ASSOCIATION OF CANADA LANDS SURVEYORS - BOARD OF EXAMINERS
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SCHEDULE I / ITEM 3
Advanced Surveying (including Survey Astronomy)

February 2000
(1990 Regulations)
(Closed Book)

Time: 3 hours — Marks

Note: This examination consists of 8 questions on 3 pages.
Astronomical tables and formula sheets are attached.
All numerical answers must be supported with calculations.

1. The line of sight of a theodolite is out of adjustment by 12". — 10

   (a) In prolonging a line by plunging the telescope between backsight and foresight, but not double centring, what angular error is introduced?

   (b) What off-line linear error results on a foresight of 500 m?

   (c) Describe the process of double centring.

   (d) Many electronic theodolites / total stations allow saving certain instrumentally errors internally so that they may be automatically applied to observed angles. What is the name of this theodolite error? How should it be determined in the field? Is double-centring necessary with an electronic theodolite if this error is correctly determined, saved internally, and applied to observed angles?

2. Theodolite errors can be minimized by appropriate observing procedures. — 15

   (a) Describe the procedures used to measure precise horizontal angles with a directional theodolite such as a Wild T2 or Kern E2.

   (b) Indicate the theodolite errors that are minimized by each observing procedure.

3. Stations A, B and C are on a straight line. The following distances are measured with an EDM: 5

Distance AB = 2012.535 m
Distance AC = 4021.909 m
Distance BC = 2009.342 m

(a) Determine the EDM system measurement constant

(b) Determine the length of each segment corrected for the EDM system measurement constant.

4. The NAD83(CSRS) position of the Algonquin Active Control Point (ACP) is 15

latitude =	45°57′20.883160″ N
longitude =	78°04′16.90782″ W
ellipsoidal height =	201.953 m
geoidal height =	-35.87 m
orthometric height =	237.823 m

The reference ellipsoid has a = 6378137 m and 1/f = 298.257222101.

The stability of the Algonquin ACP is confirmed by measuring to several reference stations. The northing and easting of the Algonquin ACP and reference station A, in the Universal Transverse Mercator projection, are as follows:

Station	**Northing (m)**	**Easting (m)**
Algonquin ACP	5 093 306.576	726 948.472
Reference Station A	5 093 627.600	727 359.364

(a) What is the grid distance from the Algonquin ACP to Reference Station A?

(b) What is the distance on the reference ellipsoid?

(c) What is the combined scale factor?

(d) What should the measured horizontal distance be?

(e) What is the UTM zone number?

5. Discuss the differences among geodetic azimuths derived from GPS observations, astronomic azimuth derived from observations to Polaris and a grid azimuth derived from UTM coordinates. 10

6. Discuss the differences among ellipsoidal heights derived from GPS, heights derived directly from levelling, published CGVD28 orthometric heights and geopotential height differences. 10

7. The following data was obtained from observations on Polaris: 25

Date: 9:00 pm PST, January 3, 2000
Latitude: 49°19′21″ N
Longitude: 119°37′30″ W

Point Sighted	**D/R**	**HCR**	**Universal Time**
RO	D	45°02′30″	
Polaris	D	118°55′20″	$5^h\ 38^m\ 39^s$
Polaris	R	298°55′54″	$5^h\ 41^m\ 42^s$
RO	R	225°02′42″	

(a) Determine the astronomic azimuth of the Reference Object (RO).

(b) Illustrate, on a Celestial sphere, for these observations:
the Greenwich Hour Angle (GHA), Local Hour Angle (LHA) and declination (δ) of Polaris at the time of observation; the Azimuth of Polaris ($Az_{\star}$); Local Meridian of the observer, Greenwich meridian, Longitude of local meridian, Celestial equator, North Celestial Pole (NCP), Horizon, Zenith, North point and East point.

8. The latitude and longitude of a point is: 10

Latitude: 49°19′21″ N
Longitude: 119°37′30″ W

(a) Compute the time the sun crosses the local meridian on January 3, 2000.

(b) Compute the maximum altitude of the sun on January 3, 2000.

Hint: At Culmination, the sun crosses the local meridian and attains its maximum altitude.

Total marks: 100

Formulas

Horizontal Collimation Error – Error in Circle reading

$$e_C = {i_C}/{\cos b}$$

where e_C : error in circle reading

i_C : inclination of collimation axis wrt horizontal axis

β : angle of elevation of observed target

Horizontal axis error – Error in circle reading

$$e_t = i_t \tan b$$

where e_t : error in circle reading

i_t : inclination of horizontal axis wrt vertical axis

β : angle of elevation of observed target

Influence of tilt of vertical axis on

(a) Vertical angles $e_{t_V} = t \cos a$

(b) Horizontal angle $e_{t_H} \approx -t \sin a \tan b$

where τ: angle vertical axis inclined wrt direction of gravity

α: angle between plane of tilted axis and direction of telescope

Group refractive index of Light and NIR waves at standard conditions (Dry air, 0°C = 273.15 K, 760 mmHG = 1013.246mb)

$$Ng = (n_g - 1)x10^6 = 287.604 + \frac{4.8864}{l^2} + \frac{0.0680}{l^4}$$

where λ : carrier wavelength in μm

Group refractive index of Light and NIR waves at ambient temperature

$$N = Ng\frac{P}{T}\frac{273.15}{760} - \frac{273.15}{T}e\left[\frac{Ng}{760} - \frac{Ng_w}{760}\right]$$

where $Ng_w = 240.08 + \frac{6.756}{l^2}$

λ : carrier wavelength in μm

P : Pressure in mb

T : thermodynamic temperature T = 273.15 + t °C

e : water vapour pressure (ambient) in mmHg

Refractive index for Microwaves

$$N_M = (n_M - 1)x10^6 = \frac{77.624}{T}(P - e) + \frac{64.70}{T}\left(1 + \frac{5748}{T}\right)e$$

where P : Pressure in mb
T : thermodynamic temperature T = 273.15 + t °C
e : water vapour pressure (ambient) in mmHg

Partial Water vapour Pressure

$$e = E'_W - 0.000662\,p(t - t')$$

$$e = E'_{ICE} - 0.000583\,p(t - t')$$ from frozen wet bulb wick

$$E'_W = \left[1.0007 + \left(3.46x10^{-6}\,p\right)\right] * 6.1121\exp\left[\frac{17.502t'}{240.97 + t'}\right]$$

$$E'_{ICE} = \left[1.0003 + \left(4.18x10^{-6}\,p\right)\right] * 6.1115\exp\left[\frac{22.452t'}{272.55 + t'}\right]$$

where e: partial water vapour pressure in mb
p : atmospheric pressure in mb
t : dry bulb temperature in °C
t′: wet bulb temperature
E'_W: saturation water vapour pressure over water
E'_{ICE}: saturation water vapour pressure over water

Azimuth from Astronomic Triangle

$$\tan Az = \frac{\sin t}{\cos j\ \tan d - \sin j\ \cos t}$$

where Az : Azimuth

t : LHA or 360°-LHA
φ : latitude of observer’s position
δ : declination

Universal Transverse Mercator Projection

Semi-major axis a
Semi-minor axis b

Flattening $f = \frac{a-b}{a}$

Eccentricity $e^2 = \frac{a^2 - b^2}{a^2}$

Radius of curvature in meridian $r = \frac{a\left(1-e^2\right)}{\left(1-e^2 \sin^2 \varphi\right)^{3/2}}$

Radius of curvature in prime vertical $n = \frac{a}{\left(1-e^2 \sin^2 \varphi\right)^{1/2}}$

Geometric mean radius $R_M = \sqrt{rn}$

Scale factor $K = K_o\left[1 + \frac{X^2}{2R_M{}^2}\right]$ where $K_o = 0.9996$

$X = (E-500000)/0.9996$

Elevation factor $M_e = \frac{R_M}{R_M + h}$ where h : mean height above reference ellipsoid

Combined scale factor $M_C = K * M_e$

Scale = Map (Grid) Distance / Ground Distance

POLARIS DATA FOR 0 HOURS UT JANUARY 2000												
Date	**Right Ascension**			**G. App. Sid. Time**			**GHA**			**Declination**		
	h	**m**	**s**	**h**	**m**	**s**	**°**	**'**	**"**	**°**	**'**	**"**
2000 Jan 01	2	32	45.912	6	39	51.4191	61	46	22.607	89	16	0.96
2000 Jan 02	2	32	44.631	6	43	47.9749	62	45	50.159	89	16	1.14
2000 Jan 03	2	32	43.373	6	47	44.5327	63	45	17.395	89	16	1.33
2000 Jan 04	2	32	42.113	6	51	41.0923	64	44	44.689	89	16	1.53
2000 Jan 05	2	32	40.822	6	55	37.6532	65	44	12.468	89	16	1.73
2000 Jan 06	2	32	39.474	6	59	34.2148	66	43	41.112	89	16	1.94
2000 Jan 07	2	32	38.048	7	3	30.7763	67	43	10.924	89	16	2.15
2000 Jan 08	2	32	36.532	7	7	27.3369	68	42	42.073	89	16	2.36
2000 Jan 09	2	32	34.924	7	11	23.8959	69	42	14.578	89	16	2.56
2000 Jan 10	2	32	33.236	7	15	20.4528	70	41	48.252	89	16	2.75
2000 Jan 11	2	32	31.490	7	19	17.0075	71	41	22.762	89	16	2.92
2000 Jan 12	2	32	29.722	7	23	13.5603	72	40	57.574	89	16	3.06
2000 Jan 13	2	32	27.969	7	27	10.1118	73	40	32.142	89	16	3.19
2000 Jan 14	2	32	26.271	7	31	6.6630	74	40	5.880	89	16	3.30
2000 Jan 15	2	32	24.661	7	35	3.2151	75	39	38.311	89	16	3.40

SOLAR EPHEMERIS FOR 0 HOURS UT JANUARY 2000															
Date	**Right Ascension**			**G. App. Sid. Time**			**GHA**			**Declination**			**Distance**	**Equation of Time**	
	h	**m**	**s**	**h**	**m**	**s**	**°**	**'**	**"**	**°**	**'**	**"**	**AU**	**m**	**s**
2000 Jan 01	18	42	54.256	6	39	51.4191	179	14	17.447	-23	4	16.03	0.9833319	-3	2.8
2000 Jan 02	18	47	19.307	6	43	47.9749	179	7	10.019	-22	59	30.55	0.9833245	-3	31.3
2000 Jan 03	18	51	44.054	6	47	44.5327	179	0	7.180	-22	54	17.54	0.9833215	-3	59.5
2000 Jan 04	18	56	8.464	6	51	41.0923	178	53	9.425	-22	48	37.18	0.9833227	-4	27.4
2000 Jan 05	19	0	32.504	6	55	37.6532	178	46	17.238	-22	42	29.61	0.9833279	-4	54.9
2000 Jan 06	19	4	56.141	6	59	34.2148	178	39	31.107	-22	35	55.03	0.9833370	-5	21.9
2000 Jan 07	19	9	19.341	7	3	30.7763	178	32	51.530	-22	28	53.62	0.9833500	-5	48.6
2000 Jan 08	19	13	42.073	7	7	27.3369	178	26	18.958	-22	21	25.60	0.9833669	-6	14.7
2000 Jan 09	19	18	4.304	7	11	23.8959	178	19	53.879	-22	13	31.18	0.9833877	-6	40.4
2000 Jan 10	19	22	26.006	7	15	20.4528	178	13	36.702	-22	5	10.60	0.9834124	-7	5.6