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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)

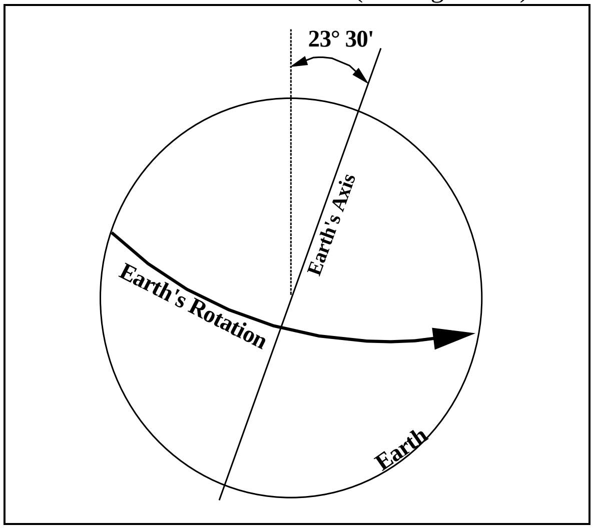

Figure 8-1 Earth's Rotational Axis

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.)

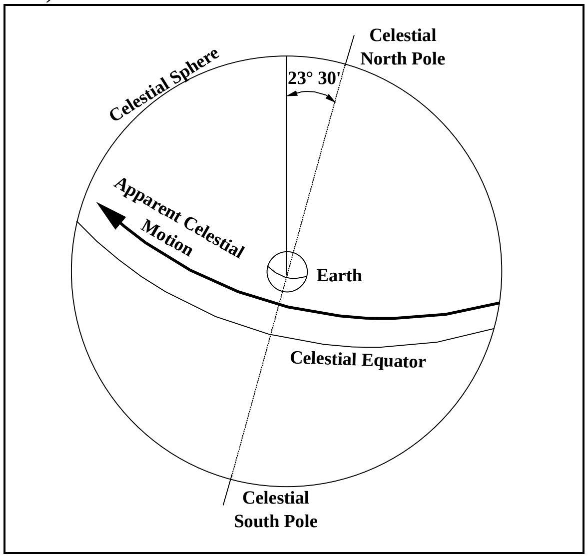

Figure 8-2 Celestial Sphere

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.)

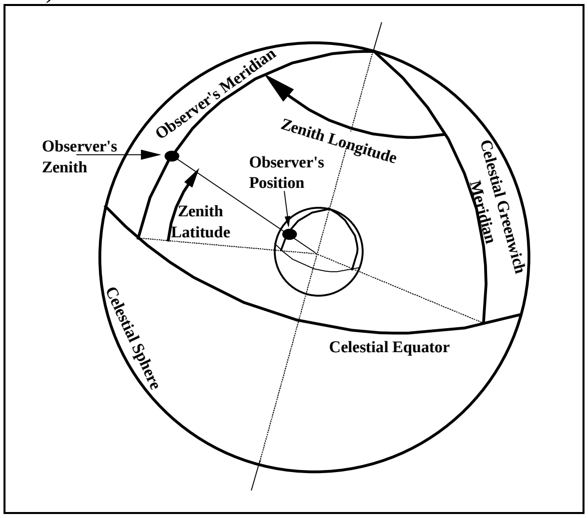

Figure 8-3 Zenith Position

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.

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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.)

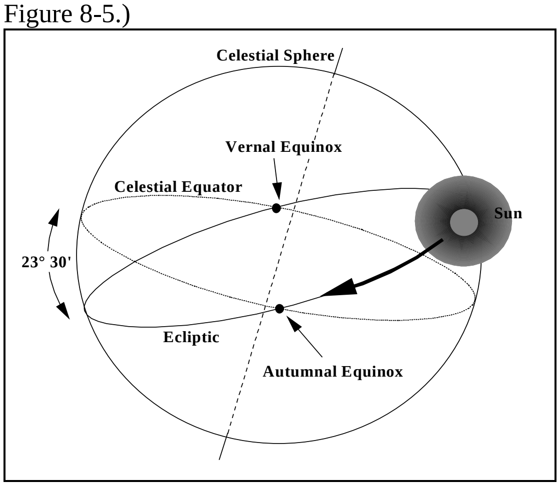

Figure 8-4 Ecliptic and Vernal Equinox

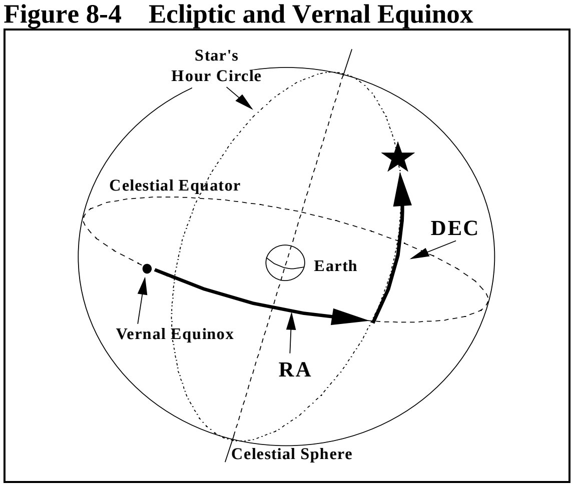

Figure 8-5 Right Ascension and Declination

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.)

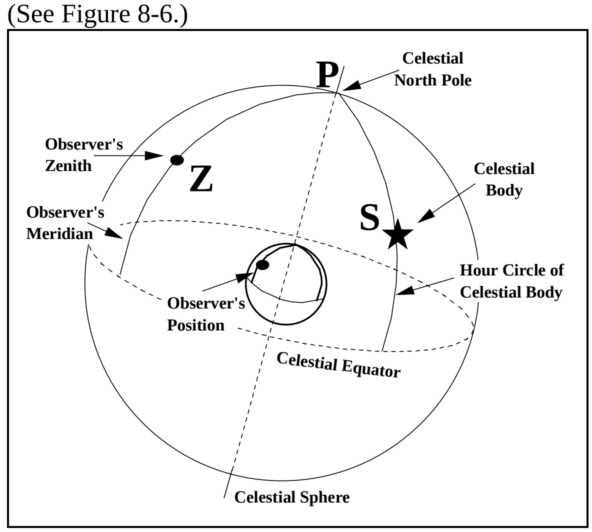

Figure 8-6 Vertices of the PZS Triangle

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.)

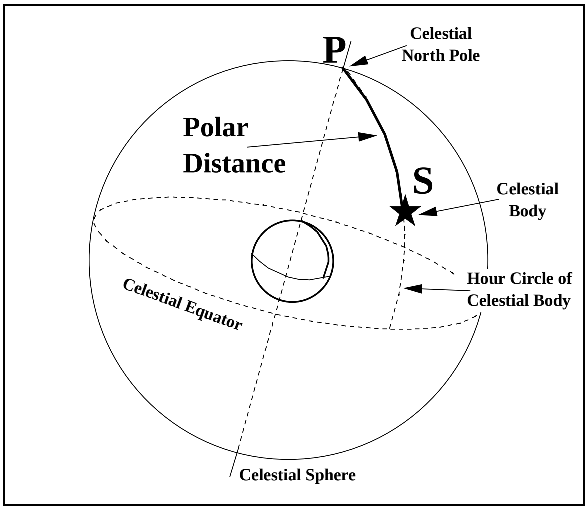

Figure 8-7 Polar Distance

2. **Coaltitude.** Coaltitude is the arc length of the side of the PZS triangle from the celestial body to the observer's zenith.

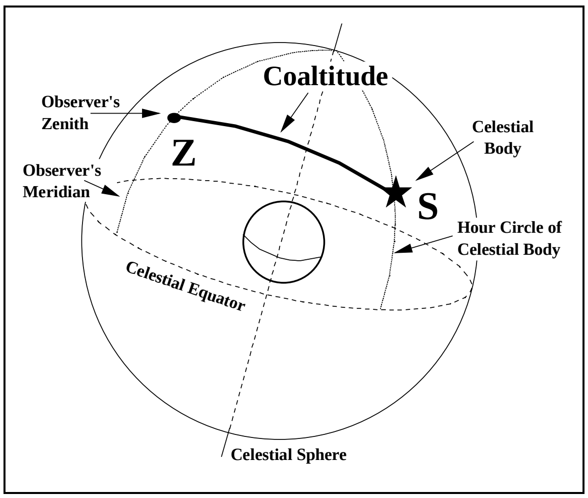

Figure 8-8 Coaltitude

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.)

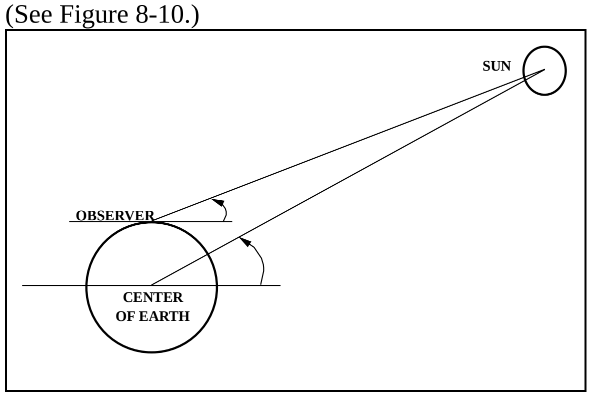

Figure 9-10 Parallax

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.)

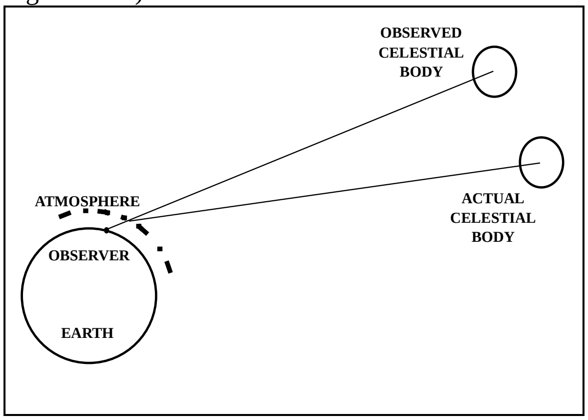

Figure 8-11 Refraction

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.)

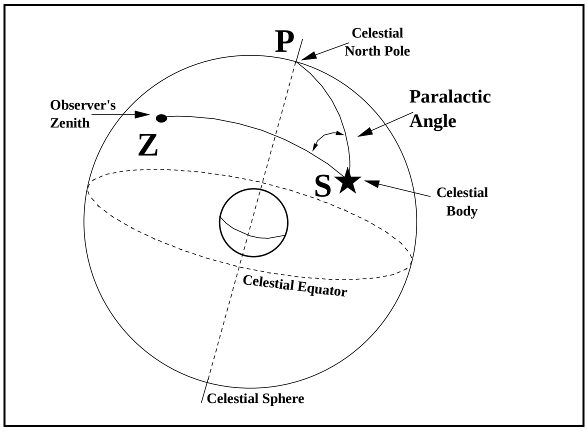

Figure 8-13 Parallactic Angle

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.)

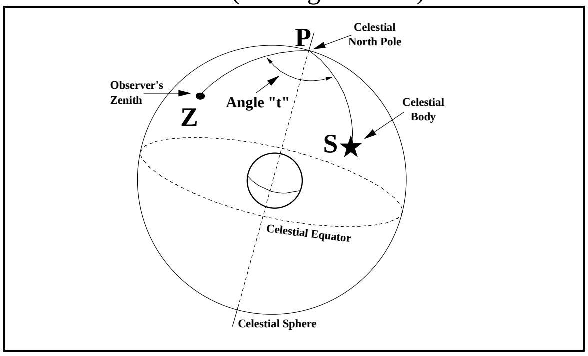

Figure 9-14 Hour Angle (Time Angle or Angle t")

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.)

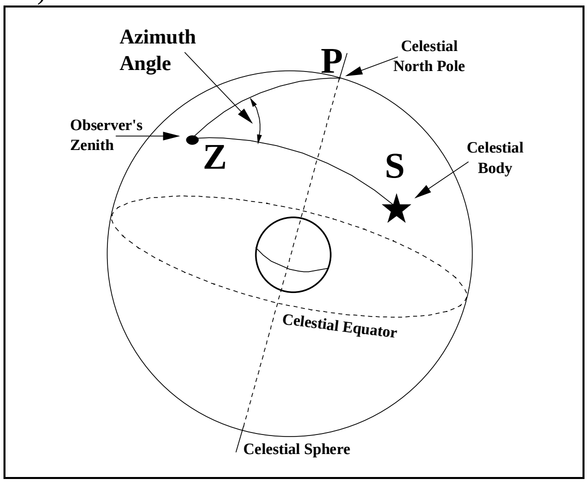

Figure 8-15 Azimuth Angle

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.

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.

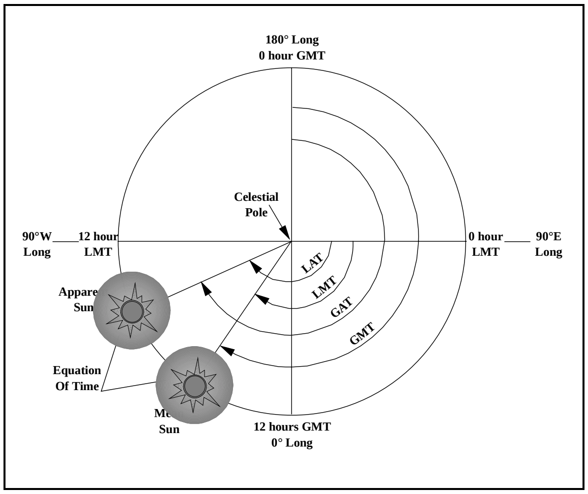

Figure 8-18 Concepts of Solar Time

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).

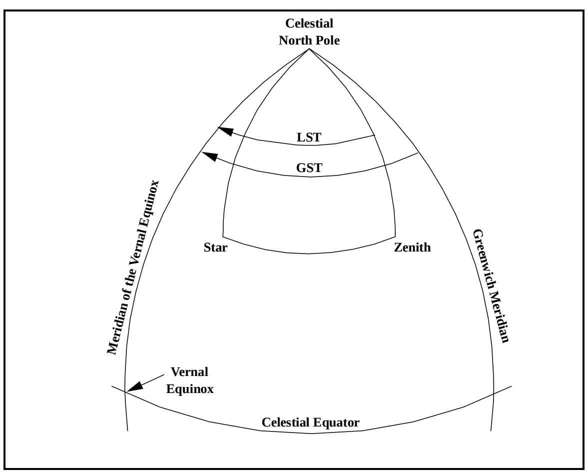

Figure 8-19 Concepts of Sidereal Time

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.)

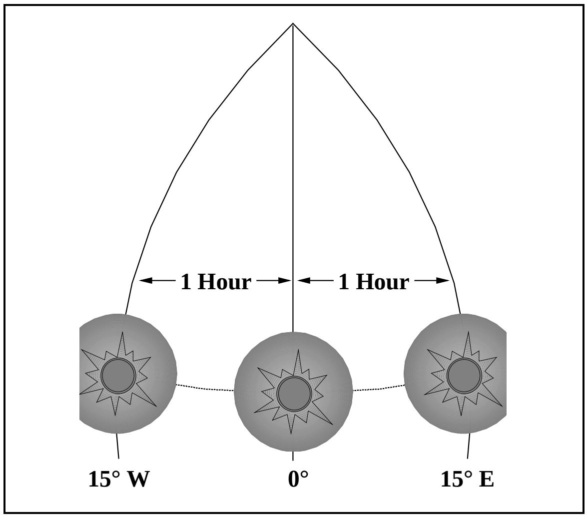

Figure 9-20 Time and Apparent Motion of the Sun

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.

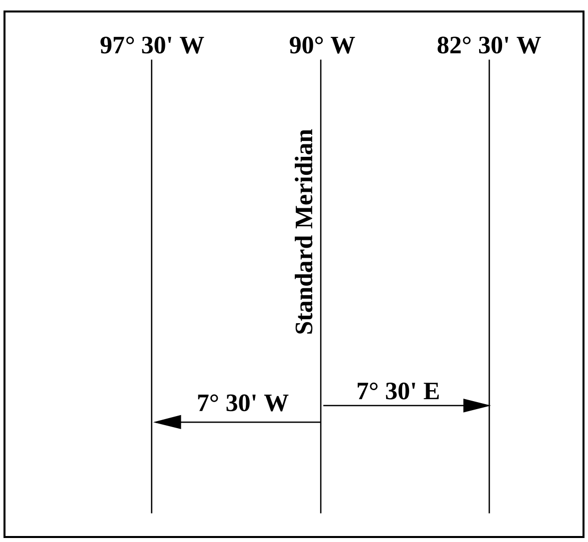

Figure 8-21 Time Zone Boundaries

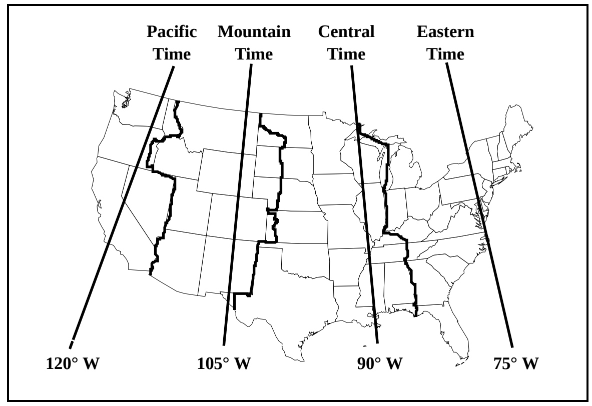

Figure 8-22 Political Time Zones in the US

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.

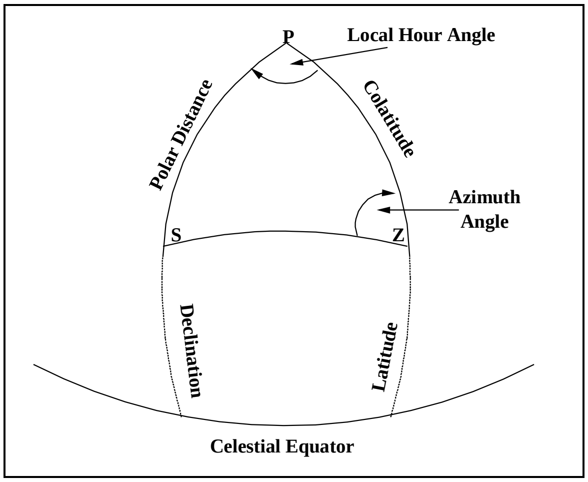

Figure 8-25 Solving the Arty Astro Method

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.)

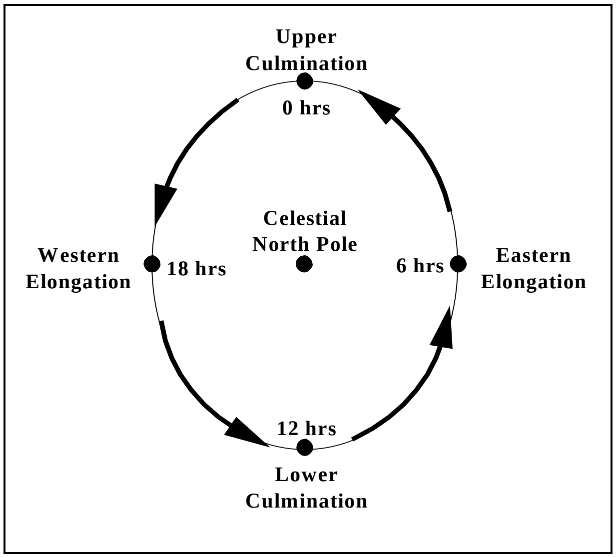

Figure 9-27 Orbit of Polaris

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

Figure 8-28 Identification of Polaris

angle to Polaris is approximately equal to observer's latitude.

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.

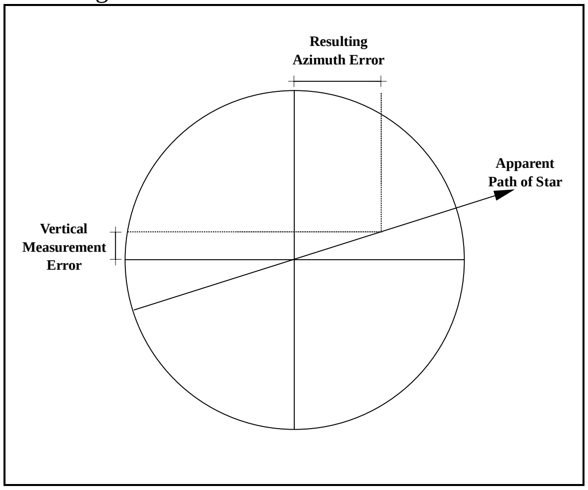

Figure 9-30 High Star Rate

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.)

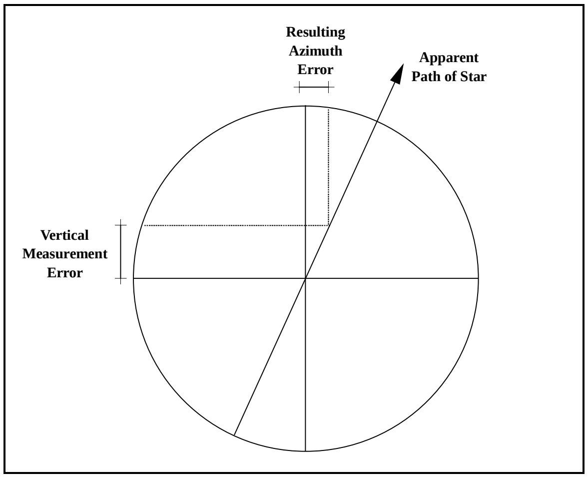

Figure 8-31 Low Star Rate

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.

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.

3. The heading of the right side of the page will be

8 **Figure 8-32 Heading and Column Titles (5th Order Arty Astro)**

include the weather description, T-2E serial number, Party Chief (COP) name, Instrument Operator (IO) name, and Recorder (RCDR) name.

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,

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

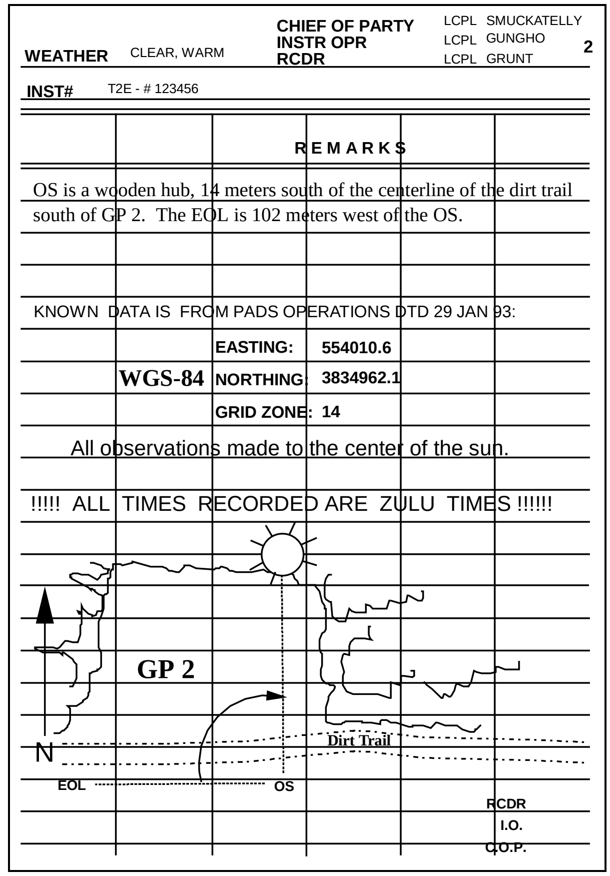

Figure 8-33 Remarks For Arty Astro

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.

DRAFT

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.

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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