AIRBORNE GPS CONTROLLED PHOTOGRAMMETRY

The Maine Experience

DEPARTMENT OF TRANSPORTATION
Maine

FINAL REPORT

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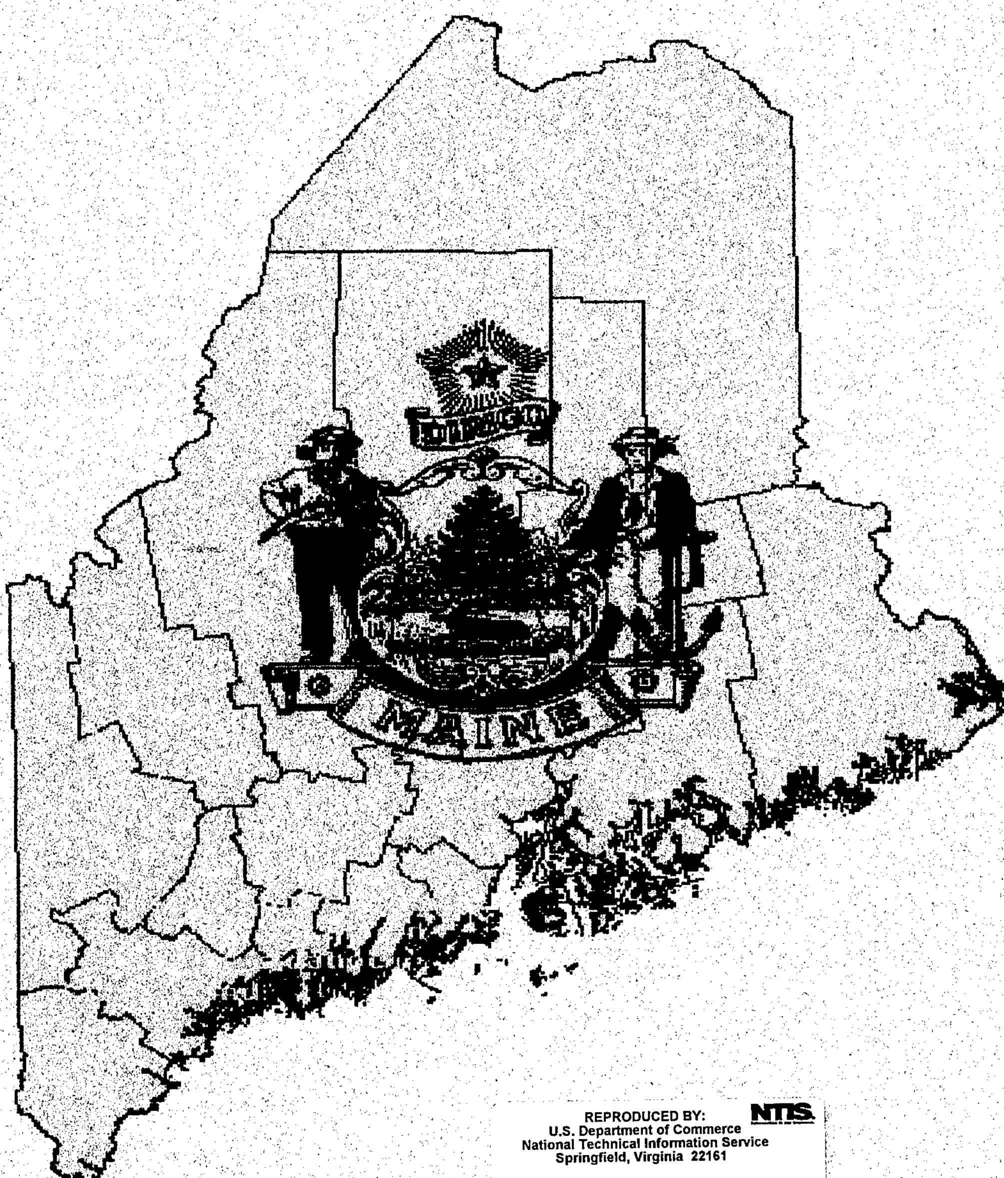
Research



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The research was to provide data toward solving questions of cost savings, accuracy and acceptability of this technology in terrain of changing topography. Since accuracy and procedural standards are still being developed for this new technology, and few practical papers showing results have been published, the MDOT decided to try it and published the results. Two different projects with different terrain patterns and different scopes were chosen and targeted traditionally. The number of control points used in the final aerotriangulation was determined by resolving error propagation of the remaining targeted control points. Once current map accuracy standards were met within the control target coordinate set, the photogrammetric mapping was completed. Each project was mapped by a different consultant, using different aerotriangulation methods. The results indicate that current standard map accuracy standards can be met using Airborne GPS controlled photogrammetry with changing terrain and changing topography. The cost savings of the Airborne GPS controlled photogrammetry is mostly in the targeting stage of the projects, as would be expected.

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AIRBORNE GPS CONTROLLED PHOTOGRAMMETRY
THE MAINE EXPERIENCE

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ABSTRACT

In the fall of 1997, the Photogrammetry and Control Unit of the Survey Section requested authorization to research the use of Airborne GPS controlled Photogrammetry for engineering and design purposes. The research was to provide data toward solving questions of cost savings, accuracy and acceptability of this technology in terrain of changing topography. Since accuracy and procedural standards are still being developed for this new technology, and few practical papers showing results have been published, the MDOT decided to try it and publish the results. Two different projects with different terrain patterns and different scopes were chosen and targeted traditionally. The number of control points used in the final aerotriangulation was determined by resolving error propagation of the remaining targeted control points. Once current map accuracy standards were met within the control target coordinate set, the photogrammetric mapping was completed. Each project was mapped by a different consultant, using different aerotriangulation methods. The results indicate that current standard map accuracy standards can be met using Airborne GPS controlled photogrammetry with changing terrain and changing topography. The cost savings of the Airborne GPS controlled photogrammetry is mostly in the targeting stage of the projects, as would be expected.

INTRODUCTION

Airborne GPS

Airborne GPS has a number of connotations dependent upon the context of its usage. In the photogrammetry and surveying industries two uses come to mind, flight planning and photogrammetric mapping control. The use of a GPS receiver in an aircraft is a given with many of the photogrammetric companies in the world. The GPS data can be used in real time to aid in flight line planning and execution to allow for more accurate flights. This use has proven itself effective over the past decade or so and therefore will not be explored any further in this paper. The use of airborne GPS for photogrammetric mapping is in the theoretically proven yet not fully implemented stage still. Many companies can and should dispute this statement. The use of this technology for high altitude mapping (e.g., USGS Quad mapping) is in a production stage and globally accepted. Unfortunately, the use of airborne GPS controlled photogrammetry for engineering and design purposes has not been completely proven, published, standardized and implemented. There are hints of standards for this application / technology floating around the photogrammetry community, but nothing definite has been published.

Photogrammetry

Photogrammetry is defined by the American Society of Photogrammetry and Remote Sensing as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patters of recorded radiant electromagnetic energy and other phenomena. Websters Dictionary simply defines it as 1. The use of photography in surveying, 2. Map-making from photographs. The use of aerial photography to create topologically correct maps has been around for ages. The Department used it extensively during the years of location analysis and studies such as the interstate. With today's technology, we can obtain these maps quicker, more accurately, and electronically. By obtaining electronic photogrammetric mapping files, designers can use this mapping like it would use a typical mapping file obtained by a survey crew except that it is larger and typically covers more area. This type of mapping is primarily used for new location and/or major alignment change projects.

Photogrammetric Mapping at Maine DOT

Photogrammetric mapping is an underutilized resource at the Maine DOT. The primary lack of usage is based on the need for very few location studies. Another part of the problem is the lack of understanding of the resource by the existing designers. Prior to this research, the last mapping project was done in 1992. The last three projects mapped in 1991 and 1992 were done with an electronic file as the final mapping medium. These files were submitted in MOSS GENIO format and, unfortunately, used very little as paper copies were used to design the alignment. MDOT has very few employees with experience in photogrammetric map manipulation using electronic media. The research projects have been submitted to the designers in electronic format, again in MOSS GENIO form.

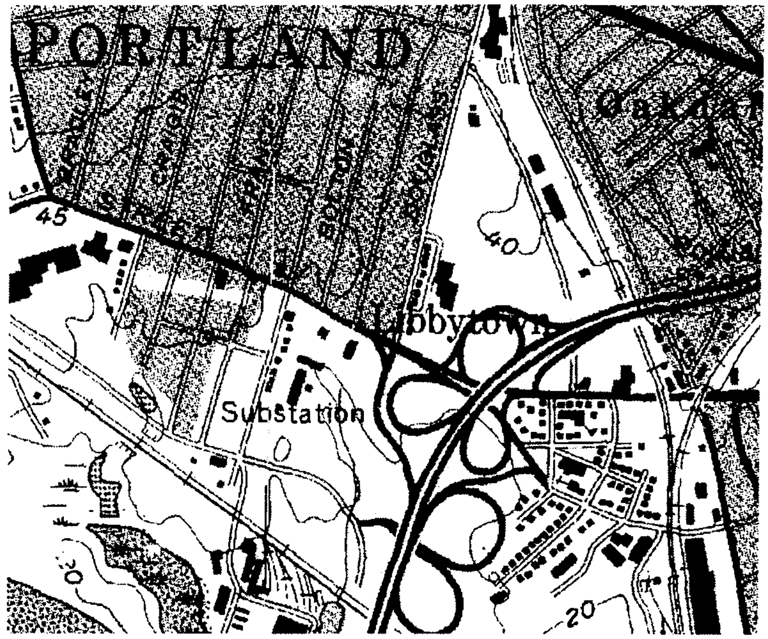
Photogrammetric Control for Mapping

All photogrammetric control is set and located by Maine DOT personnel. The control survey crew is responsible for the geodetic quality of the coordinates used for photogrammetric mapping control points. For two of the last three mapping projects, the photo control was set using GPS methods and the third was done using traditional survey methods. The GPS equipment currently consists of two Trimble 4000 SSse's and one Trimble 4000 SSi. The Trimble 4000 SSi was purchased after the '91-'92 mapping projects.

THE RESEARCH PROJECT SITES

Portland

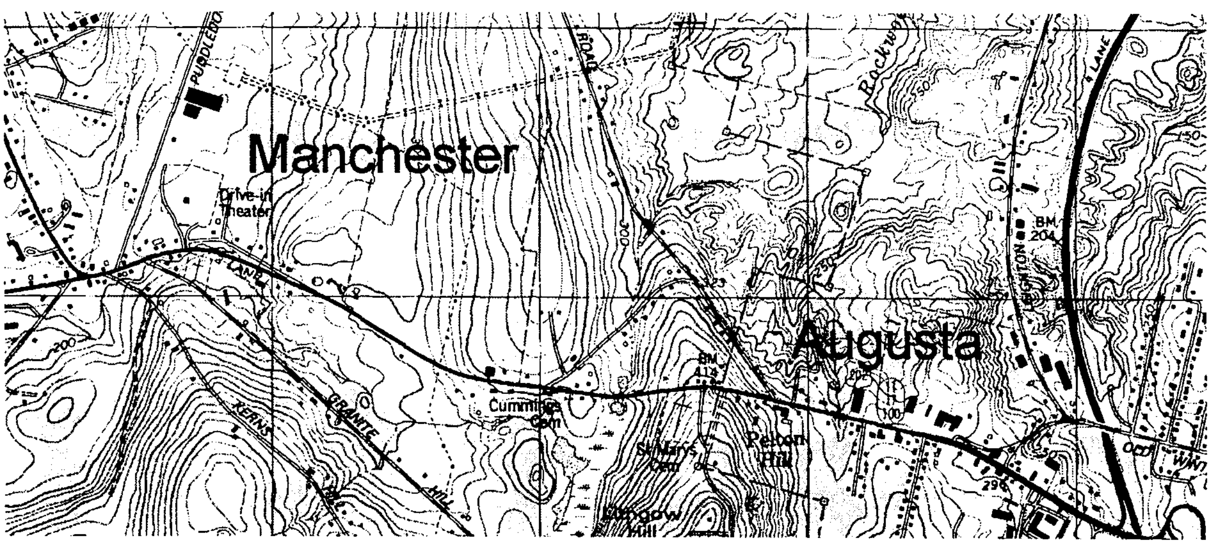
Portland is the largest city in Maine, and is located on the coast in the southwestern portion of the state. It is the most populous city in the state. The terrain is undulating from sea level to about 50 meters above sea level. The topology is urban varying between residential and commercial buildings. Most of the major interstates cut through the center of the city. Being the major port in the state, you can imagine the amount of commerce that crosses the local highways and byways. One of the bigger problems of the area is access from the ports themselves to the hardtop. The project that we are developing is a connector that will link US Route 1 with Interstate 295 and then continue into State Route 9 (see Map 1). Some of the features in the project area include a port facility, a county jail, a shopping mall, rail lines, and a number of bridges. Because of the size of the area involved and the traffic counts on the roads, the Design Unit inquired about the availability of photogrammetric mapping. The decision was made to obtain new photography and new photogrammetric mapping at an engineering and final design scale.



Map 1. Portland Mapping Site

Augusta-Manchester

Augusta is the capital of Maine, and is the sixth most populous city in the state. The terrain is greatly undulating from sea level to 150 meters above sea level. The city is located forty miles north from the Gulf of Maine at the head of tide and is bisected by the Kennebec River. The topology ranges from rural to urban with a



Map 2. Augusta-Manchester Mapping Site

good mix of residential and commercial properties. One of the bigger problems in the city is the road capacity on the highways that connect the surrounding towns to the commercial center of Augusta. The project being developed is a partial widening / partial new alignment in an environmentally constraining area (see Map 2). Some of the features in the project area include numerous car dealerships, a cemetery, a sensitive watershed, multiple businesses, and numerous streams. The project was a good candidate for mapping for environmental reasons.

PROJECT OVERVIEW

Research Plan

In the spring of 1997, the Photogrammetry & Control Survey Unit of the Survey Section requested projects to add to its spring photography list. At that time, our unit was approached about some possible mapping projects for the fall flying season. These requests came at an opportune time to try something new. As noted above, our department hasn't done photogrammetric mapping since 1992. Our section met with project leaders Steve Landry (Portland) and Holly Anderson (Augusta-Manchester) to discuss the merits of the mapping and the facts surrounding the methodology of photogrammetric mapping. The two projects had differing specification needs to be met for the different map uses. It was at this time that we discussed Airborne GPS. Being a new technology to us and, for practical purposes, unproven, we needed a way to assure the accuracy of the mapping and still attempt something new. The Survey Section approached the Transportation Research Division of MDOT about obtaining research money to buffer the cost of the two projects to allow for the implementation of the research. The plan was to target the projects traditionally, obtain the coordinates to all of the targets, fly the projects with Airborne GPS and map the projects using a few targets as needed to provide accurate maps. The research moneys were approved in early fall 1997, and the project leaders agreed to the terms of the research.

General Specifics

The Geodetic Control Crew of MDOT was (and is) responsible for setting all of the ground targets and obtaining all of the coordinates for control purposes. They used three geodetic grade Trimble receivers in fast static mode to generate the base control for the photography. This same crew was responsible for operating the ground units during the aerial photography aspect of the projects. The receiver in the plane was a Trimble 4000 SSi being operated by James W. Sewall personnel.

During the flight planning, the James W. Sewall Company proposed collecting the GPS data at one second epochs according to industry suggestions. Being newcomers, we did not disagree. Two base stations were occupied during the time of photography, one per project.

Portland Project Specifics

A set of two parallel flightlines were created with a thirty percent sidelap to cover the initial project scope. Thirty-six targets were set throughout the project area and, using fast static GPS, we obtained the coordinates to all of them. We planned to do all of the design engineering directly from the mapping data, so the Portland project was flown at a scale of 1:2500 to create mapping at 1:500 with 0.25 m contours. The project scope was extended a season after the initial flight was completed, an additional seven targets were set and the area flown.

Augusta-Manchester Project Specifics

For this project a single flightline was needed at an altitude that would generate mapping at 1:1250 with 0.50 m contours. The photography scale was set at 1:6000. The control crew set 30 targets throughout the project area. This particular project has been a high priority project since its conception, the mapping, however, was to be used primarily for environmental purposes only. That being noted, the decision had been made to ground survey the primary project area. This provides another layer of quality checks of the Airborne GPS mapping!

MAPPING PROCEDURES

Maine DOT

Requests for proposal were solicited and evaluated by the Survey Section of MDOT. Adjustment of the ground control data was the responsibility of the Photogrammetry & Control Unit of the Survey Section. The coordinate accuracy of targets for both projects was held at +/- 1.5 cm in the XY plane and +/- 2 cm in elevation All map checks were the responsibility of MDOT personnel. The decision on acceptable Airborne GPS map coordinates as compared to observed coordinates rested solely with the Photogrammetry & Control Unit.

Contractors

Bradstreet Consultants, Inc., of Manchester, Maine, was awarded the Portland mapping contract(s) and James W. Sewall Co., of Old Town, Maine received the Augusta-Manchester mapping contract. Each of these contracts included: calculating the GPS exposure station coordinates, using the exposure station coordinates and holding a minimum number of known targets to solve for the coordinates of the rest of the targets, submitting the solved target coordinate data for comparison, and compiling complete photogrammetric mapping that meets national map accuracy standards.

Bradstreet Consultants chose to have the flight data computed and reduced by Geosurv in Ottawa. Computing the exact (within 2-4 cm) position of the aircraft was absolutely essential to the overall accuracy of the project. The company used Albany from ERIO Technologies as their aerotriangulation adjustment software. After many different calculations using four target coordinates, and many constraint alternatives, we determined that two additional coordinated targets in the center of the project area would be needed to tighten the control for the mapping to within 5 centimeters both horizontally and vertically. Final constraints decided upon by MDOT and Bradstreet Consultants were 4 cm for the Airborne GPS, 1 cm for the surveyed ground control and 5 microns for the photogrammetric measurements. The mapping was compiled by Bradstreet Consultants using an Intergraph / Zeiss P1. Planimetric and topographic data were collected using the KORK TRACK program. All planimetric features needed to be collected according to standards set forth in the "Surveying and Mapping Manual" developed by the Aerial Survey Group, Design Division, FHA in November of 1985. Topology was obtained by creating a digital terrain model (DTM). Masspoints and breaklines were also located to create a Triangulated Irregular Network (TIN). The TIN was then modeled to create the index and intermediate contours. The DTM and TIN enabled MDOT to generate our own contours.

The James W. Sewall company was able to compute the flight data in-house using Albany by ERIO Technologies as their adjustment program of choice. After an initial data error in the surveyed ground control was discovered and corrected, we again discussed adding another coordinated point to the adjustment for a total of five for a single flight line. The results of the adjustments seemed to indicate that the National Map Accuracy's could be met for this project also. Unfortunately, due to time constraints and scope changes, the mapping area had been reduced. This did not affect the research or the results of the GPS adjustments. The adjustment constraints mutually decided upon were 3 cm for the Airborne GPS, 1 cm for the surveyed ground control and 5 microns for the photogrammetric measurements. The James W. Sewall Company compiled the mapping using direct data capture methods on a Kern DSR-11 and/or a Zeiss P3. Again all planimetric features needed to be collected according to standards set forth in the "Surveying and Mapping Manual" developed by the Aerial Survey Group, Design Division, FHA in November of 1985. All of the contours were compiled through direct

Control					Aerotriangulated			Delta	Delta	Delta
Station	North	East	Elev.	Station	North	East	Elev.	North	East	Elev.
201	89986.021	891485.440	6.177	201	89986.021	891485.440	6.177	0.000	0.000	0.000
202	89940.917	891230.672	5.122	202	89940.924	891230.717	5.130	0.007	0.045	0.008
203	90030.967	891290.266	17.847	203	90030.940	891290.344	17.858	0.027	0.078	0.011
204	90193.874	891208.998	36.634	204	90193.843	891209.055	36.639	0.031	0.057	0.005
205	90382.395	891167.411	51.583	205	90382.337	891167.489	51.660	0.058	0.078	0.077
206	89903.837	891009.741	5.867	206	89903.837	891009.741	5.867	0.000	0.000	0.000
207	90209.361	891036.071	10.611	207	90209.334	891036.153	10.662	0.027	0.082	0.051
208	90065.003	891036.765	15.251	208	90064.949	891036.847	15.351	0.054	0.082	0.100
209	90493.228	890989.944	12.532	209	90493.142	890989.997	12.523	0.086	0.053	0.009
210	90794.777	890495.749	8.582	210						
211	90524.367	890575.776	3.332	211	90524.225	890575.845	3.360	0.142	0.069	0.028
212	90404.090	890667.492	3.721	212						
213	90248.981	890751.677	3.817	213						
214	90082.134	890809.736	4.215	214						
215	90403.210	890877.725	5.875	215	90403.159	890877.797	5.919	0.051	0.072	0.044
216	90630.197	890830.651	8.220	216	90630.096	890830.729	8.183	0.101	0.078	0.037
217	90946.720	890793.130	7.565	217	90946.632	890793.254	7.601	0.088	0.124	0.036
218	90837.889	890333.460	3.568	218	90837.815	890333.478	3.636	0.074	0.018	0.068
219	90956.398	890366.178	8.843	219	90956.398	890366.178	8.843	0.000	0.000	0.000
220	90831.243	890143.277	10.483	220						
221	90952.002	890048.308	4.624	221						
222	91042.581	890188.487	10.480	222						
223	91184.184	890384.449	10.092	223	91184.129	890384.508	10.088	0.055	0.059	0.004
224	91007.733	890447.904	8.556	224	91007.733	890447.904	8.556	0.000	0.000	0.000
225	91202.271	890633.147	7.562	225	91202.234	890633.270	7.534	0.037	0.123	0.028
226	91352.769	890438.077	9.712	226	91352.713	890438.171	9.816	0.056	0.094	0.104
227	91597.845	890379.161	9.692	227	91597.857	890379.228	9.722	0.012	0.067	0.030
228	91384.182	890181.203	13.866	228	91384.122	890181.229	13.851	0.060	0.026	0.015
229	91200.118	890034.270	9.562	229						
230	91090.164	889882.617	6.480	230						
231	91279.350	889808.601	10.301	231						
232	91504.313	889899.211	11.787	232	91504.313	889899.211	11.787	0.000	0.000	0.000
233	91540.764	890045.292	10.710	233	91540.726	890045.318	10.675	0.038	0.026	0.035
234	91631.757	890155.541	12.308	234	91631.757	890155.541	12.308	0.000	0.000	0.000
238	90673.475	890540.827	4.875	238	90673.381	890540.878	4.866	0.094	0.051	0.009
239	90705.678	890440.632	3.261	239						
							Absolute			
							Average	0.058	0.067	0.037
					Table 1.					

stereophotogrammetric compilation (also known as "chasing" the contour).

FINAL ANALYSIS

Aerotriangulation Results

The results of the aerotriangulation from the Portland project exceeded MDOT's expectations. Bradstreet Consultants, Inc. / GeoSurv was supplied with the ground coordinates of seven targets, five on the original project site and two on the extension. Of the 42 targets set, only 31 showed up in the photography in a usable fashion. The eleven missing targets were from the original project site, some were covered by parked vehicles, some were off the edge of the photography and some were destroyed. The aerotriangulated coordinates for the twenty-six "unknown" targets were submitted to MDOT for comparison. The absolute value of the difference between the aerotriangulated coordinates and the field GPS generated coordinates did not exceed 0.148 meters in the Northing, 0.114 meters in the Easting and 0.106 meters in elevation. These were the maximum errors. The facts are that nearly seventy-four percent (74%) of the points had elevation differences at 0.05 meters (5 centimeters) or less. Sixty-eight percent (68%) of the Northing values came within 0.06 meters and ninety-four percent (94%) were within 0.10 meters. In the Easting, coordinate values were under 0.08 meters seventy-four percent (74%) of the time and ninety percent (90%) were within 0.10 meters (see Table 1). The extension aerotriangulation incorporated the data from the initial aerotriangulation and the results were very similar. The resulting mapping from Bradstreet Consultants met, and in some areas exceeded, National Map Accuracy Standards. According to Mark Bradstreet, ASPRS Certified Photogrammetrist and President of Bradstreet Consultants, Inc., "excellent flight data reduction, crisp photos from Sewall's Zeiss RMK and flexible aerotriangulation adjustment software" allowed us to meet the specifications with 6 known targets, eliminating the need for the remaining 30 targets. We have since determined that we can generate comparable results using only five known targets.

The results from the Augusta-Manchester aerotriangulation were encouraging even though many professionals in the industry expressed pessimistic views on using Airborne GPS on a single flightline project. The James W. Sewall Company was ultimately supplied the coordinates to five of the ground control targets. Of the thirty targets set, only one was unusable for calculations as it appeared monoscopically. The aerotriangulated coordinates for the twenty-four "unknown" targets were submitted to MDOT for comparison. The absolute value of the difference between the aerotriangulated coordinate and the field GPS generated coordinate did not exceed 0.218 meters in the Northing, 0.161 meters in the Easting and 0.377 meters in elevation. These were the maximum errors. The facts are that nearly seventy-five percent (75%) of the points had elevation differences at 0.20 meters (20 centimeters) or less. Sixty-three percent (63%) of the

Control				Aerotriangulated Data				Delta	Delta	Delta
Station	North	East	Elev.	Station	North	East	Elev.	North	East	Elev
201	165097.732	928937.022	76.958	201	165097.732	928937.022	76.959	0.000	0.000	0.001
202	165209.966	928421.178	72.392	202	165210.081	928421.222	72.389	0.115	0.044	0.003
203	165525.299	927909.342	69.632	203	165525.463	927909.430	69.437	0.1644	0.088	0.195
204	164888.347	927669.299	99.551	204	164888.387	927669.359	99.805	0.040	0.061	0.254
205	164466.104	927775.817	109.385	205	164466.223	927775.837	109.762	0.119	0.020	0.377
206	164398.178	928160.078	78.634	206	164398.297	928160.085	78.810	0.119	0.007	0.176
207	164753.744	928259.635	71.420	207	164753.894	928259.720	71.577	0.150	0.085	0.157
208	164592.407	927284.488	123.393	208	164592.350	927284.580	123.561	0.057	0.092	0.168
209	165104.672	927276.333	99.348	209	165104.653	927276.363	99.519	0.019	0.030	0.171
210	165398.777	927315.422	93.044	210	165398.777	927315.454	93.222	0.000	0.032	0.178
211	165381.152	926661.554	123.878	211	165381.152	926661.554	123.878	0.000	0.000	0.000
212	165577.316	926115.450	115.123	212	165577.205	926115.562	115.157	0.111	0.112	0.034
213	166188.889	926367.193	89.949	213	166189.603	926367.324	88.757	0.714	0.132	1.192
214	166712.282	924820.492	63.241	214	166712.282	924820.492	63.241	0.000	0.000	0.000
215	166173.669	924637.370	66.113	215	166173.748	924637.379	66.389	0.079	0.009	0.276
216	165727.822	924498.925	64.727	216	165727.822	924498.925	64.727	0.000	0.000	0.000
217	165833.339	924002.771	68.222	217	165833.425	924002.857	68.414	0.086	0.086	0.192
218	166420.023	924194.120	74.610	218	166420.042	924194.184	74.657	0.019	0.064	0.047
219	166632.053	924357.857	84.754	219	166632.127	924357.993	84.824	0.074	0.136	0.070
220	165547.547	924969.864	82.504	220	165547.484	924969.837	82.549	0.063	0.027	0.045
221	165060.076	926675.408	143.879	221	165060.099	926675.467	144.072	0.023	0.059	0.193
222	165837.640	925199.786	93.006	222	165837.756	925199.947	93.264	0.116	0.161	0.258
223	165716.898	926786.319	85.954	223	165716.775	926786.448	86.011	0.123	0.129	0.057
224	165802.664	925580.671	92.255	224	165802.654	925580.757	92.358	0.010	0.086	0.103
225	166137.816	925702.658	99.803	225	166137.840	925702.788	99.754	0.024	0.130	0.049
226	166364.396	925222.823	73.812	226	166364.614	925222.869	73.579	0.218	0.046	0.233
227	165425.025	925514.640	91.780	227	165425.017	925514.654	92.015	0.008	0.014	0.235
228	165307.725	926053.405	106.760	228	165307.629	926053.392	106.859	0.096	0.013	0.099
229	164101.549	928595.876	72.720	229	164101.548	928595.876	72.721	0.000	0.000	0.001
230	164512.109	928786.246	98.081	230	164512.209	928786.303	98.057	0.100	0.057	0.024
	Control point 213 was observed monoscopically and therefore taken out of averaging.									
							Absolute			
							Average	0.081	0.066	0.150
					Table 2.					

Northing values came within 0.10 meters and eighty-three percent (83%) were within 0.12 meters. In the Easting, coordinate values were under 0.10 meters seventy-nine percent (79%) of the time and eighty-three percent (83%) were within 0.12 meters (see Table 2). The final mapping from the James W. Sewall Company met, and in some areas exceeded, National Map Accuracy Standards.

Cost Analysis

In finalizing a cost analysis many variables came into play, the reconnaissance of the area to be mapped for target placement, target setting, GPS observation time, the additional cost of obtaining GPS data during the photography, and the additional cost for flight reduction.

The cost of recon, target setting and observation for the Portland project(s) totaled $6813.19. Because of doubling up the observations on four targets for the extension, the average per target cost was $145.00. The same cost associations for the Augusta-Manchester project totaled $4352.81, also averaging $145 per target. The cost of the obtaining GPS during the flights totaled $133.12 for the initial Portland site, $284.16 for the extension, and $90.00 for the Augusta-Manchester project. The cost for Airborne GPS flight reduction was $1400.00 per site in Portland, and $2000.00 for the Augusta-Manchester project. Using a five target arrangement (two on either end and one in the middle per flight path set), the cost for the Augusta-Manchester project would be a total of $2815.00 and the Portland project would total out at $2977.00 (a total of eight targets used -- the three additional used on the extension flightline set). The difference between mapping traditionally and using Airborne GPS techniques is $1538.00 for the Augusta-Manchester type project (single flightline set) and $3836.00 for the Portland type project (two flightline sets). If we chose to buffer the number of targets used for ground control when using Airborne GPS, it would take an additional ten (10) targets in an Augusta-Manchester type project and an additional twenty-six (26) targets in a Portland type project just to hit the break even point between traditional mapping techniques and Airborne GPS techniques. This calculates to an exceptional cost savings, not to mention the man-hour savings that would allow for the targeting of more projects for Airborne GPS mapping. Factors not considered include GPS adjustment of the ground control data, travel time to the project sites and the cost of mapping the project, as these costs are associated on an equal basis.

Mapping Results

Both the Portland and Augusta-Manchester research projects provided mapping that met National Mapping Accuracy Standards proving to MDOT that Airborne GPS is a viable alternative. Engineering and design grade mapping can be achieved with the right conditions and for a more affordable price. We have, however, found a glitch. The good news is that the glitch is not with the Airborne GPS photogrammetric mapping. The bad news is that the glitch we encountered was with the hardware / software that the Maine DOT uses to put this data into production usage. We found that the existing mixed CADD network of Digital workstations including Apha series and model 90 VAXstations that the Preliminary Engineering Processing Unit of the Survey Section uses in conjunction with MOSS cannot handle the MOSS GENIO files supplied by the contractors. We recently acquired some Compaq 4000 personal computers that run MOSS for Windows, these machines do handle the files to our satisfaction. However, the Design Unit uses the same variation of computer equipment, and most of the users are still in the training stages of using MOSS for Windows and our new 2D drafting package, Microstation. Due to the perseverance of the staff within the Survey Section and assistance from the Highway Design Divisions computer expert, we were able to overcome any hurdles necessary to complete the research project and associated project tasks.

CONCLUSION

The results from both mapping projects look extremely promising. Both mapping scales and mapping uses look attainable using Airborne GPS. The big question of practicality has been answered and shows that Airborne GPS is a practical alternative. Timing and coordination are key factors in obtaining the right information the first time. Most flying seasons in the Northeast are short, therefore, including turnaround time, any mistakes could prove fatal. Keeping in close communication with both the ground unit and the aircraft was tantamount to the success that we encountered. We were extremely lucky to have gotten good results our very first time out. Our research shows that Airborne GPS photogrammetric mapping will work for highway engineering / design purposes. Our research has also shown that five targets seem to be the minimum required for similar projects. A safety net of three targets seems to be a reasonable offering in the off chance that something happens to any of the primary targets. By discussing the research with our photography contractor and other professionals, we have determined that kinematic GPS collected with one-second epochs used in the airborne data and fast static collection with one-second epochs in the ground receiver are the widely accepted "industry standards". We have ground-truthed the targeted points and the results are acceptable and meet accuracy standards. Our results show that the research will pay dividends for both MDOT and our industry.

The Department should consider using more photogrammetric mapping to accomplish our mission. Photogrammetric mapping has always been a valuable resource in location design and can be used for engineering purposes. The advent of electronic files that are fully design capable have made this resource even easier to use. Now that we have research that validates the usability of Airborne GPS controlled photogrammetry, the process is even more affordable. Given the right circumstances, photogrammetric mapping can meet or exceed our expectations and should therefore be used more often by the Department. This research substantiates the validity of Airborne GPS controlled photogrammetry and therefore makes it a cost effective alternative to traditional photogrammetric mapping.

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