty survey is discussed in Chapter 11.

b. Traverse has several advantages over other conventional survey methods.

1. It is well suited for any terrain. Whether surveying in a forested area with 100-meter legs or a desert region with 12 km legs, traverse is the preferred method.

2. Traverse allows a great deal of flexibility. If necessary, a survey plan can be easily modified while traversing. In many cases, a traverse can be laid out ahead of the instrument operator during the survey.

3. Traverse requires less planning and reconnaissance than other conventional survey methods.

c. A traverse works similar to determining a polar plot grid from a map sheet. If your location is plotted on a map sheet and you know the azimuth and distance to a target you can draw an azimuth line from your location with a protractor and scale the distance along that line. The coordinates of the end of that line can be scaled. Traverse works the same way; we know the coordinates of a point on the ground, we can determine an azimuth to another point, and we can measure the distance to that point. Instead of plotting the azimuth and distance, we compute the coordinates of the station with plane trigonometry. (See Figure 9-1.)

Figure 9-1 Traverse

9-2 Types Of Traverse

There are three types of traverse used in artillery survey. These are open traverse, closed traverse, and directional traverse.

a. Open Traverse. An open traverse begins at a point of known control and ends at a station whose relative position is known only by computations. The open traverse is considered to be the least desirable type of traverse because it provides no check on the accuracy of the control, fieldwork, or computations. For this reason, a traverse is never deliberately left open. Open traverse is used only when time or enemy situation does not permit closure on a known point. (See Figure 9-2.)

Figure 9-2 Open Traverse

b. Closed Traverse. This traverse starts and ends at stations of known control. A closed traverse provides a basis for comparison of computed data against known data; therefore, a closing accuracy can be determined. There are two types of closed traverse: closed on a second known point and closed on the starting point.

1. **Closed on a second known point**. This type of closed traverse 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, 4th order or higher. This is the preferred type of traverse, as it provides checks on fieldwork, computations, and control. (See Figure 9-3.)

Figure 9-3 Traverse, Closed on Second Point

Figure 9-4 Traverse, Closed on Starting Point

2. **Closed on the starting point**. This type of closed traverse begins at a point of known control, moves through the various required unknown points, and ends (closes) at the same point. This type of closed traverse is more desirable than an open traverse but less than closing on a second known point. It provides checks on fieldwork and computations; however, does not provide a check on the accuracy of the starting data or ensure detection of any systematic errors. (See Figure 9-4.)

c. Directional Traverse. A directional traverse is a traverse that extends directional (azimuth) control only. This type of traverse can be either open or closed. If open, the traverse should be closed at the earliest opportunity. It can be closed on either the starting azimuth or another known azimuth. Since direction is the most critical element of artillery survey and time is frequently an important consideration, it is sometimes necessary at lower echelons to assume battery location and extend direction only.

9-3 Survey Control Requirements

a. General. The purpose of traverse is to locate points relative to each other and to a local control network. Three elements of survey control must be known to start and to close a traverse: the UTM grid coordinates and elevation of a point and an azimuth from that point to a visible azimuth mark (see Figure 9-5).

Figure 9-5 Starting and Ending Control

b. Sources of Control Data. Starting and ending data may be obtained from many different sources; however, there are only two basic types of control, known and assumed.

1. **Known Control.** Position and elevation may be acquired from trig lists of local or national survey agencies (e.g., NGS, NIMA) or supporting survey elements of a higher headquarters. An azimuth to an azimuth mark may be determined from astronomic observation, by computation from known coordinates, or by reference to an existing trig list. An azimuth determined by PADS two-position mark or PADS autoreflection could be used as a starting and ending azimuth for a Fifth order traverse. An azimuth cannot be determined from computations between PADS points. Pads positions can be used for extending 5th order traverse, but the survey must be closed on the

starting station. Known survey control must be of a higher order than that of the echelon conducting the survey for it to meet their order specification.

2. **Assumed.** If no known control is available, survey data may be obtained by assuming control. In other words, "map spotting" control through the best available resources. **If any of the three elements of survey (coordinates, elevation, and azimuth) have to be assumed, the traverse must open and close on the same station.**

9-4 Fieldwork

a. Stations. In a traverse, three stations are considered to be of immediate significance. These stations are the rear station, the occupied station, and the forward station. (See Figure 9-6)

Figure 9-6 Rear, Occupied, and Fwd Stations,

1. The **occupied station** (occ sta) is the station at which the theodolite is set up or occupies.

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

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

b. Measurements. At each occupied station, except the closing station, three measurements are made: the horizontal angle, the vertical angle, and the distance. Only a horizontal angle is required at the closing station.

1. **Horizontal Angles.** 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. The horizontal angle is necessary to determine the azimuth to the forward station. (See Figure 9-6.)

2. **Vertical Angles**. 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. (See Figure 9-7.)

Figure 9-7 Vertical Angles

a. 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 is used to negate errors caused by curvature and refraction. (See Figure 9-8.)

b. The Earth curvature correction increases with distance. For example, at a distance of 1200 meters, the earth curvature correction is 0.1 meters; at a distance of 2700 meters, the correction is 0.5 meters; and at a distance of 9800 meters, the correction is 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.

and Horizontal Angles

c. Refraction varies dependent on the altitude of the sun, temperature, and distance; therefore, it cannot be modeled like Earth curvature.

Figure 9-8 Reciprocal Vertical Angles

d. Some survey computer systems will correct

the vertical angle for Earth curvature if non-reciprocal vertical angles were measured, but not for refraction. This is because there is no way for a computer to determine its value with the data provided. This is only a partial correction; therefore, it is recommended that reciprocal vertical angles be measured over all lines when time is available to negate the effects of both refraction and Earth curvature. This is especially important during measurements in high heat shimmer conditions.

3. **Distance**. The distance between the occupied station and the forward station is measured by using electronic distance measuring equipment (i.e., DI3000), horizontal taping, or trig-traverse.

c. Recording Traverse Field Notes. Traverse field notes are recorded in the currently available field recorder's notebook.

9-5 Distances in Traverse

a. General. The distance used to determine the coordinates of the forward station is not necessarily the distance measured. Three types of distances must be considered: slope, horizontal, and grid.

b. Slope Distance. A slope distance is a straight-line distance between two stations, which includes the effects of terrain. In other words, 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 (i.e., DI3000) is a slope distance. (See Figure 9-9.)

c. Horizontal Distance. A horizontal distance is a straight-line distance between two stations, determined without the effects of terrain. (See Figure 9-9.)

Figure 9-9 Slope and Horizontal Distances

1. Any distance measured with a steel tape or determined through trigonometric computations (i.e., trig-traverse) is a horizontal distance.

2. A slope distance can be converted to a horizontal distance using the formula: horizontal distance = cos (vertical angle) x slope distance.

a. The vertical angle should be the mean of the reciprocal vertical angles if the slope distance exceeds 1000 meters.

b. With most calculators, an angle must be in degrees to determine the trigonometric function of that angle.

d. Grid Distance. A UTM grid distance is the distance needed to compute the traverse leg. This distance is the same as a map distance.

1. A grid distance is determined by reducing the horizontal distance to sea level, then by correcting the sea level distance to grid by applying a scale factor correction. (See Figure 9-10.)

a. If the horizontal distance was determined by horizontal taping, the correction for reduction to sea level is usually not applied. This is because this type of distance is not highly accurate and also because this type of distance is usually relatively short.

b. Figure 9-10 shows that the correction for reduction to sea level increases as the elevation of the traverse lines increase.

Figure 9-10 Reductions to Sea Level

2. The reduction to sea level correction is negative when elevation is positive. 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.

3. The current survey computer systems apply the

reduction to sea level correction to the horizontal distance automatically; therefore, the scale corrections (PPM) for the DI3000 must not include this correction.

9-6 Traverse Legs

a. General. 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. Two types of traverse legs are considered in artillery survey: main scheme legs and offset legs. (See Figure 10-11.)

Figure 9-11 Traverse Legs

1. Main Scheme Leg. A main scheme leg is one on which both ends of the leg are an occupied station in the traverse.

2. Offset Leg (Dogleg). An offset leg is one on which only the first station of the leg is occupied.

b. Computing an Offset Leg.

1. The computations of an offset leg are the same as with a main scheme leg. The important difference in computations is that an offset leg is left open; in other words, the coordinates and elevation determined for the offset station are not used in computations of other stations.

2. Computations of an offset leg are performed prior to the computations of the main scheme leg that originates from the same station.

c. Recording Offset Legs. The field data for the offset leg is measured and recorded in the same occupation as the main scheme data.

1. The horizontal angle measured is called a **multiple angle** because it includes the determination of two horizontal angles from one set of observations.

2. The vertical angle is determined in the same manner as with a main scheme leg to include the determination of reciprocal vertical angles if the offset leg is longer than 1000 meters.

Section II

TRIGONOMETRY OF TR

9-7 Extending Azimuth

a. General.

1. In artillery survey, we compute traverses relative to the UTM or UPS grid systems. Only the UTM grid system will be mentioned; however, computations of traverses in UPS are performed the same as in UTM.

2. An azimuth is the clockwise angle from a known reference line to a second line. For our purposes, the reference line is grid north and the second line is the traverse line to the forward station. Every line has two azimuths, a forward azimuth and a back azimuth. In artillery survey we consider the earth to be a flat surface; therefore, a forward azimuth and back azimuth differ exactly 3200 mils. (See Figure 9-12.)

Figure 9-12 Azimuth

b. Azimuth-Angle Relationship.

1. When traverse computations are begun, 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. (See Figure 9-13.)

Figure 9-13 Azimuth-Angle Relationship

2. In some cases, the sum of the azimuth to rear and the horizontal angle will produce an azimuth larger than 6400 mils. When this occurs, subtract 6400 mils from that sum to determine the azimuth necessary for computations.

c. Azimuth to the Rear. Once the azimuth to the forward station is determined, the computations necessary to determine the coordinates of the forward station can be performed. 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. This is done by applying 3200 mils to the forward azimuth as shown in Figure 9-12 and the following example:

Az to Fwd Sta (Cain to Abel):	2520.254 mils
± 3200 mils	3200.000 mils
Az to Rear (Abel to Cain)	5720.254 mils

In this example, the azimuth to the forward station (Abel) from Cain is 2520.254 mils. This azimuth is used to compute the coordinates of Abel. To determine the coordinates of the forward station when Abel is occupied, we must first know the azimuth from Abel to the rear station (Cain), in this example, 5720.254 mils.

9-8 Solutions of Right Triangles

a. General. A traverse performed by Marine artillery surveyors is computed considering the Earth as a flat

surface. This means that simple plane trigonometry can be used to compute the survey. In this case, the solution of two right triangles is necessary, one to determine differences in coordinates and one to determine the difference in elevation.

b. Forming the Coordinate Triangle. The distance and azimuth between two points can be used to form a right triangle. The grid distance (see paragraph 9-6) 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. (See Figure 9-14.)

Figure 9-14 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. (See Figure 9-15.)

Figure 9-15 Elevation Triangle

d. Trigonometric Functions. Three trigonometric functions are used to compute a traverse. These are the sine (sin), cosine (cos), and tangent (tan) functions.

1. The sin and cos functions are used to compute the differences in easting and northing coordinates. The tan is used to compute the difference in height.

2. The values of the sin and cos functions are the distances corresponding to an angle formed at the center of a circle whose radius is one. Figure 9-15 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 9-15 Value of Trigonometric Functions of Angles

3. The value of the tan function is equal to the value of the sin divided by the value of the cos.

e. Determining Coordinate and Elevation Differences.

1. The formulas for solving a right triangle are generally written as follows:

$$\sin(angle) = \frac{O}{H}$$

$$\cos(angle) = \frac{A}{H}$$

$$\tan(angle) = \frac{O}{A}$$

whereas: *O* is the side opposite the angle,
A is the side adjacent the angle,
H is the hypotenuse.

and: Angles are converted to degrees from mils using the formula:
degrees = mils x (0.05625).

Figure 9-16 shows the sides of a right triangle as described above.

Figure 9-16 Right Triangle

2. 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:

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

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

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

3. The formulas listed in paragraph 2 above can also be written as follows:

dE = sin (Az Fwd x 0.05625) x Grid Dist

dN = cos (Az Fwd x 0.05625) x Grid Dist

dH = tan (Vert Angle x 0.05625) x Grid Dist

4. The example shown in paragraph 9-8.b and Figure 9-13 produced an azimuth forward (Cain to Abel) of 2520.254 mils. If the grid distance from Cain to Abel 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 in paragraph 3 above.

dE = sin (2520.254 x 0.05625) x 524.876
dE = 324.84 meters

dN = cos (2520.254 x 0.05625) x 524.876
dN = 412.28 meters

dH = tan (27.821 x 0.05625) x 524.876
dH = 14.34 meters

9-9 Determining the Coordinates and Elevation of the Forward Station

a. Determining Coordinates at the Forward Station.

1. The coordinates of the forward station can be determined 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.

a. The sign of the dE and dN is determined by plotting the azimuth to the forward station. (See Figure 9-17.)

Figure 9-17 Determining the Sign of dE and dN

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

b. Determine Elevation at the Forward Station. The

elevation of the forward station is determined 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.

c. Example. The example shown in paragraph 9-8.b and Figure 9-13 produced an azimuth forward (Cain to Abel) of 2520.254 mils. The example in paragraph 9-9.e.4 produced a dE of 324.84 meters, a dN of 412.28 meters, and a dH of14.34 meters.

1. The coordinates of Cain are as follows:

E: 5 40666.21 N: 34 13666.78 El (m): 666.34

2. The azimuth from Cain to Abel is 2520.254 mils, which plots in quadrant II in Figure 9-17; therefore, the dE is positive, the dN is negative. The coordinates of Abel are determined as follows:

Cain	5 40666.21	34 13666.78	666.34
dE,N,H	+324.84	-412.28	+14.34
Abel	5 40991.05	34 13254.50	680.68

9-10 Computing the Traverse

a. Main Scheme Legs.

1. 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 is used to determine the coordinates and elevation of the next forward station.

2. Figure 9-18 shows a traverse with only main scheme legs; it can be seen that the coordinates and elevation of Abel, will be used to compute the coordinates of John Boy.

Figure 9-18 Main Scheme Legs

c. Offset Legs.

1. A traverse cannot continue from an offset station because the offset station is not occupied; therefore, 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.

2. Figure 9-19 shows a traverse with an offset leg from Cain to Abel. The main scheme portion of the traverse runs from Cain to John Boy, then to Jim Bob. The coordinates and elevation of Abel will not be used to compute the coordinates and elevation of John Boy; the coordinates and elevation of John Boy must be computed using the data from Cain.

Figure 9-19 Offset Legs

Section III

TRAVERSE CLOSUR

9-11 Traverse Closure

a. General. 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, which must meet certain specifications for the order of traverse being performed. Three comparisons must be made to determine if a traverse meets closure specifications: coordinate comparison, elevation comparison, and an azimuth comparison. (See Figure 9-20.)

Figure 9-20 Traverse Closing Data Comparison

b. Closing Data. Closing data for a traverse consists of Radial Error (RE) of closure, Elevation Error, Azimuth Error, and Accuracy Ratio.

a. General. A comparison between known and computed coordinates of the closing station is performed to produce a Radial Error (RE) of closure. The radial error is the distance from the known coordinates to the computed coordinates. (See Figure 9-21.)

b. Computing Radial Error. There are several ways to determine the RE. If the traverse was computed on a survey computer system (i.e.. HCS), the radial error will be computed automatically. Otherwise, it would be computed using the Azimuth and Distance programs, or with the Pythagorean Theorem manually.

1. Azimuths and Distance Program. The radial error of closure can be determined by performing the azimuth and distance computations available in survey computer programs. The 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, which may be necessary to determine the location of traverse errors should the survey not meet specifications.

2. Pythagorean Theorem. The radial error of closure can be determined by solving a right triangle with the Pythagorean Theorem. This method considers the radial error as the hypotenuse of a right triangle and as sides of the triangle. (See Figure 9-22.)

Figure 9-21 Radial Error of Closure

Figure 9-22 Pythagorean Theorem

a. 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 in the following manner:

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

9-12 Radial Error (RE).

-Where *C* is the hypotenuse, *A* and *B* are the sides of the triangle.

b. The eE, eN, and RE can be substituted into the formula as follows:

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

.

c. The eE is the difference between the known and computed easting. If the known easting value is a larger number than the computed, the eE is negative; if the known easting value is a smaller number than the computed, the eE is positive.

d. 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.

e. The following is an example of using the Pythagorean theorem to compute RE.

Step 1 Determine eE and eN.

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

Step 2 Determine RE

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

c. Allowable Radial Error. The allowable position closure (radial error) for a traverse is dependent on the order of survey and the total traverse length (TTL).

1. **Fourth Order.**

a. **Traverse Length Less Than 9 Km.** The allowable RE in closure for a fourth-order traverse whose total traverse length (TTL) is less than 9000 meters is 1:3000, or 1 meter of radial error for each 3,000 meters of traverse. The allowable RE is determined by dividing the total traverse length by 3000. For example, if the traverse length of a 4th order survey is 3,469.910 meters, the allowable RE is 1.16 meters (3,469.910/3,000 = 1.1566).

b. **Traverse Length Greater Than 9 Km.** When the TTL exceeds 9000 meters, the accuracy achieved may be better than 1:3000, yet the RE may be excessive. Therefore, allowable RE is determined by the following formula: $\sqrt{K}$ (whereas *K* equals the TTL in kilometers. In other words, 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 3000, the Allowable RE would be 3.66 meters, 0.35 meters *more* than with the square root of *K*.

2. **Fifth Order.** The allowable RE in closure for a fifth-order traverse is 1:1000, or 1 meter of radial error for each 1,000 meters of traverse. The allowable RE is determined by dividing the total traverse length by 1000. For example, if the traverse length of a 5th 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 is equal to *K* (TTL in Km).

d. Excessive Radial Error. If the radial error of a traverse exceeds the specifications listed above for Allowable RE, the traverse has "busted." The location of the traverse error must be determined and corrected.

9-13 Elevation Errors

a. General. A comparison between known and computed elevations of the closing station is performed to produce an elevation error (eH). The elevation error is the vertical distance from the known elevation to the computed elevation. (See Figure 9-23.)

Figure 9-23 Elevation Errors

b. Computing Elevation Error. Elevation error is the difference between the known and computed elevations of the closing station. 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 10-23 shows station Judas 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. Survey Computer Systems. The eH is computed automatically by Survey programs. In some cases the value displayed by the program is the elevation correction. Elevation correction is the same value as elevation error with the opposite sign, and is used for traverse adjustments.

d. Allowable Elevation Error. The allowable elevation error (eH) for a traverse is dependent on the order of survey and the total traverse length (TTL).

1. **Fourth Order.** The allowable eH for a fourth order traverse is equal to 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 elevation error in this example is equal to 2.764735972928, or 2.8 meters.

2. **Fifth Order.**

a. Traverse Length Less Than 4 Km. The allowable elevation error for a fifth order traverse whose TTL is less than 4000 meters is ± 2 meters. In other words, as long as the computed elevation is within 2 meters of the known, the elevation closes.

b. Traverse Length Greater Than or Equal to 4 Km. The allowable eH for a fifth order traverse whose TTL is equal to or greater than 4000 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 2.616079891, or 2.6 meters.

e. Excessive Elevation Error. If the elevation error of a traverse exceeds the specifications listed above for allowable eH, the traverse has "busted." The location of the elevation error must be determined and corrected.

9-14 Azimuth Errors

a. General. 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. (See Figure 9-24.)

b. Computing Azimuth Error. Azimuth error is the difference between the known and computed azimuths to the forward station (AzMk) at the closing station. 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 10-24 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 eAz is written as -0.126 mils.

Figure 9-24 Azimuth Errors

c. Survey Computer Programs. Survey computer programs compute the eAz automatically. In some cases 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. Allowable Azimuth Error. The allowable azimuth error (eAz) for a traverse is dependent on the order of survey and the number of main scheme angles, including the closing angle, in the traverse.

1. **Fourth Order.**

a. **Six or fewer Main Scheme Angles.** The allowable azimuth error for a fourth order traverse with six or fewer main scheme angles is determined from the formula: Allowable eAz = 0.04 mils x 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 x 5 = 0.200 mils.

b. **Seven or More Main Scheme Angles.** The allowable azimuth error for a fourth order traverse with seven or more main scheme angles is determined from the formula: 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.

2. **Fifth Order.** The allowable azimuth error for a fifth order traverse is determined using the formula: Allowable eAz = 0.1 mils x *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.

e. Excessive Azimuth Error. If the azimuth error of a traverse exceeds the specifications listed above for allowable eAz, the traverse has "busted." The location of the traverse error must be determined and corrected.

9-15 Accuracy Ratios

a. General. Certain minimum position accuracy requirements are prescribed for survey fieldwork and computations. To determine whether this position requirement has been met for a closed traverse, an accuracy ratio (AR) is computed.

b. Total Traverse Length (TTL). Total traverse length is sum of the main scheme grid distances used to compute the traverse.

c. Computing Accuracy Ratio (AR). An accuracy ratio is the ratio of position error to total traverse length (TTL).

1. Accuracy ratio is computed by dividing the TTL by the radial error (RE): AR = TTL / 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.

2. AR may be expressed as either a fraction with a numerator of one (i.e.. 1/3000, 1/1000) or as a ratio (i.e.. 1:3000, 1:1000). An accuracy ratio is read, "one to the computed value"; for example, "one to three thousand."

3. After the accuracy ratio has been computed, the denominator of the fraction is always reduced to the next lower hundred (for example, 1/4897 is recorded as 1/4800).

d. Minimum Accuracy Ratio. The minimum accepted value for an accuracy ratio is dependent on the order of survey being performed. A traverse performed to fifth order specifications must produce an accuracy ratio equal to or higher than 1/1000. A traverse performed to fourth order specifications must produce an accuracy ratio equal to or higher than 1/3000; however, if the TTL exceeds 9 Km, the RE must be within specifications.

e. Accuracy Ratios Not Meeting Specifications. If the computed accuracy ratio of a traverse does not meet the specifications listed above, the traverse "busted." The location of the traverse error must be determined and corrected.

Section IV

TRAVERSE ADJUSTM

9-16 Purpose Of Adjustment

a. General. An adjusted traverse is one in which the

errors have been distributed systematically so that the computed closing station coincides with the known closing station.

1. In artillery survey, only fourth order traverses are adjusted. Fifth order traverses are not adjusted.

2. There is no way of determining the true magnitude of errors in the angle and distance measurements that occur throughout a traverse; therefore, a traverse adjustment is based on the assumption that the errors have accumulated gradually, and the corrections are made accordingly. A traverse adjustment is also based on the assumption that all errors causing misclosure in the traverse are from field measurements. In other words, no errors are brought into the closure from previous adjustments or a lack of commonality.

3. Three adjustments must be made when adjusting a traverse. These are azimuth, coordinates, and elevation. These adjustments eliminate the effects of systematic (accumulative) errors on the assumption that 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.

4. A traverse that does not meet the closure specifications listed in Section III is not adjusted. It is checked for error using the location of traverse error procedures discussed in Section V, and corrected.

b. Errors. In most cases, a traverse will close within specifications; however, because some error sources cannot always be accounted for, closure will not be absolute. In other words, there will always be some measure of position, elevation, and azimuth error.

1. Accumulative Errors. A large majority of the errors causing survey misclosure are cumulative errors. A cumulative error will generally be of the same magnitude, in the same direction, and occur in every measurement of that type. An example is error introduced by instruments that are not properly adjusted.

2. Random Errors. Random errors are those errors that cannot be accounted for. They are of varying magnitude and direction, and do not occur in all measurements. Examples of random errors include plumbing errors, leveling errors, and sighting errors.

c. Survey Computer Systems. Survey computer systems will automatically adjust the main scheme portion of a traverse if so prompted.

9-17 Azimuth Adjustments

a. Determining Azimuth Correction. The difference in easting and northing between two stations is determined by multiplying the grid distance by the sine or cosine of the azimuth to the forward station. 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 as follows:

1. Compute the azimuth error.

2. The azimuth correction is the azimuth error with the proper sign affixed so that the computed azimuth with the azimuth correction applied will equal the known azimuth. In other words, the azimuth correction is the same value as the azimuth error with the opposite sign.

b. Application of Azimuth Correction. Since traverse adjustment is based on the assumption that errors have accumulated gradually and systematically throughout the traverse, the azimuth correction is applied accordingly. The 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 azimuth error for the traverse equals +0.966 mils; the azimuth correction would equal -0.966 mils and is divided by the number of angles in the traverse. In this case, -0.966 mils / 5 = -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. (See Figure 9-25.)

c. Adjusted Angle Computations. After the main scheme angles have been adjusted, the entire traverse is recomputed using those adjusted angles. This will produce new coordinates and closing data for the traverse with an azimuth error of zero mils. There will be no change in elevation error or total traverse length. It is now assumed that all azimuth error has been eliminated. Any remaining error is assumed to be a distance error.

Figure 9-25 Azimuth Adjustments

9-18 Coordinate Adjustment

a. Determining Total Coordinate Corrections.

1. The total easting and northing corrections (tcE, tcN) 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.

2. The following is an example of how 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. Determining Station Corrections. The easting and northing corrections determined above are for the entire traverse. It is assumed that errors causing coordinate misclosure are accumulated proportionately throughout the traverse. Therefore, the corrections must be distributed proportionately throughout the traverse.

1. 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 (tcE, tcN) by the partial traverse length, (PTL = sum of the traverse legs up to that station), then dividing by the total traverse length (TTL).

2. 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 Judas whose PTL is 3974.652 meters is determined as follows:

cE = +0.16 meters cN = -0.27 meters

c. Determining Adjusted Coordinates.

1. 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.

2. The following is an example of how to determine adjusted coordinates using the coordinate corrections determined above:

	Easting	Northing
Judas (Az Adj)	5 24987.56	34 85673.87
correction	+0.16	-0.27
Judas (Adjusted)	5 24987.72	34 85673.60

d. Offset Legs (Doglegs). 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 used to determine the offset station coordinates. To insure relativity, offset legs should be adjusted by 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.

9-19 Elevation Adjustments

a. General. Because elevation is the least important of the three elements of survey, it can safely be assumed that, for artillery's accuracy, elevation closure error is accumulated throughout a traverse in equal amounts at each traverse station and not proportionately to the length of the traverse legs.

b. Determining Elevation Correction.

1. Elevation correction is determined by comparing the computed elevation of the closing station, with the known elevation of the closing station, and applying a sign (±) that will cause the established height to equal the known height. In other words, the elevation correction is the same value as the elevation error with the opposite sign.

2. As an example, if the known elevation for station Judas 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, 0.6 meters would have to be subtracted from the elevation of the computed closing station.

c. Determining Adjusted Elevation. The elevation correction is distributed equally among the stations of the traverse with any remainder distributed to those stations computed from the longest legs.

1. As an example, assume that the traverse for which the elevation correction was determined 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. From the example above, the elevation correction is -0.6 meters; therefore, the elevation correction is determined from the formula: -0.6 / 4 = 0.1 with a remainder of .2 meters.

2. The adjustment is an accumulation of the correction, since the correction is applied to the differences in elevation between the stations and not directly applied to the station elevations.

9-20 Discretion Adjustments

Traverse adjustment is usually considered to be a systematic operation. There will be times in the field when a surveyor will rely on judgment alone. In these cases, the error may be distributed arbitrarily in accordance with the surveyor's estimation of the 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 artillery surveyor should not use this method of adjustment unless he is experienced and has a keen knowledge of where errors are most likely to occur and of their effect on the overall survey. In any event, the field notebook should contain a detailed account of any unfavorable survey conditions so that is may be used to substantiate any arbitrary adjustments.

Section V

LOCATION OF TRAVERSE

9-21 General

A good survey plan executed by a well-trained party provides for numerous checks in both computations and fieldwork. These checks do not always eliminate errors,

as errors made both in fieldwork and in computations often are not discovered until the survey has been completed. The artillery surveyor must, therefore, be able to isolate these errors and determine their causes. Often, a critical analysis of both the fieldwork and the computations of a survey in error will result in timely delivery of the surveyed data to the firing unit.

9-22 Sources of Error

a. General. 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 fieldwork or computations.

b. Higher Echelon Trig Data. 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.

1. **Coordinate Errors.** When a higher echelon trig list includes a misprint of a station's coordinates, it is usually a typographical error in either easting or northing, but not both. 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 Survey Information Center (SIC) must determine which is the most accurate with respect to commonality.

a. A coordinate error from a higher echelon trig list 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.

b. A coordinate error from a higher echelon trig list will appear as if a distance error is present in the survey if the traverse is closed on a second known point.

2. **Elevation Error.** When a higher echelon 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 Survey Information Center (SIC) must determine which is the most accurate with respect to commonality.

a. An elevation error from a higher echelon trig list 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.

b. An elevation error from a higher echelon trig list 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, not for elevation.

3. **Azimuth Error.** When a higher echelon trig list includes a misprint of an azimuth between two stations, it is usually a typographical error of either a computed or astronomic azimuth. In some cases, 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. It is always advisable to perform your own computation of an azimuth, when using a computed azimuth from a trig list.

a. An azimuth error from a higher echelon trig list 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 both coordinate and azimuth errors.

b. An azimuth error from a higher echelon trig list will appear as if an angle error exists in the traverse if the traverse is closed on a second station.

c. Fieldwork Errors. Errors from fieldwork 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 surveyors. The following are a few examples of errors caused by that lack of precise action.

1. **Reading Errors.** 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. Improper instrument readings can result in distance, horizontal angle, and vertical angle errors.

2. **Recording Errors.** Recording errors are generally found in the meaning of the recorded data. When possible, and practical, the instrument operator (IO) or Team Chief should verify those means before march ordering the equipment. The recorder must record the entire reading from the IO then read back what he has written, *not* what he heard. The recorder must listen for the command "bubble level", indicating the use of the automatic index by the IO, prior to recording vertical readings. Improper recording procedures can result in distance, horizontal angle, and vertical angle errors.

3. **Computer Error.** Errors caused by computations are generally attributed to improper computation, and check computation procedures. Computations and check computations must be performed independent of each other.

4. **Pointing Errors.** Pointing errors can be located by measuring a direct and reverse reading over each station. In some cases, 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 which create a measure of azimuth and/or elevation error at closure. Very small distance errors are introduced in a survey, which includes vertical angle errors, and slope distances; this is because the vertical angle is used to convert the slope distance to a horizontal distance.

5. **Plumb/Leveling Errors.** Plumb and leveling errors can account for small amounts of distance and horizontal angle errors.

a. If a target set and/or a theodolite is not properly plumb and level over their respective control points, the azimuth line being occupied is not the same azimuth line used in computations, thus creating AZIMUTH/ANGLE ERROR.

b. Forward stations must be properly plumb and level. The forward station is the next occupied station; therefore, 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 very 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; introducing small angle and distance errors.

d. Eliminating Errors. Proper training, planning, organization, and field procedures will eliminate most errors in a traverse. If all fieldwork and computations are done properly, the cause of position, azimuth, and elevation errors in traverse closure will be primarily due to the level of relativity of the survey control. In most cases, this will not bust a survey.

9-23 Locating A Traverse Error

a. General. 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 which is large enough to cause the excessive misclosure; they also assume that 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. Steps For Locating Traverse Errors. Procedures for locating and correcting traverse errors can be performed in four steps:

1. Close the traverse. Determine the azimuth error, radial error, and elevation error.

2. Determine which type of error is indicated.

3. Isolate the suspect station or leg.

4. Check the field recorder's notebook and computations for math errors. If no error can be found in the recorded data or the computations, return to the field and measure the necessary legs of the traverse.

9-24 Traverse Error Indicators

a. General. Figure 9-26 is a table, which shows the indicated traverse error based on the type of traverse and the status of the azimuth, and coordinate misclosure.

b. Azimuth Good Coordinates Good. Obviously, if both azimuth and coordinates close, the traverse is good.

c. Azimuth Good, Coordinates Bust. 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. Azimuth Bust Coordinates Good.

1. When closing on the starting point, if azimuth

busts and the coordinates are good, the error must be in either 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.

2. 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 misclosure.

e. Azimuth Bust, Coordinates Bust.

1. 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.

2. 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. Elevation Busts

1. I f coordinates close, and azimuth closes, but height busts, refer to paragraph 9-28.

Figure 9-28 Error Indicators

9-25 Isolation of Distance Errors

a. General. A distance error is indicated when the azimuth for a traverse closes within tolerance but coordinate closure (radial error) 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. Parallel Line Method. To determine which line in a traverse contains a distance error, Marine surveyors can use the parallel line method. This method will identify the indicated line by creating a line, which lies along the same azimuth, or parallel to, the error.

Step 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. (See Figure 9-29.)

Figure 9-29 Plotting the Traverse

Step 2. Using a straight edge, trace a line between the known and computed closing stations. Allow this line to extend beyond the plotted points. (See Figure 9-30.)

Figure 9-30 Determining the Error Leg

Step 3. Identify the leg containing the error. The leg containing the error lies roughly parallel to the line traced in step 2. The example in Figure 9-30 indicates that the leg between TS-2 and TS-3 contains the distance error.

c. Computation of Azimuth of Radial Error (RE). Another way to locate a distance error in a traverse is to compute the azimuth of the radial error (RE).

Step 1. Compute the azimuth of the RE from the known closing coordinates to the computed closing coordinates with a survey computer program

Step 2. Either on the traverse form or the printout find an "azimuth to rear" that roughly matches the azimuth of the RE. The leg with an azimuth or back azimuth closest to the computed azimuth is the suspect leg.

d. Analysis of Errors. In analyzing an error of this nature, some tolerance and judgment must be used to determine the traverse leg in error. This is because in both angular and distance measurements, minor errors occur that have a small affect on the overall accuracy but are large enough to make error analysis difficult. In some traverses, several legs with azimuths nearly parallel to the azimuth of the radial error could be indicated as the leg containing 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 measured until the leg containing the error is found.

9-26 Isolation of Angle Errors

a. General. An angle error is indicated when the azimuth does not meet allowable closure specifications for that level of survey. In some cases an angle error, dependent on it's location, will result in coordinate error exceeding allowable RE. Two methods of isolating an angle error can be used: Perpendicular Bisector Method and the Mil Relation Formula (WeRM rule).

b. Perpendicular Bisector Method. To determine which station in a traverse contains an angle error, Marine surveyors can use the perpendicular bisector method. This method will identify the indicated station by creating a line, which passes over or near the station.

Step 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. (See Figure 9-31.)

Figure 9-31 Plotting the Traverse

Step 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 radial error is large enough, divide the RE by two and measure the distance to ensure the dot is halfway between the points. (See Figure 9-32.)

Step 3. Using a protractor, trace a line that is perpendicular to the RE line, extending into the survey. (See Figure 9-32.)

Figure 9-32 Determining the Error Station

Step 4. Identify the station containing the error. The line traced in step 3 above will pass through or near the station containing the angle error. The example in Figure 9-32 indicates that station TS-3 contains the angle error.

c. Mil Relation Formula (WeRM Rule). In some traverses, 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. When this happens, the WeRM rule is a very good tool to isolate the error station.

1. **General.** The mil relation formula states that one mil of angle over a one kilometer distance will cause a one meter shift at the other end. (See Figure 9-33.)

Figure 9-33 Mil Relation Formula

2. **WeRM Rule.** The WeRM rule uses this relationship between angle and distance to determine a distance to a station containing an angle error, which 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:

$$R = W/m$$

When: R is the Range in kilometers
W is the radial error of closure
m is the azimuth error

Once the distance in kilometers is computed, locate a station which 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.

3. Sample. Using a busted traverse, which follows a linear path along a highway, the team chief has determined that an angle error exists. He has isolated three possible stations, which 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 follows:

$$R = 66.32 / 10.178$$
$$R = 6.516 \text{ Km } (6{,}516 \text{ meters})$$

d. Analysis of Errors. In analyzing an error of this nature, some tolerance and judgment must be used to determine the traverse station in error. This is because in both angular and distance measurements, minor errors occur that have a small affect on the overall accuracy but are large 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 measured until the station containing the error is found.

9-27 Isolation of Multiple Errors

Multiple errors are errors in both azimuth and distance or more than one error in either azimuth or distance. When there are multiple errors in a traverse, the indications will be the same as for an azimuth error. It is possible that in the procedure for azimuth error determination, definite suspect stations will be located but an analysis of the fieldwork and computations at these stations will not produce the error. When this occurs, the entire traverse should be performed again to locate the errors that were made.

9-28 Isolation of Elevation Errors

Elevation errors are caused by vertical angle errors. When a traverse does not meet allowable elevation error specifications, the suspect station can usually be isolated by comparison of 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 station prior. 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 remeasure the vertical angle.

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CHAPTER 10
FIELD NOTES

The field notes of any survey are the only original record of the survey that the survey team has once it leaves the field. Therefore, the field recorder's notebook must contain a complete record of all measurements made or determined during the execution of the survey. It should include complete sketches, descriptions, and remarks, when necessary, to clarify the notes. The best survey fieldwork is of no value to the team if the notes are not accurate, legible, and complete in every detail.

10-1 Recorder's Notes

a. General. The field recorder's notebook designated as DA Form 4446; Level, Transit, and General Survey Record Book, will be used until stocks are depleted. Currently a "new" version of the field recorder's notebook will be issued when replenishment is requested. The following text applies to any, and all recorder's notes, regardless of the edition.

1. It is a hardback, permanently bound book for recording all data necessary for computations, problem solving, and archiving of field surveys. The recorder's notebook is considered a legal document, and should be treated as such during the course of recording survey fieldwork.

b. Duties of the Survey Recorder. The recorder is responsible to maintain the only original record of all field measurements and any occurrences, which may affect those measurements. He must also be thoroughly trained in the requirements for all survey methods. His duties include the following:

- Neatly and legibly records all survey data.
- Checks and means angular data.
- Records and means distances.
- Provides required data to the survey computers.

c. Recorded Data. Data recorded for a field survey includes, but is not limited to, the following:

1. **Measurements.** Field measurements such as horizontal angles, vertical angles, and distances from the instrument operator must be recorded.

2. **Sketches.** All surveys should include a sketch. The sketch 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.

3. **Descriptions.** Descriptions of stations necessary to supplement the sketch should be written in the remarks section. This would 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.

4. **Remarks.** The remarks section should include any remarks necessary to clarify survey data. These remarks could 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 DI3000, instrument heights, and target heights should also be included.

10-2 Rules For Recording Field Notes

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

- All recording will be done in pencil.
- Be sure the pencil is sharpened to a fine point.
- Never erase in the recorder's notebook.
- Use only upper case letters.
- Do not slant letters and numbers.
- Do not strike over letters or numbers.
- Use approved abbreviations and symbols
- Use a straight edge and protractor for the sketch.

- Record directly into the recorder's book. Never record into an extract or on paper, and then transcribe recorded data to the recorder's notebook.
- Do not use the pages of the recorder's book to perform math computations, use scratch paper.

b. Abbreviations. When recording field notes, certain abbreviations can be used. Some are listed below:

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

c. Symbols. When recording field notes, it is sometimes necessary to use symbols, especially in the sketch. As a general rule, the symbols in the legend of a map sheet from the area of operations should be used. (See Figure 10-1.)

d. Index. The first numbered page of the recorder's book is the index. Page one includes both the left and right sides. The heading and column blocks for the index are set up as follows. (See Figure 10-2.)

1. The designation block will be filled in with the word "INDEX".

2. The **date** block will be filled in with the date the book was officially opened, usually the day the first survey in that book was performed.

3. No information will be listed heading blocks on the right side.

4. The column titles under the heading will be labeled (from left to right) as follows:

a. Column 1: **PAGE**; to identify the page number that includes a particular set of survey data.

b. Column 2: **DATE**; lists the date written in the date block of that particular page.

Figure 10-1 Standard Symbols for Recording

Figure 10-2 Index Page

c. Column 3: **TITLE**; lists the designation written in the designation block of that particular page.

d. Columns 7, 8, and 9: Same as columns 1, 2, and 3 respectively.

10-3 Recording For Methods Not Included In This Chapter

a. GPS-S Surveys. Recording procedures for RTK/OTF are discussed in the 4000 MSGR job aids.

b. PADS. Recording procedures for PADS operations are discussed in Chapter 6 of this text.

c. Astronomic Observations. Recording procedures for astronomic observations are discussed in Chapter 8, text.

10-4 Recording A One-Position Angle

a. General. The procedures listed below are for recording a one-position angle. This type of angle is used for both fourth and fifth order traverse, as well as most fifth order conventional methods and PADS autoreflection.

b. Heading and Column Titles. The heading and column titles will be filled out as described below. (See Figure 10-3.)

1. The designation block will be filled in with the survey method (e.g., Traverse, Triangulation, etc.) being conducted. Other entries may be included after the method of survey.

2. The date block will be filled in with the date the fieldwork was performed.

3. The heading of the right side of the page will be filled out as follows: (See Figure 10-3)

a. Weather: Weather conditions will be listed at the left side of the top line. It is a two-word description of the weather, (e.g. sunny, cold.)

b. Inst: The instrument types and serial numbers will be listed on the left side of the second line of the header. This will help identify which instruments may require adjustments due to errors.

c. Team Members. The Chief of Party (COP), instrument operator (IO), and recorder (RCDR) will be listed at the right side of the right page, above the top line.

4. Column titles will be filled in as follows:

a. Column 1: **STA**; to identify the occupied, rear, and forward stations.

b. Column 2: **T**; to identify the telescope mode, direct (D), or reverse (R).

c. Column 3: **HORZ;** to record horizontal readings measured at the occupied station and the mean horizontal angle used for computations.

d. Column 4: **MEAN**; to record the mean of the direct and reverse horizontal readings at the forward and rear stations.

e. Column 5: **VERT READ**; to record vertical readings measured by the IO.

f. Column 6: **VERT;** to record direct and reverse vertical angles calculated by the RCDR from the vertical readings and to record the mean vertical angle used for computations.

g. Column 7: **SLOPE DIST**; to record slope distances from the DI3000. If only horizontal distances are measured, then this column will be titled DIST.

h. Columns 8-12: **REMARKS**; columns 8-12 will be used to record any information pertinent to the measurements and subsequent computations.

Figure 10-3 Heading and Column titles

c. "STA" and "T" Columns. The "T" (telescope) column will be filled out as shown in figure 10-4. The rear station (AzMk) name will be recorded in the direct (D) mode row directly below the "STA" column title. Skip one line and record the occupied station name. Skip one line and record the forward station name.

Figure 10-4 "STA" and "T" Columns

d. Recording Field Data.

1. Field data will be recorded in the columns and rows corresponding to the pointing. For example, when the instrument operator determines the initial circle setting, the theodolite is in the direct mode, pointed at the rear station, and the measurement is determined from the horizontal circle. With this in mind, the initial circle setting must be recorded in the horizontal angle column; in the direct mode row for the rear station.

2. Figure 10-5 shows the standard sequence that measurements should be made and recorded for a one-position angle.

3. Figure 10-6 shows an example of data recorded with means computed. Note that only data that will be used by the computer is circled.

10-5 Recording A Two-Position Angle

a. General. The procedures listed below are for recording a two-position angle. This type of angle is required for certain fourth order methods such as triangulation and trig traverse. Use of this method of angle determination for other survey methods is a matter of local SOP.

b. Heading and Column Titles. Heading and column titles for a two-position angle are the same as for a one-position angle. (See Figure 10-3.)

c. "STA" and "T" Columns. The "STA" and "T" columns for a two-position angle are the same as for a one-position angle. The second angle is started two spaces below the first angle. (See Figure 10-4.)

d. Recording Field Data.

1. The first of the two measured angles is determined exactly the same as a one-position angle.

2. 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 4800.000 mils, ± 0.100 mils.

3. Vertical angles and distances are determined during the first position angle.

4. The mean of the two position angles is determined by adding the two angles together, then dividing that

5. 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, both angles must be rejected and measured again.

Figure 10-5 Standard Order for recording a One-position Angle

Figure 10-6 Example of a completed One-Position Angle

Figure 10-7 Example of a completed Two- Position angle

6. Figure 10-8 shows an example of data recorded with the means computed. Note that the mean horizontal angle of each position angle is recorded in parenthesis; the mean of the two position angles is circled.

10-6 Closing an Angle On the Horizon

a. General.

1. The procedures listed below are for recording an angle closed on the horizon. This type of angle can be used when a two-position angle is required or as local SOP directs.

2. Closing on the horizon simply means that the second angle measured closes a horizontal circle at 6400 mils. The first angle is the station angle; the second is the explement angle. (See Figure 10-10.)

Figure 10-8 Angle Closed On The Horizon

b. Heading and Column Titles. Heading and column titles for an angle closed on the horizon are the same as for a one-position angle. (See Figure 10-3.)

c. "STA" and "T" Columns. The "STA" and "T" columns for an angle closed on the horizon are the same as for a one-position angle. The explement angle is started two spaces below the position angle. (See Figure 10-9.)

d. Recording Field Data.

1. The station angle is determined exactly the same as a one-position angle.

2. The explement angle is the same as it is for a position angle except that the rear and forward stations are reversed to measure the rest of the horizontal circle.

3. Vertical angles and distances are determined with the station angle.

4. The sum of the station angle and the explement angle would equal 6400 mils if no error were present. The mean horizontal angle is determined by applying half of the error (from 6400 mils) to the station angle. (See Figure 10-9.)

5. 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 measured again.

6. Figure 10-9 shows an example of data recorded with the means computed. Note that the mean horizontal angle of each measured angle is recorded in parenthesis; the corrected station angle is circled.

10-7 Recording Reciprocal Vertical Angles

a. General. When conducting a fourth order traverse, or surveying a traverse leg of more than 1000 meters, measurement of reciprocal vertical angles is required.

b. Heading and Column Titles. Heading and column titles, (for columns 1-6), are the same as for a one position angle. Columns 7-12 are discussed below. (See Figure 10-10.)

1. Column 7: **MN RECIP VERT**; to record the mean of the reciprocal vertical

2. Column 8: **SLOPE DIST**; to record slope distances from the DI3000. If only horizontal distances are measured, this column will be titled DIST.

3. Columns 9-12: **REMARKS**; these columns will be used to record any information pertinent to the measurement and subsequent computations.

c. "STA" and "T" Columns. The "STA" and "T" columns for recording a reciprocal vertical angle 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 (See Figure 10-10.)

Figure 10-9 Example of an Angle closed on the horizon

Figure 10-10 Example of recording with Reciprocal Vertical Angles

d. Recording Field Data.

1. 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; in other words, the vertical reading to the rear station in the direct mode is made directly after the initial circle setting is recorded.

2. Vertical angles determined by the recorder that will be included in the mean of reciprocal vertical angles will be recorded in parenthesis. 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.

10-8 Recording Angles From An M2A2 Aiming Circle

a. General. Angles measured with an M2A2 Aiming Circle are generally used for hasty survey purposes. Hasty survey is discussed in Chapter 11 of this text. As with all field notes, the first page of the field recorder's notebook is the index.

b. Heading and Column Titles. The heading and column titles will be filled out as described below. (See Figure 10-11.)

1. The **designation** block will be filled out with the survey method (e.g., Hasty Traverse) being conducted. Other entries may be included after the method of survey.

2. The **date** block will be filled out with the date the fieldwork was performed.

3. The heading of the right side of the page will be filled out as follows: (See Figure 10-13.)

a. **Weather:** Weather conditions will be listed at the left side of the top line. It is a two-word description of the weather. (e.g., clear, warm)

b. **Inst:** The instrument types and serial numbers will be listed on the left side of the second line of the header.

c. **Team Members.** The Chief of Party (COP), instrument operator (IO), and recorder (RCDR) will be listed at the right side of the right page, above the top line.

4. Column titles will be filled in as follows:

a. Column 1: **STA**; to identify the occupied, rear, and forward stations.

b. Column 2: **R**; to identify the reading.

c. Column 3: **HORZ;** to record the horizontal readings and the mean horizontal angle.

d. Column 4: **VERT;** to record the uncorrected vertical angle to the forward station.

e. Column 5: **CORR**; to record the vertical angle correction determined during operator tests.

f. Column 6: **CORR VERT;** to record the corrected vertical angles and the mean corrected vertical angle.

g. Column 7: **SUBT DIST**; to record the subtended distance as extracted from the subtense tables in the FM 6-50 and XO's handbook. This column may also be labeled for the subtended angle or horizontal distance if taped or paced.

Figure 10-11 Heading and Column Titles M2A2

h. Columns 8-12: **REMARKS**; columns 8-12 will be used to record any information pertinent to the measurements and subsequent computations.

c. "STA" and "R" Columns. The "STA" and "R" columns will be filled out as shown in Figure 10-13. The rear station name will be recorded directly below the "STA" column title. The occupied station name will be recorded directly below the rear station. The forward station name will be recorded directly below the occupied station. A "1" will be recorded in the row Directly below the "R", a "2" below the "1", and MN will be recorded directly below the "2".

Figure 10-12 "STA" and "R" Columns (M2A2)

d. Recording Field Data.

1. The horizontal, vertical, and subtended angles are recorded to the nearest 0.5 mils.

2. A subtended distance is recorded directly out of the FM 6-50 or the XO's handbook.

3. The mean horizontal angle is recorded to the nearest 0.1 mil.

a. If the second reading is greater than the first reading; the mean horizontal angle is computed by dividing the 2nd reading by 2. The mean horizontal angle is circled.

b. If the second reading is less than the first reading; the mean horizontal angle is computed by adding 6400 mils to the second reading, then dividing by 2. The mean horizontal angle is circled.

c. The mean horizontal angle must match the first reading within ± 0.5 mils. If not, the angle must be void and measured again.

4. Figure 10-13 shows an example of recorded data for a hasty traverse.

10-9 Recording Intersection Method

a. General. The intersection method is the Marine surveyor's preferred method of providing target location, when the target cannot be occupied. The recording method described below is used when computation of the target location is performed with azimuths measured to the target, vice horizontal angles.

b. Heading and Column Titles. The heading and column titles will be filled out as described below. (See Figure 10-14.)

1. The **designation** block will be filled out with the survey method (i.e. Intersection) being conducted. Other entries may be included after the method of survey.

2. The **date** block will be filled out with the date the fieldwork was performed.

3. The heading of the right side of the page will be filled out as follows: (See Figure 10-14.)

a. Weather: Weather conditions will be listed at the left side of the top line. It is a two-word description of the weather, (e.g., clear, hot)

Figure 10-13 Example of recording Angles for M2A2

b. Inst: The instrument types and serial numbers will be listed on the left side of the second line of the header.

c. Team Members. The Chief of Party (COP), instrument operator (IO), and recorder (RCDR) will be listed at the right side of the right page, above the top line.

4. Column titles will be filled in as follows:

a. Column 1: **OCC STA**; to identify the occupied stations.

b. Column 2: **AZ TO AZMK**; to record the computed azimuth to the rear station. This is the azimuth set on the horizontal scale of the aiming circle.

c. Columns 3-5: **TARGET DESCRIPTION**; to identify the target, forward station.

d. Column 6: **AZ TO TGT**; to record the measured azimuth to the target.

e. Column 7: **VERT;** to record the vertical angle to the target.

f. Columns 8-12: **REMARKS**; columns 8-12 will be used to record any information pertinent to the measurements and subsequent computations.

c. Recording Field Data. Field data for an intersection is recorded as described below:

1. The azimuth to the azimuth mark is recorded to the nearest 0.5 mils.

2. The azimuths and vertical angles to the targets are recorded to the nearest 0.5 mils.

3. The target description should be adequate for another observer to identify that particular target.

4. Figure 10-15 shows an example of recorded data for a target area intersection.

10-10 Correcting Errors and Voiding

a. Correcting Errors. The recorder must make entries small enough that if an error is made in the data, there is sufficient room left in the block to write the correct data. (See Figure 10-16.)

1. When a value is recorded incorrectly, the value is lined out with a single straight line and the correct value written above the lined o

2. Errors will not be erased in the recorder's notebook.

Figure 10-14 Heading and Column Titles (Intersection)

Figure 10-15 Example of Completed Intersection Method (M2A2)

b. Partial Void. A partial void is used to void an area of a recorder's page. This is usually done over a single angle. When this occurs, the reason for the partial void must be included in the remarks section. A partial void is performed by sketching an "X" over the area to be void, using a straight edge, and writing "VOID" over the "X". (See Figure 10-16.)

c. Full Page Void. A full-page void is used to void 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. When this occurs, the reason for the void must be included in the remarks section. Sketching an “X” performs a full-page void over each page, using a straight edge, and writing "VOID" over the "X" on each page. (See Figure 10-17.)

10-11 Security of Field Notes

a. General. The information maintained in the recorder's book could provide the enemy with a large amount of valuable information if it were to fall into his hands.

1. The recorder's book can provide the enemy with information he could use to locate firing positions, radar sites, met sites, OPs, etc.

2. The recorder's book also includes names of personnel, equipment types, locations of survey control points, and other information that can be used for intelligence purposes.

Figure 10-16 Example of correcting an error and a Partial Void

Figure 10-17 Example of a Full Page Void

b. Safeguarding the Recorder's book. In a contingency situation, the recorder's notebook must be safeguarded from the enemy.

1. Some of the information recorded could actually be classified (e.g., OS coordinates, Survey Control Point coordinates, etc.); therefore, the book becomes classified.

2. When the threat of capture becomes imminent, a decision must be made as to the disposition of the Recorder’s notebook. If the capture cannot be avoided, the recorder's notebook must be destroyed.

10-12 Storing The Recorder's Notebook

a. The recorder's book should be used until filled then properly stored to eliminate damage. The storage area must be dry and safe from accidental damage such as spills.

b. The recorder's notebook must be maintained for at least the minimum times as discussed below.

1. If a recorder's notebook includes information used in the establishment of permanent control, the recorder's notebooks must be maintained at least as long as those control points are in tact or until they are resurveyed.

2. Recorder's notebooks containing information used in the establishment of non-permanent control must be maintained for at least the same amount of time as position safety, per local SOP.

3. Recorder's notes may be maintained for archive purposes; in other words, if a unit establishes survey control, permanent or non-permanent, in an area that is not used very often, or had not been used before; the recorder's notebook could include information necessary for planning future operations in that area.

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CHAPTER 11
HASTY SURVEY

Marine Surveyors will at times be put in situations where either no control exists or it is too distant or inaccessible to meet mission requirements. The surveyor must then use Hasty Survey procedures to establish the needed control until a common grid is established. Additionally firing units and, fire support assets may need to use hasty survey to self locate until a common grid is carried forward by the battalion survey section.

Section I
SURVEY CONTROL

11-1 General

a. The ability to provide survey control to supported units in the absence of existing control enhances the capabilities of the units being supported.

b. Control established by hasty methods is generally not common to other survey control on the battlefield. When control established by hasty methods is common, it is considered to be of a very reduced accuracy. The accuracy of hasty survey is considered to be only 1 part in 500 (1/500) at best. For this reason, a hasty survey must always be converted to common control at the earliest available time.

11-2 Assumed Control

a. General. If no known control is available, survey data may be obtained by assuming control. In other words, establishing control through the best available resources. Assuming control allows all echelons of survey to start their survey mission immediately, without having to wait for higher echelon survey teams to provide control. Once higher echelon control is available, conversion to common control procedures must be performed by all lower echelon units.

1. **4000 MSGR (AN/PSN-13) Absolute.** An absolute position from the GPS-S (4000 MSGR) is one source of assumed control. Using the 4000 MSGR in the absolute mode 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.

2. **PLGR (AN/PSN-11).** If no 4000 MSGR Absolute points are available, the PLGR is the next best source of assumed control. Using the PLGR 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 PLGR stations**, even for assumed control.

3. **Mapspot.** A careful map inspection may be used to determine assumed control. If possible, the azimuth should be determined from a source other than the map.

b. Azimuth. Azimuth is the most important of the three elements of survey; therefore, assuming azimuth must be a *last* resort. A declinated aiming circle or declinated compass can be used to assume azimuth when necessary. Otherwise, an azimuth can be assumed from carefully scaling the azimuth from a large scale map.

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Section II
M2A2 AIMING CIRCLE

11-3 Description

a. General. The M2A2 Aiming Circle is a small, lightweight instrument used in firing battery and artillery survey operations. In the firing battery, it is the instrument used for orienting (laying) howitzers and for performing hasty survey operations. In the artillery survey section, it is used primarily for target area surveys (intersection), checking surveyed azimuths, and for hasty survey operations.

b. Specifications. The M2A2 Aiming Circle consists of a 4 power, fixed-focus, 10° field of view telescope mounted on a body that permits unlimited (6400 mils) horizontal angle measurements and vertical angle measurements from -400 mils to +1100 mils. The M2A2 weighs approximately 9 lbs. by itself and with its associated equipment weighs 21 lbs.

11-4 M2A2 Body

The aiming circle body is made up of four principle parts: the telescope assembly, the body assembly, the worm housing, and the base plate assembly.

a. Telescope Assembly. The telescope assembly consists of the optical system, the vertical level vial, the reflector, the eyeshield, and the solar filter.

1. **Optical System.** A four power, fixed-focus telescope forms the optical system of the aiming circle. The telescope reticle is formed by a glass etched with a horizontal and vertical crosshair intersecting at the center of the field of view.

a. The crosshairs are graduated every 5 mils from 0 to 85 mils from the center of the reticle. The graduations are numbered every 10 mils.

b. The Polaris 2 Reticle is installed in most aiming circles. This includes the reticle pattern described above as well as three concentric circles that were used for aligning stars for the Polaris 2 method of astronomic observations. This method is no longer valid therefore the Polaris 2 portion of the reticle is not used.

c. The telescope body is inclined 45° to allow the observer to stand erect and look down into the telescope.

Figure 11-1 M2A2 Aiming Circle

2. **Telescope Level Vial.** The telescope level vial is located on the left side of the telescope. This level is used to establish a horizontal plane along the telescope's line of sight. It is not used in artillery survey.

3. **Reflector.** The reflector is a plastic signal post mounted on top of the telescope at the vertical axis of the instrument. The reflector is used as an aiming point for other instruments sighting on the aiming circle. It can be illuminated using the aiming circles illumination kit.

4. **Eyeshield.** The eyeshield is a rubber shield that blocks light from entering your eyes from the side.

5. **Solar Filter.** The solar filter is mounted over the eyepiece end of the telescope when used for observations on the sun. When not in use, it is stored on the filter post on the right side of the telescope, above the serial number plate.

b. Body Assembly. The body assembly consists of the azimuth (horizontal) and elevation (vertical) worm mechanisms, the magnetic compass, the magnetic compass locking lever, and two horizontal plate levels.

1. **Azimuth (horizontal) Mechanism.**

a. The azimuth mechanism is generally referred to as either recording motion or upper motion. Lateral movement of the azimuth micrometer knob allows for fast motion over the azimuth scale. Rotating the azimuth knob allows for slow motion.

b. Two scales are used to read a horizontal angle: the azimuth scale and the micrometer scale. The azimuth scale is used to read hundreds (0100) of mils. It is graduated in 100 mil intervals and numbered every 200 mils from 0-6400. The micrometer scale is used to read tens, ones, and half mils. It is graduated every whole mil and numbered every ten mils through a 100 mil circle. The scale can be interpolated to 0.5 mils.

2. **Elevation (Vertical) Mechanism.**

a. The elevation mechanism is generally referred to as the vertical motion. Rotating the elevation micrometer knob raises and lowers the telescope through its 1500 mil arc. Stop rings in the mechanism prevent the telescope from striking the body assembly when the telescope is depressed.

b. Two scales are used to read a vertical angle: the elevation scale and the micrometer scale. The elevation scale is used to read hundreds (0100) of mils. It is graduated in 100 mil intervals and numbered every 100 mils from -400 to +1100 mils. Negative graduations are labeled in red, positive in black. The micrometer scale is used to read tens, ones, and half mils. It is graduated every whole mil and numbered every ten mils through a 100 mil circle. The red numbers designate negative values, the black numbers designate positive values. The scale can be interpolated to 0.5 mils.

3. **Magnetic Compass**. The magnetic compass is located in the oblong recess in the top of the body assembly. The magnetic needle is limited in movement to approximately 11° arc and is provided with copper dampers to aid in settling the needle quickly.

a. Two viewing windows are available to center the needle. The large window on the top of the body assembly is used for rough centering of the needle. The second window is comprised of a small glass magnifier and a reticle with three etched lines at one end of the recess to aid in aligning the south end of the needle.

b. On the opposite end of the recess is the magnetic compass locking lever. When pointing down, the needle is locked in place; when rotated left or right, the needle is unlocked. The needle must always remain locked except when it is being used to prevent damage to the magnetic compass.

4. **Horizontal Plate Levels.** On the body assembly at the left side of the magnetic compass, are two horizontal plate levels: a circular level for rough leveling and a tube level fine leveling.

c. Worm Housing. The worm housing is the portion of the aiming circle between the horizontal azimuth scale and the baseplate. It contains the worm gearing for the orienting motion and the leveling screws.

1. The orienting motion is generally referred to as the lower or non-recording motion. Nonrecording motion is similar to the recording motion in that lateral movement of the orienting knob allows for fast motion, and rotating the knobs allows for slow motion. Non-recording motion rotates the aiming circle around a vertical axis without changing values on the horizontal scales. Caps are provided to cover the orienting knobs when they are not being used.

2. Each of the leveling screws are fitted into a threaded socket in the worm housing and attached to the base plate by means of a spring plate.

d. Base Plate Assembly. The base plate assembly is the base of the instrument when it is mounted on a tripod and also serves as the base of the carrying case. The instrument is attached to the base plate by means of the spring plate. The top of the base plate contains a rectangular notation pad for recording the declination constant and vertical angle correction. The bottom of the base plate assembly has a spring loaded cap which covers a 5/8" threaded hole. This hole allows the instrument to be mounted on any tripod with a 5/8" fixing screw (i.e. GST-20, M24). The base plate is fitted with a rubber gasket that creates a watertight seal when the cover is properly attached.

11-5 Associated Equipment

The associated equipment for the M2A2 Aiming Circle include the tripod (M24), the carrying case cover, and the accessory kit.

a. Tripod (M24). The M24 tripod has telescoping legs, an aluminum head and cover, and a carrying strap. The legs are adjusted for height and held in place by clamping screws. The hinges at the tripod head are adjusted for friction by clamping screws. The carrying strap is used to hold the legs together in the retracted position and for carrying the tripod. The head cover is affixed to the tripod by a canvas strap.

b. Carrying Case Cover. The cover of the carrying case is a lightweight, dome-shaped, aluminum cover that clamps to the base plate assembly, creating a watertight seal.

c. Accessory Kit. The accessory kit consists of the backplate and cover, the instrument light, the plumb bob, and two lamp extractors (see Figure 11-2).

1. Backplate and Cover. The backplate and canvas cover serve as the carrying case for the instrument light, plumb bob, and extractors. The backplate and cover attach to two clamps on one of the tripod legs.

2. Instrument Light (M51). The instrument light provides artificial illumination to the instrument and the operator. It consists of a battery tube (two D cell), a rheostat knob, and two flexible cords. The rheostat knob is used to adjust the light intensity. One of the cords provides illumination to the instrument through a lamp bracket which attaches to the machined slot on the top of the telescope assembly, the other cord is used as a penlight for the operator and recorder.

3. Plumb Bob. The plumb bob suspends from a hook attached to the fixing screw when used, it is rolled and stored in a loop in the canvas cover when not in use.

4. Lamp Extractor. The accessory kit contains two lamp extractors. They are use to store extra lamps and to remove bad bulbs from their sockets.

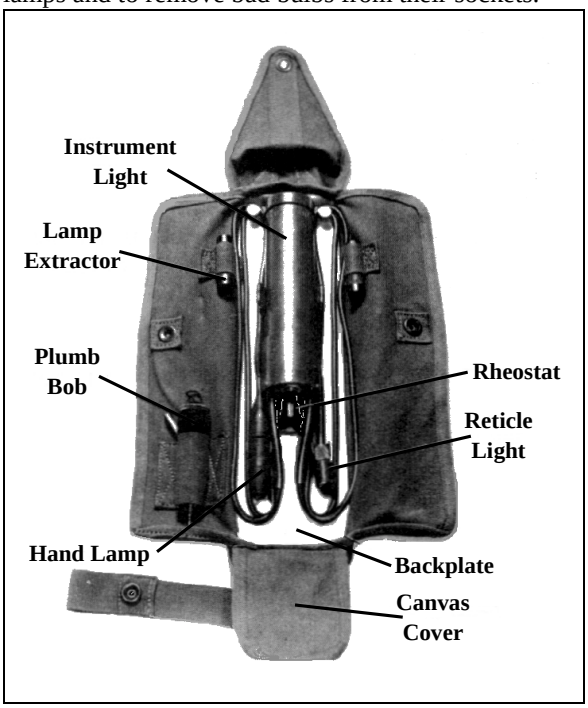


Figure 11-2 M2A2 Accessory Kit

11-6 Setting Up the M2A2 Aiming Circle

a. Setting Up The Tripod. The M24 tripod is the primary tripod used with M2A2 aiming circle; however, the instrument will mount on any tripod with a 5/8" fixing screw.

1. Upend the tripod, place the tripod head on the toe of your boot, and unbuckle the restraining strap.

2. Loosen the leg clamp thumbscrews and extend the tripod legs to the desired length. Tighten the leg clamp thumbscrews sufficiently to maintain the weight of a instrument. Do not force the thumbscrews.

3. Spread the legs and place the tripod over the occupied station with one leg bisecting the angle to be measured. Set up the tripod head so that the telescope will be at a convenient height for the operator. Rough level the tripod.

4. Place the plumb bob loop over the hook at the fixing screw. The plumb bob should hang about 1 inch above the station. Center the tripod over the station to within approximately 1" of plumb.

5. Firmly embed the tripod legs in the ground. The plumb bob should now be within 0.5 inches laterally of center of the station. The tripod head must approximate level once the legs are embedded in the ground.

6. Remove the tripod head cover. Leave the cover hang on the side of the tripod and lightly wipe your hand over the tripod head to remove any sand or dirt.

b. Attaching the Aiming Circle To The Tripod. With the cover still on the instrument, open the spring loaded cover on the bottom of the base plate and thread the fixing screw into the socket until the aiming circle is firmly attached to the tripod. Unsnap the cover latches and remove the cover; hang the cover on the leg clamp of the forward tripod leg.

c. Plumbing And Leveling The Aiming Circle. The procedures for plumbing and leveling the aiming circle are outlined below.

1. Keeping one hand on the instrument, loosen the tripod fixing screw. Carefully slide the instrument over the tripod head until the plumb bob is centered exactly over the point.

2. Tighten the tripod fixing screw. **Do not overtighten the fixing screw as this will bend the slotted arm and damage the tripod head.**

3. Loosen the leveling screws to expose approximately ½" of threads. Rotate the instrument so that the level vial is aligned with any two leveling screws. Grasp the leveling screw knobs between the thumb and forefinger of each hand. Turn the knobs simultaneously so the thumbs of both hands move either toward each other or away from each other. This movement tightens one screw as it loosens the other. **The bubble always moves in the same direction as the left thumb.** Center the bubble by using these two leveling screw knobs. This is the first position.

4. Rotate the instrument clockwise 1600 mils. This second position places the axis of the tubular level at a right angle to the first position. Using the third leveling screw knob only, center the bubble.

5. Rotate the instrument clockwise 1600 mils so that it is 3200 mils from the first position. Level the instrument using the same two leveling screws as were used in the first position. This is the third position.

6. Rotate the instrument clockwise 1600 mils so that it is 3200 mils from the second position. Level the instrument using the same single leveling screw that was used in the second position, this is the fourth position.

7. Repeat Steps 5 and 6 above until the bubble remains centered in both positions.

8. Rotate the instrument to the first position. If the bubble remains centered in this position, rotate the alidade to the second position. If the bubble remains centered in this position, rotate the alidade throughout 6,400 mils. If the bubble remains centered the instrument is level.

9. If the bubble does not remain centered during the procedures in Step 8 but does remain within one graduation, level the instrument by bringing the bubble halfway back towards the centered position.

11-7 Taking Down the Aiming Circle

The procedures for taking down (march ordering) the M2A2 Aiming Circle are discussed below:

a. Tighten the leveling screws to their lowest point, then back them off ½ turn.

b. Ensure the magnetic needle is locked, the level vials are covered, and the orienting knob covers are closed.

c. Place the azimuth knob over the notation pad.
d. Set 0 mils on the vertical angle scale.

e. Place the cover over the instrument and latch the cover locks.

f. Roll the plumb bob and place it in the accessory case.

g. Keeping one hand on the instrument, unscrew the tripod fixing screw and remove the aiming circle from

the tripod. Tighten the tripod cap onto the tripod head.

h. Keeping one hand on the tripod head, loosen the thumbscrews and collapse the tripod legs. Tighten the thumbscrews. Strap the legs together.

11-8 Measuring A Horizontal And Vertical Angle With An M2A2 Aiming Circle

In artillery survey, horizontal angles are measured at the occupied station from the rear station to the forward station. When horizontal angles are made with the aiming circle, two repetitions of the angle are measured and the accumulative value is divided by two to determine the mean angle. The procedures for measuring a horizontal angle are as follows:

a. Set up and level the aiming circle.

b. Zero the azimuth and micrometer scales.

c. Sight approximately on the rear station using the lower (non-recording) fast motion.

d. Using the lower slow motion, sight on the rear station with the vertical crossline. The last motion should be from left to right to reduce backlash due to play in the worm gear mechanism. Check to make sure the scales are still set to zero. Close the orienting knob covers.

e. Using the upper (recording) fast motion, rotate the instrument near the forward station, to the left of the forward station.

f. Using the upper slow motion, bring the crosshairs exactly on the station. Read the horizontal angle to the nearest 0.5 mils to the recorder.

g. If vertical angles are required, sight the telescope to instrument height at the target using the vertical angle knob. Read the vertical angle to the nearest 0.5 mils to the recorder.

h. With the horizontal angle on the azimuth scale, repeat steps c through g above. The horizontal angle measured this time will be an accumulative measure of two angles.

i. Recording and meaning a horizontal angle measured with an aiming circle is discussed in paragraph 10-10.

11-9 Determining Vertical Angle Correction

To obtain correct measurements of vertical angles with the aiming circle, the horizontal axis of the telescope must lie in a true horizontal plane when the elevation scale is at zero. If it does not, a vertical angle correction must be determined and applied to each vertical angle measured. Two methods may be used to determine a vertical angle correction: the comparison method and the alternate set up method.

a. Comparison Method. In this method, the measured vertical angle is compared to a known vertical angle. This is normally performed at a declination station. The correction is determined as follows:

1. After determining the declination constant, verify the level of the instrument. Measure and record the vertical angle to each azimuth mark to the nearest 0.5 mils, making sure that instrument height of the aiming circle is the aiming point at the azimuth marks.

2. Verify the level of the instrument. Measure and record the vertical angles to each azimuth mark to the nearest 0.5 mils a second time.

3. Determine the mean of the measured vertical angles to the nearest 0.1 mils. Determine the differences (±) between the mean measured vertical angles and the known vertical angles (Correction = Known Vertical Angle - Mean Measured Vertical Angle). If the differences agree within 1 mil of each other, determine the mean difference to the nearest 0.1 mil and record this value with the declination constant on the notation pad.

4. If the differences do not agree within 1 mil, repeat steps 1-3 above.

5. **Example.** Using a declination station with two azimuth marks, the following values are determined:

AzMk 1:	Kn Vert:	+23.0 mils
	Mn Meas Vert:	+21.4 mils
	Corr 1:	+1.6 mils
AzMk 2:	Kn Vert:	-9.0 mils
	Mn Meas Vert:	-10.8 mils
	Corr 2:	+1.8 mils

Mn Corr = (Corr 1 + Corr 2) / 2
= (1.6 + 1.8) / 2

= +1.7

b. Alternate Set Up Method. In this method, two stations are set up approximately 100 meters apart and properly marked. It is not necessary to know the coordinates and elevation of the stations or the azimuth between the stations.

1. The aiming circle is set up and leveled over one of the stations (station A).

2. The instrument height is measured and marked on a range pole. The range pole is set up over the other station (station B).

3. Measure and record the vertical angle to the mark on the range pole to the nearest 0.5 mils.

4. The aiming circle is then moved to station B, set up and leveled.

5. The instrument height is measured and marked on the range pole. The range pole is set up over station A.

6. Measure and record the vertical angle to the mark on the range pole to the nearest 0.5 mils.

7. The vertical angles measured over the two lines are compared; if they are numerically equal, no vertical angle correction is necessary. If they are not equal, the vertical angle correction is determined in the following manner:

a. The correction is numerically equal to one half of the algebraic sum of the two vertical angles. In other words, add the angles together and then divide by two. Express the solution to the nearest 0.1 mils.

b. The sign of the correction is opposite the sign of the algebraic sum of the two vertical angles.

8. Example: If the first angle is +22.0 mils and the second angle is -24.0, the algebraic sum is -2.0 mils. The value of the correction is one half the sum, or 1.0 mils. The sign of the correction is opposite the sign of the sum; therefore, the vertical angle correction in this example is +1.0 mils.

11-10 UTM Grid Declination Constant

a. Three types of north are considered of importance to artillery surveyors: true, magnetic, and UTM grid. True north is the northerly direction of the meridian of longitude which includes your position. Magnetic north is the direction from your position to the north pole of the earth's magnetic field. UTM grid north is the northerly direction of a line which includes your position and is parallel to the central meridian of your UTM grid zone (See Chapter 3, Section II).

b. To determine grid north with an instrument equipped with a magnetic needle, the angular difference between UTM grid north and magnetic north must first be determined. The clockwise angle from UTM grid north to magnetic north is the UTM grid declination constant (see Figure 11-3). It may also be referred to as the UTM grid azimuth of magnetic north.

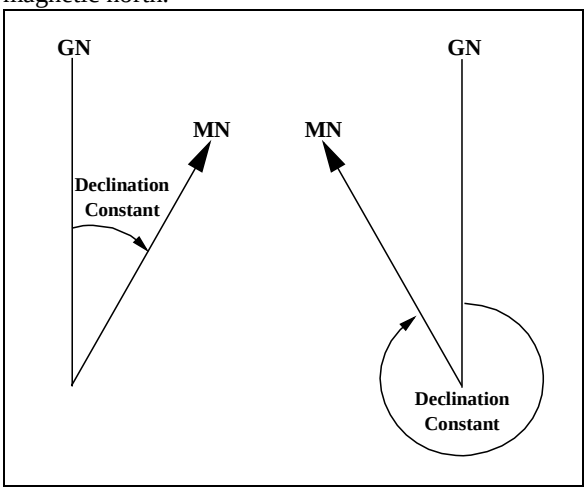


Figure 11-3 Angular Value Representing UTM Grid Declination

11-11 When To Declinate An Aiming Circle

The following rules apply to the circumstances which indicate that declination of an aiming circle is *required*:

1. The aiming circle must be declinated after an electrical storm or after a severe shock such as falling from a vehicle. The magnetic needle is a delicately balanced mechanism and any shock can cause a significant change in the declination constant of the instrument.

2. The aiming circle should be declinated when moved more than 25 miles(40 Km) from the area in which it was last declinated. The change in the angle between magnetic north and UTM grid north is significant enough over 25 miles (40 Km) to change the declination constant. Also, the effects of local

magnetic attraction may cause a change in the declination constant over a few hundred meters.

3. The aiming circle should be declinated at least every 30 days.

1. This is to minimize the effects of accidents which have occurred to the instrument and to factor in the changes in the Earth's magnetic field. The Earth's magnetic field has an annual change which can be calculated under standard conditions, the field is also affected by other forces such as sun spots, and the Sun's and the Moon's gravity field.

2. If a radical change (± 2 mils) in the declination constant is observed after a monthly declination, the instrument should be redeclinated after a few days to ensure that the change was not caused by the temporary effects of a magnetic storm or sun spots.

4. When an aiming circle is returned from a maintenance facility or upon initial issue of an aiming circle, it must be declinated.

5. Batteries should check the declination of their aiming circles at each firing position established by battalion surveyors. This will provide the battery with a valid declination should they move to a new location before the battalion surveyors have established known control.

11-12 Declination Stations

a. General. A declination station should be established at a location that is convenient to the using units.

1. It may be established by any echelon of survey, regimental, battalion, or battery, as required by the situation. Declination stations within a battalion area of operations are the responsibility of the battalion survey section; however, for garrison training, most declination stations on Marine Corps installations are established by the regimental section.

2. Declination stations should have at least two (four if possible) well defined azimuth marks with known azimuths in different quadrants; however, one azimuth mark may be sufficient to declinate an aiming circle. The azimuth marks should be more than 1000 meters from the declination station; however, in heavily wooded areas, this may not be possible. An azimuth mark must never be less than 300 meters from the declination station.

b. Declination Station Survey Control. The 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 5th order. These azimuths can be determined by astronomic observations, real-time kinematic (OTF) survey, PADS, traverse, or by computations when coordinates of the declination station and azimuth marks are of sufficient accuracy to provide 5th order azimuths.

c. Location of the Declination Station. The declination station should be established in an area free of local magnetic attraction. The following minimum distances from common objects are prescribed:

- Power lines150 meters
- Electronic equipment150 meters
- Railroad tracks75 meters
- Artillery, tanks, etc.75 meters
- Vehicles50 meters
- Wire fences30 meters
- Personal weapons10 meters

d. Vertical Angles. When a declination station is established, the vertical angle to each azimuth mark should be measured to determine the vertical angle correction.

e. Azimuth. The UTM grid azimuth should be listed to the nearest 0.1 mils. The true azimuth to the nearest 0.1degree should also be listed for declination of meteorological theodolites.

11-13 Declinating The M2A2 Aiming Circle At A Declination Station

When a declination station is available, use the following procedures to declinate the aiming circle:

a. Set up and level the aiming circle over the station.

b. Using the recording motion, set the known azimuth to the first azimuth mark on the azimuth scale. Using the non-recording motion, sight on the azimuth mark.

c. Using the recording fast motion, rotate the instrument towards north. Unlock the magnetic needle. Once the magnetic needle stops bouncing,

center the magnetic needle with the recording motion while looking through the magnetic needle magnifier.
d. Once the magnetic needle is centered, lock the magnetic needle.

e. Read and record the declination constant to the nearest 0.5 mils.

f. Check the level of the aiming circle, then repeat steps b. through e. over the remaining azimuth marks.

g. Compare the values determined in the procedures above. If the spread between the largest and smallest reading is less than 2 mils, determine the mean declination constant to the nearest 0.5 mils by adding the individual readings together, then dividing by the number of readings. If the values do not agree within 2 mils, repeat the entire process.

h. Record the declination constant on the notation pad.

11-14 Converting A Grid-Magnetic Angle To A Declination Constant

a. General. If a declination station is not available, the Grid-Magnetic (GM) angle can be used to determine a declination constant. The GM angle is the angle, east or west, between UTM grid north and magnetic north. This method must be used only in the absence of a known azimuth and must be updated as soon as a known azimuth is available, even if that known azimuth is from hasty methods. Also, if the map declination diagram is more than 10 years old, the GM angle may be questionable due to annual change in the Earth's magnetic field.

b. Determining A Declination Constant. A declination constant can easily be determined by simple math. The following paragraphs discuss the relationship between a GM angle and grid declination.

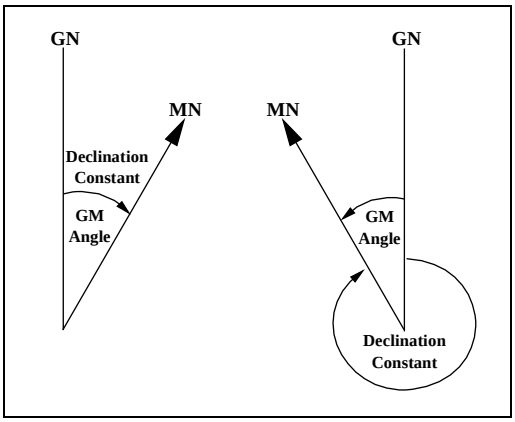


Figure 11-4 Relationship Between A GM Angle And A Declination Constant

1. If magnetic north is east of grid north, the declination constant is equal to the GM angle.

2. If magnetic north is west of grid north, the declination constant is equal to 6400 mils minus the GM angle.

11-15 Hasty Declination Of The M2A2 Aiming Circle

When a declination station is not available and the map declination is questionable, use the following procedures to determine a hasty declination station:

a. Select a point on the map that is easily identifiable on the ground. Set up and level the aiming circle over that point.

b. Select two distant points that can be identified both on the map and the ground. Scale the azimuth to the two points from the occupied station.

c. Use the azimuths scaled from the map as if they were known azimuths. Declinate the aiming circle as described in paragraph 11-13.

d. Compare the two values determined for the declination constant; they must agree within 10 mils. If they do, mean the values to determine the declination constant. If they do not, repeat the entire process.

e. A declination constant determined in this manner must be verified at the first opportunity.

11-16 Determining A Grid Azimuth With The M2A2 Aiming Circle

A declinated aiming circle can be used to determine a grid azimuth. This is used in artillery survey mostly for verifying azimuths determined by other methods, but can also be used for determining azimuths to targets from an observation post without a surveyed azimuth mark. The procedures for determining a grid azimuth with a declinated aiming circle are as follows:

a. Set up and level the aiming circle.

b. Using the recording motion, set the declination constant on the azimuth scales.

c. With the non-recording fast motion, rotate the instrument towards north. Unlock the magnetic needle. Once the magnetic needle stops bouncing, center the needle using the non-recording slow motion while looking into the magnetic needle magnifier.

d. Lock the magnetic needle.

e. Using the recording motion, sight on the forward station or target. Read and record the grid azimuth to the nearest 0.5 mils.

11-17 Orienting The M2A2 Aiming Circle On A Known Azimuth

An aiming circle can be oriented to a known azimuth and then used to determine a grid azimuth. This is used in artillery survey mostly for determining azimuths to targets from an observation post with a surveyed azimuth mark. The procedures for orienting the aiming circle on a known azimuth are as follows:

a. Set up and level the aiming circle over the station.

b. Using the recording motion, set the known azimuth on the azimuth scales.

c. With the non-recording motion, sight on the azimuth mark.

d. Using the recording motion, sight on the forward station or target. Read and record the grid azimuth to the nearest 0.5 mils.

11-18 Care Of The Aiming Circle And Its Associated Equipment

Proper care of an instrument will prolong its life and ensure its usability when needed. Care and maintenance of the aiming circle is discussed in detail in TM 9-1290-262-10.

a. Lenses. The lenses should cleaned with a camel hair brush and lens paper. If a smudge will not come clean with the lens paper, moisten the paper with clean water, then wipe the lens with a lint free cloth. Care should be taken not to scratch the lens or to remove the bluish coating. The bluish coating reduces glare for the observer.

b. Tripod. The tripod head should be wiped clean of dirt and moisture and should be examined for nicks or burrs before mounting the aiming circle. The screws and bolts must be kept snug. Loose screws can allow the tripod to twist slightly, causing measurement errors. Do not overtighten the bolts and screws to prevent stripping the threads.

c. Magnetic Needle. Always ensure the magnetic needle is locked when not in use.

d. Cleaning. The instrument and its accessories must be kept clean and dry. Metal parts should be cleaned of grease and oil with mineral spirits and wiped dry. Care must be taken to insure that the threads of the leveling screws are clean and turn easily. Polished surfaces can be given a thin coat of light grade aircraft instrument lubricating oil to prevent rust. Electrical equipment can be cleaned with trichlorethylene. Canvas parts can be cleaned with soap and water and a scrub brush, as can wood and metal parts not on the aiming circle itself.

e. Storing The Aiming Circle. The aiming circle should be stored in a dry ventilated area. Never store the aiming circle or its equipment while wet or damp. Allow the aiming circle to air dry with its cover off before storing.

11-19 Maintenance Checks And Adjustments

Five maintenance checks should be made on the aiming circle. If any of these checks, other than the micrometer knob check, indicates an adjustment is necessary; the instrument must be turned into a maintenance facility.

a. Level Vial Check. After the aiming circle is set up and leveled, rotate the instrument through 6400 mils. If either the fisheye level or the vial level do not stay centered, turn the instrument in to a maintenance facility.

b. Tilted Reticle Check. After the aiming circle has been set up and leveled, place the vertical crosshair on a distant well defined point. Elevate and depress the telescope. If the vertical crosshair moves off the point as the telescope is elevated and depressed, the instrument should be turned in to a maintenance facility.

c. Micrometer Knob Adjustment. The only adjustment that may be made by the operator is the micrometer knob adjustment.

1. **Checking and Adjusting the Azimuth Micrometer.** The azimuth micrometer is checked and adjusted as follows:

a. Set the zero of the azimuth scale opposite the index mark.

b. If the zero of the micrometer knob is opposite the index mark, no adjustment is necessary. If the zero is not opposite the index, loosen the screws on the end of the micrometer knob and slip the micrometer scale to align the zero and the index.

c. Hold the azimuth knob and the micrometer scale in position and tighten the azimuth micrometer screws. These screws strip easily, do not overtighten the screws.

d. Check to ensure both the zero on the azimuth scale and the zero on the azimuth micrometer are opposite their respective index marks.

2. **Checking and Adjusting the Elevation Micrometer.** The elevation micrometer is checked and adjusted as follows:

a. Set the zero of the elevation scale opposite the index mark.

b. If the zero of the micrometer knob is opposite the index mark, no adjustment is necessary. If the zero is not opposite the index, loosen the screws on the end of the elevation micrometer knob and slip the micrometer scale to align the zero and the index.

c. Hold the elevation knob and the micrometer scale in position and tighten the elevation micrometer screws. These screws strip easily, do not overtighten the screws.

d. Check to ensure both the zero on the elevation scale and the zero on the elevation micrometer are opposite their respective index marks.

d. Level Line Check. The level line check is the same procedure as the steps for determining the vertical angle correction (see paragraph 11-9). The purpose of the level line check is to determine whether the correct values are obtained when vertical angles are measured with the aiming circle. If correct vertical angles are not obtained with the instrument and there is not adequate time to turn the instrument in for repair, a vertical angle correction can be determined. This check must be made after the micrometer knob adjustment described above.

e. Magnetic Needle Check. The magnetic needle is checked to insure the needle does not stick and that it settles smoothly when centered in the needle magnifier. Once the instrument is set up and leveled, orient the telescope towards north. Release the magnetic needle and center it in the needle magnifying window. Slowly move a piece of iron or steel back and forth in front of the instrument to cause the needle to move on its pivot. Allow the needle to settle. If the needle does not settle centered in the window, turn it in to a maintenance facility. This test must be performed each time the instrument is declinated and should be performed each time the instrument is used to determine any values with the magnetic needle.

declination station) is considered accurate to ±10

Section III
HASTY SURVEY METHODS

11-20 General

a. The capabilities afforded to a survey section with respect to hasty survey are limited only to the surveyors imagination and innovation. The surveyor must provide the most accurate data available at the time. Marine surveyors must maintain a certain level of proficiency with all hasty survey methods to ensure a necessary level of flexibility in the survey section.

b. Hasty survey methods available to Marine surveyors are generally grouped by the survey element (azimuth, position, and elevation) they provide.

c. All data determined by hasty survey methods must be converted to common control as soon as the situation permits (See Chapter 13).

11-21 Azimuth Determination

a. General. Azimuth is the most important element of artillery survey. For this reason, most hasty survey methods are designed to determine azimuth.

b. Currently the methods of determining azimuth to hasty survey specifications are:

Hasty Astro
Simultaneous Observation
Declinated Aiming Circle
Directional Traverse
Scaled from a map
Compass (e.g. M2 or Lensatic)

c. Accuracy.

1. For any astronomic method listed above, the considered accuracy is ±2 mils when determined with an aiming circle.

2. The azimuth accuracy of a directional traverse using an aiming circle is determined by multiplying the number of horizontal angles measured by 0.5 mils.

3. An azimuth determined by a declinated aiming circle (declination performed at a surveyed

counting the effects of local magnetic attraction. If the declination was made from a map G-M angle, the accuracy is diminished by the age of the map's declination diagram information.

4. Accuracy of an azimuth determined by a compass (M2 or lensatic) is dependent on the accuracy of the type of grid to magnetic conversion used and local magnetic attraction. Generally 10 to 20 mils.

5. Accuracy of an azimuth determined by scaling from a map is dependent 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.

d. Verification. All azimuths determined by these hasty methods must be verified by a mapspot to reduce the incidence of blunders.

e. The preferred "hasty" method of determining azimuth is the one that will provide the most accuracy for that particular situation.

11-22 Position Determination

a. General. Position can be determined by several different methods as well.

b. Methods. Some hasty methods used by artillery surveyors to determine a position are listed below:

- PLGR/4000 MSGR (Absolute)
- Traverse
- Graphic Resection
- Scaled from map

c. Accuracy.

1. Accuracy of positions determined by GPS absolute survey is dependent mostly on the amount of averaging time allowed. When properly set up and operated, the PLGR can provide data accurate to 10 meters CEP, (Averaging mode,FOM 1, 1 day old

almanac, and 300 averages obtained). These values assume the presence of a valid daily crypto key and correct datum selection.

2. Position accuracy from a hasty traverse is dependent mostly on the means of data determination. In other words, if graphic traverse procedures are used, the position accuracy is considered in the area of 50 meters radial error, if the field data is computed by a survey computer system or by the LCU (BCS), the accuracy is in the range of 25 to 50 meters. The largest error source in hasty traverse is distance determination. Subtense tables leave a large margin of error. For example, using the M16A2 tables, a horizontal angle of 7.0 mils corresponds to a distance of 146 meters, a horizontal angle of 7.5 mils corresponds to a distance of 137 meters. A 0.5 mil error in angle determination works out to a possible 9 meter distance error on this leg.

3. Position accuracy of a graphic traverse is considered to be approximately 50 meters radial error.

4. Mapspot positions are dependent on the scale of the mapsheet and the abilities of the surveyor. In practice, a mapspot position can be considered accurate to approximately 100 meters on a 1:50,000 scale map.

d. Verification. All positions determined by these hasty methods must be verified by a mapspot to reduce the incidence of blunders.

11-23 Elevation Determination

A hasty elevation can be determined by absolute GPS methods, altimetric observations, or by mapsot.

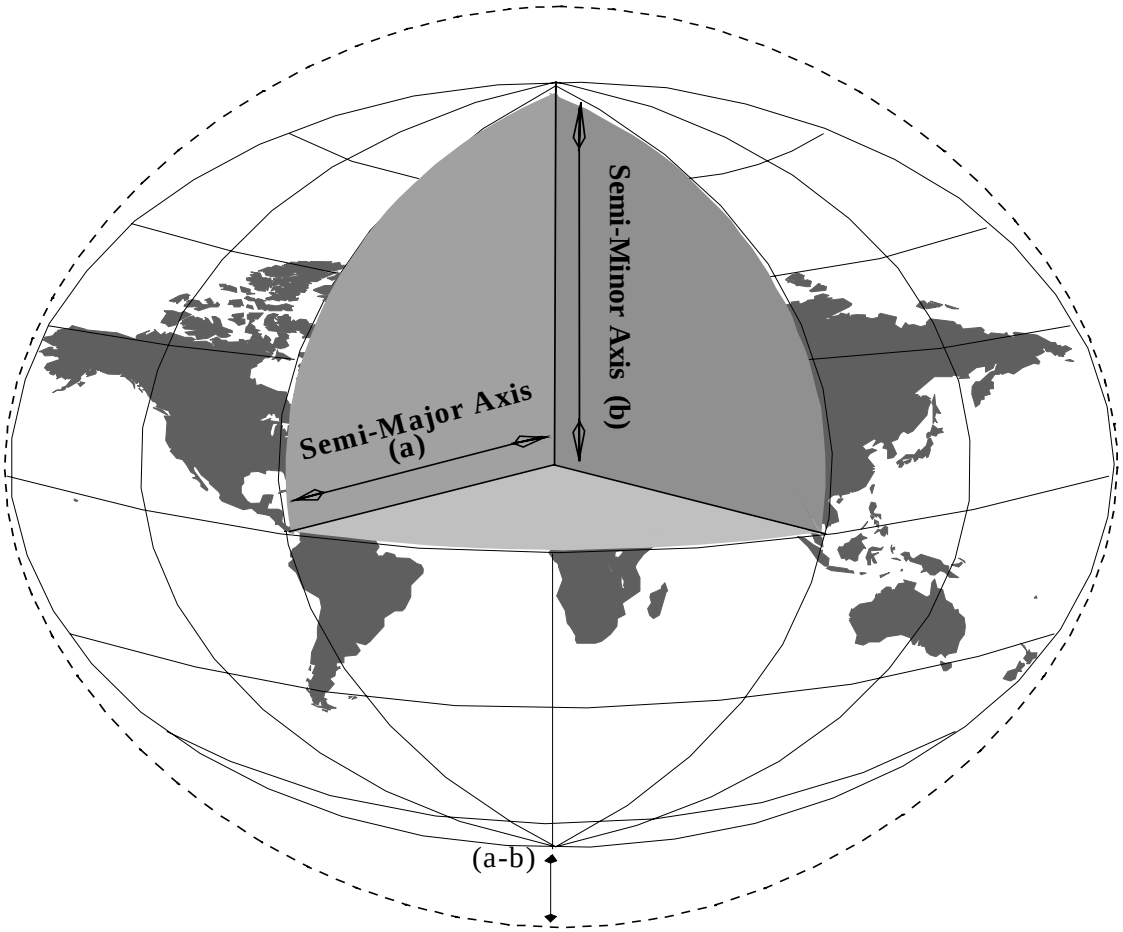
a. Elevation is the weakest component of a GPS absolute position; therefore, when a GPS elevation is determined, that elevation must be verified by mapspot. A properly operated GPS can provide elevations accurate to ±10 meters.

b. Altimetric elevation accuracy is dependant largely on the quality of the barometer in the altimeter. All altimetric elevations must be verified by mapspot.

c. The contour lines on a NIMA topographic map (1:50,000 scale) are considered to be accurate to 1/2 contour interval, 90% of the time; in other words, a mapspot elevation should never be considered more accurate than 1 contour interval for that mapsheet.

APPENDIX A

ELLIPSOIDS AND DATUMS



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GENERAL INFORMATION
(APPENDIX A)

1. REFERENCES.

a. The following references were used to compile the information found in this appendix:

1. DMA TM 8358.1 (Sept 1990)
2. NIMA TR 8350.2 Third Edition (4 July 1997)
3. National Geodetic Survey, Geodetic Glossary (Sept 1986)
4. ST 6-2-40 (1 Mar 1991) BUCS DDCT
5. MADTRAN, Edition 2 and 4 (NIMA Program referencing NIMA TR 8350.2 above)
6. DOD Glossary of Mapping, Charting, and Geodetic Terms (1991)
7. MERCATOR Program (NIMA Program referencing DMA TM 8358.2 dtd Sept 1989)
8. TM 08837A-12/1A (28 Oct 1988) w/ ch3 (9 Sept 1992) PADS

b. When the information in the references above conflicted, NIMA TR 8350.2 was considered the senior publication.

c. The numbers in front of the references above correspond to the reference numbers in the tables of this appendix. Reference #8 was used to determine the PADS Ellipsoid Code; reference #4 was used to determine the BUCS DDCT (Rev 0) code.

2. TABLES.

a. Ellipsoids:

1. Tables A-1a and A-1b are a compilation of all ellipsoids and their parameters as published in the references above. This is not a list of all ellipsoids, however it is the most complete list of ellipsoids and their parameters available to artillery surveyors in one table. Table A-1a includes those reference ellipsoids that have datum transformation parameters in Tables A-3 through A-25. Table A-1b includes those ellipsoids that do **not** have datum transformation parameters in Tables A-3 through A-25.

2. Table A-2 is a cross-reference between Datums and Reference Ellipsoids.

b. Datums:

1. The Datum Transformation Parameters are listed corresponding to the ellipsoid they are referenced to. The transformation parameters are from the local geodetic datum to WGS 84, therefore, a datum table with WGS 84 will not be published. Only the reference ellipsoids in Table A-1a will have a corresponding Datum Table in A-3 through A-25.

2. Differences in data published in the above references are explained in the notes section at the end of this appendix.

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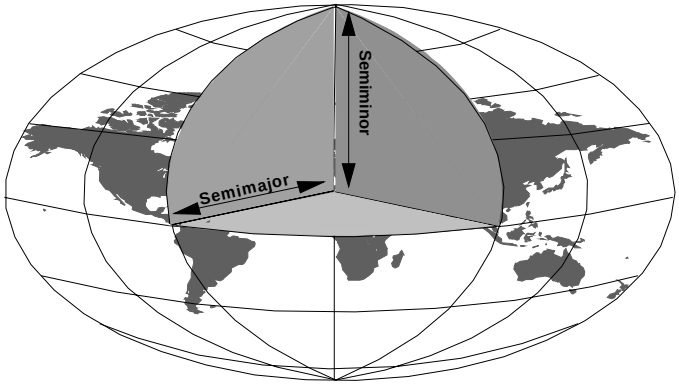
World Geodetic System 1984



Semi-Major Axis (a)	Semi-Minor Axis (b)	Flattening (1/f)
6,378,137	6,356,752.3142	298.257223563

NIMA has designated WGS-84 as the preferred ellipsoid and datum for all mapping, charting, and geodetic products, however, some areas of the world can still be covered by other systems. This section is intended to show the need for updating to WGS-84 and also to explain the similarities as well as the differences between the WGS-84 and GRS-80 ellipsoids.

Because of the large amount of mapping, charting, and geodetic products produced by the National Imagery and Mapping Agency (NIMA) for the Department of Defense (DoD); it became apparent that a single geocentric coordinate system was needed to insure accuracy and easier user interface. A geocentric system provides a basic reference for the mathematical figure of the Earth. It also provides a means for establishing various geodetic datums to an Earth Centered, Earth-Fixed (ECEF) coordinate system. This system is termed the World Geodetic System (WGS).

Previously, DoD has adopted three such systems: WGS-60, WGS-66, and WGS-72. With each system proving more accurate than the last, WGS-72 can still be used for some applications, although it does have several shortcomings. For example, the WGS-72 Earth Gravitational Model and Geoid are obsolete. Also, more accurate datum shifts from local geodetic datums to a WGS were needed. Several other factors contributed to the need to replace WGS-72. These include the replacement of NAD 27 with NAD 83 and the development of the Australian Geodetic Datum 1984. Also, a large increase in data and more advanced types of data (satellite ranging for example) became available. WGS-84 was developed as the replacement for WGS-72.

In determining the WGS-84 ellipsoid and its defining parameters, the WGS-84 Development Committee closely followed the procedures used by the International Union of Geodesy and Geophysics (IUGG) who had already developed the Geodetic Reference System 1980 (GRS-80). Four parameters were used to develop WGS-84: the semi-major axis (a), the Earth's gravitational constant (GM), the normalized second degree zonal gravitational constant, and the angular velocity of the Earth. All are identical to GRS-80 except that the normalized second degree zonal used is that of the WGS-84 gravitational model instead of the notation used for GRS-80.

As a result of that difference, the ellipsoid parameters differ slightly between GRS-80 and WGS-84. These differences are insignificant from a practical application standpoint; therefore, it has been accepted that GRS-80 and WGS-84 are the same and their associated datums are based on the same ellipsoid.

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Ellipsoid Parameters

(Ellipsoids Referenced to Datum Tables A-3 through A-25)

Ellipsoid	a	△ a	b	1/f	△ f x 10^4
Airy	6,377,563.396	+573.604	6,356,256.910	299.32496 46	+0.11960023
Modified Airy	6,377,340.189	+796.811	6,356,034.446	299.32496 46	+0.11960023
Australian National ‡	6,378,160	-23	6,356,774.7192	298.25	-0.00081204
Bessel 1841	6,377,397.155	+739.845	6,356,078.9629	299.15281 28	+0.10037483
Bessel 1841 (Namibia)	6,377,483.865	+653.135	**6,356,165.383**	299.15281 28	+0.10037483
Clarke 1866	6,378,206.4	-69.4	6,356,583.8	294.97869 82	-0.37264639
Clarke 1880 †	6,378,249.145	-112.145	6,356,514.8696	293.465	-0.54750714
Everest 1830	6,377,276.34518	+860.655	6,356,075.41511	300.8017	+0.28361368
Everest 1948	6,377,298.556	+838.444	**6,356,097.550**	300.8017	+0.28361368
Mod. Everest 1948 *	6,377,304.063	+832.937	6,356,103.039	300.8017	+0.28361368
Everest 1956	6,377,301.243	+835.757	**6,356,100.228**	300.8017	+0.28361368
Everest (Pakistan)	6,377,309.613	+827.397	**6,356,108.571**	300.8017	+0.28361368
Mod. Fischer 1960	6,378,155.0	-18	**6,356,773.320**	298.3	+0.00480795
GRS-80	6,378,137	0	6,356,752.3141	298.25722 2101	+0.00000016
GRS-80 CHINA	6,378,140	-3	**6,356,755.288**	298.257	-0.00002514
Helmert 1906	6,378,200	-63	**6,356,818.170**	298.3	+0.00480795
Hough 1960	6,378,270	-133	**6,356,684.34343**	297	-0.14192702
Indonesian 1974	6,378,160.0	-23	**6,356,774.504**	298.247	-0.00114930
International 1924	6,378,388	-251	6,356,911.9462	297	-0.14192702
Krassovsky 1940	6,378,245	-108	**6,356,863.019**	298.3	+0.00480795
SGS-85	6,378,136	+1	**6,356,751.302**	298.257	-0.00002514
South American 1969‡	6,378,160	-23	6,356,774.7192	298.25	-0.00081204
WGS-72	6,378,135	+2	6,356,750.5	298.26	+0.00031211
WGS-84	6,378,137	N/A	6,356,752.3142	298.25722 3563	N/A

Table A-1a

a : semi-major axis **b : semi-minor axis** **1/f : inverse of flattening**

△ a: is the difference between the WGS-84 semi-major axis and the local ellipsoid semi-major axis. WGS-84 - Local Ellipsoid = △ a

△ f x 10^4 : is the difference between the WGS-84 flattening and the local ellipsoid flattening multiplied by 10,000.

Semi-minor Axes printed in bold were computed using the formula b=a(1-f), then rounded to three places.

* Also known as Malayan Ellipsoid.

† See NOTE 2 on Pg Appendix A-44

‡ See NOTE 6 on Pg Appendix A-45

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Ellipsoid Parameters

(Ellipsoids NOT Referenced to Datum Tables A-3 through A-25)

Ellipsoid	a	△ a	b	1/f	△ f x 10^4
Airy 1830	6,377,563.541	+573.459	6,356,257.053	299.325	+0.11960418
Clarke 1858	6,378,361	-224	6,356,685	294.26	-0.45544531
Clarke 1880 French †	6,378,249.2	-112.2	6,356,515.0	293.46598	-0.54739335
Clarke 1880 Mod. †	6,378,249.145	-112.145	**6,356,514.966**	293.46630 7656	+0.54735530
Clarke 1880 Palistine†	6,378,300.790	-163.79	**6,356,566.435**	293.46630 7656	+0.54735530
Clarke 1880 †	6,378,249.14532 6	-112.145326	6,356,514.96672 1	293.46630 76	-0.54735531
Danish	6,377,104.430	+1032.57	**6,355,847.415**	300.0000	+0.19477331
Delambre	6,376,523.300	+1613.7	**6,355,863.232**	308.640	+1.12789929
Everest 1969	6,377,295.664	+841.336	**6,356,094.668**	300.8017	+0.28361368
Fischer 1960	6,378,166.0	-29	**6,356,784.284**	298.3	+0.00480795
GRS-1967 ‡	6,378,160	-23	**6,356,774.504**	298.247	-0.00114930.
Hayford 1909	6,378,388.0	-251	6,356,909.0	297.00	-0.14192702
Plessis	6,376,523.3	-1613.7	**6,355,863.232**	308.640	+1.12789929
Schott 1900	6,378,157	-20	**6,357,210.672**	304.5	+0.68738415
Struve	6,378,298.3	-161.3	**6,356,657.143**	294.730	-0.40125243
War Office 1924	6,378,300.58	-163.58	**6,356,752.267**	296	-0.25567714
WGS-60	6,378,165	-28	**6,356,783.287**	298.3	+0.00480795
WGS-66	6,378,145	-8	**6,356,759.769**	298.25	-0.00081204
WGS-84	6,378,137	N/A	6,356,752.3142	298.25722 3563	N/A

Table A-1b

a : semi-major axis **b : semi-minor axis** **1/f : inverse of flattening**

△ a: is the difference between the WGS-84 semi-major axis and the local ellipsoid semi-major axis. WGS-84 - Local Ellipsoid = △ a

△ f x 10^4 : is the difference between the WGS-84 flattening and the local ellipsoid flattening multiplied by 10,000.

Semi-minor Axes printed in bold were computed using the formula b=a(1-f), then rounded to three places.

* Also known as Malayan Ellipsoid.

† See NOTE 2 on Pg Appendix A-44

‡ See NOTE 6 on Pg Appendix A-45

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DATUM TO ELLIPSOID
CROSS REFERENCE
Table A-2

DATUM	AREA	ELLIPSOID	TABLE
Adindan	North Africa	Clarke 1880	A-9a
Afgooye	Somalia	Krassovsky 1940	A-22
Ain El Abd 1970	Bahrain Island	International 1924	A-21a
American Samoa 1962	US Samoan Islands	Clarke 1866	A-8a
Anna 1 Astro 1965	Cocos Islands	Australian National	A-5
Antigua Island Astro 1943	Antigua and Leeward Islands	Clarke 1880	A-9a
Arc 1950	Central Africa	Clarke 1880	A-9a,b
Arc 1960	Kenya and Tanzania	Clarke 1880	A-9b
Ascension Island 1958	Ascension Island	International 1924	A-21a
Astro Beacon "E" 1945	Iwo Jima	International 1924	A-21a
Astro Dos 71/4	St Helena Island	International 1924	A-21a
Astro Tern Island (Frig) 1961	Tern Island	International 1924	A-21a
Astronomical Station 1952	Marcus Island	International 1924	A-21a
Australian Geodetic 1966	Australia and Tasmania	Australian National	A-5
Australian Geodetic 1984	Australia and Tasmania	Australian National	A-5
Ayabelle Lighthouse	Djibouti	Clarke 1880	A-9b
Beijing 1982 (Peking 1982)	China	GRS 1980 (China)	A-17
Bellevue (IGN)	Efate and Erromango Islands	International 1924	A-21a
Bermuda 1957	Bermuda	Clarke 1866	A-8a
Bissau	Guinea-Bissau	International 1924	A-21a
Bogota Observatory	Columbia	International 1924	A-21a
Bukit Rimpah	Indonesia	Bessel 1841	A-6
Camp Area Astro	Camp McMurdo, Antarctica	International 1924	A-21a
Campo Inchauspe 1969	Argentina	International 1924	A-21a
Canton Astro 1966	Phoenix Islands	International 1924	A-21b
Cape	South Africa	Clarke 1880	A-9b
Cape Canaveral	Florida and Bahamas	Clarke 1866	A-8a
Carthage	Tunisia	Clarke 1880	A-9b
Chatham Island Astro 1971	Chatham Island	International 1924	A-21b
Chua Astro	Paraguay	International 1924	A-21b
Corrego Alegre	Brazil	International 1924	A-21b
Coordinate System 1937 (Estonia)	Estonia	Bessel 1841	A-6
Dabola	Guinea	Clarke 1880	A-9b
Deception Island	Deception Is. Antarctica	Clarke 1880	A-9b
Djakarta (Batavia)	Indonesia	Bessel 1841	A-6
Dos 1968	Gizo Island	International 1924	A-21b
Easter Island 1967	Easter Island	International 1924	A-21b
European 1950	North Africa/Europe/Middle East	International 1924	A-21b,c
European 1979	Europe	International 1924	A-21c
Fort Thomas 1955	Nevis and St Kitts	Clarke 1880	A-9c

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DATUM TO ELLIPSOID
CROSS REFERENCE
Table A-2 Cont.

DATUM	AREA	ELLIPSOID	TABLE
Gan 1970 (Gandajika Base)	Republic of Maldives	International 1924	A-21d
Geodetic Datum 1949	New Zealand	International 1924	A-21d
Graciosa Base SW 1948	Azores	International 1924	A-21d
Guam 1963	Guam	Clarke 1866	A-8a
Gunung Segara	Indonesia	Bessel 1841	A-6
Gux 1 Astro	Guadalcanal	International 1924	A-21d
Herat North	Afghanistan	International 1924	A-21d
Herat North	Afghanistan	Krassovsky 1940	A-22
Hermannskogel	Croat Republics	Bessel 1841	A-6
Hjorsey 1955	Iceland	International 1924	A-21d
Hong Kong 1963	Hong Kong	International 1924	A-21d
Hu-Tzu-Shan	Taiwan	International 1924	A-21d
Indian	Bangledesh	Everest 1830	A-10
Indian	India and Nepal	Everest 1956	A-13
Indian	Pakistan	Everest (Pakistan)	A-14
Indian 1954	Thailand	Everest 1830	A-10
Indian 1960	Vietnam	Everest 1830	A-10
Indian 1975	Thailand	Everest 1830	A-10
Indonesian 1974	Indonesia	Indonesian 1974	A-20
Ireland 1965	Ireland	Modified Airy	A-4
ISTS 061 Astro 1968	South Georgia Islands	International 1924	A-21d
ISTS 073 Astro 1969	Diego Garcia	International 1924	A-21d
Johnston Island 1961	Johnston Island	International 1924	A-21d
Kandawala	Sri Lanka	Everest 1830	A-10
Kerguelen Island 1949	Kerguelen Island	International 1924	A-21e
Kertau 1948	West Malaysia and Singapore	Mod. Everest 1948	A-12
Kusaie Astro 1961	Caroline Islands/Micronesia	International 1924	A-21e
LC 5 Astro 1961	Cayman Brac Islands	Clarke 1866	A-8a
Leigon	Ghana	Clarke 1880	A-9c
Liberia 1964	Liberia	Clarke 1880	A-9c
Luzon	Philippines	Clarke 1866	A-8a
Mahe 1971	Mahe Island	Clarke 1880	A-9c
Massawa	Ethiopia	Bessel 1841	A-6
Merchich	Morocco	Clarke 1880	A-9c
Midway Astro 1961	Midway Islands	International 1924	A-21e
Minna	Cameroon and Nigeria	Clarke 1880	A-9c
Montserrat Island Astro 1958	Montserrat	Clarke 1880	A-9a
M'Poraloko	Gabon	Clarke 1880	A-9c

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DATUM TO ELLIPSOID
CROSS REFERENCE
Table A-2 Cont.

DATUM	AREA	ELLIPSOID	TABLE
Nahrwan	Sanai Peninsula	Clarke 1880	A-9c
Naparima BWI	Trinidad and Tobago	International 1924	A-21e
North American Datum 1927	North and Central America	Clarke 1866	A-8a,b,c
North American Datum 1983	North and Central America	GRS 1980	A-16
North Sahara 1959	Algeria	Clarke 1880	A-9d
Observatorio Meteorologico 1939	Azores	International 1924	A-21e
Old Egyptian 1907	Egypt	Helmert 1906	A-18
Old Hawaiian	Hawaiian Islands	Clarke 1866	A-8a
Oman	Oman	Clarke 1880	A-9d
Ord. Survey of Great Britain 1936	United Kingdom	Airy	A-3
Peking 1954	Shanghai, China	Krassovsky 1940	A-22
Pico De Las Nieves	Canary Islands	International 1924	A-21e
Pitcairn Astro 1967	Pitcairn Island	International 1924	A-21e
Point 58	Burkino Faso and Niger	Clarke 1880	A-9d
Pointe Noire 1948	Congo	Clarke 1880	A-9d
Porto Santo 1936 (Southeast Base)	Porto Santo and Madeira Islands	International 1924	A-21e
Potsdam	Germany	Bessel 1841	A-6
Provisional South American 1956	South America	International 1924	A-21e,f
Provisional South Chilean 1963	Southern Chile	International 1924	A-21f
Puerto Rico	Puerto Rico and Virgin Is.	Clarke 1866	A-8c
Pulkovo 1942	Russia	Krassovsky 1940	A-22
Qatar National	Qatar	International 1924	A-21f
Qornoq	South Greenland	International 1924	A-21f
Reunion	Mascarene Island	International 1924	A-21f
Rome 1940	Sardinia	International 1924	A-21f
S-42 (Pulkovo 1942)	Eastern Europe	Krassovsky 1940	A-22
Santo (Dos) 1965	Espirito Santo Islands	International 1924	A-21f
Sao Braz	Azores	International 1924	A-21g
Sapper Hill 1943	East Falkland Islands	International 1924	A-21g
Schwarzeck	Namibia	Bessel 1841 (Namibia)	A-7
Selvagem Grande 1938	Salvage Islands	International 1924	A-21g
Sierra Leone1960	Sierra Leone	Clarke1880	A-9d
S-JTSK	Czechoslovakia	Bessel 1841	A-6
South American 1969	South America	South American 1969	A-23
South Asia	Singapore	Mod. Fischer 1960	A-15
Soviet Geodetic System 1985	Asia and Europe	SGS 1985	A-24
Tananarive Observatory 1925	Madagascar	International 1924	A-21g
Timbalai 1948	Brunei and East Malaysia	Everest 1948	A-11
Tokyo	Korea and Japan	Bessel 1841	A-6
Tristan Astro 1968	Tristan Da Cunha	International 1924	A-21g

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DATUM TO ELLIPSOID
CROSS REFERENCE
Table A-2 Cont.

DATUM	AREA	ELLIPSOID	TABLE
Viti Levu 1916	Viti Levu Island	Clarke 1880	A-9d
Voirol 1874	Tunisia and Algeria	Clarke 1880	A-9d
Voirol 1960	Algeria	Clarke 1880	A-9d
Wake-Eniwetok 1960	Marshall Islands	Hough 1960	A-19
Wake Island Astro 1952	Wake Atoll	International 1924	A-21g
Yacare	Uraguay	International 1924	A-21g
Zanderij	Suriname	International 1924	A-21g

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DATUM TABLES

MODIFIED AIRY

a: 6377340.189 b: 6356034.446 1/f: 299.32496 46

△ a: +796.811 △ f x 10^4 : +0.11960023

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
IRELAND 1965	IRELAND	506	-122	611	IRL	38	2

Table A-4 △ f x 10^7: +119.600 PADS CODE: 11

1. The Datum Transformation Tables include the following information:

a. Ellipsoid Name, Semi-major axis (a), Semi-minor axis (b), Flattening (1/f), , and as listed in Table A-1a.

b. △ *f* x10 listed at the bottom of the table and is to be used along with △*a* for the user defined option in the AN/PSN-11 (PLGR) program version 613-9854-002.

c. PADS Code as listed in TM 08837A-12/1A. In cases where two or more ellipsoids have the same parameters, the same PADS code was listed for each even when not listed in the reference. For example, Australian National and South American 1969 can both use code 8. **These codes are for Version 4 PADS.** If a PADS Code is not listed, the User Defined option should be used.

d. Local Geodetic Datum. The datum name as it appears in NIMA TR 8350.2. In cases where a datum has more than one name, the second name is listed in parenthesis.

e. Country/Area. This information is mostly as it appears in NIMA TR 8350.2. The only variations from the reference are listings of states and countries published under Mean Solutions.

f. Transformation Parameters (shifts in X,Y, and Z axis) as listed in NIMA TR 8350.2. These parameters are from the local datum to WGS 84.

g. Datum Code. The codes in this column match the programmed datum codes from the AN/PSN-11 (PLGR). The datum codes listed in this column that are not a programmed option of the PLGR must be selected as User Defined. All Datum Codes published in this table are from NIMA TR 8350.2.

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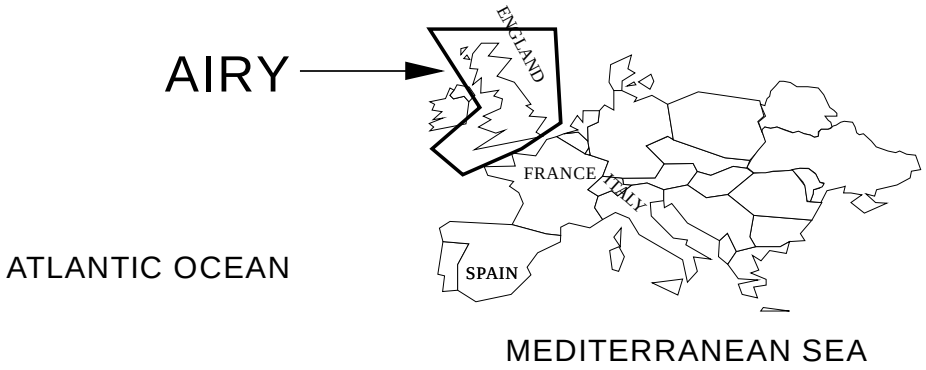
AIRY

a: 6377563.396 b: 6356256.910 1/f: 299.32496 46

△ a: +573.604 △ f x 10^4 : +0.11960023

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
ORDNANCE SURVEY OF GREAT BRITAIN 1936					OGB		2
	MEAN SOLUTION	375	-111	431	OGB-M	76	2
	(ENGLAND, ISLE OF MAN, SCOTLAND, SHETLAND ISLANDS, AND WALES						
	ENGLAND	371	-112	434	OGB-A		2
	ENGLAND, ISLE OF MAN, AND WALES	371	-111	434	OGB-B		2
	SCOTLAND AND THE SHETLAND ISLANDS	384	-111	425	OGB-C		2
	WALES	370	-108	434	OGB-D		2

Table A-3 △ f x 10^7: +119.600 PADS CODE: 10



DRAFT

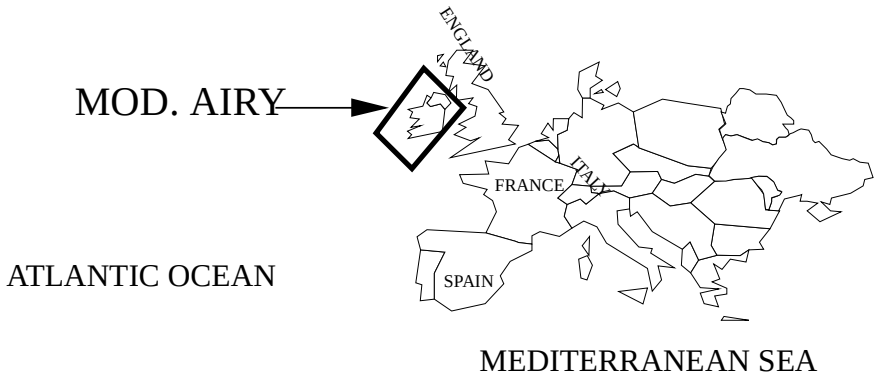
MODIFIED AIRY

a: 6377340.189 b: 6356034.446 1/f: 299.32496 46

△ a: +796.811 △ f x 10^4 : +0.11960023

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
IRELAND 1965	IRELAND	506	-122	611	IRL	38	2

Table A-4 △ f x 10^7: +119.600 PADS CODE: 11



DRAFT

AUSTRALIAN NATIONAL SEE NOTE SIX

a: 6378160 b: 6356774.7192 1/f: 298.25

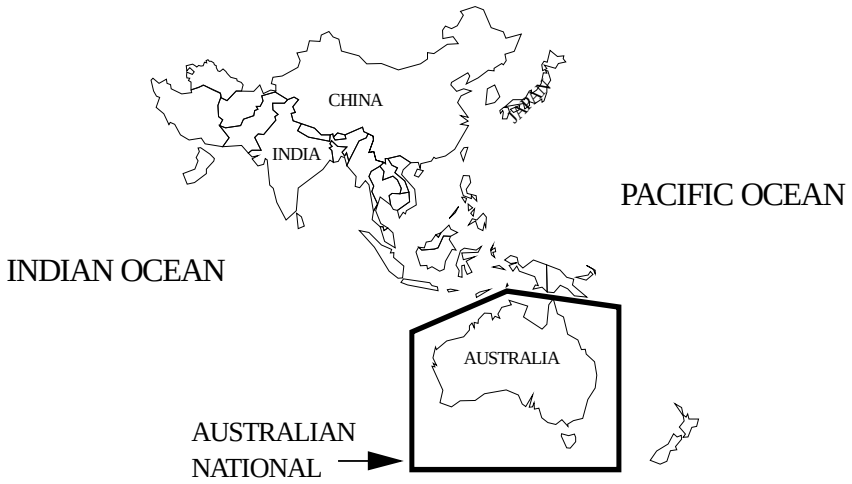
△ a: -023.000 △ f x 10^4 : -0.00081204

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
ANNA 1 ASTRO 1965	COCOS ISLANDS	-491	-22	435	ANO	4	2
AUSTRALIAN GEODETIC 1966	AUSTRALIA AND TASMANIA	-133	-48	148	AUA	12	2
AUSTRALIAN GEODETIC 1984	AUSTRALIA AND TASMANIA	-134	-48	149	AUG	13	2

Table A-5 △ f x 10^7: -000.812 PADS CODE: 8



DRAFT

BESSEL 1841

a: 6377397.155 b: 6356078.9629 1/f: 299.15281 28

△ a: +739.845 △ f x 10^4 : +0.10037483

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
BUKIT RIMPAH	INDONESIA	-384	664	-48	BUR		2
SEE NOTE EIGHT	(BANGKA AND BELITUNG ISLS)						
COORDINATE SYSTEM 1937 OF ESTONIA	ESTONIA	374	150	588	EST		2
DJAKARTA (BATAVIA)	INDONESIA (SUMATRA)	-377	681	-50	BAT		2
GUNUNG SEGARA	INDONESIA (KALIMANTAN)	-403	684	41	GSE		2
HERMANNSKOGEL	YUGOSLAVIA	682	-203	480	HER		2
SEE NOTE EIGHT	(Prior to 1990) (Currently Serbia, Slovenia, Croatia, and Bosnia and Herzegovina)						
MASSAWA	ETHIOPIA (ERITREA)	639	405	60	MAS		2
POTSDAM	GERMANY						4
SEE NOTE FIVE							
S-JTSK	CZECHOSLOVAKIA	589	76	480	CCD		2
	PRIOR TO 1 JAN 1993						
TOKYO					TOY		2
	MEAN SOLUTION	-148	507	685	TOY-M	SEE NOTE ONE	2
	(JAPAN, OKINAWA, AND SOUTH KOREA)						
	JAPAN	-148	507	685	TOY-A		2
	OKINAWA	-158	507	676	TOY-C		2
	KOREAN PENIN.	-147	506	687	TOY-B		2
	(NORTH AND SOUTH KOREA)						

Table A-6 △ f x 10^7: +100.374 PADS CODE: 5

Map on next page.

DRAFT

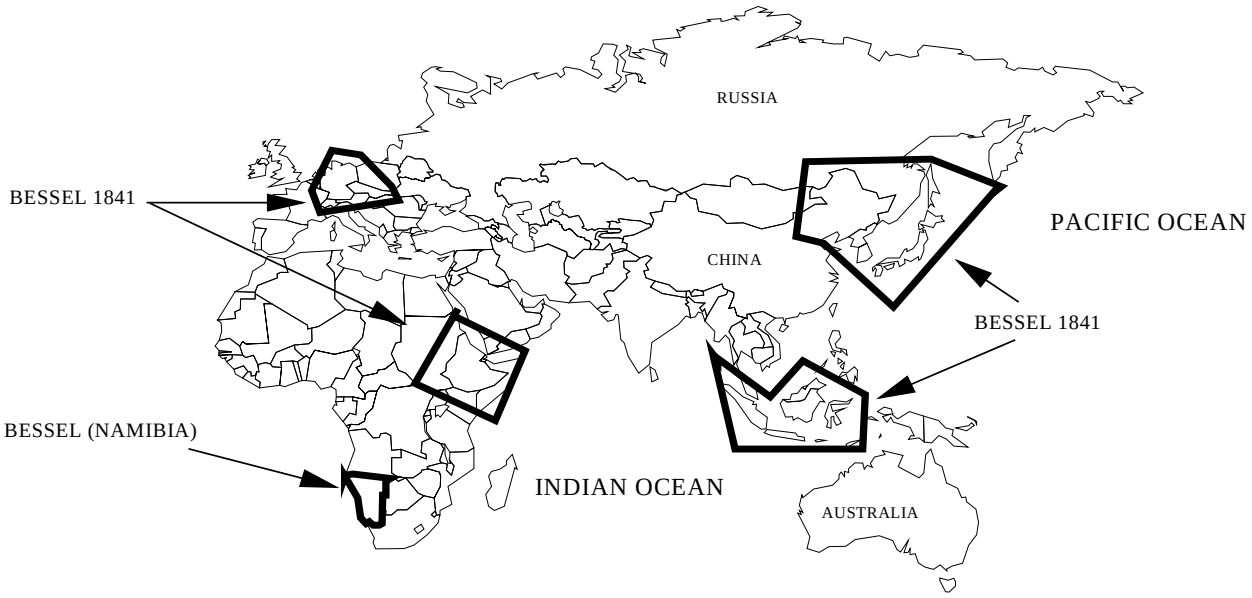
BESSEL 1841 (Namibia)

a: 6377483.865 b: 6356165.383 1/f: 299.15281 28

△ a: +653.135 △ f x 10^4 : +0.10037483

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
SCHWARZECK	NAMIBIA	616	97	-251	SCK	SEE NOTE ONE	2

Table A-7 △ f x 10^7: +100.374 PADS CODE:



DRAFT

CLARKE 1866

a: 6378206.4 b: 6356583.8 1/f: 294.97869 82

△ a: -069.400 △ f x 10^4 : -0.37264639

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
AMERICAN SAMOA 1962							
	US SAMOAN IS.	-115	118	426	AMA		2
BERMUDA 1957	BERMUDA IS.	-73	213	296	BER	15	2
CAPE CANAVERAL	MEAN SOLUTION	-2	151	181	CAC	SEE NOTE ONE	2
	BAHAMAS AND FLORIDA						
GUAM 1963	GUAM	-100	-248	259	GUA	32	2
LC 5 ASTRO 1961	CAYMAN BRAC IS.	42	124	147	LCF	45	2
LUZON					LUZ		2
	PHILIPPINES	-133	-77	-51	LUZ-A	47	2
	(EXCLUDING MINDANAO IS.)						
	MINDANAO IS.	-133	-79	-72	LUZ-B	48	2
NORTH AMERICAN 1927					NAS		2
	MEAN SOLUTION	-8	160	176	NAS-C	60	2
UNITED STATES	(CONUS)						
	EASTERN U.S.	-9	161	179	NAS-A		2
	WESTERN U.S.	-8	159	175	NAS-B		2
	ALASKA	-5	135	172	NAS-D	61	2
	(EXCLUDING THE ALEUTIAN ISLANDS)						
	ALEUTIAN IS.						
	EAST OF 180 Deg WEST	-2	152	149	NAS-V		2
	WEST OF 180 Deg WEST	2	204	105	NAS-W		2

Table A-8a △ f x 10^7: -372.646 PADS CODE: 1

DRAFT

CLARKE 1866 cont.

a: 6378206.4 b: 6356583.8 1/f: 294.97869 82

△ a: -069.400 △ f x 10^4 : -0.37264639

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
NORTH AMERICAN 1927					NAS		2
	MEAN SOLUTION	-10	158	187	NAS-E	64	2
CANADA	CANADA; INCLUDING NEWFOUNDLAND						
	ALBERTA AND BRITISH COLUMBIA	-7	162	188	NAS-F		2
	EASTERN CANADA (NEWFOUNDLAND, NEW BRUNSWICK, NOVA SCOTIA, AND QUEBEC)	-22	160	190	NAS-G		2
	MANITOBA AND ONTARIO	-9	157	184	NAS-H		2
	NORTHWEST TERRITORIES AND SASKATCHEWAN	4	159	188	NAS-I		2
	YUKON	-7	139	181	NAS-J		2
NORTH AMERICAN 1927							
OTHER THAN US AND CANADA	BAHAMAS (EXCLUDING SAN SALVADOR IS.)	-4	154	178	NAS-Q	62	2
	CANAL ZONE	0	125	201	NAS-O	65	2
	CARIBBEAN	-3	142	183	NAS-P	66	2
	CENTRAL AMERICA (BELIZE, COSTA RICA, EL SALVADOR, GUATEMALA, HONDURAS, AND NICARAGUA)	0	125	194	NAS-N	67	2
	CUBA	-9	152	178	NAS-T	68	2

Table A-8b △ f x 10^7: -372.646 PADS CODE: 1

DRAFT

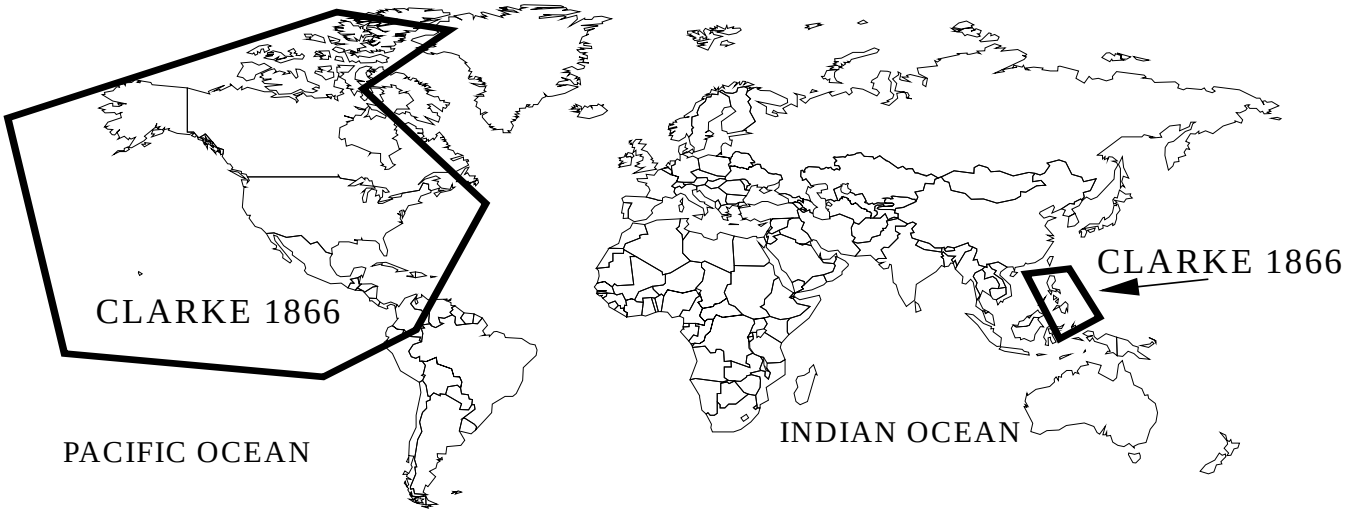
CLARKE 1866 cont.

a: 6378206.4 b: 6356583.8 1/f: 294.97869 82

△ a: -069.400 △ f x 10^4 : -0.37264639

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
NORTH AMERICAN 1927					NAS		2
	GREENLAND	11	114	195	NAS-U	69	2
	(HAYES PENINSULA)						
	MEXICO	-12	130	190	NAS-L	70	2
	SAN SALVADOR IS.	1	140	165	NAS-R	63	2
OLD HAWAIIAN					OHA		
	MEAN SOLUTION	61	-285	-181	OHA-M	74	2
	HAWAII	89	-279	-183	OHA-A		2
	KAUAI	45	-290	-172	OHA-B		2
	MAUI	65	-290	-190	OHA-C		2
	OAHU	58	-283	-182	OHA-D		2
PUERTO RICO	PUERTO RICO AND VIRGIN ISLANDS	11	72	-101	PUR	81	2

Table A-8c △ f x 10^7: -372.646 PADS CODE: 1



DRAFT

CLARKE 1880 SEE NOTE TWO

a: 6378249.145 b: 6356514.8696 1/f: 293.465

△ a: -112.145 △ f x 10^4 : -0.54750714

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
ADINDAN					ADI		2
	MEAN SOLUTION	-166	-15	204	ADI-M	1	2
	(ETHIOPIA AND SUDAN)						
	BURKINA FASO	-118	-14	218	ADI-E		2
	CAMEROON	-134	-2	210	ADI-F		2
	ETHIOPIA	-165	-11	206	ADI-A		2
	MALI	-123	-20	220	ADI-C		2
	SENEGAL	-128	-18	224	ADI-D		2
	SUDAN	-161	-14	205	ADI-B		2
ANTIGUA ISLAND ASTRO 1943							2
	ANTIGUA AND						
	LEEWARD ISLANDS	-270	13	62	AIA		2
ARC 1950 SEE NOTE TWO					ARF		2
	MEAN SOLUTION	-143	-90	-294	ARF-M	5	2
	(BOTSWANA, LESOTHO, MALAWI,						
	SWAZILAND, ZAIRE, ZAMBIA, AND						
	ZIMBABWE)						
	BOTSWANA	-138	-105	-289	ARF-A		2
	BURUNDI	-153	-5	-292	ARF-H		2

Table A-9a △ f x 10^7: -547.507 PADS CODE: 2

DRAFT

CLARKE 1880 cont. SEE NOTE TWO

a: 6378249.145 b: 6356514.8696 1/f: 293.465

△ a: -112.145 △ f x 10^4 : -0.54750714

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
ARC 1950 cont SEE NOTE TWO					ARF		2
	LESOTHO	-125	-108	-295	ARF-B		2
	MALAWI	-161	-73	-317	ARF-C		2
	SWAZILAND	-134	-105	-295	ARF-D		2
	ZAIRE	-169	-19	-278	ARF-E		2
	ZAMBIA	-147	-74	-283	ARF-F		2
	ZIMBABWE	-142	-96	-293	ARF-G		2
ARC 1960	MEAN SOLUTION	-160	-6	-302	ARS-M	6	2
	KENYA	-157	-2	-299	ARS-A		2
	TANZANIA	-175	-23	-303	ARS-B		2
AYABELLE LIGHTHOUSE	DJIBOUTI	-79	-129	145	PHA		2
CAPE	SOUTH AFRICA	-136	-108	-292	CAP	19	2
CARTHAGE SEE NOTE TWO	TUNISIA	-263	6	431	CGE		2
DABOLA	GUINEA	-83	37	124	DAL		2
DECEPTION ISLAND	DECEPTION IS., ANTARCTICA	260	12	-147	DID		2

Table A-9b △ f x 10^7: -547.507 PADS CODE: 2

DRAFT

CLARKE 1880 cont. SEE NOTE TWO

a: 6378249.145 b: 6356514.8696 1/f: 293.465

△ a: -112.145 △ f x 10^4 : -0.54750714

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
FORT THOMAS 1955	NEVIS AND ST KITTS (LEEWARDS IS)	-7	215	225	FOT		2
LEIGON	GHANA	-130	29	364	LEH		2
LIBERIA 1964	LIBERIA	-90	40	88	LIB	46	2
MAHE 1971	MAHE ISLAND	41	-220	-134	MIK	49	2
MERCHICH SEE NOTE TWO	MOROCCO	31	146	47	MER		2
MINNA					MIN		
	CAMEROON	-81	-84	115	MIN-A		2
	NIGERIA	-92	-93	122	MIN-B	54	2
MONTSERRAT ISLAND ASTRO 1958	MONTSERRAT (LEEWARDS IS)	174	359	365	ASM		2
M'PORALOKO	GABON	-74	-130	42	MPO		2
NAHRWAN					NAH		
	MASIRAH ISLAND (OMAN)	-247	-148	369	NAH-A	55	2
	SAUDI ARABIA	-243	-192	477	NAH-C	SEE NOTE ONE	2
	UNITED ARAB EMIRATES	-249	-156	381	NAH-B	56	2

Table A-9c △ f x 10^7: -547.507 PADS CODE: 2

DRAFT

CLARKE 1880 cont. SEE NOTE TWO

a: 6378249.145 b: 6356514.8696 1/f: 293.465

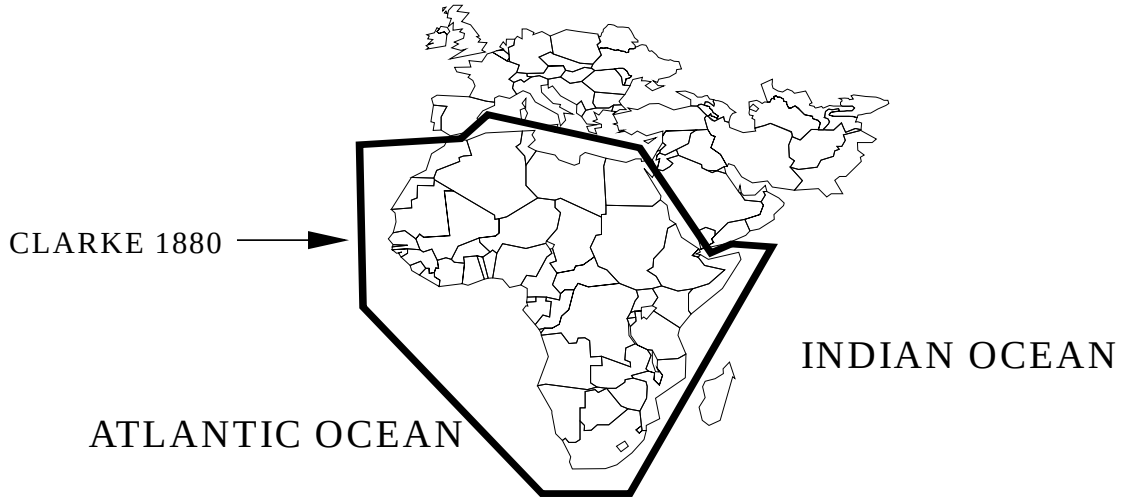
△ a: -112.145 △ f x 10^4 : -0.54750714

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
NORTH SAHARA 1959	ALGERIA	-186	-93	310	NSD		2
OMAN	OMAN	-346	-1	224	FAH	75	2
POINT 58	MEAN SOLUTION (BURKINO FASO AND NIGER)	-106	-129	165	PTB		2
POINTE NOIRE 1948	CONGO	-148	51	-291	PTN		2
SIERRA LEONE 1960	SIERRA LEONE	-88	4	101	SRL		2
VITI LEVU 1916	VITI LEVU ISLAND (FIJI ISLANDS)	51	391	-36	MVS	95	2
VOIROL 1874 SEE NOTE EIGHT	TANZANIA/ALGERIA	-73	-247	227	VOI		2
VOIROL 1960 SEE NOTE TWO	ALGERIA	-123	-206	219	VOR		2

Table A-9d △ f x 10^7: -547.507 PADS CODE: 2



DRAFT

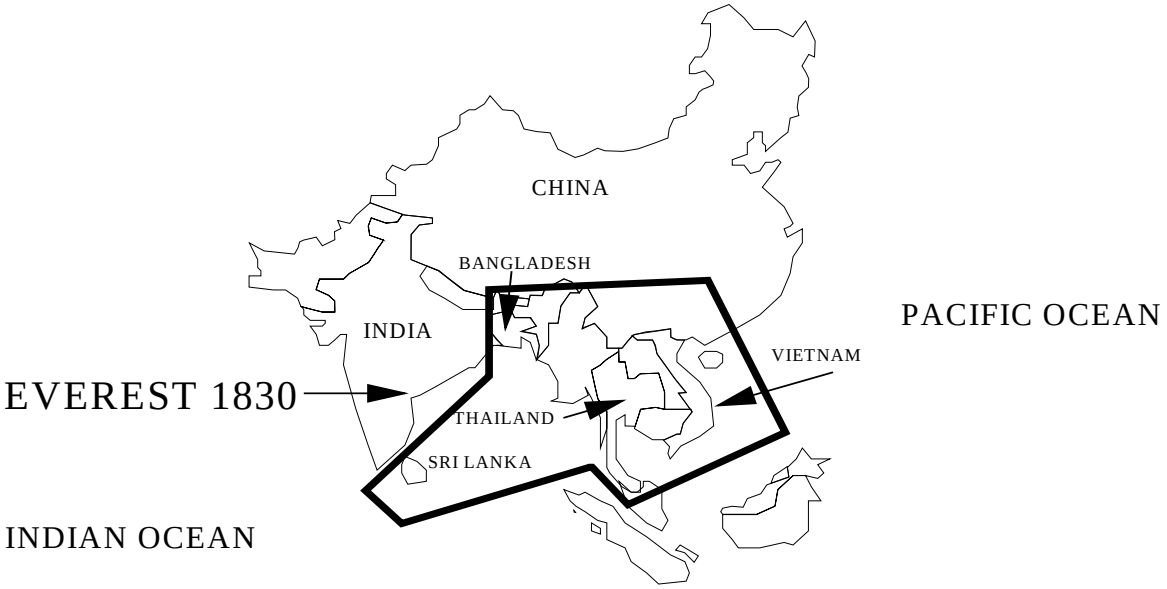
EVEREST 1830

a: 6377276.34518 b: 6356075.41511 1/f: 300.8017

△ a: +860.655 △ f x 10^4 : +0.28361368

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
INDIAN	BANGLADESH	282	726	254	IND-B	SEE NOTE ONE	2
INDIAN 1954	THAILAND	217	823	299	INF-A	SEE NOTE ONE	2
INDIAN 1960					ING		2
	CON SON ISLAND (VIETNAM)	182	915	344	ING-B	SEE NOTE ONE	2
	VIETNAM Near 16 deg N	198	881	317	ING-A	SEE NOTE ONE	2
INDIAN 1975					INH		
	THAILAND	210	814	289	INH-A	SEE NOTE ONE	2
KANDAWALA	SRI LANKA	-97	787	86	KAN	41	2

Table A-10 △ f x 10^7: +283.614 PADS CODE: 4



DRAFT

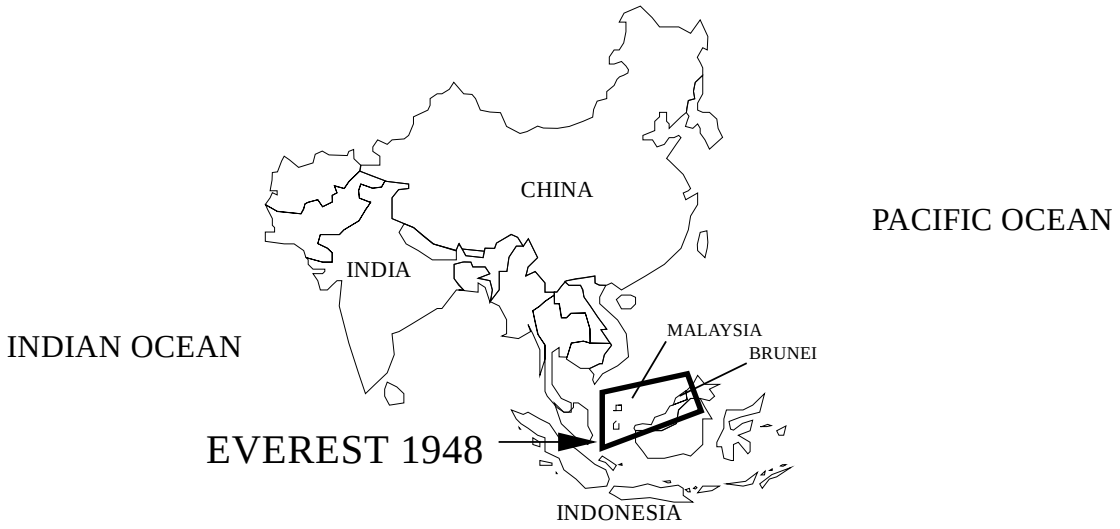
EVEREST 1948

a: 6377298.556 b: 6356097.550 1/f: 300.8017

△ a: +838.444 △ f x 10^4 : +0.28361368

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
TIMBALAI 1948	BRUNEI AND	-679	669	-48	TIL	**SEE NOTE ONE**	2
	EAST MALAYSIA						
	(SARAWAK AND SABAH)						

Table A-11 △ f x 10^7: +283.614 PADS CODE:



DRAFT

MOD. EVEREST 1948

a: 6377304.063 b: 6356103.039 1/f: 300.8017

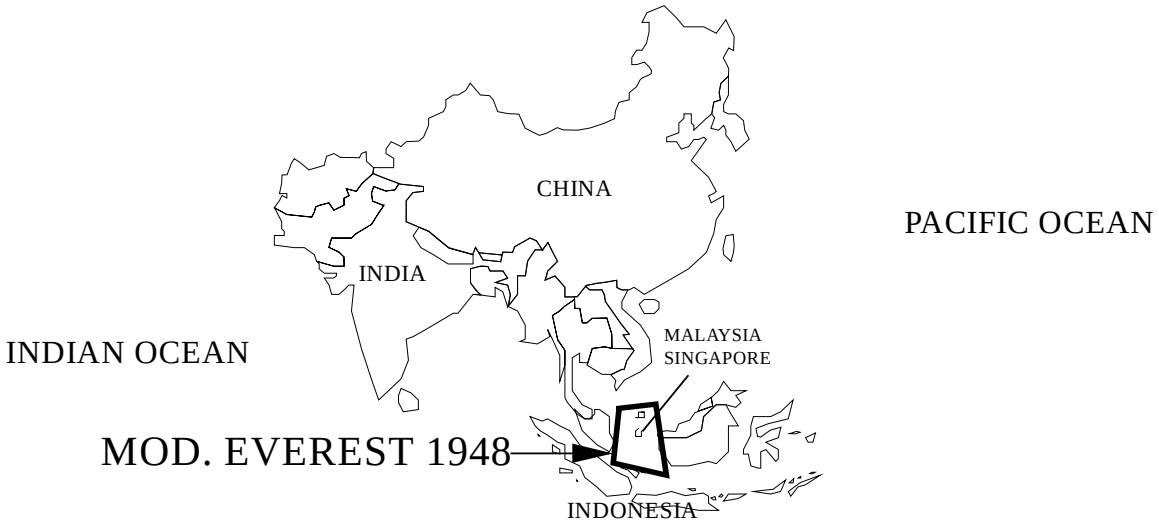
△ a: +832.937 △ f x 10^4 : +0.28361368

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
KERTAU 1948	WEST MALAYSIA AND SINGAPORE	-11	851	5	KEA	43	2

Table A-12 △ f x 10^7: +283.614 PADS CODE: 12



DRAFT

EVEREST 1956

a: 6377301.243 b: 6356100.228 1/f: 300.8017

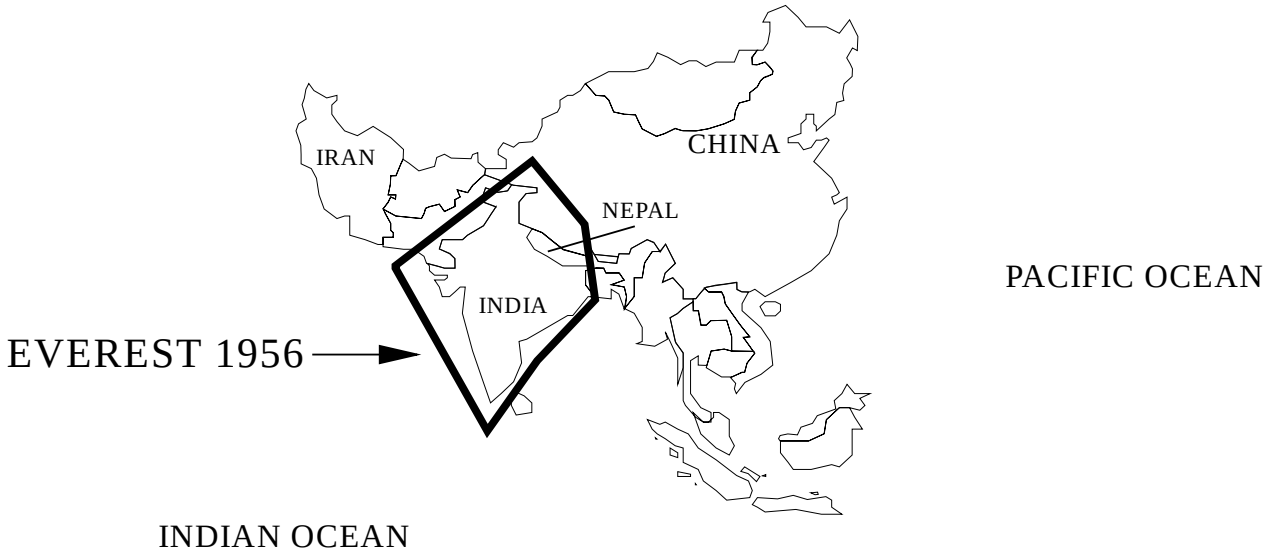
△ a: +835.757 △ f x 10^4 : +0.28361368

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
INDIAN	INDIA AND NEPAL	295	736	257	IND-I	SEE NOTE ONE	2

Table A-13 △ f x 10^7: +283.614 PADS CODE:



DRAFT

EVEREST (PAKISTAN)

a: 6377309.613 b: 6356108.571 1/f: 300.8017

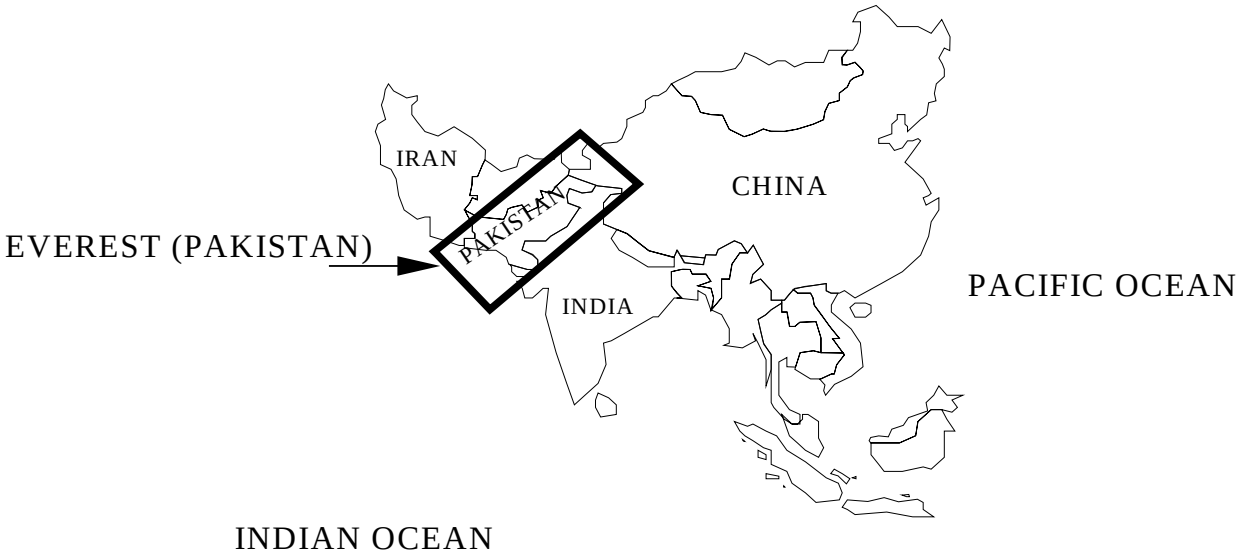
△ a: +827.387 △ f x 10^4 : +0.28361368

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
INDIAN SEE NOTE EIGHT	PAKISTAN	283	682	231	IND-P	SEE NOTE ONE	2

Table A-14 △ f x 10^7: +283.614 PADS CODE:



DRAFT

MODIFIED FISCHER 1960

a: 6378155.0 b: 6356773.320 1/f: 298.3

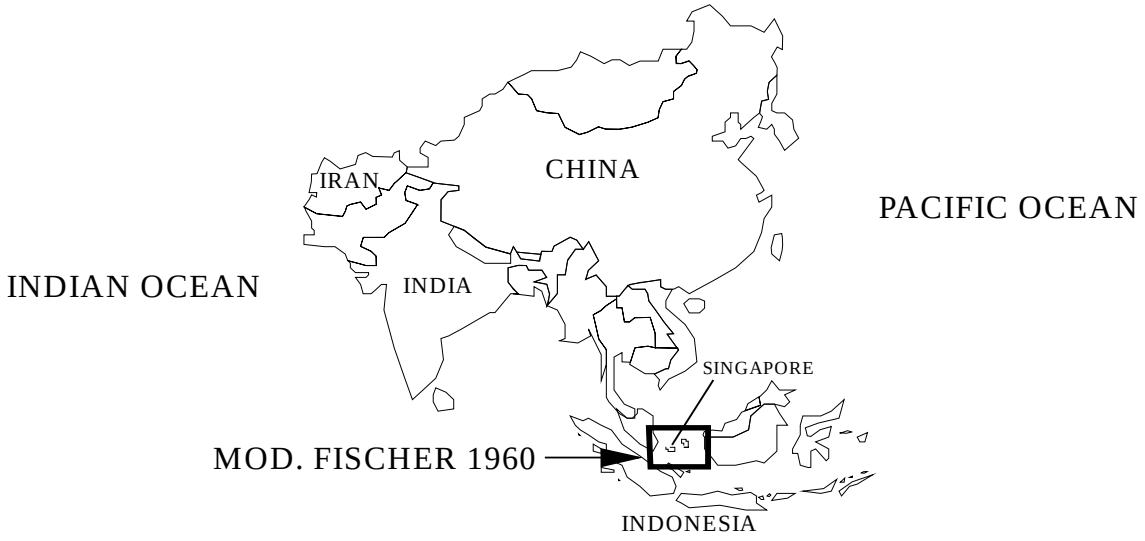
△ a: -018.000 △ f x 10^4 : +0.00480795

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
SOUTH ASIA	SINGAPORE	7	-10	-26	SOA	89	2

Table A-15 △ f x 10^7: +004.808 PADS CODE:



DRAFT

GEODETIC REFERENCE SYSTEM 1980

a: 6378137 b: 6356752.3141 1/f: 298.25722 2101

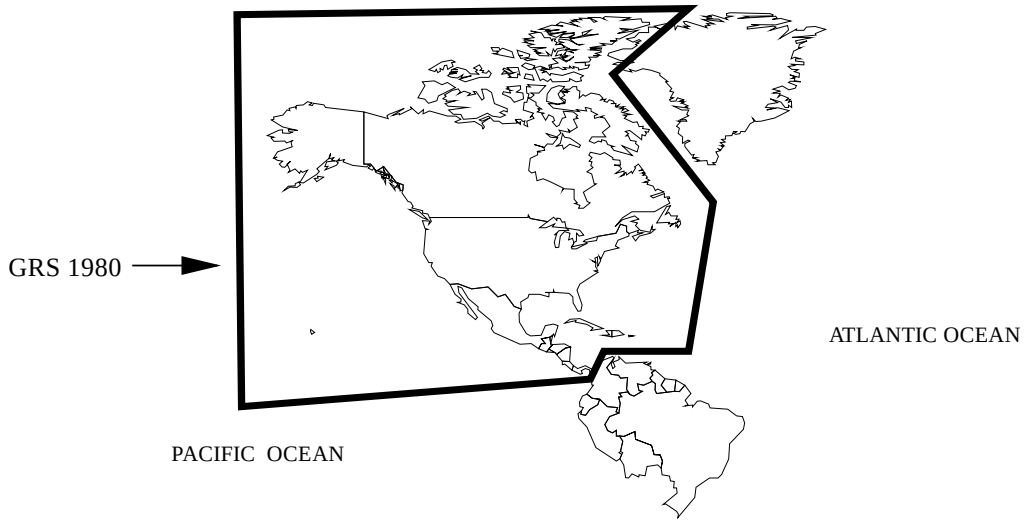
△ a: 000.000 △ f x 10^4 : +0.00000016

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △X	△Y	△Z	DATUM CODE	DDCT CODE	REF
NORTH AMERICAN 1983					NAR		2
	ALASKA	0	0	0	NAR-A	71	2
	(EXCLUDING THE ALEUTIAN ISLANDS)						
	ALEUTIAN ISLANDS	-2	0	4	NAR-E		2
	CANADA	0	0	0	NAR-B	71	2
	CONUS	0	0	0	NAR-C	71	2
	HAWAII	1	1	-1	NAR-H		2
	MEXICO AND	0	0	0	NAR-D	71	2
	CENTRAL AMERICA						

Table A-16 △ f x 10^7: +000.000 PADS CODE: 9



DRAFT

GEODETIC REFERENCE SYSTEM 1980 CHINA

a: 6378140 b: 6356755.288 1/f: 298.257

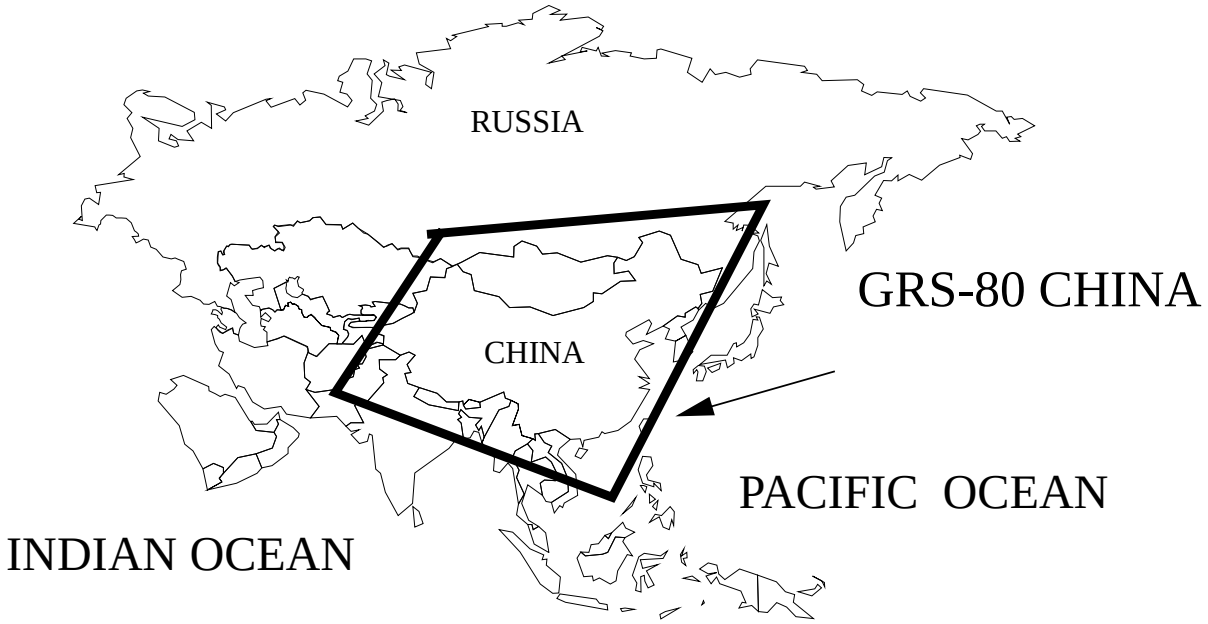
△ a: -003.000 △ f x 10^4 : -0.00002514

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
BEIJING 1982 (PEKING 1982)	CHINA AFTER 31 DEC 1980						

Table A-17 △ f x 10^7: -000.025 PADS CODE:



DRAFT

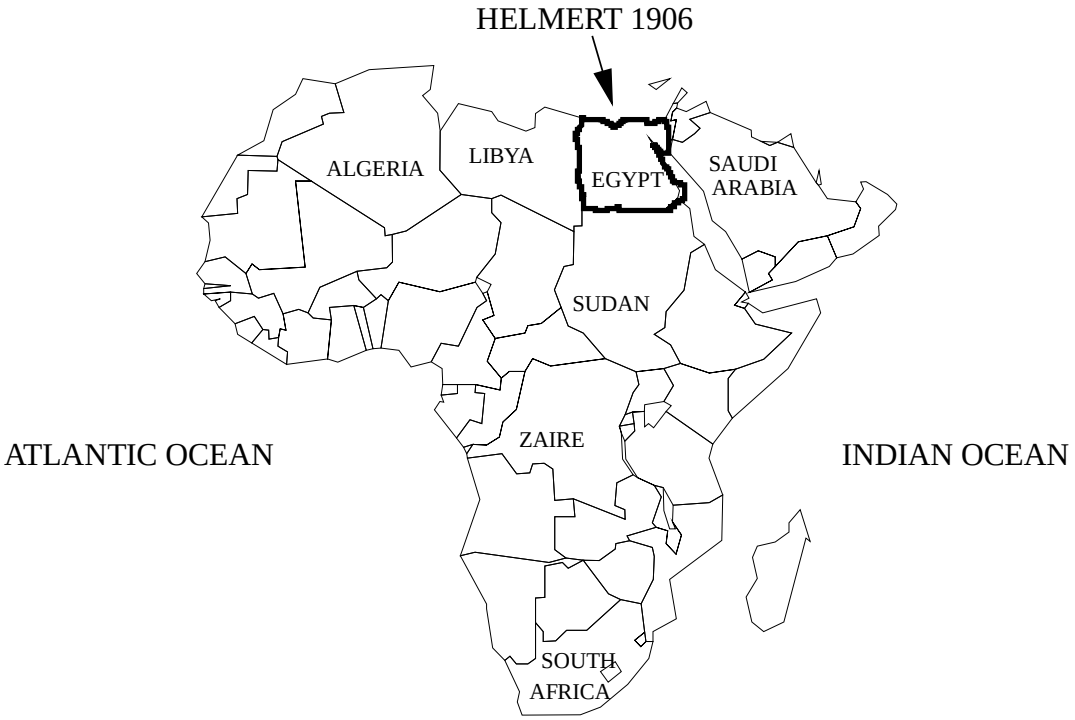
HELMERT 1906

a: 6378200 b: 6356818.170 1/f: 298.3

△ a: -063.000 △ f x 10^4 : +0.00480795

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
OLD EGYPTIAN 1907							
	EGYPT	-130	110	-13	OEG	73	2

Table A-18 △ f x 10^7: +004.808 PADS CODE:



AFRICA

DRAFT

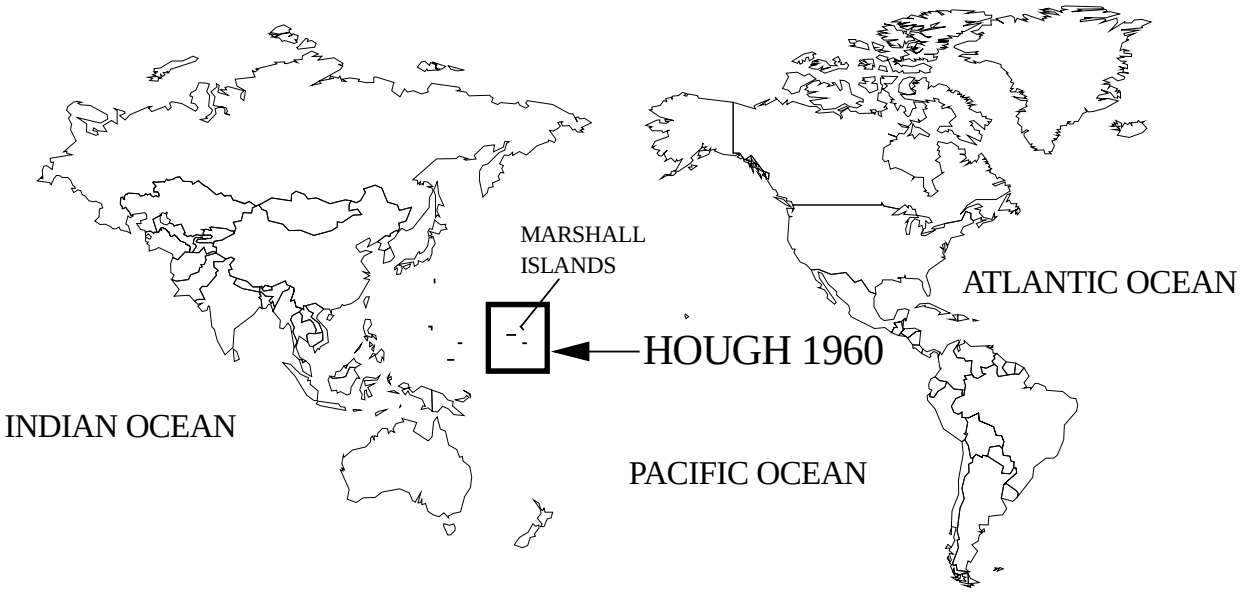
HOUGH 1960

a: 6378270 b: 6356684.34343 1/f: 297

△ a: -133.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
WAKE-ENIWETOK 1960							
	MARSHALL IS.	102	52	-38	ENW	SEE NOTE ONE	2

Table A-19 △ f x 10^7: -141.927 PADS CODE: 14



DRAFT

INDONESIAN 1974

a: 6378160.0 b: 6356774.504 1/f: 298.247

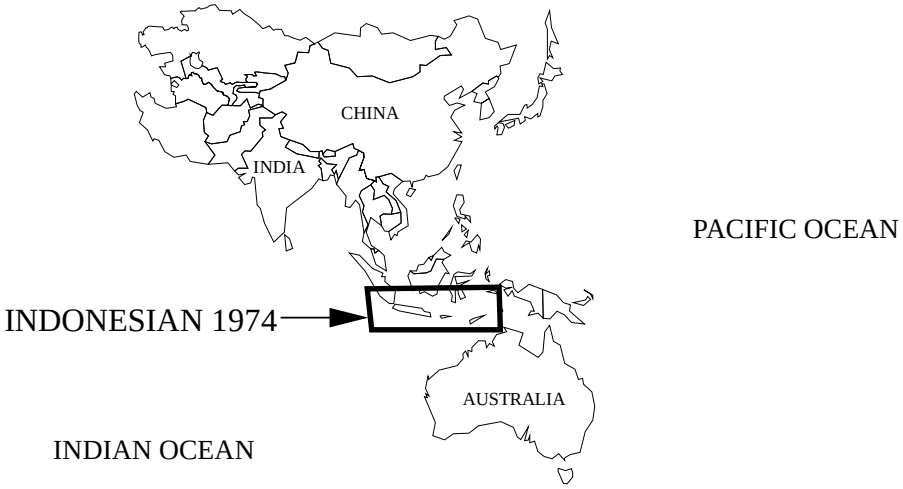
△ a: -023.000 △ f x 10^4 : -0.00114930

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
INDONESIAN 1974							
	INDONESIA	-24	-15	5	IDN		2

Table A-20 △ f x 10^7: -001.149 PADS CODE:



DRAFT

INTERNATIONAL 1924

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
AIN EL ABD 1970					AIN		
	BAHRAIN ISLAND	-150	-250	-1	AIN-A	SEE NOTE ONE	2
	SAUDI ARABIA	-143	-236	7	AIN-B		2
ASCENSION ISLAND 1958	ASCENSION IS.	-205	107	53	ASC	SEE NOTE ONE	2
ASTRO BEACON "E" 1945	IWO JIMA	145	75	-272	ATF	8	2
ASTRO DOS 71/4	ST. HELENA IS.	-320	550	-494	SHB	10	2
ASTRO TERN IS. (FRIG) 1961	TERN ISLAND	114	-116	-333	TRN	9	2
ASTRONOMICAL STATION 1952	MARCUS ISLAND	124	-234	-25	ASQ	11	2
BELLEVUE (IGN)	EFATE AND ERROMANGO IS.	-127	-769	472	IBE	14	2
BISSAU	GUINEA-BISSAU	-173	253	27	BID		2
BOGOTA OBSERVATORY	COLUMBIA	307	304	-318	BOO	16	2
CAMP AREA ASTRO SEE NOTE EIGHT	CAMP McMURDO, ANTARCTICA	-104	-129	239	CAZ		2
CAMPO INCHAUSPE 1969	ARGENTINA	-148	136	90	CAI	17	2

Table A-21a △f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
CANTON ASTRO 1966	PHOENIX ISLANDS	298	-304	-375	CAO	18	2
CHATHAM IS. ASTRO 1971	CHATHAM ISLAND (NEW ZEALAND)	175	-38	113	CHI	22	2
CHUA ASTRO	PARAGUAY	-134	229	-29	CHU	23	2
CORREGO ALEGRE	BRAZIL	-206	172	-6	COA	24	2
DOS 1968	GIZO ISLAND (NEW GEORGIA IS.)	230	-199	-752	GIZ	26	2
EASTER ISLAND 1967	EASTER ISLAND	211	147	111	EAS	27	2
EUROPEAN 1950 AFRICA					EUR		
	EGYPT	-130	-117	-151	EUR-F		2
	TUNISIA	-112	-77	-145	EUR-T		2
EUROPEAN 1950 EUROPE					EUR		2
	MEAN SOLUTION	-87	-98	-121	EUR-M	28	2
	WESTERN EUROPE (AUSTRIA, DENMARK, FRANCE, GERMANY, NETHERLANDS, AND SWITZERLAND)	-87	-96	-120	EUR-A		2
	CYPRUS	-104	-101	-140	EUR-E		2
	ENGLAND, CHANNEL ISLANDS, SCOTLAND, AND SHETLAND ISLANDS	-86	-96	-120	EUR-G		2

Table A-21b △ f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
EUROPEAN 1950					EUR		2
EUROPE Cont.	ENGLAND, IRELAND,	-86	-96	-120	EUR-K		2
	SCOTLAND, AND SHETLAND						
	ISLANDS						
	GREECE	-84	-95	-130	EUR-B		2
	ITALY	-97	-103	-120	EUR-I		2
	(SARDINIA)						
	ITALY	-97	-88	-135	EUR-J		2
	(SICILY)						
	MALTA	-107	-88	-149	EUR-L		2
	NORWAY AND	-87	-95	-120	EUR-C		2
	FINLAND						
	PORTUGAL	-84	-107	-120	EUR-D		2
	AND SPAIN						
EUROPEAN 1950					EUR		
MIDDLE EAST	IRAN	-117	-132	-164	EUR-H		2
EUROPEAN 1950	ISRAEL, KUWAIT,	-103	-106	-141	EUR-S		2
MIDDLE EAST	JORDAN, LEBANON,						
SEE NOTE EIGHT	SAUDI ARABIA,						
	IRAQ, AND SYRIA						
EUROPEAN 1979	MEAN SOLUTION	-86	-98	-119	EUS	29	2
	(AUSTRIA, FINLAND, NETHERLANDS,						
	NORWAY, SPAIN, SWEDEN, AND						
	SWITZERLAND)						

Table A-21c △ f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
GAN 1970 (GANDAJIKA BASE)	REPUBLIC OF MALDIVES	-133	-321	50	GAA	30	2
GEODETIC DATUM 1949	NEW ZEALAND	84	-22	209	GEO	31	2
GRACIOSA BASE SW 1948	AZORES (FAIAL, GRACIOSA, PICO, SAO JORGE, AND TERCEIRA IS.)	-104	167	-38	GRA		2
GUX 1 ASTRO	GUADALCANAL	252	-209	-751	DOB	33	2
HERAT NORTH SEE NOTE FOUR SEE NOTE EIGHT	AFGHANISTAN	-333	-222	114	HEN		2
HJORSEY 1955	ICELAND	-73	46	-86	HJO	34	2
HONG KONG 1963	HONG KONG	-156	-271	-189	HKD	35	2
HU-TZU-SHAN	TAIWAN	-637	-549	-203	HTN		2
ISTS 061 ASTRO 1968	SOUTH GEORGIA IS	-794	119	-298	ISG		2
ISTS 073 ASTRO 1969	DIEGO GARCIA	208	-435	-229	IST	39	2
JOHNSTON ISLAND 1961	JOHNSTON ISLAND	189	-79	-202	JOH	SEE NOTE ONE	2

Table A-21d △ f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
KERGUELEN ISLAND 1949	KERGUELEN IS.	145	-187	103	KEG	42	2
KUSAIE ASTRO 1951	CAROLINE ISLANDS	647	1777	-1124	KUS		2
	MICRONESIA						
MIDWAY ASTRO 1961	MIDWAY ISLANDS	912	-58	1227	MID	53	2
NAPARIMA BWI	TRINIDAD AND TOBAGO	-10	375	165	NAP	SEE NOTE ONE	2
OBSERVATORIO METEORO-LOGICO 1939	AZORES (CORVO AND FLORES ISLANDS)	-425	-169	81	FLO	72	2
PICO DE LAS NIEVES	CANARY ISLANDS	-307	-92	127	PLN	77	2
PITCAIRN ASTRO 1967	PITCAIRN ISLAND	185	165	42	PIT	78	2
PORTO SANTO 1936 (SOUTHEAST BASE)	PORTO SANTO AND MADEIRA ISLANDS	-499	-249	314	POS	90	2
PROVISIONAL SOUTH AMERICAN 1956					PRP		
	MEAN SOLUTION (BOLIVIA, CHILE, COLUMBIA, PERU, ECUADOR, GUYANA, AND VENEZUELA)	-288	175	-376	PRP-M	80	2
	BOLIVIA	-270	188	-388	PRP-A		2

Table A-21e △ f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
PROVISIONAL SOUTH AMERICAN 1956 Cont.					PRP		
	NORTHERN CHILE (Near 19 deg S)	-270	183	-390	PRP-B		2
	SOUTHERN CHILE (Near 43 deg S)	-305	243	-442	PRP-C		2
	COLUMBIA	-282	169	-371	PRP-D		2
	ECUADOR	-278	171	-367	PRP-E		2
	GUYANA	-298	159	-369	PRP-F		2
	PERU	-279	175	-379	PRP-G		2
	VENEZUELA	-295	173	-371	PRP-H		2
PROVISIONAL SOUTH CHILEAN 1963 (HITO XVIII 1963)	SOUTHERN CHILE (Near 53 deg S)	16	196	93	HIT	79	2
QATAR NATIONAL	QATAR	-129	-283	21	QAT	82	2
SEE NOTE SEVEN							
QORNOQ	SOUTH GREENLAND	164	138	-189	QUO	83	2
REUNION	MASCARENE IS.	94	-948	-1262	REU	44	2
ROME 1940	SARDINIA	-225	-65	9	MOD	84	2
SANTO (DOS) 1965	ESPIRITO SANTO IS.	170	42	84	SAE	86	2

Table A-21f △ f x 10^7: -141.927 PADS CODE: 2

DRAFT

INTERNATIONAL 1924 Cont.

a: 6378388 b: 6356911.9462 1/f: 297

△ a: -251.000 △ f x 10^4 : -0.14192702

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
SAO BRAZ	AZORES (SAO MIGUEL, SANTA MARIA IS.)	-203	141	53	SAO	85	2
SAPPER HILL 1943	EAST FALKLAND IS.	-355	21	72	SAP	SEE NOTE ONE	2
SELVAGEM GRANDE 1938 (MARCO ASTRO)	SALVAGE ISLANDS	-289	-124	60	SGM	50	2
TANANARIVE OBSERVATORY 1925 SEE NOTE EIGHT	MADAGASCAR	-189	-242	-91	TAN		2
TRISTAN ASTRO 1968	TRISTAN DA CUNHA	-632	438	-609	TDC	94	2
WAKE ISLAND ASTRO 1952	WAKE ATOLL	276	-57	149	WAK		2
YACARE SEE NOTE EIGHT	URUGUAY	-155	171	37	YAC		2
ZANDERIJ	SURINAME	-265	120	-358	ZAN	84	2

Table A-21g △ f x 10^7: -141.927 PADS CODE: 2

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KRASSOVSKY 1940

a: 6378245 b: 6356863.019 1/f: 298.3

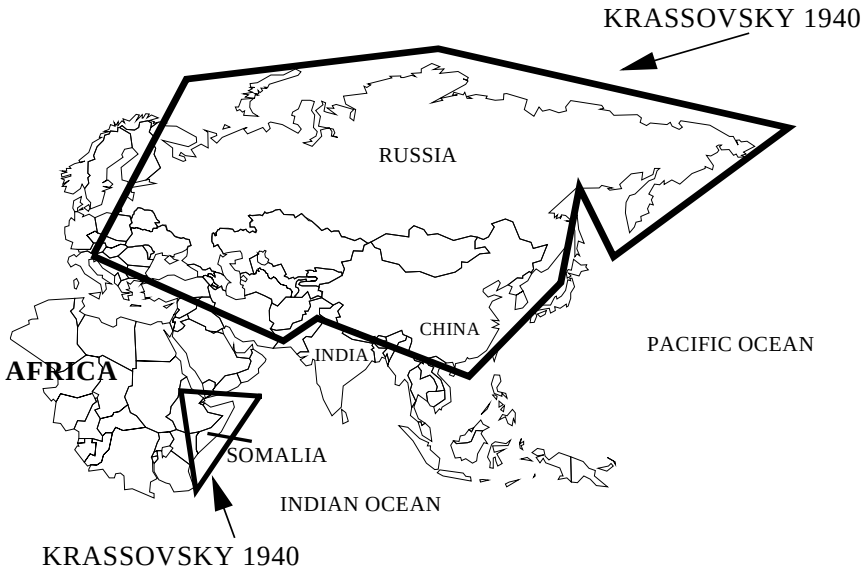
△a: -108.000 △f x 10^4 : +0.00480795

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △X	△Y	△Z	DATUM CODE	DDCT CODE	REF
AFGOOYE	SOMALIA	-43	-163	45	AFG	2	2
HERAT NORTH	AFGHANISTAN						4
SEE NOTE FOUR							
PEKING 1954	SHANGHAI, CHINA	-12	-113	-41			
SEE NOTE EIGHT							
PULKOVO 1942	RUSSIA	28	-130	-95	PUK		2
S-42					SPK		
(PULKOVO 1942)	HUNGARY	28	-121	-77	SPK-A		2
	POLAND	23	-124	-82	SPK-B		2
	CZECHOSLOVAKIA PRIOR TO 1 JAN 1993	26	-121	-78	SPK-C		2
	LATVIA	24	-124	-82	SPK-D		2
	KAZAKHSTAN	15	-130	-84	SPK-E		2
	ALBANIA	24	-130	-92	SPK-F		2
	ROMANIA	28	-121	-77	SPK-G		2

Table A-22 △f x 10^7: +004.808 PADS CODE:



DRAFT

SOUTH AMERICAN 1969 SEE NOTE SIX

a: 6378160 b: 6356774.7192 1/f: 298.25

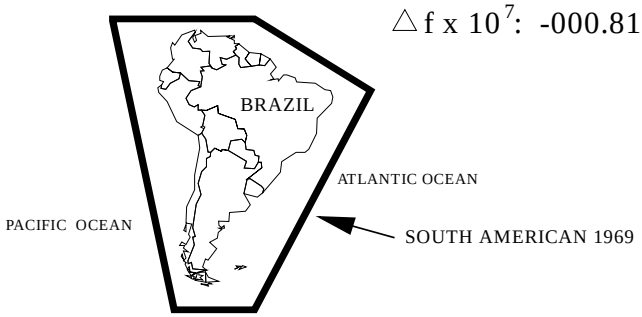
△ a: -023.000 △ f x 10^4 : -0.00081204

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
					SAN		
SOUTH AMERICAN 1969	MEAN SOLUTION SOUTH AMERICA	-57	1	-41	SAN-M	88	2
	ARGENTINA	-62	-1	-37	SAN-A		2
	BOLIVIA	-61	2	-48	SAN-B		2
	BRAZIL	-60	-2	-41	SAN-C		2
	CHILE	-75	-1	-44	SAN-D		2
	COLOMBIA	-44	6	-36	SAN-E		2
	ECUADOR (EXCLUDING GALAPAGOS IS)	-48	3	-44	SAN-F		2
	ECUADOR (BALTRA, GALAPAOS ISLANDS)	-47	26	-42	SAN-J		2
	GUYANA	-53	3	-47	SAN-G		2
	PARAGUAY	-61	2	-33	SAN-H		2
	PERU	-58	0	-44	SAN-I		2
	TRINIDAD AND TOBAGO	-45	12	-33	SAN-K		2
	VENEZUELA	-45	8	-33	SAN-L		2

Table A-23 △ f x 10^7: -000.812 PADS CODE: 8



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SOVIET GEODETIC SYSTEM 1985

a: 6378136 b: 6356751.302 1/f: 298.257

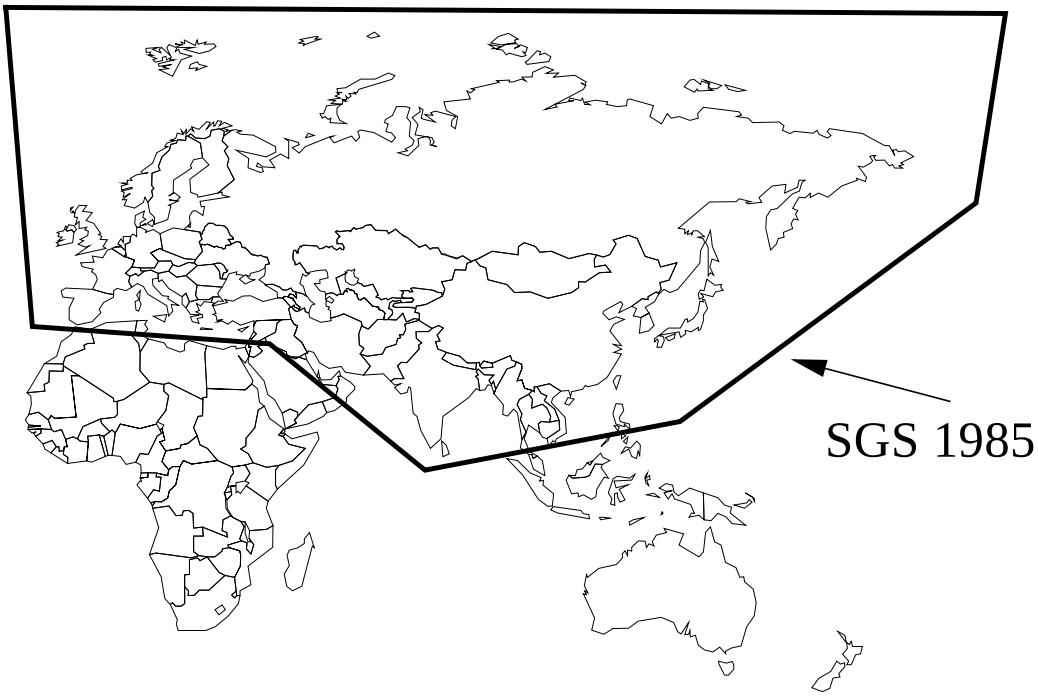
△ a: +001.000 △ f x 10^4 : -0.00002514

DATUM TRANSFORMATION PARAMETERS

LOCAL DATUM TO WGS 84

LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
SGS 1985	ASIA AND EUROPE	3	9	-9			5

Table A-24 △ f x 10^7: -000.025 PADS CODE:



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WORLD GEODETIC SYSTEM 1972

a: 6378135 b: 6356750.5 1/f: 298.26

△ a: +2 △ f x 10^4 : +0.00031211

DATUM TRANSFORMATION PARAMETERS							
LOCAL DATUM TO WGS 84							
LOCAL GEODETIC DATUM	COUNTRY/ AREA	TRANSFORMATION PARAMETERS △ X	△ Y	△ Z	DATUM CODE	DDCT CODE	REF
WGS 1972	GLOBAL	N/A	N/A	N/A	WD	97	2
SEE NOTE THREE							

Table A-25 △ f x 10^7: +000.312 PADS CODE: 13

WGS 1972

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NOTES FOR DATUM TABLES
(APPENDIX A)

NOTE 1: Any entry reading **SEE NOTE ONE** in Tables A-3 through A-24 of this appendix are so noted due to differences between the ST 6-2-40 Appendix C and NIMA TR 8350.2. The differences are both in ellipsoid and datum areas. The data in Tables A-3 through A-24 is from the NIMA TR 8350.2 and therefore considered more accurate. Any datum with **SEE NOTE ONE** in the DDCT Code column should be transformed to other datums with the user defined option.

NOTE 2: Any entry reading **SEE NOTE TWO** in Tables A-3 through A-24 of this appendix are so noted due to inconsistent listings of datums referenced to the Clarke 1880 ellipsoid. Table A-1 lists five different Clarke 1880 ellipsoids, the National Imagery and Mapping Agency (NIMA) has adopted only one. Different countries have adopted different dimensions for the Clarke 1880 ellipsoid. These differences depend on two things; which of Clarke's original numbers were used: (a,b) or (a,f), and which feet to meters conversion was used.

In areas referenced to the ARC 1950 datum, the Clarke 1880 dimensions adopted are:

a: 6378249.145326 b: 6356514.966721 f: 1/293.4663076

In areas referenced to Carthage, Merchich, and Voirol datums, the adopted dimensions are:

a: 6378249.2 b: 6356515.0 f: 1/293.46598

The NIMA adopted dimensions are:

a: 6378249.145 b: 6356514.8696 f: 1/293.465

NIMA TR 8350.2 lists datum transformation parameters for local datums referenced to the NIMA adopted Clarke 1880 and not the dimensions adopted by other countries. Any datum with **SEE NOTE TWO** in the DDCT Code column should be transformed to other datums with the user defined option.

NOTE 3: WGS-72 is transformed to WGS-84 with a formula that is more accurate than the Abridged Molodensky formulas; therefore, datum shifts are not necessary. The formula used is explained in detail in NIMA TR 8350.2, and are shown below.

$$\phi WGS\ 84 = \phi WGS\ 72 + \Delta\phi$$
$$\lambda WGS\ 84 = \lambda WGS\ 72 + \Delta\lambda$$
$$hWGS\ 84 = hWGS\ 72 + \Delta h$$

Whereas:

$$\Delta\phi'' = (4.5\cos\phi) / (a \sin 1'') + (\Delta f \sin 2\phi) / (\sin 1'')$$
$$\Delta\lambda'' = 0.554$$
$$\Delta h = 4.5 \sin\phi + a\Delta f \sin^2\phi - \Delta a + \Delta r$$

When:

$\Delta f = 0.3121057 \times 10^{-7}$
$a = 6378135$ m.
$\Delta a = 2.0$ m.
$\Delta r = 1.4$ m.

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NOTES FOR DATUM TABLES Cont.
(APPENDIX A)

NOTE 4: Herat North Datum was used by the Soviet Union with Krassovsky as the reference ellipsoid in northern Afghanistan. The US and UK used Herat North Datum with International as the reference ellipsoid to triangulate in southern Afghanistan. The connection between these two systems usually differs by 20 to 30 meters. Herat North Datum referenced to Krassovsky ellipsoid is a programmed option in the Gauss-Kruger Grid (Module 15) in the BUCS DDCT Rev0.

NOTE 5: Potsdam Datum was used with the Gauss-Kruger Grid in East Germany and is a programmed option in Module 15 of the BUCS DDCT Rev0.

NOTE 6: The International Union of Geodesy and Geophysics (IUGG) recommended the adoption of the ellipsoid GRS-67 at their 1967 meeting in Lucerne, Switzerland. The new ellipsoid was adopted for use when a greater degree of accuracy was needed than could be obtained with the International 1924 ellipsoid. The ellipsoid became part of the Geodetic Reference System of 1967, which was adopted in 1971 by the IUGG meeting in Moscow. This ellipsoid is used in both South America and Australia; however, the name was changed to South American 1969 and Australian National to more conveniently describe the Reference Ellipsoid. NIMA TR 8350.2 lists the more convenient names of these ellipsoids.

NOTE 7: The State of Qatar was subject to a geodetic survey during the period of 18 May - 5 June 1993 by the Centre for Geodetic Information Systems, State of Qatar. DMA (NIMA) adjusted the survey and the resultant transformation parameters are listed here. These parameters are different than those listed in NIMA TR 8350.2. This data is published in DMA Publication GGAD-95-1519 dtd May 1993.

NOTE 8: Any entry reading **SEE NOTE EIGHT** in Tables A-3 through A-24 of this appendix are local geodetic datums related to WGS-84 through <u>non-satellite</u> ties to the local control.

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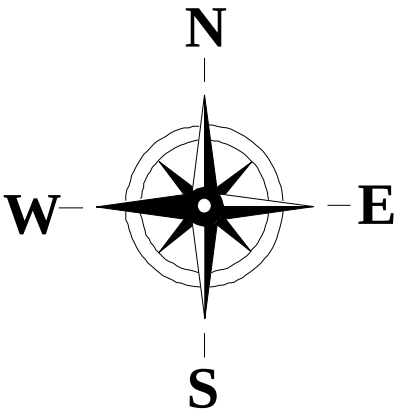
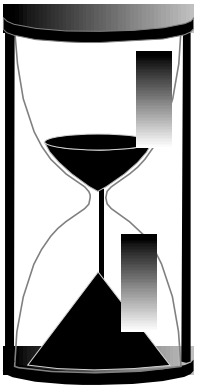
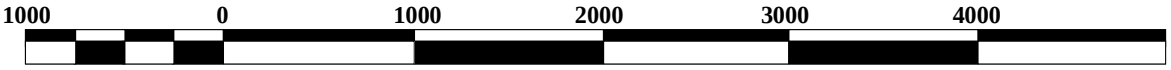
APPENDIX B

CONVERSION FACTORS, TABLES, TIME ZONE OFFSETS, AND RADIO TRANSMITTING STATIONS FOR TIME SIGNALS







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MAP DISTANCES TO LAND DISTANCES

MAP SCALE	PER INCH OF MAP		PER CM OF MAP		ONE LAND MILE		ONE LAND KILOMETER	
	LAND MILES	LAND METERS	LAND MILES	LAND METERS	MAP INCHES	MAP CM	MAP INCHES	MAP CM
500,000	7.891	12,700	3.107	5,000	0.127	0.322	0.079	0.2
250,000	3.945	6,350	1.553	2,500	0.253	0.644	0.157	0.4
100,000	1.578	2,540	0.621	1,000	0.634	1.609	0.394	1.0
50,000	0.789	1,270	0.311	500	1.267	3.218	0.787	2.0
25,000	0.394	635	0.155	250	2.534	6.436	1.575	4.0
20,000	0.316	508	0.124	200	3.168	8.046	1.968	5.0
10,000	0.158	254	0.062	100	6.336	16.090	3.937	10.0
5,000	0.079	127	0.031	50	12.672	32.180	7.874	20.0

Table B-1

CELCIUS TO FAHRENHEIT

°C	= °F	°C	= °F	°C	= °F	°C	= °F
-15	5.0	0	32.0	15	59.0	30	86.0
-14	6.8	1	33.8	16	60.8	31	87.8
-13	8.6	2	35.6	17	62.6	32	89.6
-12	10.4	3	37.4	18	64.4	33	91.4
-11	12.2	4	39.2	19	66.2	34	93.2
-10	14.0	5	41.0	20	68.0	35	95.0
-9	15.8	6	42.8	21	69.8	36	96.8
-8	17.6	7	44.6	22	71.6	37	98.6
-7	19.4	8	46.4	23	73.4	38	100.4
-6	21.2	9	48.2	24	75.2	39	102.2
-5	23.0	10	50.0	25	77.0	40	104.0
-4	24.8	11	51.8	26	78.8	41	105.8
-3	26.6	12	53.6	27	80.6	42	107.6
-2	28.4	13	55.4	28	82.4	43	109.4
-1	30.2	14	57.2	29	84.2	44	111.2

Table B-2

$$F = 9/5\ {}^{\circ}C. + 32 \qquad {}^{\circ}C = \frac{5({}^{\circ}F. - 32)}{9}$$

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LINEAR MEASUREMENT CONVERSIONS

FROM	TO	EQUATION
METERS	FEET (INTERNATIONAL)	FT = M / O.3048 exact
	FEET (US SURVEY)	FT = M / O.30480060960
	FEET (BRITISH ORDNANCE)	FT = M / O.304800756
	FEET (INDIAN old)	FT = M / O.30479842
	FEET (SURVEY OF INDIA)	FT = M / O.3047996
	YARDS (INTERNATIONAL)	YDS = M x 1.093613
	STATUTE MILES	SMi = M / 1609.344 exact
	NAUTICAL MILES	NMi = M / 1852 exact
FEET (INTERNATIONAL)	METERS	M = FT x 0.3048 exact
	STATUTE MILES	SMi = FT / 5280 exact
	NAUTICAL MILES	NMi = FT / 6076.1033333
FEET (US SURVEY)	METERS	M = FT x 0.30480060960
	METERS	M = FT x 1200 / 3937 exact
	STATUTE MILES	SMi = FT / 5280 exact
	NAUTICAL MILES	NMi = FT / 6076.1033333
FEET (GREAT BRITAIN ORDNANCE SURVEY)	METERS	M = FT x 0.304800756
FEET (INDIAN old) Used by US and Great Britain for surveys in India and border nations.	METERS	M = FT x 0.30479842
FEET (SURVEY OF INDIA)	METERS	M = FT x 0.3047996
STATUTE MILES	KILOMETERS	KM = Mi / 0.6213712
KILOMETERS	STATUTE MILES	Mi = KM x 0.6213712

Table B-3

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ANGULAR MEASUREMENT CONVERSIONS

Table B-4

SYSTEM COMPARISONS

	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				

DEGREES	1 Deg = 60 Min	1 Min = 60 Sec
GRADS	1 Grad = 100 Min	1 Min = 100 Sec
TIME	1 Hour = 60 Min	1 Min = 60 Sec

Dec. DEGREES TO MILS	MILS = DEG / 0.05625
Dec. DEGREES TO GRADS	GRADS = DEG / 0.9
Dec. DEGREES TO RADIANS	RADS = DEG x (exact)
	RADS = DEG x 0.0174532777
MILS TO Dec. DEGREES	DEG = MILS x 0.05625
MILS TO GRADS	GRADS = MILS / 16
GRADS TO MILS	MILS = GRADS x 16
GRADS TO Dec. DEGREES	DEG = GRADS x 0.9
RADIANS TO Dec. DEGREES	DEG = RADS x

MISCELLANEOUS CONVERSION FACTORS

360 DEGREES = 21600 MIN = 1296000 SEC

1 DEGREE = MILS
1 MIL = 0.05625 DEGREES = 3.375 MINUTES

1 RADIAN = 57.2957790 DEGREES = Deg
1 DEGREE = 0.0174533 RADIANS

1 HOUR = 15 DEGREES
1 DEGREE = 0 Hr 4 Min

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MISCELLANEOUS CONVERSION FACTORS (Cont.)

Area Measurements:

144 square inches	= 1 square ft
9 square ft	= 1 square yd
30 1/4 square yd	= 1 square rod
160 square rods	= 1 acre
640 acres	= 1 square mile
1 Acre	= 43,560.21 square ft. (International)

MILS TO DEG, MIN, SEC

Step 1: Mils x 0.05625 = Dec. Degrees

Step 2: 60 x number to right of decimal = Dec. Minutes

Step 3: 60 x number to right of decimal = Seconds

Example: Convert 2198.876 mils to Degrees Minutes and Seconds

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"

DEG, MIN, SEC TO MILS

Step 1: (Minutes x 60) + Seconds = Number of seconds

Step 2: (Number of seconds / 3600) + Degrees = Dec. Degrees

Step 3: Dec. Degrees / 0.05625 = mils

Example: Convert 123° 41' 12.39" to mils

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

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World Time Zones

Table B-5a

For selected countries, listed alphbetically, the local standard time **offset** from Greenwich (UTC) is given with daylight savings time where observed. These offsets can be used to convert a UTC time to a local time (ie. PLGR needs the offset to display local time). To determine Greenwich Mean Time from local time, a Time Zone correction is needed. Time Zone corrections are determined by changeing the sign of the offset.
Information accurate as of Apr 2, 1997

Country	Local Standard Time Offset
Afghanistan	+4.5 hours
Albania	+1 hours (Local summer +2 hours)
Algeria	+1 hours (Local summer +2 hours)
American Samoa	-11 hours
Andorra	+1 hours (Local summer +2 hours)
Angola	+1 hours
Anguilla	-4 hours
Antarctica	-2 hours (Local summer -3 hours)
Antigua	-4 hours
Argentina	-3 hours
Argentina western prov	-4 hours
Armenia	+4 hours (Local summer +5 hours)
Aruba	-4 hours
Ascension	0 hours
Australia Northern Territory	+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)
Australia South	+9.5 hours (Local summer +10.5 hours)
Australia Tasmania	+10 hours (Local summer +11 hours)
Australia Western	+8 hours
Austria	+1 hours (Local summer +2 hours)
Azerbajian	+3 hours
Azores	-1 hours (Local summer 0 hours)
Bahamas	-5 hours (Local summer -4 hours)
Bahrain	+3 hours
Balearic Islands	+1 hours (Local summer +2 hours)
Bangladesh	+6 hours
Barbados	-4 hours
Belarus	+2 hours (Local summer +3 hours)
Belgium	+1 hours (Local summer +2 hours)
Belize	-6 hours

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Country	Local Standard Time Offset
Benin	+1 hours
Bermuda	-4 hours (Local summer -3 hours)
Bhutan	+6 hours
Bolivia	-4 hours
Bonaire	-4 hours
Bosnia Hercegovina	+1 hours (Local summer +2 hours)
Botswana	+2 hours
Brazil Acre	-4 hours (Local summer -5 hours)
Brazil Atlantic Islands	-1 hours (Local summer -2 hours)
Brazil East	-3 hours (Local summer -1 hours)
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 & 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)
Canary Islands	0 hours (Local summer +1 hours)
Canton Enderbury Islands	-11 hours
Cape Verde	-1 hours
Caroline Island	+11 hours
Cayman Islands	-5 hours
Central African Rep	+1 hours
Chad	+1 hours
Channel Islands	0 hours (Local summer +1 hours)
Chatham Island	+12.75 hours (Local summer +13.75 hours)
Chile	-4 hours (Local summer -3 hours)
China People's Rep	+8 hours
Christmas Islands	-10 hours
Colombia	-5 hours
Congo	+1 hours
Cook Islands	-10 hours
Costa Rica	-6 hours
Cote d'Ivoire	0 hours
Croatia	+1 hours (Local summer +2 hours)
Cuba	-5 hours (Local summer -4 hours)
Curacao	-4 hours

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Country	Local Standard Time Offset
Cyprus	+2 hours (Local summer +3 hours)
Czech Republic	+1 hours (Local summer +2 hours)
Dahomey	+1 hours
Denmark	+1 hours (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 hours)
Equitorial Guinea	+1 hours
Eritrea	+3 hours
Estonia	+2 hours (Local summer +3 hours)
Ethiopia	+3 hours
Falkland Islands	-4 hours (Local summer -3 hours)
Faroe Island	0 hours (Local summer +1 hours)
Fiji	+12 hours
Finland	+2 hours (Local summer +3 hours)
France	+1 hours (Local summer +2 hours)
French Guiana	-3 hours
French Polynesia	-10 hours
Gabon	+1 hours
Galapagos Islands	-5 hours
Gambia	0 hours
Gambier Island	-9 hours
Georgia	+4 hours
Germany	+1 hours (Local summer +2 hours)
Ghana	0 hours
Gibraltar	+1 hours (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 Scoresbysun	-1 hours (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 hours (Local summer 0 hours)
Guyana	-3 hours

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Country	Local Standard Time Offset
Haiti	-5 hours (Local summer -4 hours)
Honduras	-6 hours
Hong kong	+8 hours
Hungary	+1 hours (Local summer +2 hours)
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 hours)
Israel	+2 hours (Local summer +3 hours)
Italy	+1 hours (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 hours (Local summer +2 hours)
Madagascar	+3 hours
Madeira	0 hours (Local summer +1 hours)
Malawi	+2 hours
Malaysia	+8 hours
Maldives	+5 hours
Mali	0 hours

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Country	Local Standard Time Offset
Mallorca Islands	+1 hours (Local summer +2 hours)
Malta	+1 hours (Local summer +2 hours)
Mariana Island	+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 hours (Local summer +2 hours)
Mexico	-6 hours
Mexico Baja Calif Norte	-8 hours (Local summer -7 hours)
Mexico Nayarit	-7 hours
Mexico Sinaloa	-7 hours
Mexico Sonora	-7 hours
Midway Island	-11 hours
Moldova	+2 hours (Local summer +3 hours)
Moldovian Rep Pridnestrovye	+2 hours (Local summer +3 hours)
Monaco	+1 hours (Local summer +2 hours)
Mongolia	+8 hours
Morocco	0 hours
Mozambique	+2 hours
Myanmar	+6.5 hours
Namibia	+1 hours (Local summer +2 hours)
Nauru, Republic of	+12 hours
Nepal	+5.75 hours
Netherlands	+1 hours (Local summer +2 hours)
Netherlands Antilles	-4 hours
Nevis Montserrat	-4 hours
New Caledonia	+11 hours
New Hebrides	+11 hours
New Zealand	+12 hours (Local summer +13 hours)
Nicaragua	-6 hours (Local summer -5 hours)
Niger	+1 hours
Nigeria	+1 hours
Niue Island	-11 hours
Norfolk Island	+11.5 hours
Northern Ireland	0 hours (Local summer +1 hours)
Northern Mariana Islands	+10 hours
Norway	+1 hours (Local summer +2 hours)
Oman	+4 hours

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Country	Local Standard Time Offset
Pakistan	+5 hours
Palau	+9 hours
Panama	-5 hours
Papua New Guinea	+10 hours
Paraguay	-4 hours (Local summer -3 hours)
Peru	-5 hours
Philippines	+8 hours
Pingelap	+12 hours
Poland	+1 hours (Local summer +2 hours)
Ponape Island	+11 hours
Portugal	+1 hours (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 hours (Local summer +2 hours)
Sao Tome e Principe	0 hours
Saudi Arabia	+3 hours
Scotland	0 hours (Local summer +1 hours)
Senegal	0 hours
Seychelles	+4 hours
Sierra Leone	0 hours
Singapore	+8 hours
Slovakia	+1 hours (Local summer +2 hours)
Slovenia	+1 hours (Local summer +2 hours)
Society Island	-10 hours
Solomon Islands	+11 hours
Somalia	+3 hours
South Africa	+2 hours

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Country	Local Standard Time Offset
Spain	+1 hours (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 & Miquelon	-3 hours (Local summer -2 hours)
St Thomas	-4 hours
St Vincent	-4 hours
Sudan	+2 hours
Suriname	-3 hours
Swaziland	+2 hours
Sweden	+1 hours (Local summer +2 hours)
Switzerland	+1 hours (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 Island	-10 hours
Tunisia	1 hours
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 hours)
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)

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Country	Local Standard Time Offset
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 hours (Local summer +2 hours)
Venezuela	-4 hours
Vietnam	+7 hours
Virgin Islands	-4 hours
Wake Island	+12 hours
Wales	0 hours (Local summer +1 hours)
Wallis and Futuna Islands	+12 hours
Windward Islands	-4 hours
Yemen	+3 hours
Yugoslavia	+1 hours (Local summer +2 hours)
Zaire Kasai	+2 hours
Zaire Kinshasa Mbandaka	+1 hours
Zaire Haut Zaire	+2 hours
Zaire Kivu	+2 hours
Zaire Shaba	+2 hours
Zambia	+2 hours
Zimbabwe	+2 hours

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Radio Transmitting Stations For Time Signals

Table B-5b

Call Sign	Location and Position	Freq (MHz)
BPV	Shanghai, China	5.0
	N 31° 12'	10.0
	E 121° 26'	15.0
CHU	Ottawa, Canada	3.330
	N 45° 18'	7.335
	W 75° 45'	14.670
HBG	Prangins, Switzerland	0.075
	N 46° 24'	
	E 06° 15'	
JJY	Koganei, Tokyo, Japan	2.5
	N 35° 42'	5.0
	E 139° 31'	10.0
		15.0
LOL1	Buenos-Aires, Argentina	5.0
	S 34° 27'	10.0
	W 58° 21'	15.0
MSF	Rugby, United Kingdom	2.5
	N 52° 22'	5.0
	W 01° 11'	10.0
VNG	Lyndhurst, Australia	4.5
	S 38° 00'	7.5
	E 145° 02'	12.0
WWV	Fort Collins, Colorado, USA	2.5
	N 40° 41'	5.0
	W 105° 02'	10.0
		15.0
		20.0

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Table B-5b (cont)

Call Sign	Location and Position	Freq (MHz)
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

Time by Broadcast or Telephone.

a. When using a watch or HCS in astronomic observations, the time should be checked with radio signals to determine the watch correction. The time signals for the western hemisphere are broadcast by radio station WWV at Fort Collins, Co., at frequencies 2.5, 5, 10, 15 and 20 megahertz (MHZ). Signals for the Eastern Hemisphere broadcast by radio station JJY at Koganei, Tokyo, Japan and can be received at frequencies 2.5, 5, 10, and 15 MHZ. Each minute during the day, a tone is sounded and the exact time is announced. The voice announcement begins about 10 seconds before the time signal with the words "At The Tone,_____ Hours, _____Minutes, Coordinated Universal Time." This announcement is followed by the sounding of the time. The time announced is universal time.

b. U.S. NAVAL OBSERVATORY, TIME SERVICE DEPARTMENT, 3450 Massachusetts Avenue, NW, Washington D.C. 20392-5420

VOICE ANNOUNCER: "U.S. Naval Observatory Master Clock, at the tone, Eastern (Daylight/Standard) Time (*Time*)." BEEP "Universal Time (*Time*)." BEEP
Comm: (202) 762-1401
DSN: 762-1401

TIME VIA MODEM
Comm: (202) 762-1594
DSN: 762-1594

TIME SERVICE ON THE WORLD WIDE WEB
http://tycho.usno.navy.mil

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Section 1: ACRONYMS Cont.

OS	Orienting Station
OTF	On The Fly
PADS	Position and Azimuth Determining System
PDOP	Position Dilution Of Precision
PE	Probable Error
PLGR	Precision, Lightweight, GPS, Receiver
PPM	Parts Per Million
PPS	Precise Positioning Service
PPS	Pulse Per Second
RDOP	Relative Dilution of Precision
RE	Radial Error
RF	Radio Frequency
RMS	Root Mean Square
RTK	Real Time Kinematic
S/A	Selective Availability
SCP	Survey Control Point
SEP	Spherical Error Probable
SIC	Survey Information Center (same as SPCE)
SPCE	Survey Planning and Coordination Center (same as SIC)
SPS	Standard Positioning Service
TFOM	Time Figure of Merit
TM	Transverse Mercator
TZ	Time Zone
UERE	User Equivalent Range Error
UPS	Universal Polar Stereographic
UT	Universal Time (same as GMT)
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
VDOP	Vertical Dilution of Precision
WGS	World Geodetic System

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Section 2: GLOSSARY

Absolute Positioning: The unique ability of a GPS receiver to produce positional values without the reference of another receiver.

Accelerometer: A device that measures acceleration. The output is double integrated to determine a change in distance.

Accumulative Error: An error that occurs with the same sign, and often with similar magnitude, in a number of consecutive or otherwise related observations. An example is measuring a distance with an uncalibrated Distomat (EDME); each distance measured will be consistently long or short. The total accumulated error will be equal to the error in one measurement multiplied by the total number of measurements. Repetition cannot reduce this error. Also called constant error or systematic error.

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.

Adjusted Value: A value of a quantity derived from observed data by some orderly process which eliminates discrepancies arising from errors in those observed data.

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.

Alidade: The part of a surveying instrument which consists of a sighting device with index, 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.

Angle: The arc of a circle formed by the intersection of two lines at the center of the circle.

Anti-Spoofing: An encryption technique developed by the US Department of Defense (DoD) that denies access to the P-code to any unauthorized users.

Anywhere Fix: A receiver with the unique ability to calculate a position without being given an approximate location and/or time.

Apogee: The point in the orbit of a satellite about the Earth that is the greatest distance from the center of the Earth.
Arbitrary Grid: Any reference system developed for use where no grid is available or practical, or where military security for the reference is desired.

Astronomic Position: A point on the Earth whose coordinates were determined as a result of observations of celestial bodies.

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Autoreflection: 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, Astronomic: the angle between the plane of the observer's meridian and the plane of the hour circle containing the observed body, measured in the plane of the horizon, preferably clockwise from north. An astronomic azimuth is not by definition a true azimuth.

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 UTM 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.

Bandwidth: A measure of the width of the frequency spectrum of a signal expressed in Hertz.

Baseline: The resultant three-dimensional vector, V, between any two stations from which simultaneous GPS data have been collected and processed. Generally given in Geocentric Cartesian Coordinates where: V= (ΔX, ΔY, ΔZ).

Bearing: The direction of a line as measured from the north-south axis (X-axis) of a two dimensional system.

Bearing Angle: The acute angle formed between the north-south axis (X-axis) of a two-dimensional system, and a line connecting the origin with a point. In artillery survey, it is the angle between the grid north-south line and the azimuth line to the forward station.

Bleeding Edge: The edge of a map or chart on which cartographic detail is extended to the edge of the sheet. The bleeding edge usually includes overlap of a portion of an adjoining sheet.

Binary Biphase Modulation: Phase changes on a constant carrier frequency of either 0 or 180degrees. The phase changes represent the binary digits 0 and 1 respectively. In other words, a phase change from the carrier of 0° is the binary digit 0; a phase change from the carrier of 180° is the binary digit 1.

Binary Code: A system used in communications where selected strings of 0's and 1's are assigned definite meanings.

BIT: Built-in Test, usually an internal check for proper functioning.

BITE: Built-in Test Equipment, internal components of equipment designed to conduct Built-in Tests on the equipment.

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 unmodulated 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 Geodesy: The branch of geodesy that utilizes observations of near celestial bodies, including manmade satellites, to determine the size and shape 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, perpendicular to the zenith-nadir line.

Celestial North and South Poles: The points at which the prolonged polar axis of the Earth intersects the celestial sphere. The Celestial North Pole is the "P" in the PZS Triangle.

Celestial Sphere: An 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 considered as the basis for constructing the projection.

(2) The longitude of origin at the center of each six-degree zone of the UTM grid system.

(3) The longitude of the center of a time zone.

Channel: GPS receiver hardware and software that 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 (CE): 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 a T2-E will measure the same angle between two stations no matter what direction the alidade is turned.

Coaltitudes: 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.

Codeless Receiver: An instrument that does not require knowledge of the P or C/A codes to perform measurements. This type of receiver does not record ephemeris data; consequently, before a baseline solution is computed, an ephemeris file must be obtained from another source.

Code Receiver: An instrument that does require knowledge of the P or C/A codes 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. Referred to as the compliment of latitude, or 90° minus the latitude.

Comparative Accuracy (CA): The ratio between the difference in two measurements and the mean of those measurements. It is used to describe the accuracy of distances and is usually expressed as a fraction with 1 as a numerator.

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, Tangent: A map projection produced by projecting the geographic meridians and parallels of a reference ellipsoid onto a cone that is tangent to the surface of the ellipsoid. The point of tangency is usually a parallel of latitude. Also called a conic map projection with one standard parallel.

Conic Map Projection, Secant: A map projection produced by projecting the geographic meridians and parallels of a reference ellipsoid onto a cone that 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 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.

Contour Line, Index: An index contour line is a line of equal elevation that is depicted on a map in a bold print to distinguish it from intermediate contour lines. These lines are normally depicted as every fifth line; therefore, the elevation difference between these lines is normally five times the contour interval.

Contour Line, Intermediate: The contour lines drawn between index contour lines. The elevation difference between these lines is equal to the contour interval.

Contour Line, Supplementary: A contour line drawn between two intermediate contour lines. These lines are usually a dashed line and indicate an elevation difference of one-half the contour interval.

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 UTM or UPS.

Counterclockwise Angle: A horizontal angle measured in a counterclockwise direction. Used for the measurement of deflection angles.

Course/Acquisition Code (C/A): The standard GPS code, it is broadcast on the L-1 frequency and is not encrypted. This code is subject to selective availability, and is sometimes called the Civilian Access Code or, the Clear Access Code.

Curvature of Earth: **(1) The** offset from the tangent to the curve as a result of the curvature of the Earth and refraction combined.

(2) The divergence of a plane surface from the surface of the Earth.

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.

Cylindrical Map Projection: A map projection produced by projecting the geographic meridians and parallels of a reference ellipsoid onto a cylinder, and then developing the cylinder into a plane. This projection can be either tangent, or secant to the ellipsoid depending on the purpose of the product.

Datum: **(1)** Any numerical or geometrical quantity, or set of such quantities which may serve as a reference or base for other quantities.

(2) A point, line, or surface used as a reference, as in surveying, mapping, or geology.

Datum, Horizontal: Also called a geodetic datum. A horizontal datum is generally defined by at least five quantities relating to position, azimuth, gravity model, 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 and 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.

D-Code: see NAV Data.

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.

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 described below:

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 (DOP): A measure of the geometric contribution to the uncertainty of a position fix. The more specific terms are given below.

(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-aiding: A signal processing strategy that uses a measured Doppler shift to help the receiver smoothly track the GPS signal, allowing more precise velocity and position measurement.

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.

Double Difference: see Differencing.

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.

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 that is perpendicular to the ellipsoid. The ellipsoid height is positive if the point is outside of the reference ellipsoid. Also called geodetic height.

Ellipsoid of Revolution: The surface generated by an ellipse rotating on one of its axes. Also called an ellipsoid of rotation.

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 Axis: The diameter of the Earth described between two points on the equator. Twice the semi-major axis of a reference ellipsoid.

Equatorial Plane: A plane that 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 that 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, fail 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, it is 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.

Fast Switching Channel: A switching channel with a time sequence short enough to recover the integer part of the carrier beat phase. The switching time is generally between 2 to 5 ms.

Fault Indicator: On the PADS, an indicator that allows an equipment operator to see that the equipment is either functioning properly or malfunctioning.

Flattening: The ratio of the difference between the Semi-Major Axis, and the Semi-Minor Axis, to the Semi-Major Axis. Also called ellipticity.

Frequency Band: A range of frequencies in a region of the electromagnetic spectrum.

Fundamental Frequency: The GPS fundamental frequency, *F*, is 10.23 MHz. The carrier frequencies are:

$$L1 = 154 * F = 1575.42 \text{ MHz}$$
$$L2 = 120 * F = 1227.60 \text{ MHz}$$

Gauss-Kruger Projection: The same as the Transverse Mercator Projection with the cylinder of projection placed tangent to the reference ellipsoid instead of secant.

GDOP: see DOP

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Geocentric: Relative to the Earth or geoid as a center, measured from the center of the Earth.

Geocentric Coordinates: Coordinates that define the position of a point with respect to the center of the Earth or geoid. Geocentric coordinates can be either Cartesian (X, Y, Z) or spherical (geocentric latitude and longitude, and radial distance). Astronomic coordinates are geocentric.

Geocentric Geodetic Coordinates: Geodetic coordinates referred to a geocentric reference ellipsoid.

Geocentric Latitude: The angle at the center of the Earth or geoid between the plane of the celestial equator and a line to a point on the surface of the Earth. An astronomic latitude is geocentric.

Geocentric Longitude: Same as geodetic longitude.

Geodesy: The science that 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 (ϕ): The angle between the plane of the equator and the normal to the ellipsoid through the computation point.

Geodetic Longitude (λ) 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 that has the same geodetic longitude at every point.

Geographic Coordinates: Any coordinate system that relates positions on the Earth in terms of latitude and longitude. Both geodetic and astronomic coordinates are geographic coordinates.

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.

GPS Time: The broadcast GPS time signals are synchronized with atomic clocks at the GPS Master Control Station. These clocks are in turn periodically synchronized with Coordinated Universal Time (UTC). However, UTC is incremented by "leap seconds" to correct for the slowing of the Earth's rotation with respect to the Sun; GPS time is not. As of Oct 1995, GPS time equals UTC + 10 sec. The fundamental time scale for all Earth time keeping is the International Atomic Time (TAI). It is a continuous time scale not corrected by "leap seconds." There is a constant offset of 10 seconds between GPS time and TAI such that GPS time = TAI + 10 seconds.

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 (GMT): Mean solar time at the meridian of Greenwich, England, used as a basis for standard time throughout the world.

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 UTM grid) and a line that 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 that designate a point on a map, photograph, or chart containing a grid.

Grid Coordinate System: A plane-rectangular coordinate system usually based on, and mathematically adjusted to, a map projection. Also called a Grid Reference System.

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.

Gyroscope: A spinning wheel, which tends to keep a fixed orientation in space. Used to sense rotation.

Gyrocompassing: A method used to find True north by sensing the Earth's rotation.

Handover Word: The word in the GPS message that contains time synchronization information for the transfer from the C/A-code to the P-code.

HDOP: see DOP.

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.

Instrument Parallax: A change in the apparent position of an object with respect to the reference marks of an instrument, which is caused by imperfect adjustment of the instrument.

Integer-cycle Ambiguity: The unknown integer number of whole carrier cycles between the satellite and the receiver.

Inter Range Operational Number (IRON): A random number assigned to various Earth orbiting objects assigned by the joint US/Canadian North American Air Defense Command (NORAD). Each GPS satellite has an individual IRON.

Intersection: The procedure of determining the horizontal position of an unoccupied point by direction observations from two or more known positions.

Intersection Station: A station whose horizontal position is determined by observations made from other stations. No observations are made from this station to determine its position.

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: A delay in the propagation of the GPS signal caused by the signal traveling through the ionosphere.

Joint Operations Graphic: The standard 1:250,000 scale DoD cartographic product which may be produced in three versions: JOG/G (Series 1501) is designed to meet ground requirements, JOG/A (Series 1501 Air) is designed to meet air requirements, JOG/R (Series 1501 Radar) is the Air Target Material version in support of radar/ intelligence planning and operations requirements.

Kinematic Positioning: A GPS differential surveying technique, whereby one GPS unit, the fixed receiver, stays on a known control point, while another unit, the rover, collects data on a constantly moving vehicle, while continually tracking four or more satellites during the observation period. This method of GPS survey is used to determine the position of the rover receiver. Also called Dynamic Positioning.

L1: see L-Band.

L2: see L-Band.

Lambert Conformal Conic Map Projection: A conformal map projection of the conical type. This projection presents all meridians as straight lines that intersect at a common point outside the boundaries of the map sheet. All parallels are represented as arcs of circles with a common center located at the intersection of the meridians. The cone can be projected either tangent or secant to the reference ellipsoid.

Lambert Grid: An informal designation for a coordinate system based on a Lambert conformal map projection.

Latitude: The angular distance for a specific spot on the surface of the Earth, from 0° to 90° degrees, north or south of the Equator.

L-Band: The 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.

Leap Second: The step adjustment made to UTC to compensate for approximately 1 second of additional time that is transmitted by UTC signals each year. Normally, UTC is decreased by exactly 1 second (i.e. the leap second) at 24 hours on the last day of December, and/or June.

Least Squares: A method of adjusting observations in which the sum of the squares of all of the deviations or residuals derived in fitting the observations to a mathematical model is made a minimum. Such an adjustment is based on the assumption that blunders and systematic errors have been removed from the data, and only random errors remain.

Lensatic Compass: A type of magnetic compass equipped with a lens that permits the observer to read the far side of the moveable dial. The scale is usually incremented in both mils and degrees.

Leveling: The operations of measuring vertical distances to determine elevations.

Local Coordinate System: A right-handed rectangular coordinate system of which the Z-axis coincides with the plumb line through the origin.

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.

Loop Traverse: A closed traverse that starts and ends at the same station. This traverse provides no check on starting position and azimuth, nor does it provide validation against systematic distance error.

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.

Loran C: A loran position fixing system using a combination of time difference of reception, and phase difference of signals from two stations to provide a line of position.

Longitude: The angular distance, from 0° to 180° degrees east or west of the Prime meridian, for a specific location on the surface of the Earth. (In most cases the Greenwich Meridian is referred to as the Prime Meridian.)

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 Series: A collection of map sheets usually having the same scale and cartographic specifications.

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 (MSL): 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. Evenly spaced parallel lines set perpendicular to the Equator represent the meridians of longitude. The parallels of latitude are depicted as a set of lines placed perpendicular to the meridians and therefore parallel to the equator. Conformality 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.

Military Grid Reference System (MGRS): 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 UTM and UPS grid systems.

Monitor Station: One of five worldwide stations maintained by the DoD and used in the GPS Control Segment to monitor and control satellite clock and orbital parameters. Corrections are calculated and uploaded to each satellite at least once per day.

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.

Multipath Error: A position error resulting from radio signals traveling from the transmitter to the receiver by two paths of different electrical lengths.

Nadir: That point where the extension of the plumb line beneath the observer intersects the celestial sphere.

National Geodetic Reference System (NGRS): A system of common or relative survey control points throughout the United States and Puerto Rico as adjusted by the **National Geodetic Survey (NGS).**

NAV 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. Sometimes referred to as the Navigation Message, Satellite Message, or the D-code.

NAVSTAR: NAVigation **S**atellite **T**iming **A**nd **R**anging. NAVSTAR is the name given to GPS satellites, originally manufactured by Rockwell International.

Neatlines: 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.

Observer's Meridian: The great circle on the celestial sphere that passes through both celestial poles, and the observer's zenith.

Open Traverse: A traverse that 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.

Optical Plummet: see Vertical Collimation.

Orienting Line: A line of known azimuth between two points on the ground.

Orthometric Height: see Elevation.

Outage: The period of time when the Dilution of Precision exceeds a specified maximum.

Overlapping Grid: The extension of a military grid beyond its designated limits to map sheets in areas bordering grid, grid zone, or ellipsoid/datum junctions. Normally a large-scale map within 25 miles of a junction will depict the overlapping grid as tick marks located outside the neatlines of the map.

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.

PDOP: see DOP.

Perigee: The point in the orbit of a satellite about the Earth that is the least distant from the center of the Earth.

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%.

Plane Rectangular Coordinates: A system of coordinates in a horizontal plane used to describe the positions of points with respect to an arbitrary origin. A pair of axes that intersect at right angles establishes the origin. The position of a point is determined by its distance from these axes.

Plane Survey: A survey in which the surface of the Earth is considered a plane. Precise results may be obtained with plane survey techniques in small areas; however, the accuracy and precision of such results will decrease as the survey increases in size.

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).

Polar Map Projection: A map projection centered on a pole.

Polar Stereographic Map Projection: A stereographic projection centered on a pole of the reference ellipsoid.

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 that 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.

Precise Code (P-Code): A sequence of pseudo- random, binary biphase modulations on the GPS carriers L1 and L2 at a chipping rate of $\pm$ 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 SV has a unique one-week segment code that 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 (PPS): 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.

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.

Preferred Datum: A geodetic datum selected as a base for consolidation of local independent datums within a geographical area.

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.

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.

Pseudolite: A ground based GPS station that can be used in a ranging solution. The station transmits a signal with a structure similar to that of an actual GPS satellite.

Pseudo-random Noise (PRN): 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.

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.

Pseudo-range Observable: The difference between the time of transmission and the time of arrival of a particular signal transmitted by the satellite.

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.

RDOP: see DOP.

Reciprocal Vertical Angle: A vertical angle measured over a line at both ends to eliminate (at least partly) the effects of curvature and refraction. Reciprocal observations must be made as simultaneously as practical to reduce error caused by changing refractive conditions.

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.

Rejection Limit: Used in survey to refer to a maximum allowable error or deviation from a standard, usually a mean value, of two or more measurements.

Relief: Inequalities of elevation and the configuration of land features on the surface of the Earth that may be represented on maps or charts by contours, shading, or spot elevations.

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.

Residual Error: The difference between any value of a quantity in a series of observations, corrected for known systematic errors, and the value of the quantity obtained from the combination or adjustment of that series. Subsequently used as the difference between an observed value and the mean of all observed values of a set.

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 right ascension (RA) of a celestial body is 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 (RMS): see Standard Deviation.

Rotation: The turning of a body on its axis. In celestial terms the body usually rotates around its north-south axis; the Earth rotates from west to east.

Satellite Surveying: **(1)** (Doppler) The process of positioning one or more points on the Earth's surface by collecting Doppler shift data from passes of Navy navigation satellites.

(2) (NAVSTAR GPS) The process of positioning one or more points by resection with Signals received from Global Positioning Satellites.

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.

S-Code: another name for C/A-code.

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.

Secondary Grid: An obsolete grid shown on maps in conjunction with the primary grid. An example is a map sheet with UTM as the primary grid and British National as a secondary grid.

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.

Simultaneous Measurements: A measurement or set of measurements referred to the same epoch.

Single Differencing: see Differencing.

Slow Switching Channel: A channel that switches with a period too long to recover the integer part of the carrier phase.

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.

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 monumented.

Squaring-Type Channel: A receiver channel that multiplies the received signal by itself to obtain a second harmonic of the carrier, which does not contain the code modulation.

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. Also called standard error and root mean square (RMS).

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 (NGS), one for each state in the US, for use in defining positions of geodetic stations in terms of plane-rectangular (X, Y) coordinates.

Stereographic Map Projection: A perspective, conformal, map projection on a tangent plane, with the point of projection at the opposite end of the diameter of the sphere from the tangent plane.

Stop-and-Go Kinematic Surveying: A GPS differential survey technique whereby one GPS receiver, the fixed receiver, remains on a station of known position while the other receiver, the rover, collects signals on an unknown station for a short period of time, then moves to subsequent points to collect signals for a another short period of time, all the while, continually tracking four or more satellites during the observation period. This technique is used to determine the position of the rover receiver.

Survey: The act or operation of making measurements for determining the relative positions of points on, above, or beneath the Earth's surface.

Survey, Geodetic: Survey procedures that take into effect the size and shape of the Earth. A reference ellipsoid that mathematically represents the geoid and the horizontal and vertical datums is used.

Survey, Plane: Those survey procedures in which the curvature of the Earth is not usually considered and computations of relative positions are made using the principles of plane geometry and plane trigonometry.

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 surveying 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.

Time Tag: The time appended to a GPS measurement.

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 that presents the vertical position of features in measurable form as well as their horizontal positions.

Translocation: see Differential Positioning.

Transverse Mercator Map Projection: A conformal, cylindrical map projection, being in principle equivalent to the Mercator map projection turned (transverse) 90° in azimuth. In this projection, a straight line represents the central meridian of each 6° zone. The cylinder can be tangent to the ellipsoid but is usually considered to be secant to the ellipsoid.

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.

Trig 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.

Trilateration: A method of surveying wherein the lengths of the triangle sides are measured, usually by electronic methods, and the angles are computed from the measured lengths.

Triple Differencing: see Differencing.

Troposphere: The inner layer of the atmosphere, located between 6 and 12 miles above the Earth's surface.

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 Polar Stereographic (UPS) Grid: A military grid system based on the polar stereographic map projection. Applied to maps of the Earth's polar regions north of 84° N latitude and south of 80° S latitude.

Universal Time: Standard universally accepted time based on the Greenwich Meridian.

Universal Time Coordinated (UTC): A uniform time system based on an atomic second maintained within 1 second of true time (UT1 and UT2) by the addition or deletion of leap seconds.

Universal Transverse Mercator (UTM) 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 (UERE): 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.

User Segment: The portion of the GPS system that is directly interfaced by the user; mainly GPS receivers.

VDOP: 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. Also 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 zenith distance, which we have termed the Vertical Reading.

Vertical Circle: Any great circle on the celestial sphere that passes through the observer's zenith-nadir.

Vertical Collimation: A telescope so mounted that its collimation axis can be made to coincide with the vertical (or direction of the plumb line). The vertical collimator serves as an optical plumb; it is usually designed for use in placing a mark on the ground directly under an instrument or for placing an instrument directly over a mark on the ground. Also called Optical Plummet.

World Geodetic System (WGS): One of several Earth-centered Earth-fixed ellipsoid/datum systems that positions its origin at the center of the Earth's mass. Designed to replace local datums, WGS-84 is the current system in use.

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.

Y-Code: Essentially the P-code after encryption.

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.

Z-count Word: The GPS satellite clock time at the leading edge of the data subframe of the transmitted NAV Data message.

Z-time: see Greenwich Mean Time.

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.

Zero-Velocity Correction: A term used with inertial survey systems, particularly the Position and Azimuth Determining System (PADS), which refers to a method of minimizing navigation errors. Whenever the vehicle is stopped, the system measures its velocity errors and the computer applies corrections to the accelerometer data.

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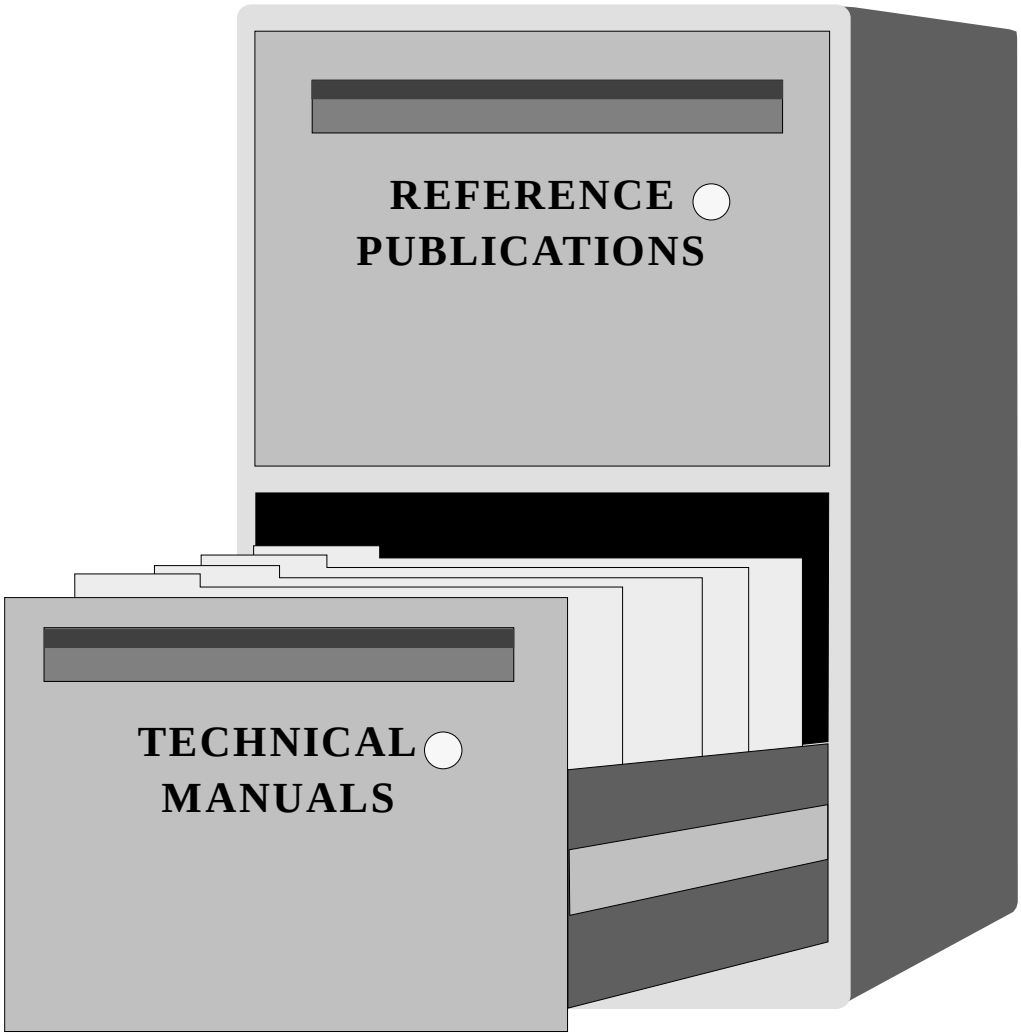
APPENDIX D
REFERENCES



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APPENDIX D

REFERENCES

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Trig Lists (Lists of Geodetic Data)

STANAG 2211 15 Jul 91 w/ Am 1-2 (Am 2 dtd 1 Jun 92)
Geodetic Datums, Ellipsoids, Grids, and Grid References

STANAG 2934 20 Jun 89 w/ Am 1-3 (Am 3 dtd 27 May 94) w/ **AArty P-1** w/ ch3 dtd 3 Feb 94
Artillery Procedures (Replaces STANAG 2373 and 2865)

STANAG 3676 2 Apr 87 w/ Am 1-3 (Am 3 dtd 26 Apr 91)
Marginal Information on Land Maps, Aeronautic Charts, and Photomaps

STANAG 3677 7 Sep 76 w/ Am 1-4 (Am 4 dtd 1 Jun 92)
Standard Scales for Land Maps and Aeronautic Charts

Copies of these agreements can be ordered from the following agency:

Combined Doctrine Branch
Doctrine Division (Code C426)
MCCDC
3300 Russell Road
Quantico Va. 22134-5021

National Imagery and Mapping Agency (NIMA) Manuals

DMA TR 80-003 Ed 5 Dec 83 (Foreward dtd 16 Mar 84) Stock # not listed
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DoD Glossary of Terms Ed 4 1981 Stock # GLOSXMCGTERMS
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NOAA Technical Memoranda

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Determination of North American Datum 1983 Coordinates of Map Corners

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Performing Centimeter-Level Surveys in Seconds With GPS Carrier Phase: Initial Results

NOAA Technical Memoranda NOS NGS -50
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Orthometric Height Determination Using GPS Observations and the Integrated Geodesy Adjustment Model

NOAA Technical Report NOS 121 NGS 39
National Geodetic Survey Gravity Network

NOAA Manuals

NOAA Manual NOS NGS 1
Geodetic Bench Marks

NOAA Manual NOS NGS 3
Geodetic Leveling

NOAA Manual NOS NGS 5
State Plane Coordinate System of 1983

NOAA Professional Papers

NOAA Professional Paper NOS 2
North American Datum of 1983

Copies of these manuals can be obtained from the following agency:

NOAA National Geodetic Survey
N/NGS 12, SSMC3 Room 9202
1315 East-West HWY
Silver Springs, Md 20910

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Coast & Geodetic Survey Publications

Coast & Geodetic Survey Special Publication No. 225
Manual of Reconnaissance for Triangulation
Coast & Geodetic Survey Special Publication No. 234
Signal Building

Coast & Geodetic Survey Special Publication No. 235
State Coordinate Systems

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Conformal Projections In Geodesy and Cartography

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FGCS Publications

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Standards and Specifications For Geodetic Control Networks
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Use and Value of a Geodetic Reference System

Input Formats and Specifications of the National Geodetic Survey Data Base: **Volume I, Horizontal**
Volume 2, Vertical
Volume 3, Gravity

Department of the Interior

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FM 5-36	Route Reconnaissance and Classification
FM 5-232	Topographic Survey
FM 5-233	Construction Survey
FM 5-553	General Drafting
FM 6-2	Field Artillery Survey
FM 6-15	Field Artillery Meteorology (MCWP 3-16.5)
FM 6-20-10	The Targeting Process
FM 6-30	Tactics, Techniques, and Procedures For Observed Fire
FM 6-40	Field Artillery Manual Cannon Gunnery
FM 6-50	Tactics, Techniques, and Procedures For The Field Artillery Cannon Battery
FM 6-121	Tactics, Techniques, and Procedures For Field Artillery Target Acquisition
FM 6-300	Army Ephemeris
FM 21-26	Map Reading and Land Navigation
FM 21-31	Topographic Symbols
FM 31-70	Basic Cold Weather Manual
FM 34-85	Conversion of Warsaw Pact Grids to UTM Grids
FM 101-5-1	Operational Terms and Symbols
FMFM 3-1	Command and Staff Planning
FMFM 6-9	Marine Artillery Support

Technical Manuals (Survey General)

TM 5-232	Elements of Surveying
TM 5-235	Special Surveys
TM 5-236	Surveying Tables and Graphs
TM 5-237	Surveying Computer's Manual
TM 5-330	Planning Roads, Airfields, and Heliports
TM 5-441	Geodetic and Topographic Surveying
TM 5-442	Precise Astronomic Surveys
TM 5-443	Field Classification Surveys
TM 5-704	Construction Field Reading

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Technical Manuals (Equipment Specific)

TM 08837A-12/_	Operators and Organizational Maintenance Manual for Position and Azimuth Determining System, AN/USQ-70
TM 9-1290-262-10	Operators Manual For Aiming Circle, M2 W/E, M2A2 W/E

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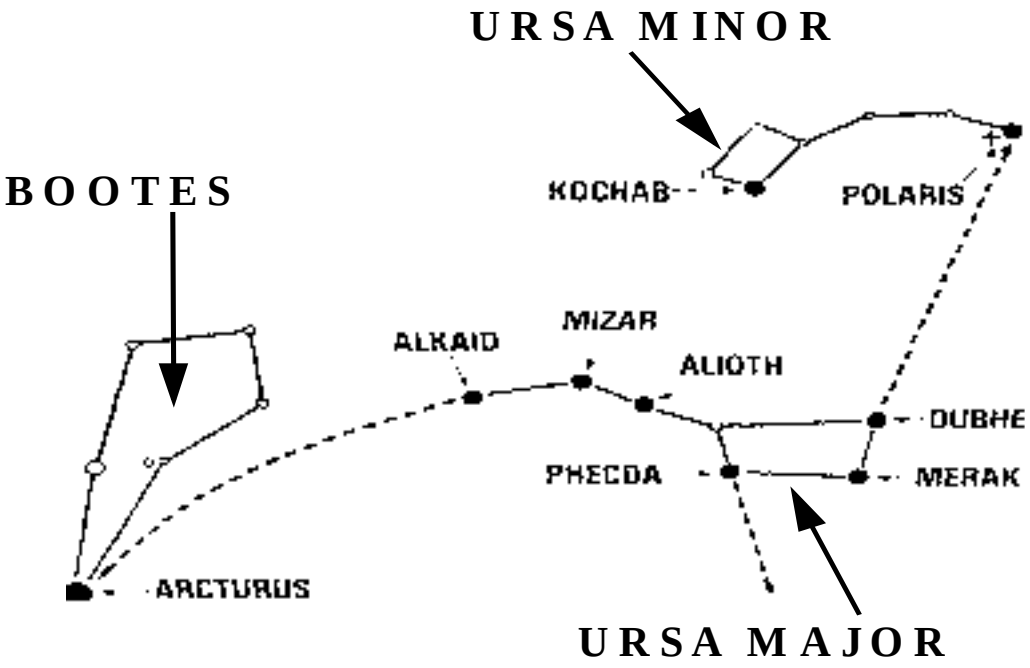
APPENDIX E

STAR CARDS
AND
STAR RATE CHARTS



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Grus	Al Na'ir (71)	2.2	10	E-5
Hydra	Alphard (35)	2.2	8	E-4
Hydrus	Beta Hydri (3)	2.9	13	E-6
Leo	Regulus (36)	1.3	14	E-6
	Denebola (39)	2.2	14	E-6

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CONSTELLATION	STAR (#)	MAG.	CARD	PAGE
Lyra	Vega (64)	0.1	6	E-4
Libra	Zebenelgenubi (53)	2.9	15	E-6
Octans	Nu (69)	3.7	13	E-6
Ophiuchus	Rasalhague (61)	2.1	15	E-6
	Sabik (59)	2.6	15	E-6
Orion	Rigel (16)	0.3	5	E-4
	Betelgeuse (22)	0.1	5	E-4
	Bellatrix (18)	1.7	5	E-4
	Alnilam (20)	1.7	5	E-4
	Alnitak (21)	2.0	5	E-4
Pavo	Peacock (87)	2.1	11	E-5
Pegasus	Enif (70)	2.5	9	E-5
	Markab (73)	2.6	9	E-5
Perseus	Mirfak (14)	1.9	7	E-4
Phoenix	Ankaa (4)	2.4	10,12	E-5
Piscis Austrinus	Fomalhaut (72)	1.3	10	E-5
Scorpius	Antares (57)	1.2	3,15	E-3, E-6
	Scaula (60)	1.7	3	E-3
	Dschubba (56)	2.5	3,15	E-3, E-6
Sagittarius	Kaus Australis (63)	1.9	3	E-3
	Nunki (65)	2.1	3	E-3
Taurus	Aldebaran (15)	1.1	4,7	E-3, E-4
	El Nath (19)	1.8	4	E-3
Triangulum Australe	Atria (58)	1.9	13	E-6
Ursa Major	Alioth (45)	1.7	16	E-6
	Alkaid (48)	1.9	16	E-6
	Dubhe (38)	1.9	16	E-6
	Mizar (46)	2.4	16	E-6
	Merak (37)	2.4	16	E-6
	Phecda (40)	2.5	16	E-6
Ursa Minor	Polaris (10)	2.1	16,17	E-6, E-7
	Kochab (54)	2.2	16,17	E-6, E-7
Vela	Gamma Velorum (31)	1.9	18	E-7
	Suhail (33)	2.2	18	E-7
Virgo	Spica (47)	1.2	14	E-6

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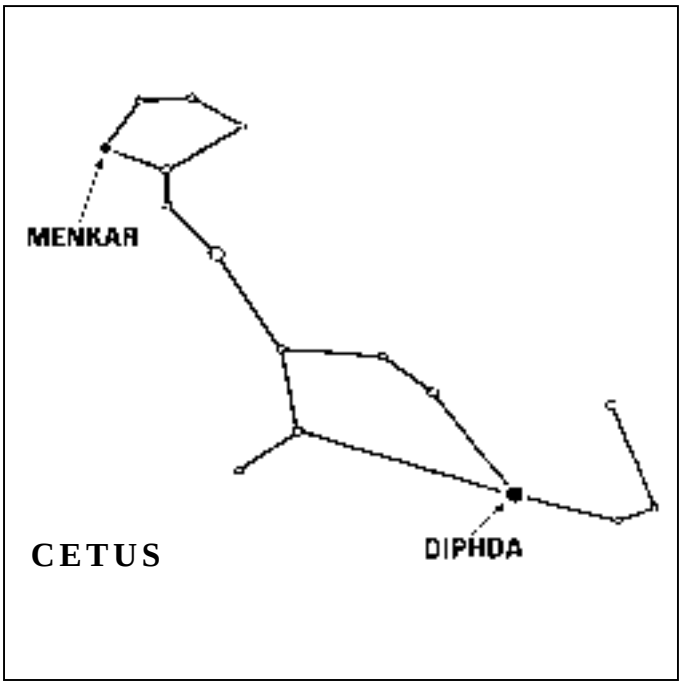

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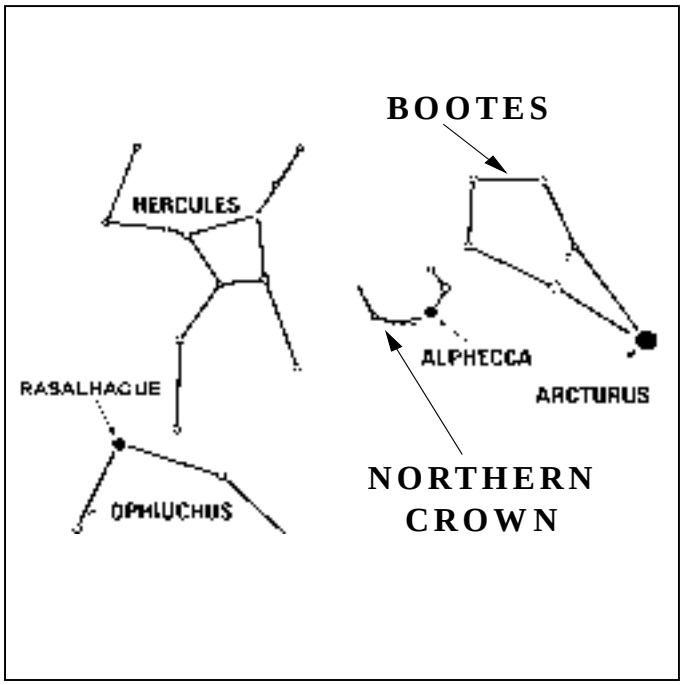

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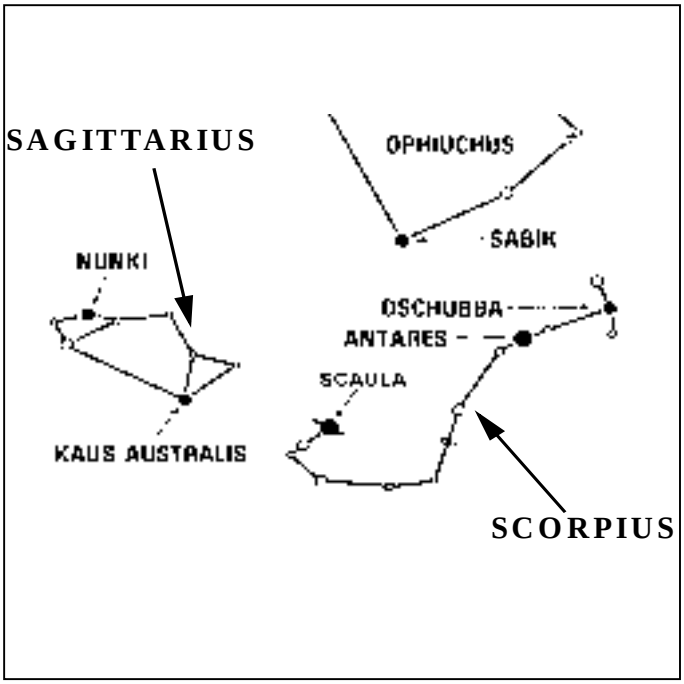

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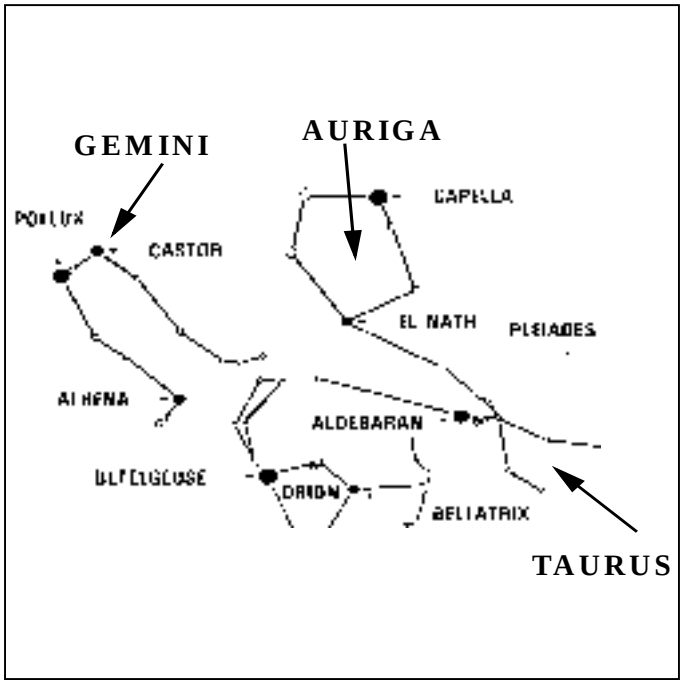

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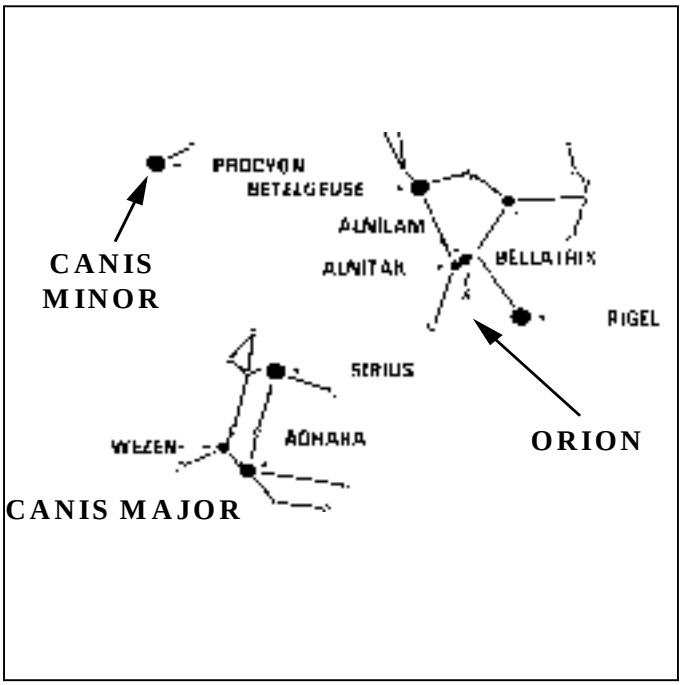

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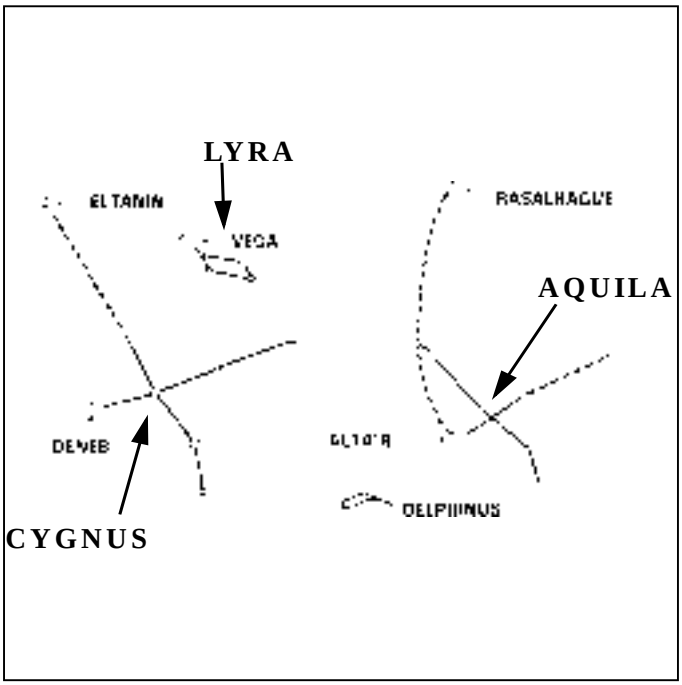

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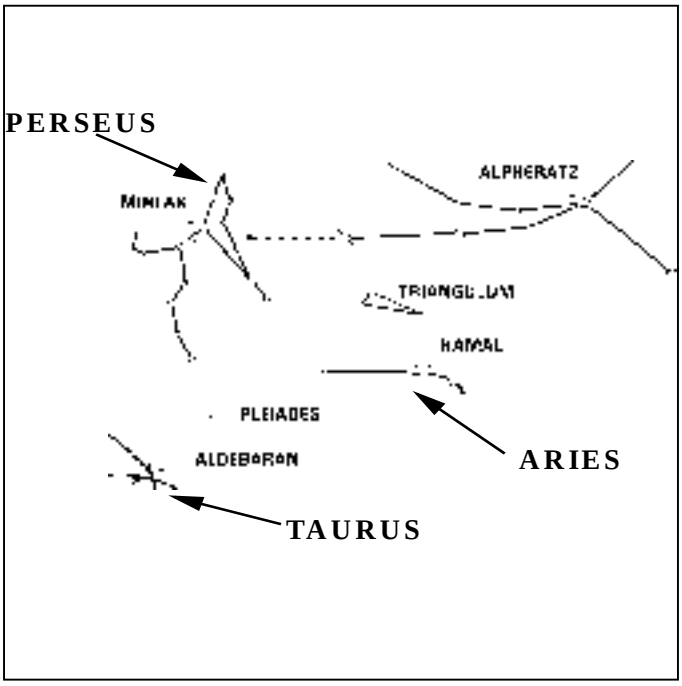

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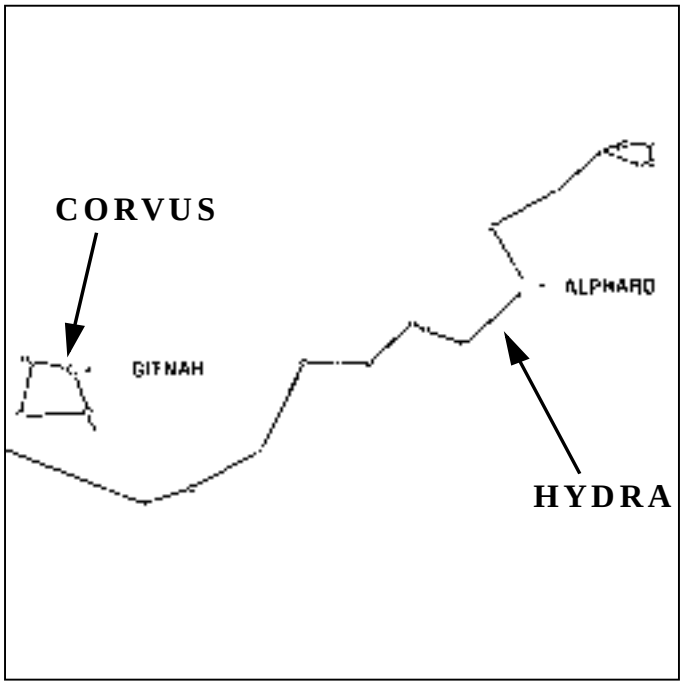

CARD 8

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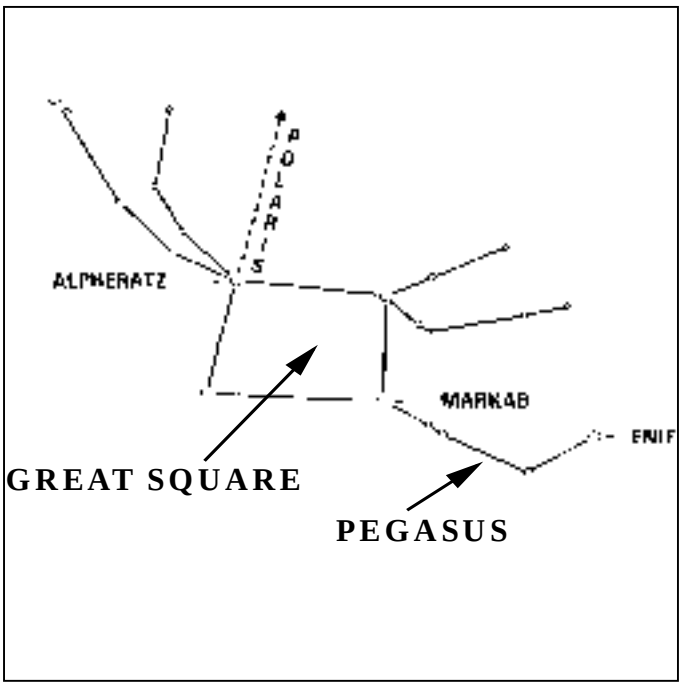

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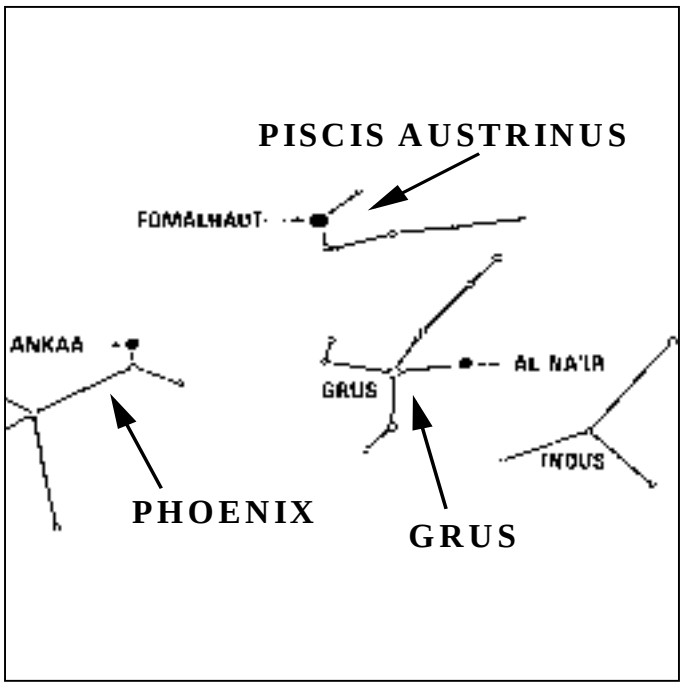

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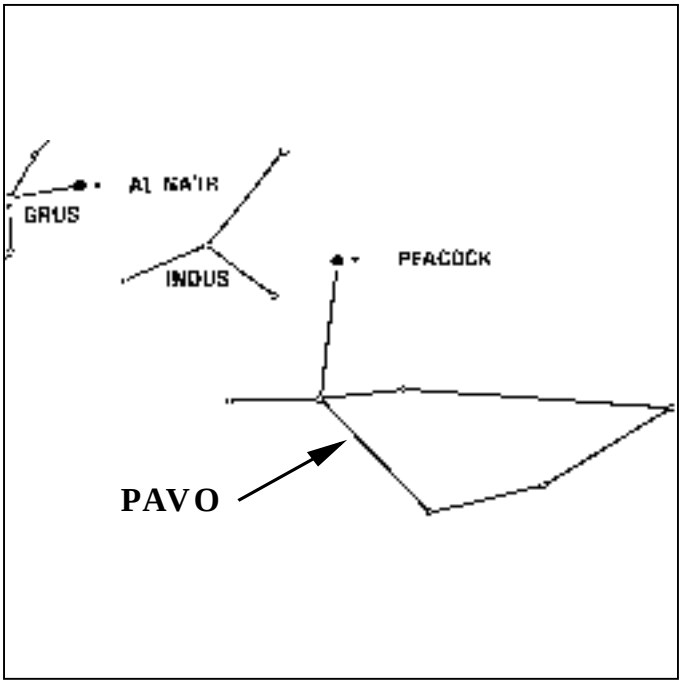

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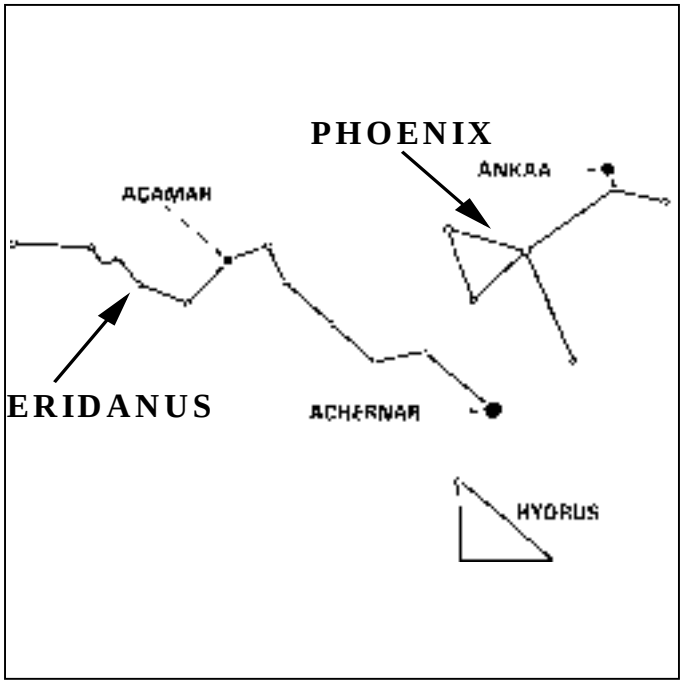

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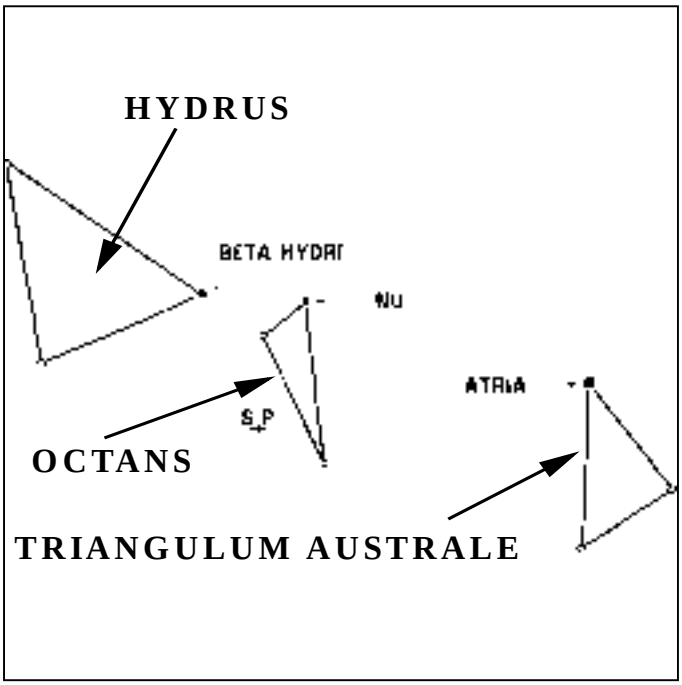

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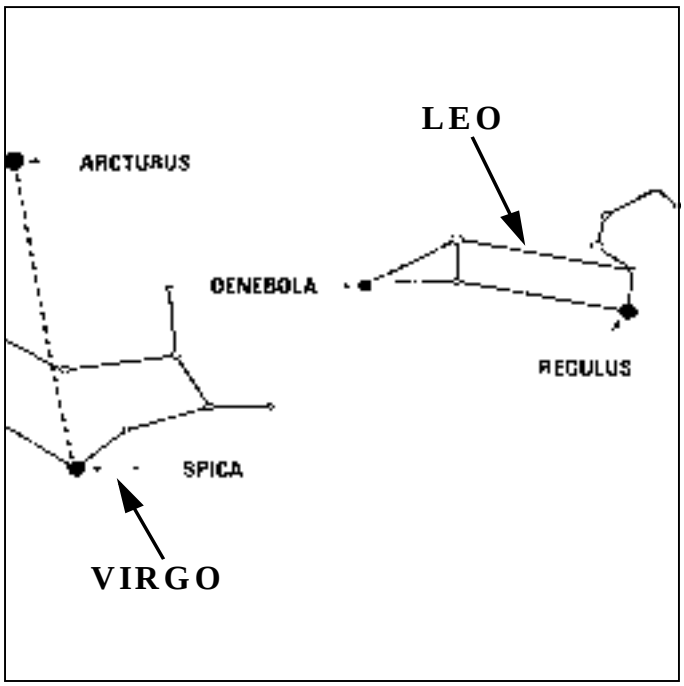

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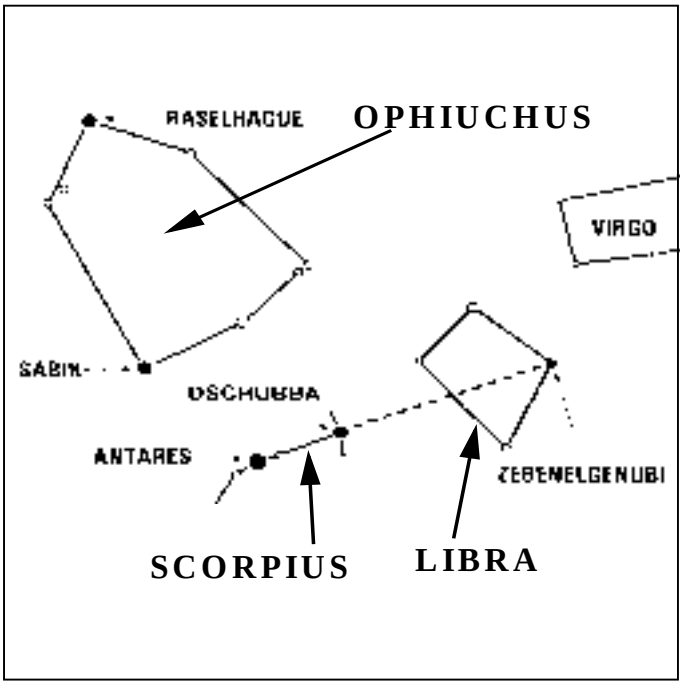

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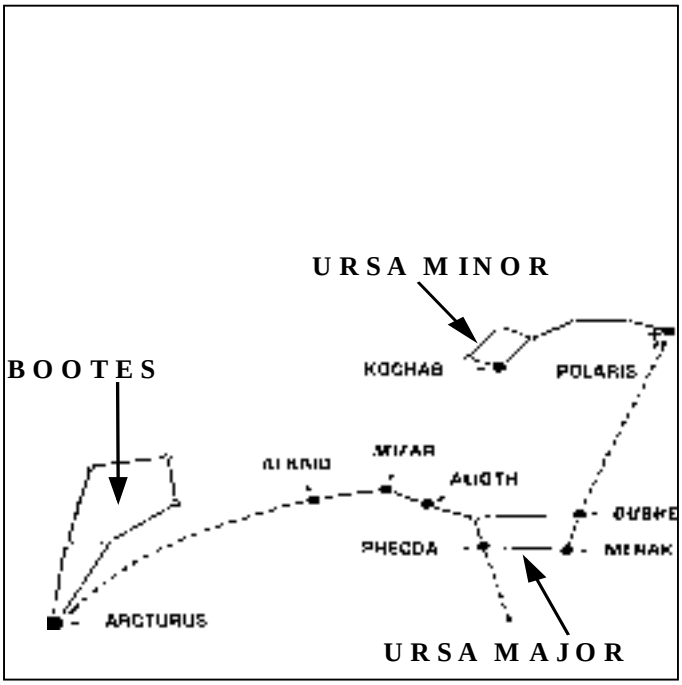

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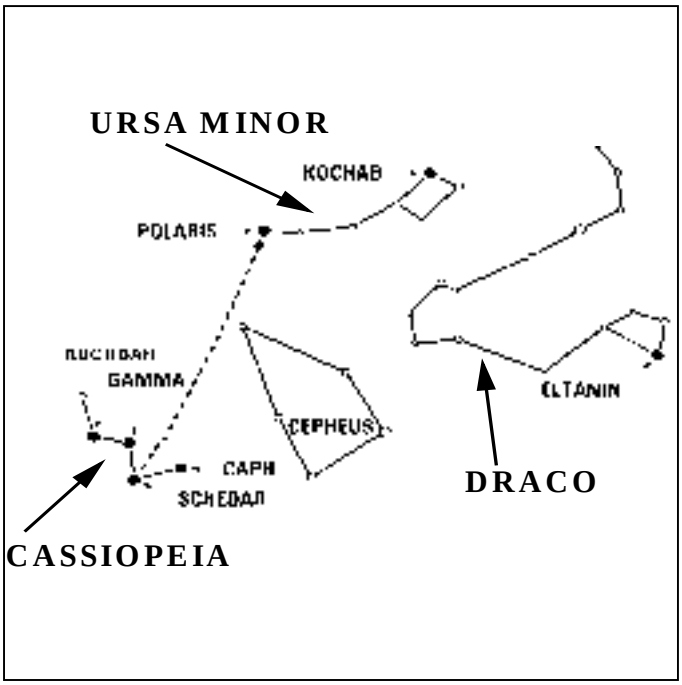

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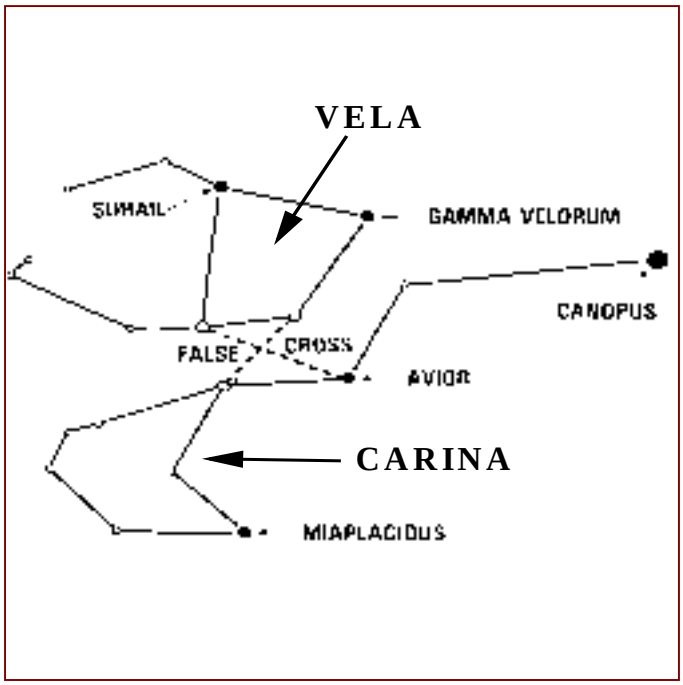

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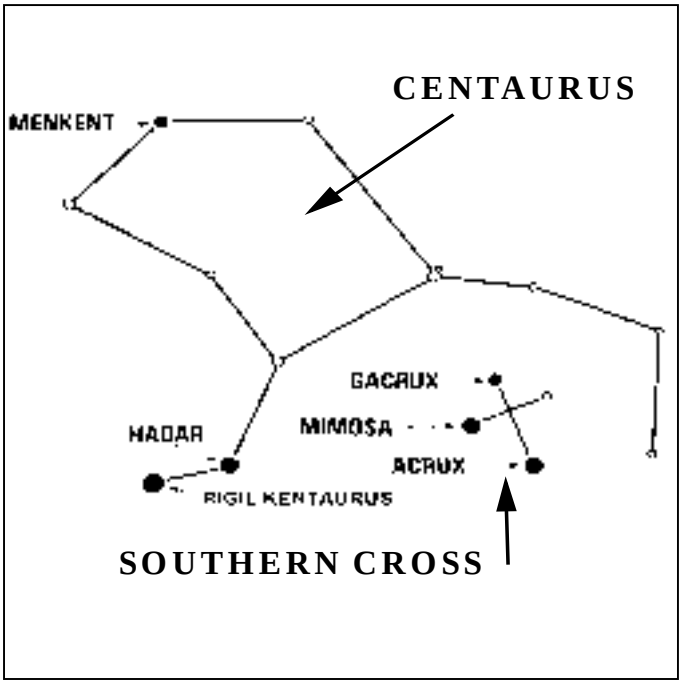

CARD 19

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STAR RATE CHARTS

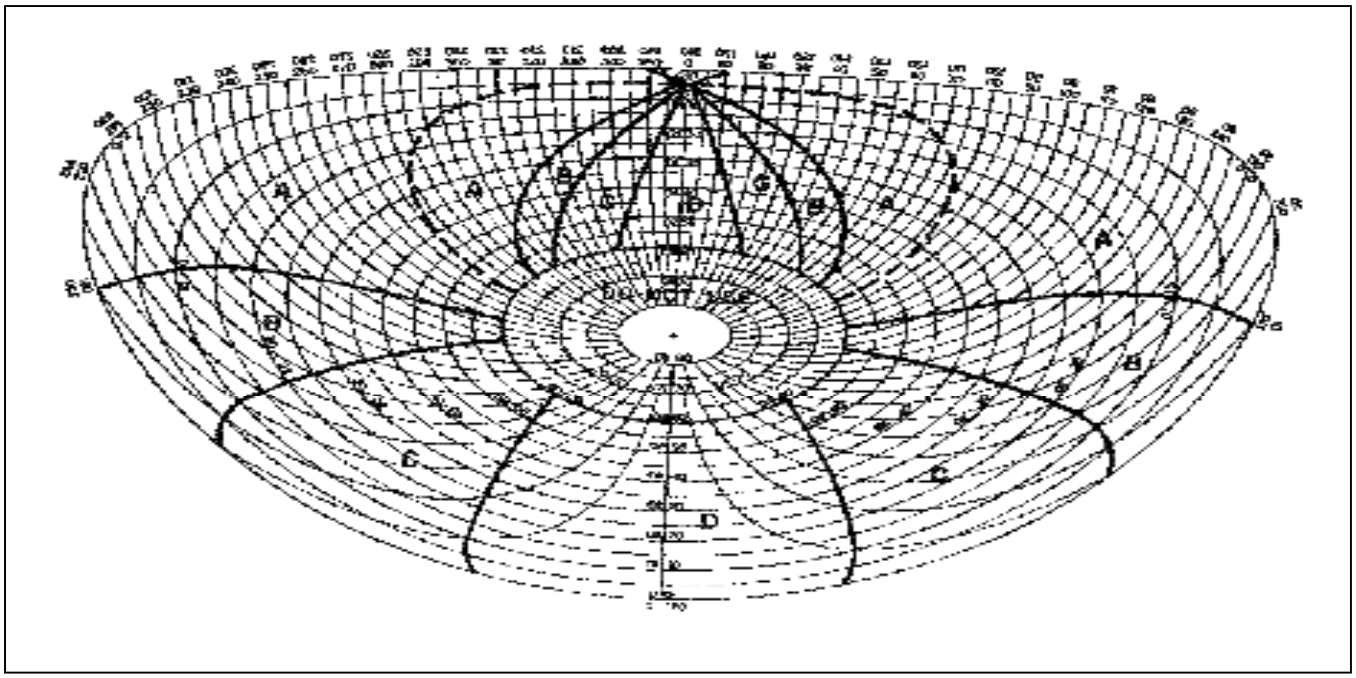

Plate 1: Latitude 5° N or S

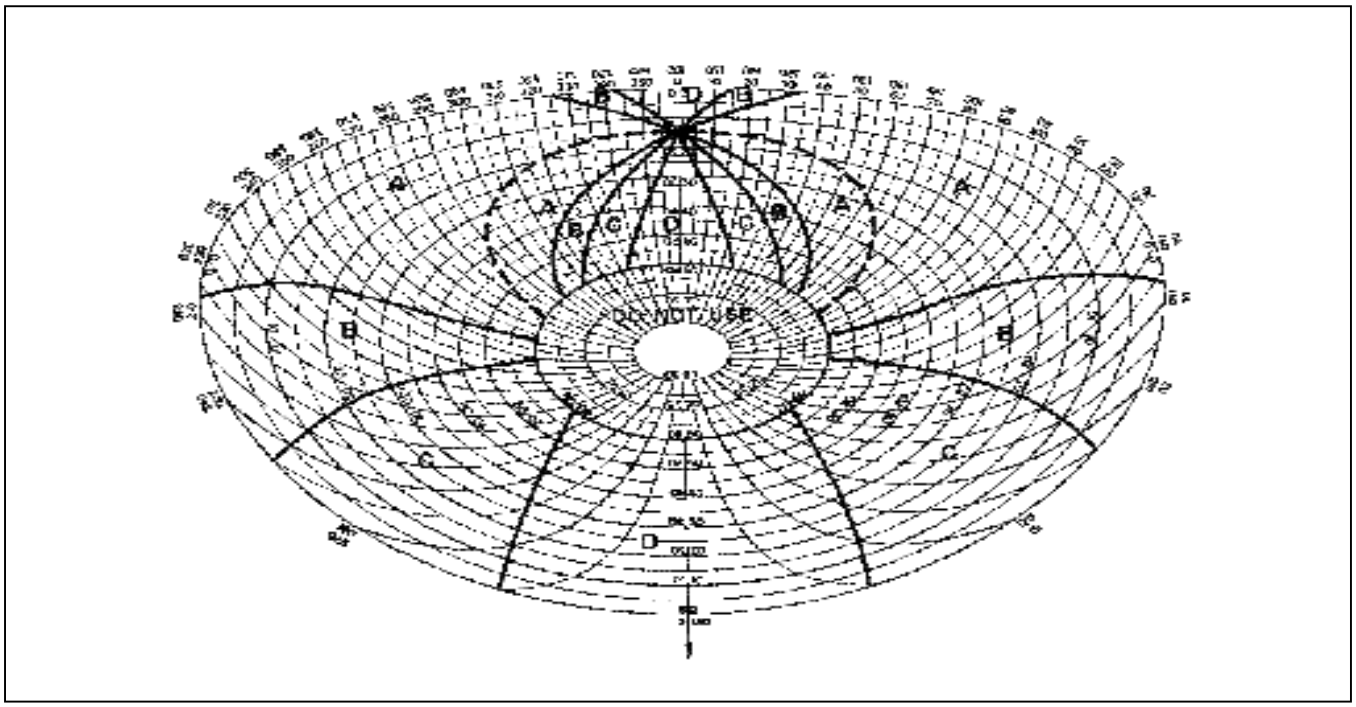

Plate 2: Latitude 15° N or S

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STAR RATE CHARTS Cont

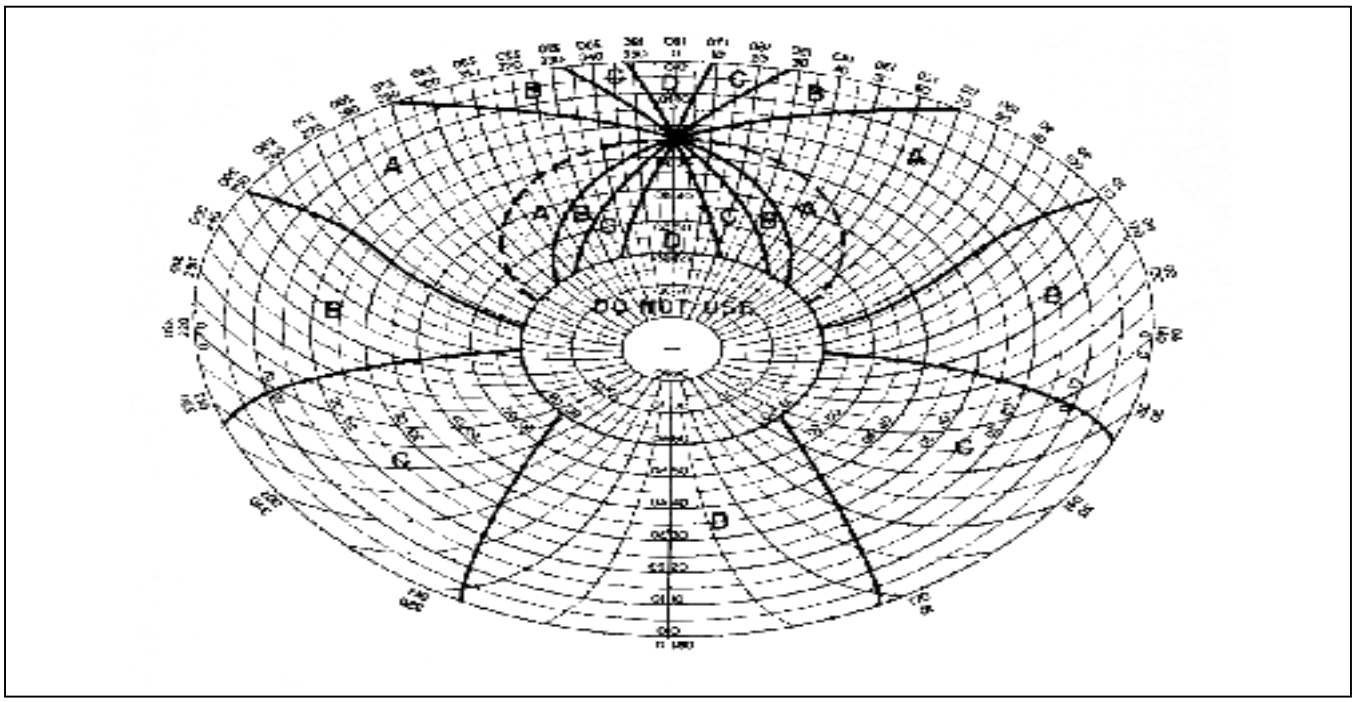
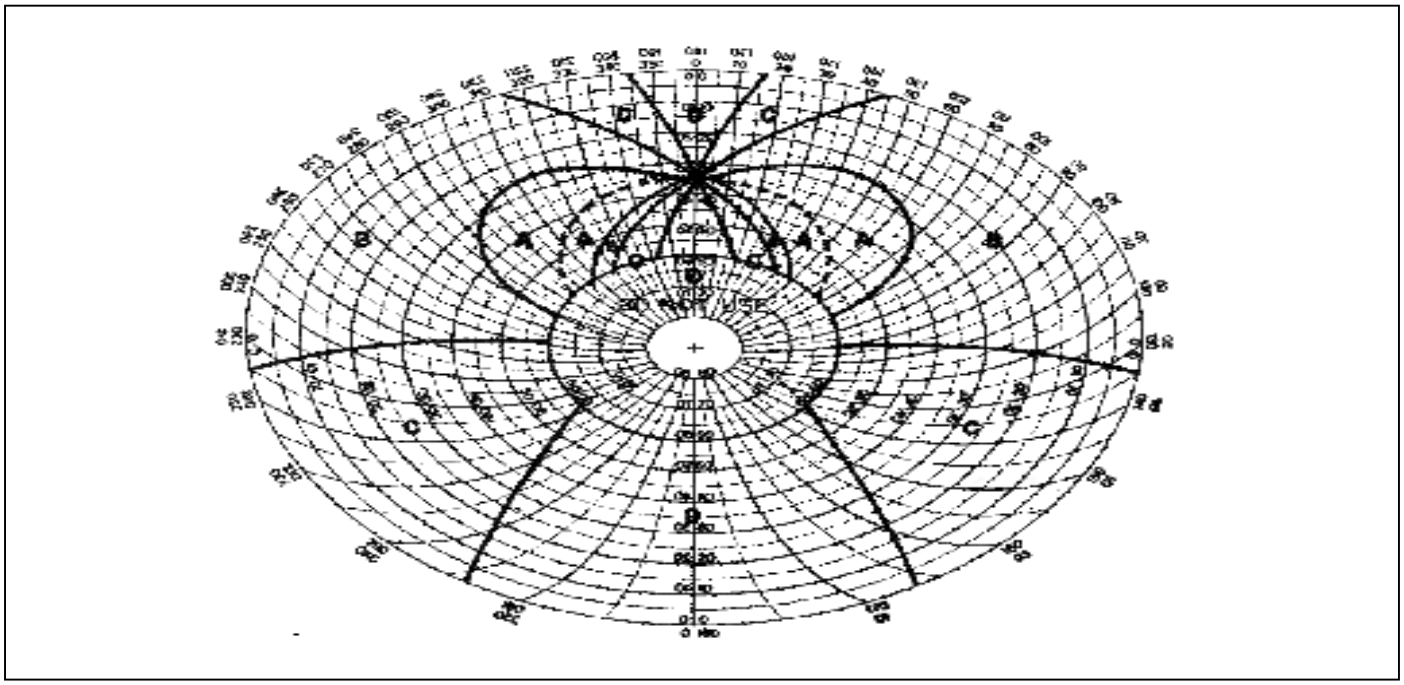


Plate 3: Latitude 25° N or S



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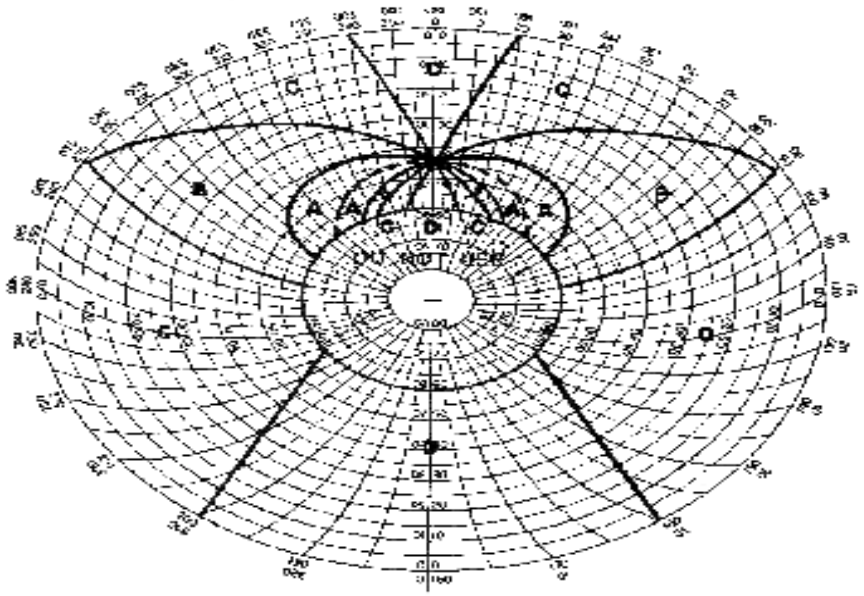

Plate 5: Latitude 45° N of 3

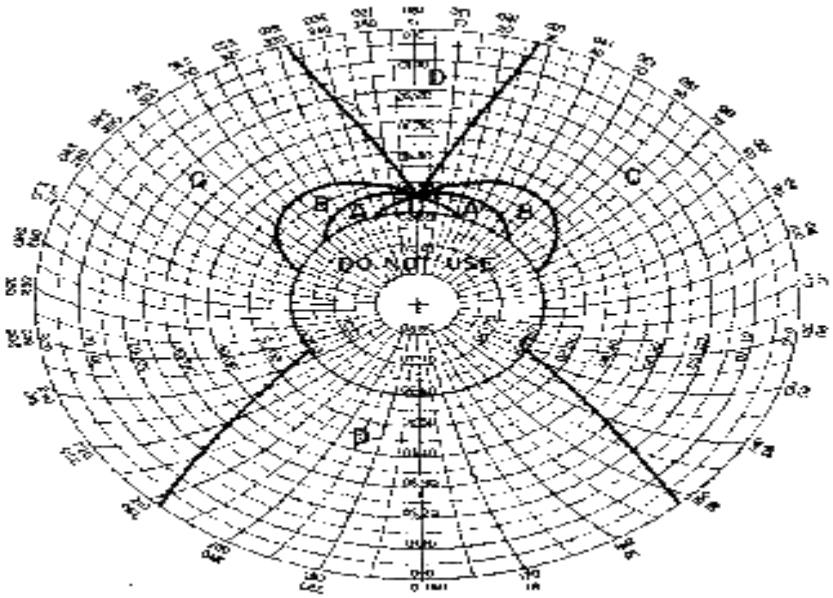

Plate 6: Lat

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STAR RATE CHARTS Cont

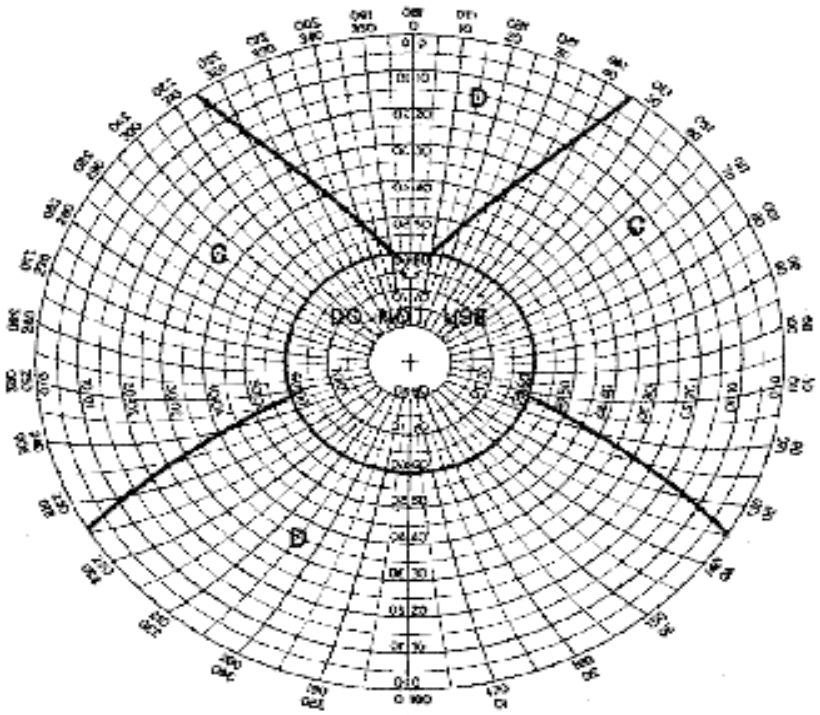
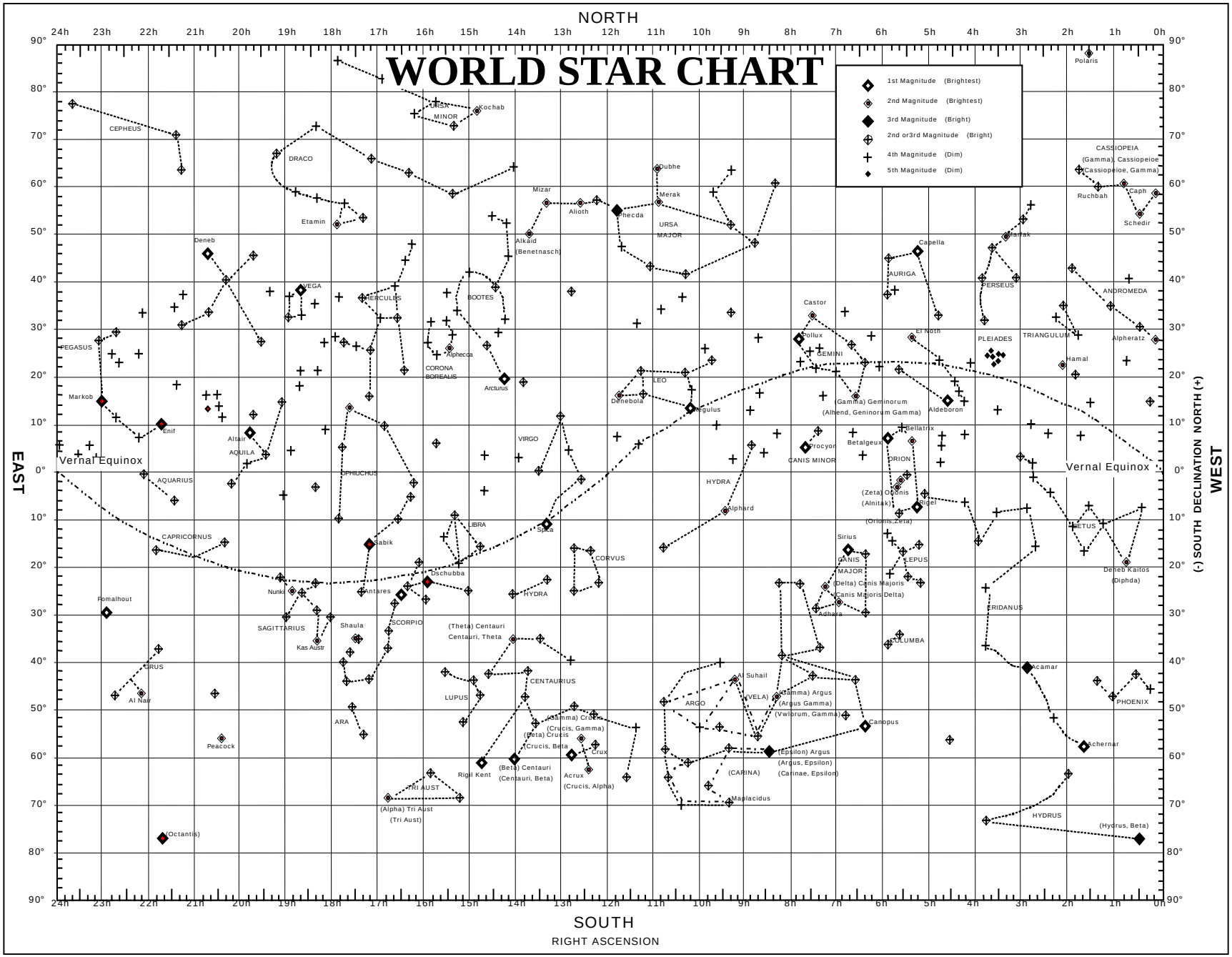


Plate 7: Latitude 65° N or S


WORLD STAR CHART
NORTH
SOUTH
RIGHT ASCENSION
EAST
WEST
(-) SOUTH DECLINATION NORTH (+)
24h 23h 22h 21h 20h 19h 18h 17h 16h 15h 14h 13h 12h 11h 10h 9h 8h 7h 6h 5h 4h 3h 2h 1h 0h
90° 80° 70° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 70° 80° 90°
1st Magnitude (Brightest)
2nd Magnitude (Brightest)
3rd Magnitude (Bright)
2nd or3rd Magnitude (Bright)
4th Magnitude (Dim)
5th Magnitude (Dim)
Vernal Equinox
Vernal Equinox
CEPHEUS
DRACO
URSA MINOR
Kochab
Polaris
CASSIOPEIA
(Gamma), Cassiopeioe
(Cassiopeioe, Gamma)
Ruchbah
Caph
Schedir
Dubhe
Merak
Mizar
Alioth
Phecda
URSA MAJOR
Etamin
Alkaid
(Benetnasch)
Deneb
VEGA
HERCULES
BOOTES
Capella
AURIGA
Mirfak
PERSEUS
ANDROMEDA
Castor
Pollux
El Nath
PLEIADES
TRIANGULUM
Alpheratz
Hamal
PEGASUS
Alphecca
CORONA BOREALIS
Arcturus
GEMINI
LEO
Denebola
Regulus
(Gamma) Geminorum
(Alhend, Geninorum Gamma)
Aldeboron
Markob
Enif
Altair
AQUILA
VIRGO
Procyon
CANIS MINOR
Bellatrix
Betalgeux
ORION
AQUARIUS
OPHIUCHUS
HYDRA
(Zeta) Orionis
(Alnitak)
Rigel
(Orionis,Zeta)
Alphard
CETUS
CAPRICORNUS
Sabik
LIBRA
Spica
Sirius
CANIS MAJOR
EPUS
CORVUS
Deneb Kaitos
(Diphda)
Dschubba
Nunki
Antares
HYDRA
(Delta) Canis Majoris
Canis Majoris Delta)
Adhara
Fomalhout
SAGITTARIUS
Shaula
SCORPIO
(Theta) Centauri
Centauri, Theta
ERIDANUS
Kas Austr
COLUMBA
GRUS
Al Nair
Acamar
CENTAURUS
Al Suhail
LUPUS
(VELA)
(Gamma) Argus
(Argus Gamma)
(Vwlorum, Gamma)
ARGO
PHOENIX
ARA
(Gamma) Crucis
(Crucis, Gamma)
(Beta) Crucis
Crucis, Beta
Canopus
Peacock
Crux
(Epsilon) Argus
(Argus, Epsilon)
(Carinae, Epsilon)
Achernar
Rigil Kent
(Beta) Centauri
(Centauri, Beta)
Acrux
(Crucis, Alpha)
(CARINA)
TRI AUST
Maplacidus
(Alpha) Tri Aust
(Tri Aust)
HYDRUS
(Hydrus, Beta)
(Octantis)

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Appendix F
PADS MISSION PROCEDURES
(from TM 08837A-12/1A)

1. Pre-Operation Checks and Services

a. Check that primary pallet, battery box, and CDU are securely mounted.
b. Inspect fluid level of vehicle and PADS batteries. Replenish as necessary.
c. Check that all cables are properly connected and that power cable to vehicle is secure.
d. Check for proper operation of flashlight.
e. Clean porro prism.
f. Check that all equipment is properly stowed and does not block airflow to PADS or interfere with vibration isolators.
g. Check that PS Battery and Vehicle circuit breakers CB1 and CB2 are off.
h. Start vehicle and verify proper operation of electrical system.

2. 30-Day Azimuth Gyro Bias

a. Perform Pre-Operation Checks and Services as listed in section 1 above.
b. Set PS Battery and Vehicle circuit breakers CB1 and CB2 to ON.
c. **Press ON/OFF**; PADS cues for GPS C-E.

PADS MUST NOT BE MOVED UNTIL THE 30-DAY IS COMPLETED

d. Set engine idle for smooth operation.
e. Perform Lamp Test.
f. **Press ENT**; PADS cues for FOM 1-9. Only a FOM of 1 should be used with the PADS except in extreme cases where more accurate data is not available.
g. **Press 1, ENT**; PADS cues for AOV C-E. If using a GPS antenna mounted to the vehicle, refer to the TM; if using a control point or GPS coordinates with a plumb bob mount, continue with step h.
h. **Press CLR**; PADS displays a flashing SS SPH ? (Last code entered).
i. **Press SPH**; display stops flashing.
j. **Press 2, 0, Spheroid Code, ENT**; PADS displays PAUSE; cues for vehicle type by displaying the last vehicle code entered.
k. **Press the vehicle code, ENT**; PADS displays a flashing E.
l. **Press E, UTM grid zone, Easting coordinate, ENT**; PADS displays a flashing N.
m. **Press N, Northing coordinate, ENT**; PADS pauses; displays a flashing EL.
n. **Press EL, + or -, Elevation (meters), ENT**; PADS displays its current mode. Operator exits vehicle.
o. Alignment takes approximately 2½ to 3 hours and ends at Mode 18 at which time the PADS will display a flashing GO; the operator can perform shutdown procedures or he can continue with a survey mission.

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PADS MISSION PROCEDURES

(from TM 08837A-12/1A)

3. Initialization with UTM Coordinates

a. Perform Pre-Operation Checks and Services as listed in section 1 above.
b. Position Vehicle within 100 meters of initialization point.
c. Set PS Battery and Vehicle circuit breakers CB1 and CB2 to ON.

PADS MUST NOT BE MOVED FOR AT LEAST ONE MINUTE AFTER TURNON.

d. **Press ON/OFF**; PADS cues for GPS C-E.
e. Set engine idle for smooth operation.
f. Perform Lamp Test.
g. **Press ENT**; PADS cues for FOM 1-9. Only a FOM of 1 should be used with the PADS except in extreme cases where more accurate data is not available.
h. **Press 1, ENT**; PADS cues for AOV C-E. If using a GPS antenna mounted to the vehicle, refer to the TM, if using a control point or GPS coordinates with a plumb bob mount, continue with step i.
i. **Press CLR**; PADS displays a flashing SS SPH? (Last code entered).
j. **Press SPH, Spheroid Code, ENT**; PADS displays PAUSE, cues for vehicle type by displaying the last vehicle code entered.
k. **Press the vehicle code, ENT**; PADS displays a flashing E.
l. **Press E, UTM grid zone, Easting coordinate, ENT**; PADS displays a flashing N.
m. **Press N, Northing coordinate, ENT**; PADS pauses; displays a flashing EL.
n. **Press EL, + or -, Elevation (meters), ENT**; PADS displays its current mode. Operator exits vehicle.
o. Alignment takes approximately 30 to 45 minutes and ends at Mode 8 at which time the PADS will display a flashing GO.

4. Initialization with Geographic Coordinates

a. Perform steps 3a through 3i above.
b. **Press SPH, 1, 0, Spheroid Code, ENT**; PADS displays PAUSE, cues for vehicle type by displaying the last vehicle code entered.
c. **Press the vehicle code, ENT**; PADS displays a flashing LO.
d. **Press E, + or -, Longitude, ENT**; (A longitude is + if in the eastern hemisphere, - if in the western hemisphere.) PADS display a flashing LA.
e. **Press N, Latitude, ENT**; PADS pauses; displays a flashing EL.
f. **Press EL, + or -, Elevation (meters), ENT**; PADS displays its current mode. Operator exits vehicle.
g. Alignment takes approximately 30 to 45 minutes and ends at Mode 8 at which time the PADS will display a flashing GO.

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PADS MISSION PROCEDURES

(from TM 08837A-12/1A)

5. Update with a Plumb Bob w/ SCP or GPS (antenna not on vehicle)

a. Maneuver vehicle to place the plumb bob over the point.
b. Stop the vehicle, set the parking brake, place transmission in neutral.
c. **Press STOP, UPDT;** CDU will display GPS C-E.
d. 1. SCP- If plumb over an SCP, **Press CLR.** CDU displays C-E. Go to step e.
   2. GPS- If plumb over a GPS position, **Press ENT.** CDU will display DIFF C-E. (For procedures concerning differential GPS with the PADS, refer to the TM)
      a. **Press CLR;** CDU will display FOM 1-9. Only a FOM of 1 should be used with the PADS except in extreme cases where more accurate data is not available.
      b. **Press 1, ENT;** CDU displays AOV C-E.
      c. **Press CLR;** CDU displays C-E.
e. **Press CLR;** CDU displays a flashing E.
f. **Press E, UTM grid zone, Easting coordinate, ENT**; PADS displays a flashing N.
g. **Press N, Northing coordinate, ENT**; PADS pauses; displays a flashing EL.
h. **Press EL, + or -, Elevation (meters), ENT**; PADS pauses, CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

6. Update Position Only with Plumb-Bob (SCP or GPS)

a. Perform steps 5a through 5g above.
b. **Press CLR;** CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

7. Update Elevation Only with Plumb-Bob (SCP or GPS)

a. Perform steps 5a through 5e above.
b. **Press CLR;** CDU displays a flashing EL.
c. **Press EL, + or -, Elevation (meters), ENT**; PADS pauses, CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

8. Update with Theodolite w/ SCP or GPS (antenna not on vehicle)

a. Setup theodolite over SCP or GPS located point.
b. Maneuver vehicle to obtain autoreflection (See section 17)
c. Stop the vehicle, set the parking brake, place transmission in neutral.
d. **Press STOP, UPDT;** CDU will display GPS C-E; exit the vehicle, level the porro prism.
e. 1. SCP- If plumb over an SCP, **Press CLR.** CDU displays C-E. Go to step f.
   2. GPS- If plumb over a GPS position, **Press ENT.** CDU will display DIFF C-E. (For procedures concerning differential GPS with the PADS, refer to the TM)
      a. **Press CLR;** CDU will display FOM 1-9. Only a FOM of 1 should be used with the PADS except in extreme cases where more accurate data is not available.
      b. **Press 1, ENT;** CDU displays AOV C-E.
      c. **Press CLR;** CDU displays C-E.
f. **Press ENT;** CDU displays a flashing E.
g. **Press E, UTM grid zone, Easting coordinate, ENT**; PADS displays a flashing N.
h. **Press N, Northing coordinate, ENT**; PADS pauses; displays a flashing D.
i. **Press DIST, offset dist. from theodolite, ENT;** PADS pauses, displays flashing EL.
j. **Press EL, + or -, Elevation (meters), ENT**; PADS pauses, CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

9. Update Position Only with Theodolite (SCP or GPS)

a. Perform steps 8a through 8i above.
b. **Press CLR;** CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

10. Update Elevation Only with Theodolite (SCP or GPS)

a. Perform steps 8a through 8e above.
b. **Press CLR;** CDU displays a flashing EL.
c. **Press EL, + or -, Elevation (meters), ENT**; PADS pauses, CDU displays update results in the form of a PAE Code. GO flashes, informing the operator the vehicle can be moved.

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PADS MISSION PROCEDURES

(from TM 08837A-12/1A)

11. Mark a Position and Elevation with a Plumb Bob

a. Position the vehicle so that a plumb bob strung over the suspension point is plumb over the station. Set parking brake, place transmission in neutral.
b. **Press STOP, MARK;** if 2 POS C-E appears, Press CLR; CDU displays C-E.
c. **Press CLR;** PADS pauses and records the position and elevation, CDU displays the results of the mark in the form of a PAE Code. Go flashes to inform the operator the vehicle can be moved.
d. **Press E;** record easting, **Press N;** record northing, **Press EL;** record elevation.

12. Mark a Two-Position Azimuth Mark

a. Perform steps 11a through 11d above.
b. Drive vehicle toward second point requiring survey in < 70 sec. (100-1000 meters).
c. **Press ID, 0, ENT, DIST;** monitor distance to ensure azimuth line exceeds 100 meters.
d. Maneuver vehicle so that the plumb bob is plumb over the azimuth mark. Set the parking brake, place the transmission in neutral.
e. **Press STOP, MARK;** CDU displays 2 POS C-E.
f. **Press ENT;** PADS pauses and records the position, azimuth, and elevation, CDU displays the results of the mark in the form of a PAE Code. Go flashes to inform the operator the vehicle can be moved.
g. **Press E;** record easting, **Press N;** record northing, **Press EL;** record elevation, **Press GAZ;** record grid azimuth (If true azimuth is needed, press GAZ again, CDU displays TAZ C-E, press ENT).

13. Mark a Position and Elevation with a Theodolite

a. Setup theodolite over point to be marked.
b. Maneuver vehicle to obtain autoreflection (See section 17)
c. Stop the vehicle, set the parking brake, place transmission in neutral.
d. **Press STOP, Mark;** if 2 POS C-E appears, Press CLR; CDU displays C-E.
e. **Press ENT;** CDU will alternate between READ and for 64 seconds. Bypass this internal motion test by pressing CLR; CDU displays flashing D.
f. **Press DIST, offset dist. from theodolite, ENT;** PADS pauses, and records the position and elevation, CDU displays the results of the mark in the form of a PAE Code. GO flashes to inform the operator the vehicle can be moved.
g. **Press E;** record easting, **Press N;** record northing, **Press EL;** record elevation.

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PADS MISSION PROCEDURES
(from TM 08837A-12/1A)

14. Mark a Position, Azimuth, and Elevation with a Theodolite

a. Setup theodolite over point to be marked.
b. Maneuver vehicle to obtain autoreflection (See section 17)
c. Stop the vehicle, set the parking brake, place transmission in neutral.
d. **Press STOP, Mark;** if 2 POS C-E appears, Press CLR; CDU displays C-E.
e. **Press ENT;** CDU will alternate between READ and for 64 seconds then displays a flashing < 00. DO NOT DISTURB THE VEHICLE.
f. Measure and record the offset distance and the horizontal angle from the autoreflection to the azimuth mark.
g. **Press <;** PADS pauses to check for azimuth motion. If azimuth motion is within limits, the CDU will display < again; if not, the CDU will display C-E and steps d through f must be repeated.
h. **Press horizontal angle to 0.01 mils, ENT;** CDU displays a flashing D.
i. **Press DIST, offset dist. from theodolite, ENT;** PADS pauses, and records the position, azimuth, and elevation, CDU displays the results of the mark in the form of a PAE Code. GO flashes to inform the operator the vehicle can be moved.
j. **Press E;** record easting, **Press N;** record northing, **Press EL;** record elevation. **Press GAZ;** record grid azimuth (If true azimuth is needed, press GAZ again, CDU displays TAZ C-E, press ENT).

15. Current Data Display

a. **Press ID, 0, ENT**
b. **Press E;** CDU will display the current Easting, even while in motion.
Press N; CDU will display the current Northing, even while in motion.
Press EL; CDU will display the current Elevation, even while in motion.
Press DIST; CDU will display the distance in meters from the last mark or update.
Press GAZ; CDU will display the current Grid Azimuth measured toward the front of the vehicle, even while in motion.

16. Recording Adjusted Data

a. Update PADS using the procedures above.
b. **Press ID, the ID# of the marked point, ENT**
c. **Press E** for adjusted Easting, **Press N** for adjusted Northing, and **Press EL** for adjusted Elevation; PADS will adjust azimuth; however, the adjusted azimuth is not recorded and is not used.

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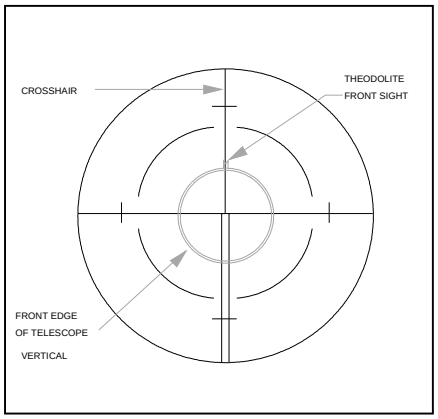
PADS MISSION PROCEDURES

(from TM 08837A-12/1A)

17. Obtaining Autoreflection

a. Position vehicle within 16 meters of station.
b. **Press STOP;** PADS performs a Z-Vel.
c. Set up theodolite over station. Open Porro Prism Cover and rough level the Porro Prism.
d. Point theodolite at Porro Prism, the instrument operator gives directions to the driver that will place the reflection of the theodolite in the Porro Prism so that the instrument operator can sight on the reflected sight of the theodolite.
e. Once autoreflection is achieved, the driver exits the vehicle.
f. **Press STOP;** PADS performs a Z-Vel.
g. The driver fine levels the porro prism. The instrument operator verifies that autoreflection is still there.
h. Instrument Operator sights on the PADS stadia bar, placing the left stadia of the reticle on the zero of the scale. If the right stadia falls on the PADS stadia bar, the distance along the autoreflection is read directly off the right stadia, distances less than 8 meters. If the right stadia does not fall on the PADS stadia bar, the instrument operator reads the center stadia and multiplies the reading by 2, distances between 8 and 16 meters.
i. If performing the Optical Azimuth Method, the horizontal angle is now measured. The angle is turned from the autoreflection (not the stadia bar) to the azimuth mark.



AUTOREFLECTION

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PADS MISSION PROCEDURES
(from TM 08837A-12/1A)

18. PADS V.4 Spheroid Codes

Clarke 1866	1
International	2
Clarke 1880	3
Everest	4
Bessel	5
Spare	6
Spare	7
Australian GRS 67	8
GRS 1980/WGS 84	9
Airy	10
Modified Airy	11
Modified Everest	12
WGS72	13
Hough	14
User Defined	15
User Defined	16

19. PLGR Checklist **(To use PLGR with PADS)**

a. Turn PLGR On, Setup Mode CONT.
b. Verify Crypto
c. Verify Setup
   1. Horizontal Datum
   2. Verify Vertical Datum
   3. SV-Type: all-Y
d. Remain in CONT Mode until:
   1. Alm Age: 1 Day
   2. FOM: 1
e. Setup Mode: AVG
f. Averages: 300 or 5 min. (must remain FOM: 1 while averaging)

APPENDIX G

MAPPING, CHARTING, & GEODESY AFTER ACTION REPORT

General. Mapping, Charting, and Geodesy After Action Reports (MC&G AARs) are used by the Survey Information Center to identify areas of operation used by Marine Air-Ground Task Forces.

a. The MC&G AAR will provide information about the area of operation, map products required, and availability of survey control.

b. The MC&G AAR will provide artillery units with information vital to the planning process for future operations.

Mapping, Charting, & Geodesy After Action Report Outline. The outline in this appendix can be used to record all pertinent information about the area of operation.

Example

1. Unit: B 1/12

2. Exercise/Operation Name: Team Spirit

3. Date of Operation: February - March 1998

4. Country: Republic of Korea

5. Name of Training Area: Tok Sok Ri

6. Name of Nearest City/Town: Pohang

7. Area of Operation Coverage:

   a. Area of Operation Coverage by Geographic Coordinates:

   Min Latitude: 36 00 00 N
   Max Latitude: 36 30 00 N
   Min Longitude: 129 12 00 E
   Max Longitude: 129 22 00 E

   b. Area of Operation Coverage by Military Grid Reference System:

   NE Corner: 52S EF 328 394
   SE Corner: 52S EE 330 840
   SW Corner: 52S EE 180 840
   NW Corner: 52S EF 179 394

8. Map Coverage:

a. Map Series: L754

b. Map Sheet Number(s): 3518 II

c. Spheroid on Map Product: WGS 84

d. Datum on Map Product: WGS 84

e. Grid on Map Product (UTM, Lambert, TM): UTM

f. Grid Zone Used: 52 S

g. What Agency Produced the Map Product (NIMA, UK, GSI): NIMA/KAMS

9. Grids to Firing Positions (Six Place Grid): OS 127 GRID: 5 30650 40 04440 HT 35 M

10. Grids to Observation Posts (Best Available Grid): OP-1 E. 5 26284 N. 40 01790 HT. 350 M

11. Grids used to Identify Impact Area or Safety Box: Impact Area Corners: EF 230 015 TO EF 300 015 TO EE 300 965TO EE 230 965

12. Target Grids (Six Place Grid): RP1 5 26294 39 98724 HT 85 M

13. Amphibious Landing Beach Grids (Left & Right Limits or Center & Length): South end of landing beach is at grid EF396 085, North end of landing beach is at grid EF 398092. LCU and LCAC can both use this beach.

14. Route of March Used During the Operation: (Identify Problems Unique to Artillery: Bridge, Culvert, Tunnel Fords, Road Restrictions or Other Problems) (1) Route of March, see accompanying map. (2) Bridge at grid EF317048 will not support a 5 ton truck with towed howitzer.

15. Restricted Areas: Buddhist Temple in Village of T'Aebaek. Do not drive vehicles through this village.

16. Points of Contact for Range Information, (Include: Name, Address, & Telephone Number): 1st Marine Division Artillery Headquarters, Republic of Korea, Marine Corps, Building 1, Pohang. No direct liaison made by the battery, Contact 31st MEU S-3.

17. Points of Contact for Survey Information, (Include: Name, Address, & Telephone Number): 12th Marines Survey Section, Camp Hansen, Okinawa. DSN 645-3393

18. Trig List Information, (If Data was Provided Prior to Deployment) List: Problems, Lack of Data, Lost or Destroyed Control Points, Accessibility of Control, Any Information Concerning Geodetic Control.
The trig list obtained from 12th Marines Survey needs to be up dated. Many new survey control points were found in the training area, but we did not have data on them, See attached recovery notes.

19. Survey Control Recovery/Survey Information: (Copies of: Recovery Notes, New Survey Control Point Information, Trig Lists) See Attachment for OP, GP, DEC STA Data.

20. Grid Convergence and/or Datum Transformation, (If Needed, What Method was Used?): Not required.

21. General Comments (Artillery Oriented or Other): Ensure local secure is enforced to prevent thievery. Ensure vehicles have tire chains for operations on icy roads.

22. Point of Contact at Unit: 1st Lt Jones (XO) DSN 645-1234

MAPPING, CHARTING, & GEODESY
AFTER ACTION REPORT
OUTLINE

1. Unit:

2. Exercise/Operation Name:

3. Date of Operation:

4. Country:

5. Name of Training Area:

6. Name of Nearest City/Town:

7. Area of Operation Coverage:

   a. Area of Operation Coverage by Geographic Coordinates:

      Min Latitude:
      Max Latitude:
      Min Longitude:
      Max Longitude:

   b. Area of Operation Coverage by Military Grid Reference System:

      NE Corner:
      SE Corner:
      SW Corner:
      NW Corner:

8. Map Coverage:

   a. Map Series:

   b. Map Sheet Number(s):

   c. Spheroid on Map Product:

   d. Datum on Map Product:

   e. Grid on Map Product (UTM, Lambert, TM):

   f. Grid Zone Used:

   g. What Agency Produced the Map Product (NIMA, UK, GSI):

9. Grids to Firing Positions (Six Place Grid):

10. Grids to Observation Posts (Best Available Grid):

MAPPING, CHARTING, & GEODESY
AFTER ACTION REPORT
OUTLINE

11. Grids used to Identify Impact Area or Safety Box:

12. Target Grids (Six Place Grid):

13. Amphibious Landing Beach Grids (Left & Right Limits or Center & Length):

14. Route of March Used During the Operation: (Identify Problems Unique to Artillery: Bridge, Culvert, Tunnel Fords, Road Restrictions or Other Problems)

15. Restricted Areas:

16. Points of Contact for Range Information, (Include: Name, Address, & Telephone Number):

17. Points of Contact for Survey Information, (Include: Name, Address, & Telephone Number):

18. Trig List Information, (If Data was Provided Prior to Deployment) List: Problems, Lack of Data, Lost or Destroyed Control Points, Accessibility of Control, Any Information Concerning Geodetic Control.

19. Survey Control Recovery/Survey Information: (Copies of: Recovery Notes, New Survey Control Point Information, Trig Lists)

20. Grid Convergence and/or Datum Transformation, (If Needed, What Method was Used?):

21. General Comments (Artillery Oriented or Other):

22. Point of Contact at Unit:

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APPENDIX H
SURVEY SPECIFICATIONS

Traverse Specifications

REQUIREMENT	FOURTH ORDER	FIFTH ORDER
Adjusted	YES	NO
Position Closure:		
* If length of traverse is *less* than 9,000 meters.	1:3,000	1:1,000
* If traverse length is 9,000 meters or *more*.	$\sqrt{K}$	1:1,000
Height Closure:		
* If length of traverse is *less* than 4,000 meters.	$\sqrt{K}$	$\pm$ 2 meters
* If length of travers is 4,000 meters or more.	$\sqrt{K}$	1.2 x $\sqrt{K}$
Azimuth Closure:		
* Six or fewer stations	0.04 x N	0.1 x N
* Seven or more stations	0.1 x $\sqrt{N}$	0.1 x N
Azimuth carried to;	0.001 mil	0.1 mil
Number of stations between azimuth checks	25	20
Horizontal Angles:		
* Measured as	One position	One position
* Recorded to	0.001 mil	0.001 mil
Vertical Angles:		
* Measured as	1 D/R	1 D/R
* Recorded to	0.001 mil	0.001 mil
* Used in computations	0.001 mil	0.001 mil
* Reciprocals measured when	Always	Legs greater than 1000 m.
Distance:		
Measured Electronically (Slope Distance)	Mean of 3 measurements after rejection limit of 0.01 from the mean.	Mean of 3 measurements after rejection limit of 0.01 from the mean.

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REQUIREMENT	FOURTH ORDER	FIFTH ORDER
UTM Coordinates computed to:	.01 meters	.01 meters
Height computed to:	.01 meters	.01 meters

****NOTE****

N = Number of Main Scheme angles
K = Total Traverse Length (TTL) in kilometers (i.e., 1000)