NOAA Technical Memorandum NOS NGS 72

A Comparison between OPUS Projects and PAGE-NT using Airport Surveys

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National Ocean Service
National Geodetic Survey

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Dr. Neil D. Weston

Daniel Callahan

Kevin Jordan

Julie Prusky

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U.S.DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
Dr. Kathryn Sullivan
NOAA Administrator

National Ocean Service
Dr. Russell Callender, Acting Assistant Administrator

National Geodetic Survey
Juliana P. Blackwell, Director

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Introduction and Background Information

NOAA's National Geodetic Survey (NGS) manages the Aeronautical Survey Program (ASP) in accordance with a series of interagency agreements with the Federal Aviation Administration (FAA). The ASP provides airport control, runway information, navigational aids, obstruction and other aeronautical data critical to the National Airspace System. Most of the raw data and information used by the ASP are collected using field survey and photogrammetric methods to develop runway approach procedures and obstruction charts to meet the demands of the Next Generation National Airspace System.

Both the FAA and NGS recommend the guidance and specifications outlined in *Advisory Circular (AC) No. 150/5300-16A* for establishing on-airport geodetic control. NGS also recommends following the specifications in this advisory circular when submitting the survey information to NGS for approval and inclusion in the National Spatial Reference System (NSRS) in support of aeronautical information surveys. *AC 150/5300-16A* does not constitute a regulation and, in general, is not mandatory. However, use of these guidelines is mandatory for surveys funded under federal grant assistance programs, and certain portions of the guidelines are mandatory (such as submitting data in Bluebook format). The advisory circulars also provide an acceptable, but not the only means, of meeting the requirements of Title 14 Code of Federal Regulations (CFR) part 139, *Certification of Airports*.

Purpose of the Investigation

The purpose of this project was to determine whether vector processing in OPUS Projects is equivalent in performance to that used in PAGE-NT. Additionally, could OPUS Projects be used as an alternative to PAGE-NT for processing vectors to Primary Airport Control Station (PACS) and Secondary Airport Control Station (SACS).

From the *AC 150/5300-16A, section 8.8.1. (9/15/2007)*:

> "*Vector processing must be performed using the latest version of the NGS software package PAGE-NT or equivalent. The 'equivalent' of PAGE-NT is subjective, based on the software's ability to correct for the same systematic errors that PAGE-NT corrects, apply the NGS required antenna offsets, and reproduce the same results as PAGE-NT. This determination will be made by NGS.*"

Processing Software Summary

PAGES/PAGE-NT

PAGES (version 1503.23) used in this comparison is the current generation of orbit and baseline (i.e., "vector") estimation software developed and used by NGS, as well as by other geodetic surveyors, particularly, in this case, by those performing Global Positioning System (GPS) surveys at airports. Using double-differenced phase measurements as observables, PAGES is suitable for a wide variety of projects requiring the highest accuracy. Numerous parameter types can be estimated including tropospheric corrections, station coordinates, linear velocities, satellite state vectors and polar motion. PAGES is commonly run using ion-free phase combinations, but optionally L1 only and L2 only, and wide-lane phase combinations can be used. These in turn can be used to create partially or completely bias fixed solutions. PAGE-NT is a Microsoft Windows Graphic User Interface (GUI) that facilitates the running of the PAGES suite.

Online Positioning User Service (OPUS)

The Online Positioning User Service (OPUS) is a suite of Web-based tools used to process GPS data. The primary purpose of OPUS is to provide end users easier access to the National Spatial Reference System (NSRS), as well as to the latest global reference frame (IGSxx/ITRFxx) by quickly, reliably, and accurately obtaining consistent geodetic positions with a precision of about 1 to 2 centimeters. The latest available versions of OPUS have been optimized to accept datasets collected from any location on Earth, returning a solution to the user within 10 minutes. OPUS-Static (OPUS-S), one of the services within OPUS, is capable of processing one GPS receiver file for a single occupation and determining geodetic coordinates in the latest realization of the international and national geometric reference frames. It does this by first computing vectors to Continuously Operating Reference Stations (CORS), whose positions are considered known.

OPUS Projects

OPUS Projects (version 1404.11)—a part of the OPUS suite of programs—is an integrated, Web-based GPS data processing and analysis environment. The primary objective behind OPUS Projects is to consolidate the planning, management, and analysis of a multi-station GPS survey in one easy-to-use online Web-based tool. Each newly defined project is assigned a unique identifying "ID" that is shared among field personnel assigned to the project. A typical GPS project may include simultaneous occupations spanning one or more days—often referred to as a session—and projects may have numerous sessions that can span several days, weeks, or months. After individual GPS data files have been collected in the field, they are submitted to OPUS with the project-specific ID. OPUS-S is used as a pre-processor at this stage to determine if the results for each data file surpass a set of pre-defined tolerances before undergoing further analysis. After all the data files for a project have been successfully submitted to OPUS, an OPUS Projects manager can begin to process each of the sessions in a least squares adjustment using PAGES. Multiple session adjustments are combined using GPSCOM, a *Helmert* blocking normal equation processor, to estimate a single set of coordinates for each station in the project. Both PAGE-NT and OPUS Projects use PAGES as their GPS data processing engine.

Conducting an FAA Airport Survey

Most GPS surveys conducted at airports across the country are performed by outside contributors in accordance with the FAA *AC 150/5300-16A* and submitted directly to the FAA via the FAA Airports GIS (AGIS) Web Portal. NGS' ASP is then responsible for downloading each survey data submission for review to ensure compliance with *AC 150/5300-16A*, including the requirement that data be submitted in the Federal Geodetic Control Subcommittee Bluebook format. Once NGS has reviewed and approved the final files for Bluebooking (Bfile, Dfile and Gfile), a set of coordinates for each survey mark is officially loaded in the NGS Integrated Database (NGSIDB). Under the specifications outlined in *AC 150/5300-16A*, the airport survey team is required to establish PACS with a minimum of two four-hour sessions with a Continuously Operating Reference Station (CORS), one four-hour session with at least one High Accuracy Reference Network (HARN) station, and one four-hour session with two NAVD88 1st or 2nd order marks. Each SACS requires two sessions with at least 1.5 hours of simultaneous data collection with the PACS. *AC 150/5300-16A* also requires that GPS processing (vector estimation) be performed by the PAGE-NT or an equivalent software package.

Procedures for Comparing OPUS Projects and PAGE-NT

Twenty-five airports, including 130 marks, were selected for the GPS processing comparison between OPUS Projects and PAGE-NT (see Appendix). These airports were surveyed within the last few years, the data were successfully submitted to NGS (in compliance with *AC 150/5300-16A*), and the resultant coordinates were loaded in the NGSIDB as "published coordinates." The original Receiver Independent Exchange Format (RINEX) files for these marks were recovered and prepared for submission to OPUS Projects. A project was created in OPUS Projects for each airport and its corresponding marks. RINEX data collected at each airport was then submitted to OPUS Projects with the appropriate project identifier. Each project was processed in turn, using procedures outlined in *OPUS Projects GNSS Background for Surveying* and *OPUS Projects Processing Guidance*. For GPS processing, the recommended network configuration in OPUS Projects is to use a CORS at one end of each vector. Multiple CORS may be used in a processing session, but only one CORS should be used as a hub per session. For this particular study, the hub CORS in each session was no further than 100 kilometers from the project area. An additional CORS, approximately 1,000 kilometers from the project area, was selected to de-correlate the tropospheric estimations during the adjustment. It is critical to note that this is not the same processing strategy used in most current airport surveys processed with PAGE-NT, and thus some deviations of output must be expected. Specifically, some vectors will only be computed under either the old strategy (using PAGE-NT) or the new strategy (using OPUS Projects), and therefore any comparison of vectors between the two methods will have to exclude such instances. Further, once all vectors are computed, a least squares adjustment is performed, and since the pseudo-observables (vectors) will not be the same between adjustments, likewise the output coordinates cannot be expected to be the same.

To begin the processing, the OPUS Projects "Preferences" were configured to change the GPS processing defaults to match the recommended processing criteria. Some of the changes for this comparison included setting the tropospheric model to piecewise linear, setting the troposphere interval to 7,200 seconds, and setting the constraint weights to normal. After the individual sessions were processed, a final OPUS Projects network adjustment was performed to produce a Bfile_op and Gfile_op. It is important to mention that this network adjustment does not yield adjusted vectors, but rather only adjusted coordinates. As such, the Bfile_op and Gfile_op created in OPUS Projects after the final network adjustment (Gfile_op) will contain all of the vectors created in each of the session processing steps, while the Bfile_op will contain adjusted coordinates for each point. As such, the Gfile_op and the Bfile_op are comparable in general content to Gfile_NT and Bfile_NT created using PAGE-NT prior to their use as input to ADJUST. Manual edits to the Bfile_op and Gfile_op were required to include the receiver manufacturer code. Other edits included replacing station four-character IDs with station names in the control point records, inserting observer initials into occupation records, creating and editing antenna records, and also making edits to the instrument records. These two files were then used as input for minimally constrained adjustments using the NGS ADJUST program (Version 6.2.3). The ADJUST program was run four times to produce the following outputs, below. Although the *AC 150/5300-16A* document references five adjustments, it is currently out of date, as only four (described below) are produced. However, these four adjustments are documented in the current ADJUST guidelines, and the *AC 150/5300-16A* specifically notes that the current ADJUST guidelines are the standard to follow in case of conflicts with the *AC 150/5300-16A.*

1. Minimally Constrained Horizontal Adjustment—Constrains the published NAD83 (2011) position (Latitude, Longitude, Ellipsoid Height) of a CORS and sigmas (either the formal network sigmas or short-term time series sigmas. The Afile option VVHU forced ADJUST to solve for variance factors for the horizontal and vertical components of the GPS observations separately. The variance factors, used in Afile option VS for the remaining adjustments, scale the uncertainty of the horizontal and vertical components of the GPS vectors before beginning the adjustment.
2. Constrained Horizontal Adjustment—Constrains the published NAD83 (2011) position (Latitude, Longitude, Ellipsoid Height) of all CORS and all passive control stations meeting the criteria for being held for a horizontal and/or ellipsoid constraint. ** For passive control, the same position, ellipsoid height, and sigmas that were constrained in the originally submitted data were also constrained in this Afile.
3. Vertical Free Adjustment—Constrains the published NAD83 (2011) position (Latitude, Longitude) of one CORS and one NAVD88 1st or 2nd order marks (Orthometric Height).
4. Vertical Constrained Adjustment—Constrains the published NAD83 (2011) position (Latitude, Longitude) of one CORS and all NAVD88 1st and 2nd order marks (Orthometric Height).

The constrained adjustments were performed using *Constrained Adjustment Guidelines* to produce a final Bfile_op_adj for each project. All the Bfile_op_adj from each project were then combined to produce a final/single Bfile_op_adj.

If we now consider all the original airport surveys, each produced a Bfile_NT_adj, with originally determined coordinates and sigmas. All Bfile_NT_adj were concatenated to form a single Bfile_NT_adj. These individual Bfiles_NT_adj were the final Bfiles made available to NGS' Observation and Analysis Division (OAD) for review and loading into the NGSIDB. These files were used instead of retrieving Bfiles from the NGSIDB, because loaded versions are subject to additional adjustments later on. A utility program was developed to search for matching horizontal positions and to perform a North, East, and Up comparison between each station in the Bfile that was created using OPUS Projects (Bfile_op_adj) and the corresponding station in the Bfile created by PAGE-NT (Bfile_NT_adj) for the airport surveys. The search for matching coordinates was repeated for all 130 marks, and a North, East, and Up comparison was performed. The statistical results from the horizontal coordinate searches and comparisons are shown in Table 1.

	North (m)	**East** (m)	**Up** (m)
Mean	-0.001	0.000	0.000
Standard Deviation	0.006	0.004	0.015
Median	0.000	0.000	0.000
Maximum	0.013	0.016	0.036
Minimum	-0.021	-0.010	-0.075
Range	0.034	0.026	0.111
Number	130	130	130

Table 1. Statistical results for the North, East, and Up comparisons for all stations in the survey.

Results and Discussion

For the comparison between OPUS Projects and PAGE-NT, we randomly chose 25 airports from across the country for the study. The total number of marks occupied during the study was 130. They are located at 25 different regions of the country with unique environments (atmospheric, geophysical, geospatial), the data collection was performed with a variety of GPS receiver and antenna types, and the field work was conducted by 14 independent companies performing airport surveys. The number of airports was considered to be a reasonable representation of the entire range of surveys encompassed by the ASP.

The mean and corresponding standard deviation for the North (-0.001 ± 0.006 m), East (0.000 ± 0.004 m), and Up (0.000 ± 0.015 m) components indicate there is very good agreement between the OPUS Projects and PAGE-NT processing methods. A mean of essentially zero for all three components indicates there does not appear to be any systematic errors or biases in either of the two processing approaches. Very small standard deviations for the North and East components (data clustered around the mean—see Figure 1.) indicate there are very little differences between the horizontal components of each comparison, a desirable outcome. The range for the vertical component is 0.111 meter and seemed a bit larger than one would expect. After closer inspection of the data, two data points at Oswego County Airport were identified as having larger differences from the mean than the rest of the points in the study. Further investigation showed there were inconsistencies in troposphere parameterization and estimation strategies, disturbances in the ionosphere (identified by the Automated Surface Observing System of the National Weather

Service), and differences in elevation cutoff angles/processing setup changes while processing data from these two points. If those two data points are removed and the statistics are re-computed, the standard deviation for the Up component and the ranges dropped to 0.012 meter and 0.062 meter respectively. The new maximum and minimum values for the Up component are 0.036 meter and -0.040 meter respectively. The standard deviation for the Up component is larger than those for the horizontal components, because the vertical component derived from GPS is usually two to four times less accurate. The vertical component is much more challenging to estimate due to the limited spatial arrangements of the satellites at the time of observation and the different combination of atmospheric (troposphere, ionosphere) and geophysical (ocean tides, solid Earth tides, antenna, etc.) models and parameters that can be selected during processing. For example, a standard deviation of zero for any of the components from a comparison would indicate that the corresponding derived coordinates from OPUS Projects and PAGE-NT would be identical, an unlikely situation in practice. Therefore, the smaller the standard deviations for North, East, and Up components derived from the comparisons, the greater the agreement between OPUS Projects and PAGE-NT.

Figures 2a, 2b, and 2c also show the North, East, and Up differences respectively between the coordinates computed using OPUS Projects and PAGE-NT. However, in these three plots, each of the 25 airports is plotted along the *x*-axis with a unique color representing one of the 14 companies that surveyed an airport. For example, the company that surveyed the marks for the first airport on the *x*-axis (blue data points) also surveyed the marks at airports 4, 21, 23 and 25. Each data point on the graph represents a mark that was surveyed, and its position along the *y*-axis represents the difference between the corresponding North, East, or Up component computed using OPUS Projects and PAGE-NT. The horizontal differences represented by Figures 2a and 2b show data points that are not only tightly clustered at each airport, but show very little discrepancy overall. However, for the vertical component shown in Figure 2c, the clustering of data points at each airport is more varied and can probably be attributed to several factors. Such factors include imperfect troposphere estimation, differences and inconsistencies in processing techniques, as well as differences in parameter selection for models that contribute to the estimation of the vertical component (tides, ionosphere, troposphere, atmospheric loading effects), both in OPUS Projects and PAGE-NT.

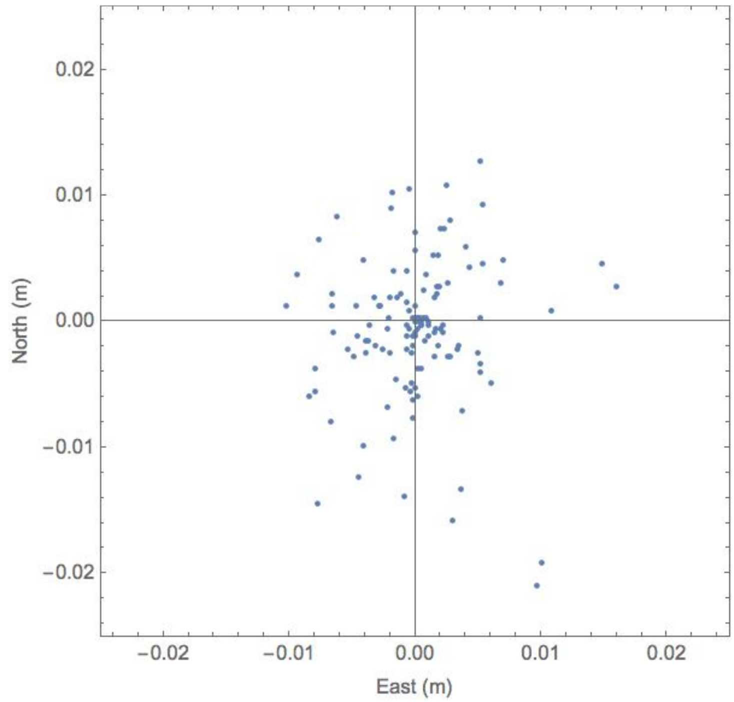

Figure 1. Horizontal offsets from the mean for all marks in the airport survey comparison. A mark with an offset of 0.0 for the North, East, and Up components would indicate OPUS Projects and PAGE-NT computed exactly the same set of coordinates for the mark. Discrepancies or offsets are attributed to the fact that the data was processed using two different processing packages, and by numerous individuals who had the choice to select many processing algorithm options, as well as processing strategy differences between traditional PAGE-NT and OPUS Projects.

Another point to mention is the fact that all of the airport surveys were conducted and processed by the 14 independent companies at various times of the year. The same datasets were also processed independently by two to four NGS personnel some time later. Given the variety of GPS data collection environments, there could be several different scenarios by which the independent survey technicians and the NGS team processed the data. The knowledge set, skill levels, and experience amongst the GPS processors are unique, and therefore their choices for network design, models, and constrained marks, etc. could and probably did vary. However, if we refer back to the statistical data presented in Table 1, the data plotted in Figures 2a, 2b, 2c, and the discussion in the preceding paragraphs, there does not appear to be a bias attributed to the data processing protocols used.

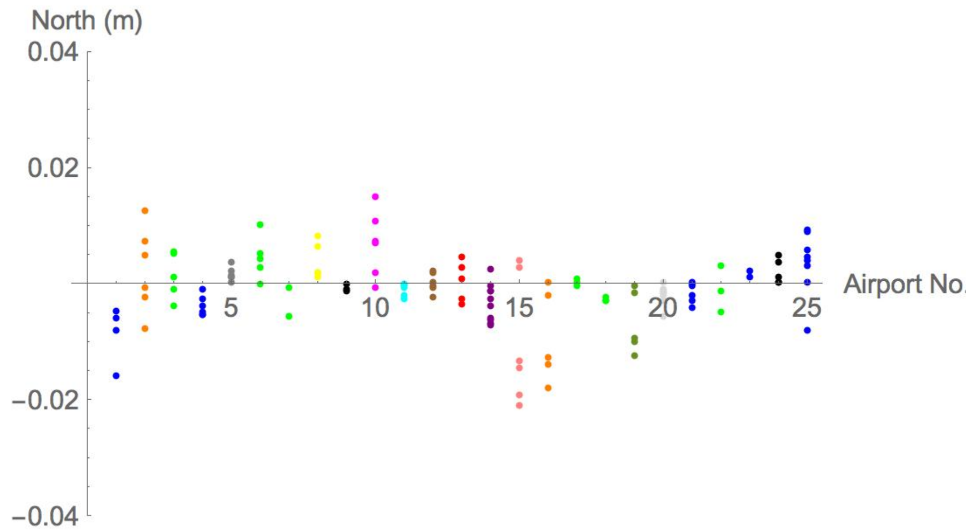

Figure 2a. North component differences for all marks surveyed at 25 airports. Airports are plotted along the *x*-axis, with a unique color representing each of the 14 companies that surveyed an airport. Each data point on the graph represents a mark that was surveyed, and its position along the *y*-axis represents the difference between the North components computed using OPUS Projects and PAGE-NT.

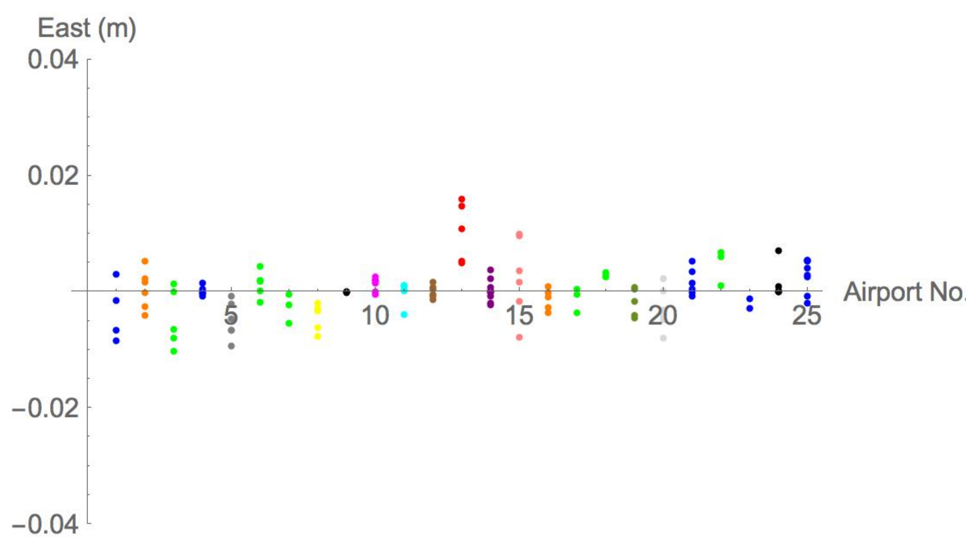

Figure 2b. East component differences for all marks surveyed at 25 airports. Airports are plotted along the *x*-axis, with a unique color representing each of the 14 companies that surveyed an airport. Each data point on the graph represents a mark that was surveyed, and its position along the *y*-axis represents the difference between the East components computed using OPUS Projects and PAGE-NT.

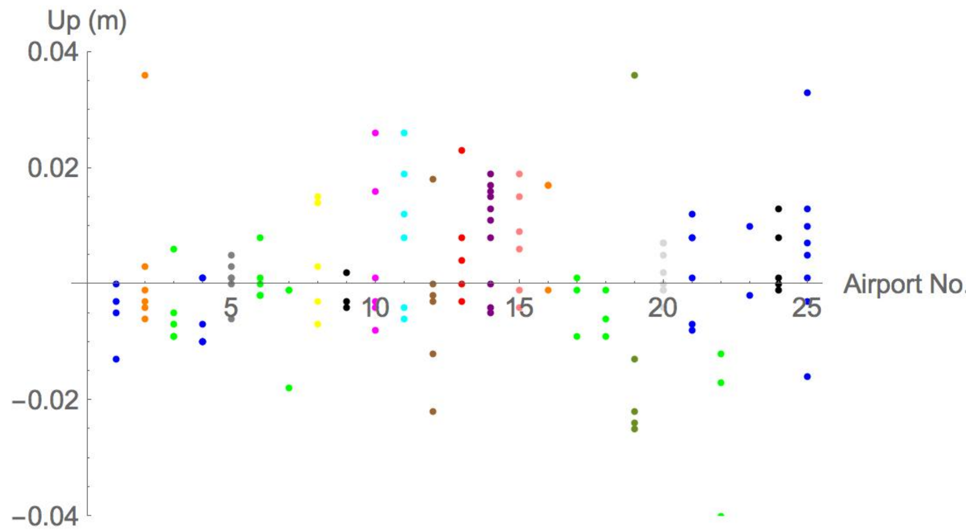

Figure 2c. Up component differences for all marks surveyed at 25 airports. Airports are plotted along the *x*-axis with a unique color representing each of the 14 companies that surveyed an airport. Each data point on the graph represents a mark that was surveyed, and its position along the *y*-axis represents the difference between the Up components computed using OPUS Projects and PAGE-NT.

Concluding Remarks

The scope of this project was to determine if OPUS Projects could be a proven equivalent to PAGE-NT for the processing of PACS and SACS data. Although the actual vectors between OPUS Projects and PAGE-NT were not compared, the vectors from the two programs were used in similar ways in NGS' ADJUST program, and the output coordinates were compared. As a result, North, East, and Up discrepancies between adjusted coordinates will reflect a combination of both vector differences and network design/processing choices. The combined effect of the processing discrepancies is small (well within the tolerance of the ASP); therefore, the National Geodetic Survey's opinion is that OPUS Projects can be used to process GPS airport survey data in an equivalent manner to PAGE-NT.

References

A. *General Guidance and Specifications for Aeronautical Surveys: Establishment of Geodetic Control and Submission to the National Geodetic Survey* AC 150/5300-16A (9/15/2007)

B. *OPUS Projects User Instructions and Technical Guide*

C. *OPUS Projects GNSS Background for Surveying*

D. *OPUS Projects Processing Guidance*

E. *Constrained Adjustment Guidelines*

Acknowledgements

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Appendix

AIRPORT ID	CITY	STATE	FAA AGIS PROJECT	CONSULTANT	SURVEY DATE
00U	HARDIN	MT	138462	WOOLPERT INC	11/28/2012
01G	PERRY	NY	137142	ERDMAN ANTHONY	6/27/2012
15Z	MCCARTHY	AK	146014	USKH INC	6/19/2013
1F0	ARDMORE	OK	131832	WOOLPERT INC	8/16/2012
2G2	STEAUBENVILLE	OH	102914	RICHLAND ENGINEERING LIMITED	3/9/2012
AFM	AMBLER	AK	132621	USKH INC	6/17/2012
ANI	ANIAK	AK	143975	USKH INC	6/4/2013
AUG	AUGUSTA	ME	136977	SHYKA SHEPPARD & GARSTER	11/16/2012
BRD	BRAINERD	MN	137535	SEH INC	2/20/2013
BVO	BARTLESVILLE	OK	118095	AERIAL DATA SERVICE	2/24/2012
BVS	BURLINGTON/MOUNT VERNON	WA	119333	WH PACIFIC	10/8/2011
BWI	BALTIMORE	MD	128204	JOHNSON MIRMIRAN AND THOMPSON	6/6/2012
COE	COEUR D'ALENE	ID	129023	DAVID EVANS AND ASSOCIATES INC	4/12/2012
CPK/PVG	NORFOLK	VA	126536	GEOMETRICS	1/31/2012
FLL	FORT LAUDERDALE	FL	104016	KEITH AND ASSOCIATES	6/8/2012
FZY	FULTON	NY	138858	ERDMAN ANTHONY	3/14/2013
GAL	GALENA	AK	137010	USKH INC	8/11/2012
HUS	HUGHES	AK	145686	USKH INC	7/26/2013
KGX	GRAYLING	AK	111831	R & M CONSULTANTS	7/15/2011
LEX	LEXINGTON	KY	127323	GRW AERIAL SURVEY	5/7/2012
LLU	LAMAR	MO	120771	WOOLPERT INC	9/28/2012
MLY	MANLEY HOT SPRINGS	AK	149647	USKH INC	5/12/2014
MMU	MORRISTOWN	NJ	138892	WOOLPERT INC	10/18/2012
MVE	MONTEVIDEO	MN	137293	SEH INC	9/6/2013
TIP	RANTOUL	IL	151489	WOOLPERT INC	9/19/2012