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Research & Development Center

Report No. CG-D-04-13

AAPSilver System Performance Validation

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AAPSilver System Performance Validation

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16. Abstract (MAXIMUM 200 WORDS) The Visual Navigation Division (CG-NAV-1) requested that the Coast Guard Research and Development Center (RDC) examine the accuracy of the new AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations. The USCG R&D Center tested the software by comparing the AAPSilver output to independently calculated results that were calculated by an algorithm obtained from the National Geodetic Survey. Combinations of test points and offsets were input to AAPSilver, which provided latitude-longitude pairs as outputs. These coordinates were then compared to calculations from the National Geodetic Survey's FORWARD program, which served as the reference for the assessment of AAPSilver. Offset positions agreed to within 8 cm in range and agreed exactly in bearing to the calculated reference measurements. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels when the adequacy of the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.					
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EXECUTIVE SUMMARY

The Coast Guard uses a software package called the Automated Aid Positioning System (AAPS) to maintain and manage its Aids to Navigation (ATON) system. The Coast Guard will be updating AAPS to a new version called AAPSilver. The software update includes changes that could potentially affect its calculations of the geographic coordinates of ATON assets. The Visual Navigation Division (CG-NAV-1) has requested that the Coast Guard Research and Development Center (RDC) examine the performance of the new AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations.

The USCG R&D Center tested the software by comparing the AAPSilver output to independently calculated results that were calculated by an algorithm obtained from the National Geodetic Survey. Combinations of test points and offsets were generated for test points in each of the four quadrants of the globe to test the accuracy of the system in the Coast Guard's Areas of responsibility. We created eight random offset range and bearing combinations for each test point. These range-bearing pairs were input to AAPSilver which provided latitude-longitude pairs as outputs. These coordinates were then compared to calculations from the National Geodetic Survey's FORWARD program, which served as the reference for the assessment of AAPSilver.

Offset positions agreed to within 8 cm in range and agreed exactly in bearing to the calculated reference measurements. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels when the adequacy of the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.



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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AAPS	Automated Aid Positioning System
AP	Assigned Position
ATON	Aids to Navigation
BPP	Buoy Port Position
CGDN	Coast Guard Data Network
CG-NAV-1	Coast Guard Headquarters Visual Navigation Division
GPS	Global Positioning System
I-ATONIS	Integrated Aids to Navigation Information System
NMEA	National Marine Electronics Association
OSC	Coast Guard Operations Systems Center, Martinsburg, WV
RDC	Research and Development Center



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1 BACKGROUND

The Coast Guard is responsible for maintaining a network of fixed and floating aids to navigation to support the nation's marine transportation system. These aids must be maintained and physically positioned, as necessary, in order to mark the boundaries of our navigable waters. The Coast Guard manages information on more than 100,000 federal and private ATONs using the Integrated Aids to Navigation Information System (I-ATONIS). I-ATONIS is a distributed and centralized database system that is maintained by the Operations Systems Center (OSC), located in Martinsburg, WV, which holds the I-ATONIS Database for the entire Coast Guard. Coast Guard units and District offices access the central I-ATONIS database using the Coast Guard Data Network (CGDN+) to track and schedule maintenance, in order to keep the nationwide ATON system operating properly.

Field users use the Automated Aid Positioning System (AAPS) software interface to document the status of the system and to manage and maintain the ATON system. The information exchanged through the AAPS interface includes:

- Physical configuration and status of the aid
- Location and location accuracy
- Light beacon and electrical power system characteristics
- Mooring system details
- The history of ATON maintenance

Coast Guard units or contractors conduct periodic visits to each ATON in the system. The position of each floating buoy is checked each time it is visited, and a determination is made as to whether the buoy is on or off station, in accordance with standards contained in the Aids to Navigation Manual – Positioning, COMDTINST M16500.1 (series). The USCG publishes the positions of floating and fixed aids to navigation in the 8 volumes of the Light List.

The Visual Navigation Division (CG-NAV-1) has updated the AAPS software to a new version called AAPSilver. The software update includes changes that could potentially affect its calculations of the geographic coordinates of ATON assets. CG-NAV-1 has asked the Coast Guard Research and Development Center (RDC) to examine the accuracy of the new AAPSilver software in calculating geographic positions (latitude and longitude) of bearing and range offsets from reference vessel locations.

This report documents a test of a function, in which a Coast Guard ATON vessel would be placing an ATON in an Assigned Position (AP). APs are conveyed to mariners through the Light Lists and other automated processes that produce charts and related hydrographic products. It is therefore of great importance to ensure that buoy and beacon positions meet Coast Guard positioning standards. The Coast Guard vessel handles and positions the ATON from a buoy port on the vessel whose position, the buoy port position (BPP), is calculated from a GPS fix, the ship's heading, and the position offset of the buoy port relative to the GPS antenna. AAPSilver provides ranges and bearings from the BPP to the AP, to assist the vessel in converging on the AP to within Coast Guard positioning tolerances.



2 PROCEDURE

The AAPSilver test focused on comparing calculations made by AAPSilver with those made by a reference software application. Eight APs were placed around each BPP, with two APs in each quadrant relative to the BPP (Figure 1).

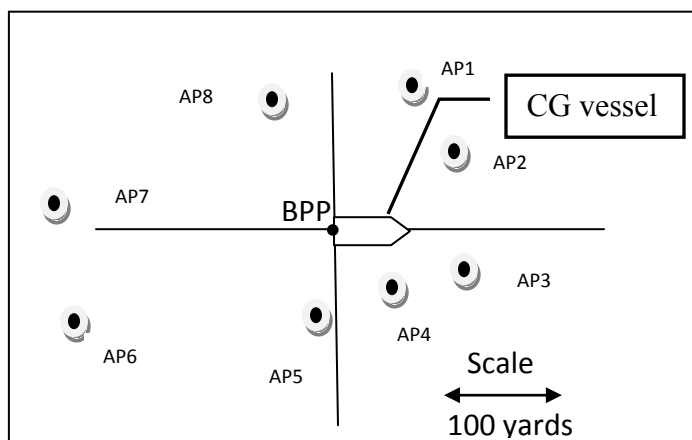


Figure 1. Assigned point and buoy port configuration.

Comparisons were made at four BPPs that were placed around the globe. The positions chosen for the four BPPs (Table 1) mirrored those of an earlier RDC study, to provide calculations that were comparable with earlier versions of AAPSilver.

Table 1. Vessel buoy port position (BPP) assigned positions used for this study.

Vessel Assigned Position (AP)	Latitude	Longitude
	(dd mm ss H)	(ddd mm ss H)
Alpha	41 00 00 N	072 00 00 W
Bravo	13 00 00 N	144 00 00 W
Charlie	60 00 00 S	087 00 00 E
Delta	10 00 00 S	170 00 00 E

The AP offsets (Table 2) were also those used in the 1999 evaluation, to permit a comparison of results, if desired. The National Geodetic Survey's FORWARD application was used to calculate the geodetic position (latitude and longitude in degrees, minutes, and seconds) of each AP from each BPP based on the AP's azimuth and range. FORWARD, which is run on-line, uses a reference position (i.e. BPP), a range, and a bearing as inputs, and calculates the resulting latitude and longitude (AP) as outputs. FORWARD was used to generate eight latitude/longitude APs at various ranges and bearings ("offsets") around each BPP. The same set of offsets was used at each of the four BPPs.

During normal use, AAPSilver accepts an output string from the ship's GPA receiver to determine the ship's BPP. The receiver's position is contained as a NMEA \$GPGGA message. For this test, AAPSilver

Table 2. Target position offsets used for each assigned position.

Test Point ID	Range	Azimuth
	(yds)	° True
AP1	100	30
AP2	75	59
AP3	60	110
AP4	20	157
AP5	87	182
AP6	300	241
AP7	640	294
AP8	31	345

was modified by the technical support contractor at the Coast Guard Operations Systems Center (OSC), Martinsburg, WV to permit the manual insertion of each BPP in a synthetic \$GPGGA string. The AP positions were input using the ‘New Federal’ button in the AAPSilver ATON page. The Range and Bearing calculated by AAPSilver were recorded and compared to the “True” Range and Bearing value used for the FORWARD calculation for each BPP.

The procedure for the test was as follows:

- 1) A spreadsheet was assembled for the input and output data that contained a separate worksheet for BPPs ALPHA through DELTA.
- 2) The FORWARD program was run to create the AP coordinates for each BPP. Eight APs were entered on each worksheet, and formatted in the spreadsheet for input to AAPSilver. The FORWARD inputs are the BPP and the Assigned Point offset (Range and Azimuth). The output of FORWARD is the resulting latitude and longitude, which are then formatted in the spreadsheet for input to AAPSilver.
- 3) AAPSilver was started. In the settings menu, right-click on the screen to enable manual \$GPGGA entry, and paste the \$GPGGA string for the first BPP. This tells the software that the vessel is at the BPP. In the “Vessel” screen, “Jump Kit” was selected as the GPS device. This sets the GPS antenna and BPP positions to the same location (i.e. zero offset).
- 4) Enter the ATON screen, select the search icon, and the Search Aids screen will come up. Select the “New Federal” icon to identify a new federal aid. Paste in the AP name and position from the worksheet file. Select “Add”, and then highlight the icon in the upper left corner. This step simulates the position of the aid at the AP.
- 5) Go to the “Positioning” screen. The vessel position will be displayed in the lower left corner. The range and bearing to the AP will be displayed in the upper right corner: that range and bearing are compared to the values input to the FORWARD Program in step 2.

3 RESULTS

An initial comparison for the eight APs at the four BPPs: Alpha, Bravo, Charlie, and Delta, is presented in the top eight rows of Tables 3 through 6. The range and bearing offsets calculated by AAPSilver were typically identical to those input into FORWARD. The observed differences ranged from 1-4 cm. The differences were examined, and in most cases could be attributed to roundoff in the seconds field of the latitude or longitude. In other words, the difference was typically due to a difference in the fourth digit in seconds of latitude or longitude.

The largest differences between the AAPSilver and FORWARD calculations were observed at BPP Charlie, and appeared to scale with range. In addition, we decided also to conduct a brief exercise of the performance of the AAPSilver software at cardinal points of the compass. A fifth BPP, Echo, was created to exercise AAPSilver at longer ranges and at the 90° and 180° bearings, and at ranges out to 2000 yards. The initial test produced range error disparity increased at an approximately linear rate, to a maximum of 0.08 yards at 2000 yards. A more significant result was that the bearing from BPP to Assigned Points at the 180° bearing was in error by 180°, so that the bearing reported by AAPSilver was 0° instead of 180° (not shown in Table 7).

This problem was reported to the sponsor and the contractor at OSC, Martinsburg. The contractor traced the problem to a bug in the software that would only occur in South latitudes and West longitudes. The contractor corrected the problem, and the BPP Echo cases were re-run. The results, shown in Table 7, were now consistent with those for the other BPPs: Range errors were on the order of a few centimeters, and increased to a maximum difference of 8 cm at 2000 yards. The bearing error problem was corrected.

Another set of runs was also conducted for BPPs Alpha, Bravo, and Delta. The results are in Tables 3, 4, and 6 as Assigned Points 9 and greater (> AP9). These runs confirmed to our satisfaction that the bearing error had been rectified. It also confirmed that the error that had once existed in the South and West quadrant of the globe did not exist in the other quadrants.



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Table 3. Comparison between FORWARD and AAPSilver calculations for BPP Alpha at 41° N 72° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	yds	m	° True		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	yds	T
N41	W72	100	91.44	30	ALPHA AP1	41-00-02.5671N	071-59-58.0437W	100	30.00
N41	W72	75	68.58	59	ALPHA AP2	41-00-01.1450N	071-59-57.4847W	75	59.00
N41	W72	60	54.864	110	ALPHA AP3	40-59-59.3917N	071-59-57.7940W	60	110.00
N41	W72	20	18.288	157	ALPHA AP4	40-59-59.4543N	071-59-59.6943W	20	157.00
N41	W72	87	79.5528	182	ALPHA AP5	40-59-57.4227N	072-00-00.1188W	87	182.00
N41	W72	300	274.32	241	ALPHA AP6	40-59-55.6887N	072-00-10.2658W*	300.01	241.00
N41	W72	640	585.216	294	ALPHA AP7	41-00-07.7155N	072-00-22.8763W‡	640.01	294.00
N41	W72	31	28.3464	345	ALPHA AP8	41-00-00.8876N	072-00-00.3139W	31	345.00
N41	W72	1000	914.4	0	ALPHA AP9	41-00-29.6418N	072-00-00.0000W	999.98	0.00
N41	W72	1000	914.4	90	ALPHA AP10	40-59-59.9982N	071-59-20.8744W	1000.03	90.00
N41	W72	1000	914.4	180	ALPHA AP11	40-59-30.3582N	072-00-00.0000W	999.98	180.00
N41	W72	1000	914.4	270	ALPHA AP12	40-59-59.9982N	072-00-39.1256W	1000.03	270.00
N41	W72	0	0	0	ALPHA AP13	41-00-00.0000N	072-00-00.0000W	0	90.00

* Changing this value to 072°-00'-10.2657"W drops the range to 300.00 yards

‡ Changing this value to 072°-00'-22.8763" drops the range to 640.00 yards



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Table 4. Comparison between FORWARD and AAPSilver calculations for BPP Bravo at 13° N 144° E.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	yds	m	° True		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	yds	T
N13	E144	100	91.44	30	BRAVO AP1	13-00-02.5769N	144-00-01.5172E	100	30.00
N13	E144	75	68.58	59	BRAVO AP2	13-00-01.1494N	144-00-01.9507E	75	59.00
N13	E144	60	54.864	110	BRAVO AP3	12-59-59.3894N	144-00-01.7108E	60	110.00
N13	E144	20	18.288	157	BRAVO AP4	12-59-59.4522N	144-00-00.2371E	20	157.00
N13	E144	87	79.5528	182	BRAVO AP5	12-59-57.4129N	143-59-59.9079E	86.99*	182.00
N13	E144	300	274.32	241	BRAVO AP6	12-59-55.6723N	143-59-52.0382E	300	241.00
N13	E144	640	585.216	294	BRAVO AP7	13-00-07.7455N	143-59-42.2588E	640	294.00
N13	E144	31	28.3464	345	BRAVO AP8	13-00-00.8910N	143-59-59.7565E	31	345.00
N13	E144	1000	914.4	0	BRAVO AP9	13-00-29.7553N	144-00-00.0000E	999.94	0.00
N13	E144	1000	914.4	90	BRAVO AP10	12-59-59.9995N	144-00-30.3438E	1000.01	90.00
N13	E144	1000	914.4	180	BRAVO AP11	12-59-30.2447N	144-00-00.0000E	999.94	180.00
N13	E144	1000	914.4	270	BRAVO AP12	12-59-59.9995N	143-59-29.6562E	1000.01	270.00

* - With latitude rounded down to 12°-59'-57.4128"N, the range calculated by AAPSilver is 87.0 yards.



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Table 5. Comparison between FORWARD and AAPSilver calculations for BPP Charlie at 60° S 87° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	yds	m	° True		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	yds	T
S60	W87	100	91.44	30	CHARLIE AP1	59-59-57.4412S	086-59-57.0504W	100	30.00
S60	W87	75	68.58	59	CHARLIE AP2	59-59-58.8587S	086-59-56.2075W	75	59.00
S60	W87	60	54.864	110	CHARLIE AP3	60-00-00.6063S	086-59-56.6738W	60	110.00
S60	W87	20	18.288	157	CHARLIE AP4	60-00-00.5439S	086-59-59.5390W	20	157.00
S60	W87	87	79.5528	182	CHARLIE AP5	60-00-02.5691S*	087-00-00.1791W	87.01	182.00
S60	W87	300	274.32	241	CHARLIE AP6	60-00-04.2971S	087-00-15.4796W	300.01	241.00
S60	W87	640	585.216	294	CHARLIE AP7	59-59-52.3075S	087-00-34.4895W	640.04	294.00
S60	W87	31	28.3464	345	CHARLIE AP8	59-59-59.1153S	087-00-00.4733W	31	345.00

* - When this position was rounded down to 60°-00'-02.5690"S, the range dropped to 87.00 yards



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Table 6. Comparison between FORWARD and AAPSilver calculations for BPP Delta at 10° S 170° E.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	yds	m	° True		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	yds	T
S10	E170	100	91.44	30	DELTA AP1	09-59-57.4226S	170-00-01.5012E	100	30.00
S10	E170	75	68.58	59	DELTA AP2	09-59-58.8504S	170-00-01.9302E	75	59.00
S10	E170	60	54.864	110	DELTA AP3	10-00-00.6107S	170-00-01.6928E	60	110.00
S10	E170	20	18.288	157	DELTA AP4	10-00-00.5479S	170-00-00.2346E	20	157.00
S10	E170	87	79.5528	182	DELTA AP5	10-00-02.5877S	169-59-59.9088E	87	182.00
S10	E170	300	274.32	241	DELTA AP6	10-00-04.3286S	169-59-52.1220E	300	241.00
S10	E170	640	585.216	294	DELTA AP7	09-59-52.2526S	169-59-42.4459E	640	294.00
S10	E170	31	28.3464	345	DELTA AP8	09-59-59.1088S	169-59-59.7591E	31	345.00
S10	E170	1000	914.4	0	DELTA AP9	09-59-30.2386S	170-00-00.0000E	999.94	0.00
S10	E170	1000	914.4	90	DELTA AP10	09-59-59.9996S	170-00-30.0243E	1000.01	90.00
S10	E170	1000	914.4	180	DELTA AP11	10-00-29.7614S	170-00-00.0000E	999.94	180.00
S10	E170	1000	914.4	270	DELTA AP12	09-59-59.9996S	169-59-29.9758E	1000.01	270.00
S10	E170	1000	914.4	360	DELTA AP13	09-59-30.2386S	170-00-00.0000E	999.94	0.00



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Table 7. Comparison between FORWARD and AAPSilver calculations for BPP Echo at 60° S 87° W.

Reference Position (BPP)		Assigned Point Offset			Assigned Point ID	AAPSilver INPUT:		AAPSilver Calculated Offset	
Latitude	Longitude	Range		Azimuth		AP Latitude	AP Longitude	Range	Bearing
Hdd	Hdd	yds	m	° True		dd-mm-ss.ssssH	ddd-mm-ss.ssssH	yds	T
S60	W87	100	91.44	90	ECHO AP1	60-00-00.0000S	086-59-54.1007W	100	90.00
S60	W87	500	457.2	90	ECHO AP2	60-00-00.0000S	086-59-30.5032W	500.02	90.00
S60	W87	1000	914.4	90	ECHO AP3	60-00-00.0000S	086-59-01.0065W	1000.04	90.00
S60	W87	2000	1828.8	90	ECHO AP4	60-00-00.0000S	086-58-02.0129W	2000.08	90.00
S60	W87	100	91.44	180	ECHO AP5	60-00-02.9547S	087-00-00.0000W	100	180.00
S60	W87	500	457.2	180	ECHO AP6	60-00-14.7732S	087-00-00.0000W	500.01	180.00
S60	W87	1000	914.4	180	ECHO AP7	60-00-29.5465S	087-00-00.0000W	1000.02	180.00
S60	W87	2000	1828.8	180	ECHO AP8	60-00-59.0929S	087-00-00.0000W	2000.04	180.00
S60	W87	100	91.44	270	ECHO AP9	60-00-00.0000S	087-00-05.8994W	100	270.00
S60	W87	500	457.2	270	ECHO AP10	59-59-59.9991S	087-00-29.4968W	500.02	270.00
S60	W87	1000	914.4	270	ECHO AP11	59-59-59.9963S	087-00-58.9936W	1000.04	270.00
S60	W87	2000	1828.8	270	ECHO AP12	59-59-59.9854S	087-01-57.9871W	2000.08	270.00
S60	W87	100	91.44	360	ECHO AP13	59-59-57.0454S	087-00-00.0000W	100	0.00
S60	W87	500	457.2	360	ECHO AP14	59-59-45.2268S	087-00-00.0000W	500.01	0.00
S60	W87	1000	914.4	360	ECHO AP15	59-59-30.4535S	087-00-00.0000W	1000.02	0.00
S60	W87	2000	1828.8	360	ECHO AP16	59-59-00.9070S	087-00-00.0000W	2000.04	0.00
S60	W87	100	91.44	359	ECHO AP17	59-59-57.0458S	087-00-00.1030W	100	359.00
S60	W87	500	457.2	359	ECHO AP18	59-59-45.2290S	087-00-00.5147W	500.01	359.00
S60	W87	1000	914.4	359	ECHO AP19	59-59-30.4580S	087-00-01.0293W	1000.02	359.00
S60	W87	2000	1828.8	359	ECHO AP20	59-59-00.9160S	087-00-02.0581W	2000.04	359.00



4 CONCLUSIONS

The Visual Navigation Division (CG-NAV-1) requested that the Coast Guard RDC examine the performance of the AAPSilver software in calculating the geographic positions (latitude and longitude) of bearing and range offsets from reference locations.

Our conclusion based on the testing described above is that the AAPSilver software performs as would be expected. The agreement between results produced by AAPSilver and the reference software was within 8 cm in range, and agreed exactly in bearing. These differences may be compared to uncertainties associated with the use of Differential Global Positioning System receivers used to position Coast Guard ATON vessels and aids when the AAPSilver software is considered for distribution throughout the Coast Guard ATON fleet.



APPENDIX A. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP ALPHA

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP1

LAT = 41 0 2.56705 North
LON = 71 59 58.04370 West

Forward azimuth FAZ = 30 0 0.0000 From North
Back azimuth BAZ = 210 0 1.2835 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP2

LAT = 41 0 1.14499 North
LON = 71 59 57.48470 West

Forward azimuth FAZ = 59 0 0.0000 From North
Back azimuth BAZ = 239 0 1.6502 From North
Ellipsoidal distance S = 68.5800 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088
First Station : AP1



AAPSilver System Performance Validation

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP3

LAT = 40 59 59.39171 North
LON = 71 59 57.79404 West

Forward azimuth FAZ = 110 0 0.0000 From North
Back azimuth BAZ = 290 0 1.4472 From North
Ellipsoidal distance S = 54.8640 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP4

LAT = 40 59 59.45429 North
LON = 71 59 59.69425 West

Forward azimuth FAZ = 157 0 0.0000 From North
Back azimuth BAZ = 337 0 0.2006 From North
Ellipsoidal distance S = 18.2880 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP5

LAT = 40 59 57.42273 North
LON = 72 0 0.11879 West

Forward azimuth FAZ = 182 0 0.0000 From North
Back azimuth BAZ = 1 59 59.9221 From North
Ellipsoidal distance S = 79.5528 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP6

LAT = 40 59 55.68868 North
LON = 72 0 10.26582 West

Forward azimuth FAZ = 241 0 0.0000 From North
Back azimuth BAZ = 60 59 53.2651 From North
Ellipsoidal distance S = 274.3200 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP7

LAT = 41 0 7.71547 North
LON = 72 0 22.87627 West

Forward azimuth FAZ = 294 0 0.0000 From North
Back azimuth BAZ = 113 59 44.9915 From North
Ellipsoidal distance S = 585.2160 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : AP1

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : TP8



AAPSilver System Performance Validation

LAT = 41 0 0.88759 North
LON = 72 0 0.31392 West

Forward azimuth FAZ = 345 0 0.0000 From North
Back azimuth BAZ = 164 59 59.7940 From North
Ellipsoidal distance S = 28.3464 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ALPHA

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : ALPHA TP9

LAT = 41 0 29.64180 North
LON = 72 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ALPHA

LAT = 41 0 0.00000 North
LON = 72 0 0.00000 West

Second Station : ALPHA TP10

LAT = 40 59 59.99816 North
LON = 71 59 20.87440 West

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 270 0 25.6687 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141



AAPSilver System Performance Validation

Inverse flattening, $1/f = 298.25722210088$

First Station : ALPHA

LAT = 41 0 0.00000 North

LON = 72 0 0.00000 West

Second Station : ALPHA TP11

LAT = 40 59 30.35816 North

LON = 72 0 0.00000 West

Forward azimuth FAZ = 180 0 0.0000 From North

Back azimuth BAZ = 0 0 0.0000 From North

Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)

Equatorial axis, a = 6378137.0000

Polar axis, b = 6356752.3141

Inverse flattening, $1/f = 298.25722210088$

First Station : ALPHA

LAT = 41 0 0.00000 North

LON = 72 0 0.00000 West

Second Station : ALPHA TP12

LAT = 40 59 59.99816 North

LON = 72 0 39.12560 West

Forward azimuth FAZ = 270 0 0.0000 From North

Back azimuth BAZ = 89 59 34.3313 From North

Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)

Equatorial axis, a = 6378137.0000

Polar axis, b = 6356752.3141

Inverse flattening, $1/f = 298.25722210088$

First Station : ALPHA

LAT = 41 0 0.00000 North

LON = 72 0 0.00000 West

Second Station : ALPHA TP13

LAT = 41 0 29.64180 North

LON = 72 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North

Back azimuth BAZ = 180 0 0.0000 From North

Ellipsoidal distance S = 914.4000 m



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APPENDIX B. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP BRAVO

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP1

LAT = 13 0 2.57688 North
LON = 144 0 1.51719 East

Forward azimuth FAZ = 30 0 0.0000 From North
Back azimuth BAZ = 210 0 0.3413 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP2

LAT = 13 0 1.14938 North
LON = 144 0 1.95073 East

Forward azimuth FAZ = 59 0 0.0000 From North
Back azimuth BAZ = 239 0 0.4388 From North
Ellipsoidal distance S = 68.5800 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO



AAPSilver System Performance Validation

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP3

LAT = 12 59 59.38938 North
LON = 144 0 1.71083 East

Forward azimuth FAZ = 110 0 0.0000 From North
Back azimuth BAZ = 290 0 0.3849 From North
Ellipsoidal distance S = 54.8640 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP4

LAT = 12 59 59.45220 North
LON = 144 0 0.23713 East

Forward azimuth FAZ = 157 0 0.0000 From North
Back azimuth BAZ = 337 0 0.0533 From North
Ellipsoidal distance S = 18.2880 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP5

LAT = 12 59 57.41287 North
LON = 143 59 59.90787 East

Forward azimuth FAZ = 182 0 0.0000 From North
Back azimuth BAZ = 1 59 59.9793 From North
Ellipsoidal distance S = 79.5528 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP6

LAT = 12 59 55.67227 North
LON = 143 59 52.03825 East

Forward azimuth FAZ = 241 0 0.0000 From North
Back azimuth BAZ = 60 59 58.2091 From North
Ellipsoidal distance S = 274.3200 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP7

LAT = 13 0 7.74547 North
LON = 143 59 42.25876 East

Forward azimuth FAZ = 294 0 0.0000 From North
Back azimuth BAZ = 113 59 56.0088 From North
Ellipsoidal distance S = 585.2160 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : AP8



AAPSilver System Performance Validation

LAT = 13 0 0.89098 North
LON = 143 59 59.75654 East

Forward azimuth FAZ = 345 0 0.0000 From North
Back azimuth BAZ = 164 59 59.9452 From North
Ellipsoidal distance S = 28.3464 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : BRAVO AP9

LAT = 13 0 29.75526 North
LON = 144 0 0.00000 East

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : BRAVO AP10

LAT = 12 59 59.99951 North
LON = 144 0 30.34380 East

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 270 0 6.8259 From North
Ellipsoidal distance S = 914.4000 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : BRAVO AP11

LAT = 12 59 30.24472 North
LON = 144 0 0.00000 East

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : BRAVO

LAT = 13 0 0.00000 North
LON = 144 0 0.00000 East

Second Station : BRAVO AP12

LAT = 12 59 59.99951 North
LON = 143 59 29.65620 East

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 89 59 53.1741 From North
Ellipsoidal distance S = 914.4000 m



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APPENDIX C. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP CHARLIE

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP1

LAT = 59 59 57.44119 South
LON = 86 59 57.05039 West

Forward azimuth FAZ = 30 0 0.0000 From North
Back azimuth BAZ = 209 59 57.4456 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP2

LAT = 59 59 58.85867 South
LON = 86 59 56.20749 West

Forward azimuth FAZ = 59 0 0.0000 From North
Back azimuth BAZ = 238 59 56.7156 From North
Ellipsoidal distance S = 68.5800 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE



AAPSilver System Performance Validation

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP3

LAT = 60 0 0.60632 South
LON = 86 59 56.67384 West

Forward azimuth FAZ = 110 0 0.0000 From North
Back azimuth BAZ = 289 59 57.1195 From North
Ellipsoidal distance S = 54.8640 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP4

LAT = 60 0 0.54395 South
LON = 86 59 59.53899 West

Forward azimuth FAZ = 157 0 0.0000 From North
Back azimuth BAZ = 336 59 59.6007 From North
Ellipsoidal distance S = 18.2880 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP5

LAT = 60 0 2.56914 South
LON = 87 0 0.17914 West

Forward azimuth FAZ = 182 0 0.0000 From North
Back azimuth BAZ = 2 0 0.1551 From North
Ellipsoidal distance S = 79.5580 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP6

LAT = 60 0 4.29707 South
LON = 87 0 15.47963 West

Forward azimuth FAZ = 241 0 0.0000 From North
Back azimuth BAZ = 61 0 13.4058 From North
Ellipsoidal distance S = 274.3200 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP7

LAT = 59 59 52.30746 South
LON = 87 0 34.48948 West

Forward azimuth FAZ = 294 0 0.0000 From North
Back azimuth BAZ = 114 0 29.8684 From North
Ellipsoidal distance S = 585.2160 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : CHARLIE

LAT = 60 0 0.00000 South



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LON = 87 0 0.00000 West

Second Station : AP8

LAT = 59 59 59.11527 South

LON = 87 0 0.47332 West

Forward azimuth FAZ = 345 0 0.0000 From North

Back azimuth BAZ = 165 0 0.4099 From North

Ellipsoidal distance S = 28.3464 m



APPENDIX D. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP DELTA

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP1

LAT = 9 59 57.42259 South
LON = 170 0 1.50121 East

Forward azimuth FAZ = 30 0 0.0000 From North
Back azimuth BAZ = 209 59 59.7393 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP2

LAT = 9 59 58.85038 South
LON = 170 0 1.93018 East

Forward azimuth FAZ = 59 0 0.0000 From North
Back azimuth BAZ = 238 59 59.6648 From North
Ellipsoidal distance S = 68.5800 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088



AAPSilver System Performance Validation

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP3

LAT = 10 0 0.61074 South
LON = 170 0 1.69282 East

Forward azimuth FAZ = 110 0 0.0000 From North
Back azimuth BAZ = 289 59 59.7060 From North
Ellipsoidal distance S = 54.8640 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP4

LAT = 10 0 0.54791 South
LON = 170 0 0.23463 East

Forward azimuth FAZ = 157 0 0.0000 From North
Back azimuth BAZ = 336 59 59.9593 From North
Ellipsoidal distance S = 18.2880 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP5

LAT = 10 0 2.58766 South
LON = 169 59 59.90884 East

Forward azimuth FAZ = 182 0 0.0000 From North
Back azimuth BAZ = 2 0 0.0158 From North
Ellipsoidal distance S = 79.5528 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP6

LAT = 10 0 4.32856 South
LON = 169 59 52.12203 East

Forward azimuth FAZ = 241 0 0.0000 From North
Back azimuth BAZ = 61 0 1.3681 From North
Ellipsoidal distance S = 274.3200 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : DELTA AP7

LAT = 9 59 52.25264 South
LON = 169 59 42.44586 East

Forward azimuth FAZ = 294 0 0.0000 From North
Back azimuth BAZ = 114 0 3.0479 From North
Ellipsoidal distance S = 585.2160 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station :

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East



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Second Station : DELTA AP8

LAT = 9 59 59.10883 South

LON = 169 59 59.75910 East

Forward azimuth FAZ = 345 0 0.0000 From North

Back azimuth BAZ = 165 0 0.0418 From North

Ellipsoidal distance S = 28.3464 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)

Equatorial axis, a = 6378137.0000

Polar axis, b = 6356752.3141

Inverse flattening, 1/f = 298.25722210088

First Station : DELTA

LAT = 10 0 0.00000 South

LON = 170 0 0.00000 East

Second Station : AP9

LAT = 9 59 30.23861 South

LON = 170 0 0.00000 East

Forward azimuth FAZ = 0 0 0.0000 From North

Back azimuth BAZ = 180 0 0.0000 From North

Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)

Equatorial axis, a = 6378137.0000

Polar axis, b = 6356752.3141

Inverse flattening, 1/f = 298.25722210088

First Station : DELTA

LAT = 10 0 0.00000 South

LON = 170 0 0.00000 East

Second Station : AP10

LAT = 9 59 59.99962 South

LON = 170 0 30.02425 East

Forward azimuth FAZ = 90 0 0.0000 From North

Back azimuth BAZ = 269 59 54.7863 From North

Ellipsoidal distance S = 914.4000 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : DELTA

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : AP11

LAT = 10 0 29.76138 South
LON = 170 0 0.00000 East

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : DELTA

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East

Second Station : AP12

LAT = 9 59 59.99962 South
LON = 169 59 29.97575 East

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 90 0 5.2137 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : DELTA

LAT = 10 0 0.00000 South
LON = 170 0 0.00000 East



AAPSilver System Performance Validation

Second Station : AP13

LAT = 9 59 30.23861 South

LON = 170 0 0.00000 East

Forward azimuth FAZ = 0 0 0.0000 From North

Back azimuth BAZ = 180 0 0.0000 From North

Ellipsoidal distance S = 914.4000 m



APPENDIX E. NATIONAL GEODETIC SURVEY FORWARD OUTPUT FOR BPP ECHO

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP1

LAT = 59 59 59.99996 South
LON = 86 59 54.10065 West

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 269 59 54.8910 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP2

LAT = 59 59 59.99909 South
LON = 86 59 30.50323 West

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 269 59 34.4550 From North
Ellipsoidal distance S = 457.2000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO



AAPSilver System Performance Validation

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP3

LAT = 59 59 59.99634 South
LON = 86 59 1.00645 West

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 269 59 8.9101 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP4

LAT = 59 59 59.98536 South
LON = 86 58 2.01292 West

Forward azimuth FAZ = 90 0 0.0000 From North
Back azimuth BAZ = 269 58 17.8202 From North
Ellipsoidal distance S = 1828.8000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP5

LAT = 60 0 2.95465 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 91.4400 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP6

LAT = 60 0 14.77323 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 457.2000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP7

LAT = 60 0 29.54645 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP8



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LAT = 60 0 59.09287 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 180 0 0.0000 From North
Back azimuth BAZ = 0 0 0.0000 From North
Ellipsoidal distance S = 1828.8000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP9

LAT = 59 59 59.99996 South
LON = 87 0 5.89935 West

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 90 0 5.1090 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP10

LAT = 59 59 59.99909 South
LON = 87 0 29.49677 West

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 90 0 25.5450 From North
Ellipsoidal distance S = 457.2000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141



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Inverse flattening, $1/f = 298.25722210088$

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP11

LAT = 59 59 59.99634 South
LON = 87 0 58.99355 West

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 90 0 51.0899 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, $1/f = 298.25722210088$

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP12

LAT = 59 59 59.98536 South
LON = 87 1 57.98708 West

Forward azimuth FAZ = 270 0 0.0000 From North
Back azimuth BAZ = 90 1 42.1798 From North
Ellipsoidal distance S = 1828.8000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, $1/f = 298.25722210088$

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP13

LAT = 59 59 57.04535 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North



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Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP14

LAT = 59 59 45.22676 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North
Ellipsoidal distance S = 457.2000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP15

LAT = 59 59 30.45351 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West



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Second Station : AP16

LAT = 59 59 0.90698 South
LON = 87 0 0.00000 West

Forward azimuth FAZ = 0 0 0.0000 From North
Back azimuth BAZ = 180 0 0.0000 From North
Ellipsoidal distance S = 1828.8000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP17

LAT = 59 59 57.04580 South
LON = 87 0 0.10296 West

Forward azimuth FAZ = 359 0 0.0000 From North
Back azimuth BAZ = 179 0 0.0892 From North
Ellipsoidal distance S = 91.4400 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP18

LAT = 59 59 45.22901 South
LON = 87 0 0.51473 West

Forward azimuth FAZ = 359 0 0.0000 From North
Back azimuth BAZ = 179 0 0.4458 From North
Ellipsoidal distance S = 457.2000 m



Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP19

LAT = 59 59 30.45801 South
LON = 87 0 1.02932 West

Forward azimuth FAZ = 359 0 0.0000 From North
Back azimuth BAZ = 179 0 0.8914 From North
Ellipsoidal distance S = 914.4000 m

Output from FORWARD

Ellipsoid : GRS80 / WGS84 (NAD83)
Equatorial axis, a = 6378137.0000
Polar axis, b = 6356752.3141
Inverse flattening, 1/f = 298.25722210088

First Station : ECHO

LAT = 60 0 0.00000 South
LON = 87 0 0.00000 West

Second Station : AP20

LAT = 59 59 0.91598 South
LON = 87 0 2.05814 West

Forward azimuth FAZ = 359 0 0.0000 From North
Back azimuth BAZ = 179 0 1.7823 From North
Ellipsoidal distance S = 1828.8000 m

