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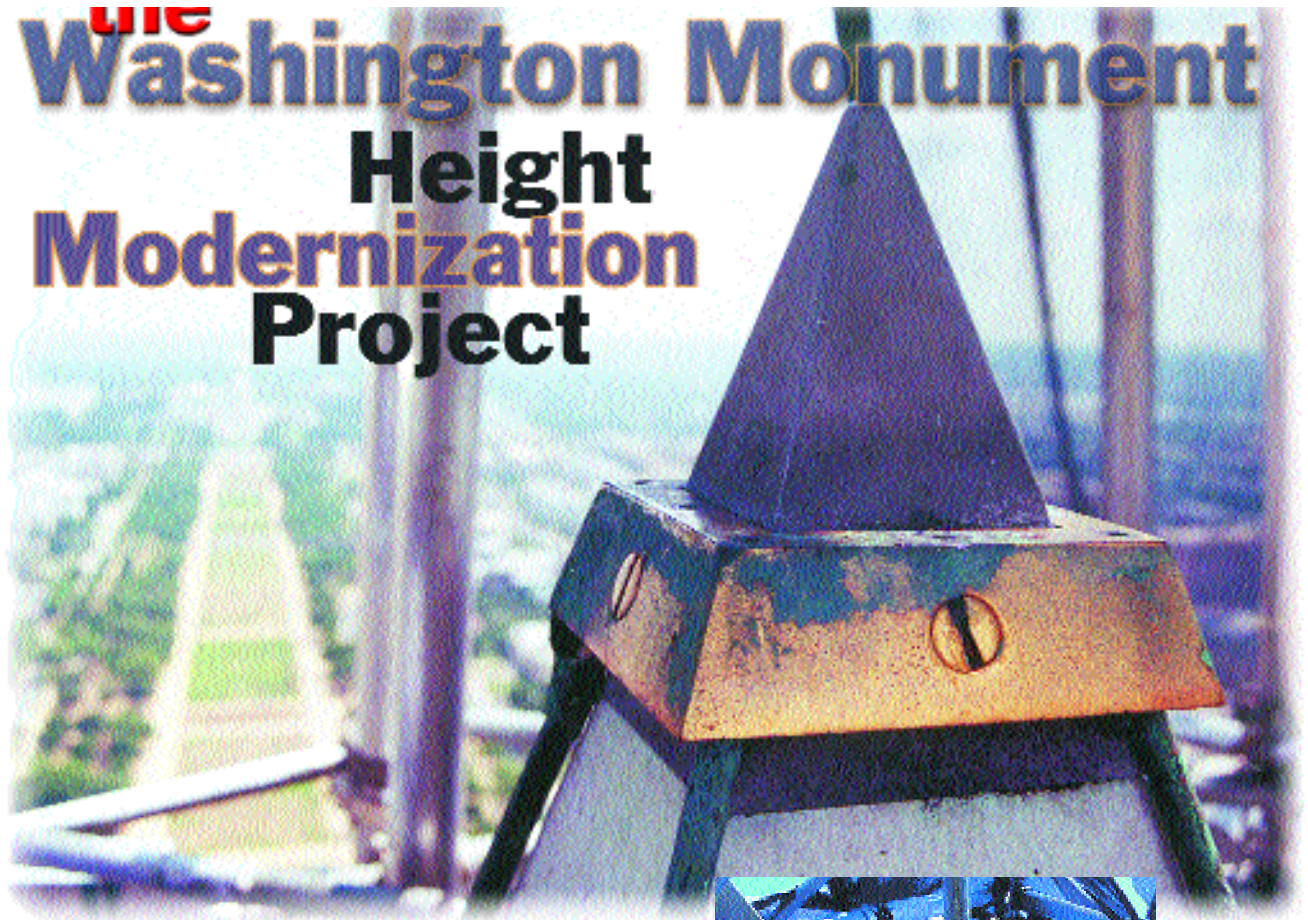
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**Washington Monument  
GPS Project**



# Washington Monument Height Modernization Project



David R. Doyle

Like the pyramids of Egypt, the Eiffel Tower, the Parthenon, or the temples of Ankor Wat, the Washington Monument in Washington D.C. is truly a monument that commands universal recognition. This marvel of 19th century engineering is a symbol of national pride, democratic principals, cultural variety, social struggle and political freedom. The monument is now also one of the most important elements of the National Spatial Reference System (NSRS) maintained by the National Geodetic Survey (NGS), an agency of the National Oceanic and Atmospheric Administration's (NOAA), National Ocean Service (NOS). Standing approximately 555 feet 5 inches, the Monument is the tallest structure in Washington D.C. and on a clear day provides a commanding and dramatic view of the Maryland and Virginia countryside.

## Authorized by Congress in 1833

Construction of a monument to honor the first President and Father of His Country was authorized by Congress in 1833, however, construction was not actually begun until 1848. The simple structure we see today is the design of architect Robert Mills who was hired by the Washington National Monument Society. Construction

was halted in 1854, when members of the "Know-Nothing Party" gained control of the Society and financial contributions from private donors stopped. A frustrated President Grant persuaded the Society to donate the project to the country in 1876, and construction was restarted in 1878, under the direction of the U.S. Army Corps of Engineers. The external structure was completed in 1884, and finally opened to the public in 1888. In 1933 the care and maintenance of the Monument was transferred to the National Park Service (NPS). Today, the Monument and the Park Service are host to approximately 3,000 visitors each day.

The first geodetic survey of the Monument was performed shortly after its completion. From April 4-11, 1886, a field unit of the U.S. Coast and Geodetic Survey (USCGS), the predecessor of NGS, performed a local triangulation network

and computed a third-order (1:10,000) position by the method of intersection using a 10-inch Gamby theodolite. These observations were computed as part of the New England Datum, later readjusted into the U.S. Standard Datum in 1901 and subsequently renamed the North American Datum in 1913. No attempt was



ABOVE Tip of the Washington Monument with the Mall and the Capitol in the background. The tip is made of aluminum and the brass bracket surrounding it normally has a lighting rod affixed at each corner. When the Monument was built, one of the States donated two aluminum tips. At the time, aluminum was more valuable than gold.

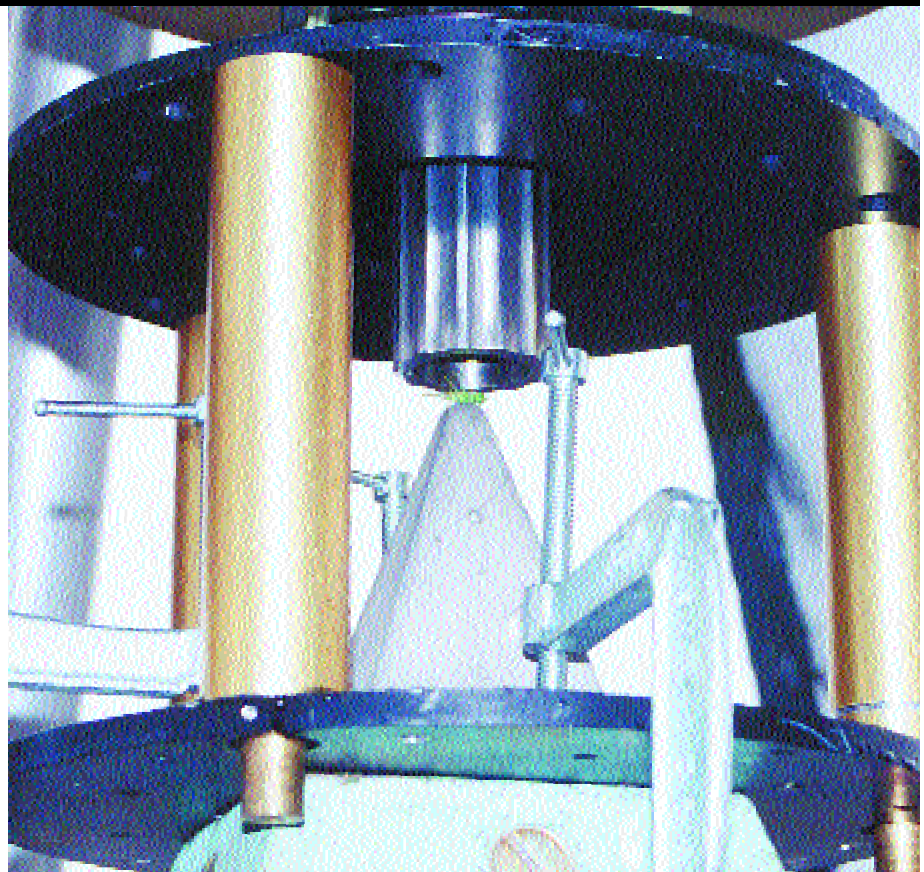
LEFT Metal scaffolding creates a difficult multipath situation.



made to determine the elevation during that survey. A wonderful picture of a previous survey from the top of the Monument hangs in the NGS offices in Silver Spring, Maryland. During a cleaning and maintenance project in 1934, USCGS actually occupied the apex as part of a D.C. area triangulation network. The Monument (PID HV4432) was positioned as a first-order (1:100,000) network station and adjusted into the North American Datum of 1927. This data was later readjusted as part of the North American Datum of 1983 in 1986 [NAD 83 (1986)] and again readjusted to fit with the Maryland High Accuracy Network (HARN), NAD 83 (1991). Unfortunately, again no observations were performed to determine the height and the published National Geodetic Vertical Datum of 1929 (NAVD 29) elevation was considered to be no better than scaled from a topographic map.

#### Unique Opportunity

Deterioration of the Monument has dramatically increased in the past several decades. Automotive and industrial pollutants as well as the natural effects of rain and wind have been very unkind to



**ABOVE A winged visitor takes a break the top of the monument. (Note high-tech C-clamps used to attach the special bracket made by NIST.)**



**Javad Positioning Systems RegAnt choke ring antenna with Lincoln Memorial in the background.**

the exterior. In early 1998, NPS announced plans to renovate the Monument. A morning radio news story about this plan led Roy Anderson of NGS's Spatial Reference System Division and myself to begin planning the occupation of the top of the Monument using the Global Positioning System (GPS). A few telephone calls led us to Mr. Steve Lorenzetti, Chief, Division of Resource Management, and NPS renovation project manager. Steve was agreeable to the initial plan, but cautioned that final approval could not come until NPS had selected the contractors to design the scaffold and perform the renovations.

#### Scaffolding Design Awarded

The final design of the scaffolding was awarded to the internationally famous architect Michael Graves of Princeton, New Jersey. The scaffolding was supplied by United Building Supply (UBS) of Mt. Vernon, New York, and the contract for restoration and renovation went to Grunley-Walsh Joint Venture of Rockville, Maryland. Overall project engineering supervision is being provided by Alpha Corporation of Baltimore, Maryland.

The overall survey plan was to make these observations a show case for the





Observation at  
the Jefferson  
Stone.

use of GPS for height determination as part of the NGS National Height Modernization initiative. The capability of determining a high accuracy horizontal position with GPS would be reasonably straightforward. Using this technology to also determine high quality ellipsoid and North American Vertical Datum of 1988 (NAVD 88) orthometric heights would be a significant challenge—a challenge that could not be imagined during the planning stages. To ensure that sufficient vertical control existed to perform the survey, a second-order class I (1.0 mm x sqrt of the level loop in km) leveling was observed around the grounds of the Monument, the Ellipse and the White House. A team of NGS employees performed leveling operations during September 29 and 30, 1998. Particular attention was given to the station JEFFERSON PIER (PID UA0024), the only Federal Base Network (FBN), High Accuracy Reference Network (HARN) station in the District of Columbia. This station had never been previously leveled to, and it was to serve as a primary station in the Monument project. Additional information about this very historic marker is published in a recently released book *The Jefferson Stone* by Silvio Bedini, renowned Historian Emeritus of the Smithsonian Institution. (See book review on page 53.)

#### Digital Level Used to Bring In Vertical Control

Using a Zeiss DiNi 11 digital bar-code level, David Crockett, Roy Anderson, Frank Maida, Joyce Turpin and Jeff Olsen, all of NGS, connected the Pier to existing NSRS vertical control points at the NPS "Survey Office" (M 17, PID HV1845) building just south of the Monument, as well as special stainless steel bench marks, A 8 (PID HV8076) and B 8 (PID HV8077) set in the north

and south faces of the Monument (used to measure subsidence) and a deep rod mark RS (PID HV7993) on the grounds of the White House. Leveling operations were completed just as UBS began the installation of the scaffolding to surround the monument for the next year. During the course of the initial level runs the field crew was unable to achieve the required second-order class I closure. After reviewing the leveling data, concerns were raised about the stability of a bench mark, 813 HV 85003 (PID HV9076) set in a sidewalk near the southwest gate of the White House. Marks set in sidewalks are notoriously unstable for geodetic applications. To resolve the misclosure, it was necessary to make additional connections to marks of very high stability. Fortunately, such a mark, RS, exists on the grounds of the White House, just inside the southeast gate. The connection between 813 HV 85003 and RS was a single level setup, however gaining access to the White House grounds is a very complex process.

#### "Close Enough For Government Work"

Making all the appropriate security connections required several weeks of extensive telephone calls and e-mails. Finally, with all the pieces in place, the level crew arrived early in the morning of November 3, 1998 to perform the observations. After clearing the security check, the crew was met by an escort from the White House Ushers Office. As it turned out, our "guide" was a graduate Civil Engineer and was intrigued by the leveling process. When it was explained that original leveling had not met the national specification and failed to close by less by 2 mm, he was impressed that the phrase "close enough for government work" had a new meaning. The level crew was quick to explain, "That's the way it's been for the last one hundred and ninety two years at NGS!" Leaving the White House grounds, the crew leveled to another high stability bench mark, S 4 (PID HV1832) on the south side of Lafayette Park, a favorite area for many protesters of U.S. Government programs and policies, and life in general. After uncovering the mark, one nearby protester was heard to remark that it had to be a listening device placed by the CIA! The results of the additional leveling were computed and found to close well within the desired tolerance. This data also helped to prove that over the last 25 years the repeated measurements of subsidence at the Monument showed differences of less than 6 mm.

Finally, after several months the clearances were



Dr. Jim Collins and author Dave Doyle with Javad equipment at the Jefferson Stone



Project participants at the Zero Milestone (left to right) Andrew Johnston (Smithsonian), Alan Dragoo (Trimble), Dave Doyle (NGS), Joe O'Mahoney (Leica), Andrew Hurley (Leica), Roy Anderson (NGS), Mike Nixon (Spectra Precision), Dr. Jim Collins (Javad), and Bob LeMoine (Ashtech-Magellan)

arranged between Alpha, Greenly-Walsh Joint Venture, and NPS to allow NGS to perform the GPS observations. Prior to any observations, Roy Anderson and David "Dave-Z" Zilkoski, Acting NGS Deputy Director and author of the guidelines for GPS derived ellipsoid heights, and myself made a reconnaissance inspection of the Monument's peak. While the ride up the construction elevator to the 490 foot level and



LEFT Ellis Veatch and Mike Nixon (Spectra Precision) at the Zero Milestone (White House in background)

survey. Additional support was also provided by the National Institutes of Science and Technology (NIST) who used their considerable expertise to devise a collar to fit the pyramid cap of the Monument and support a GPS antenna.

At this point the survey was completely an NGS operation. However, considering the historical significance of this data, an invitation was extended to all the manufacturers of dual-frequency, "geodetic" quality receivers. During the week of August 16-20, 1999, just over one hundred and thirteen years from the first geodetic survey, the following representatives gathered to take part in the observations: Mark Bryant and Bob LeMoine from Ashtech-Magellan; Dr. Jim Collins from Javad Positioning Systems; Andrew Hurley and Joe O'Mahoney from Leica Geosystems; Ellis Veatch and Mike Nixon from Spectra-Precision; and Alan Dragoo and George Ott from Trimble Navigation. Each

subsequent climb up a 65 foot ladder to the top was exhilarating, the thrill of actually standing on the top and touching the aluminum pyramid on the peak can only be described as breathtaking and awe-inspiring. Unfortunately, it only required a few seconds to realize that the observations were going to be more of a challenge than had originally been anticipated. In order to ensure the rigidity of the scaffolding, the aluminum braces had been positioned to completely enclose the area around and above the top, creating a multipath nightmare.

#### Permission Obtained for 24-hour Observations

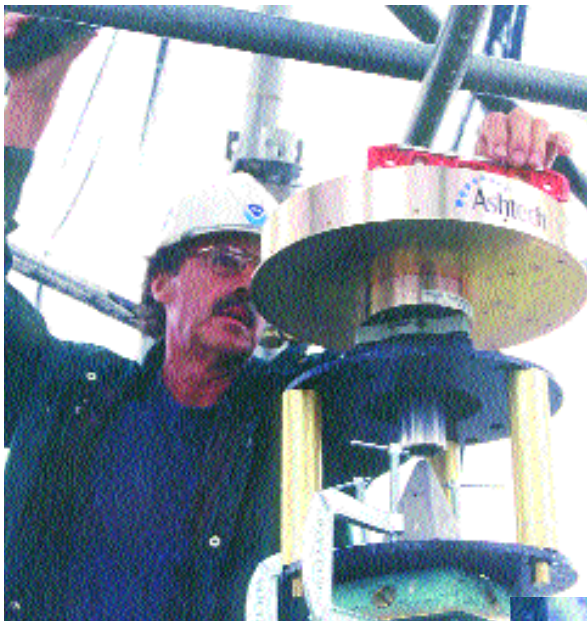
Mr. Daniel Szwed, Alpha Corporation Construction Manager saved the day. Mr. Szwed offered to allow us to mount an antenna on the monument peak 24 hours a day for the entire length of the survey campaign, in hopes that sufficient data could be collected to mitigate the effects of the multipath conditions. The support from Alpha Corporation, and Ms. Kate Beysse and Mr. Dave Bridges from Grunley-Walsh on this and subsequent activities were absolutely essential in the final success of this historic



Brass disk on top of the Zero Milestone



**Roy Anderson using a high-tech instrument to level an Ashtech choke ring antenna.**



manufacturer brought its latest receiver and highest quality choke-ring style antennas available. An observing plan was devised to ensure that each receiver was used at each station in the area of the Monument and the White House. The sight of four receivers from different companies, lined up on stations along the meridian through the White House and the Jefferson Pier, was indeed stirring. Observations were conducted from August 17-19 with each day's schedule requiring two 2-hour sessions, one in the morning and another in the afternoon.

#### Start Times Offset for Satellite Geometry

The start time of the middle day (Wednesday) was intentionally offset by 4 hours to take advantage of a different satellite constellation geometry as prescribed in NOAA Technical Memorandum NOS NGS-58. A total of 10 second-order or better NSRS NAVD 88 control points were occupied in the survey. In addition to the observations taking place on the Mall, the Smithsonian Institution was attempting to position the historically significant BRADDOCK'S ROCK (PID HV1862) station. Additional NGS observers were occupying stations on Capitol Hill (US CAPITOL 1 PID HV9074, and

US CAPITOL 2 PID HV9073), and new stations at NGS headquarters in Silver Spring (HASSLER), station OSTENSO in Rock Creek Park dedicated to former National Ocean Service senior scientist Ned Ostenso, and at Springbrook High School (SPRINGBROOK) in Colesville, Maryland as part of a cooperative program on information systems technologies supported by NGS, Trimble Navigation, ESRI and the American Congress on Surveying and Mapping (ACSM). One highlight of the week was a press briefing held on the Ellipse at the Meridian Stone on August 18, located in the shadow of the White House, and near the site of where the National Christmas Tree is displayed. The briefing was hosted by NOAA Administrator Dr. James Baker, Ted



**Ellis Veatch in position with Spectra Precision choke ring antenna and GeoDAT WIN controller.**

Lillestolen, Captain NOAA Corps, representing NOS, and NGS Director, Charles Challstrom. Each speaker highlighted the contributions that GPS has made and continues to make on numerous aspects

of geodetic, geophysical and mapping sciences, safe marine, land and air navigation and the wide range of applications yet undreamed of. They also praised the cooperative spirit exhibited by the collaboration of Federal activities and industry support of this survey.

All observations would be eventually reduced using the Continuously Operating Reference Stations (CORS), GAIT (PID AF9522) at NIST in Gaithersburg, Maryland and GODE (PID AF9646) at the Goddard Space Center in Greenbelt,

**Joe O'Mahoney and Andrew Hurley (Leica) in position with choke ring antenna and System 500 controller.**





Roy Anderson checks a Trimble choke ring antenna for level.



on bench marks set to monitor subsidence. Recovery and re-observations of these points are critical to the final analysis of these data. No final figures will be released until these points can be confirmed. A complete research and analysis of these activities and data is being investigated by NGS with the support of Dan Szwed from Alpha, and the National Archives. To date, NGS has completed an analysis of the elevation of the peak published in 1885 by Lt. Col. Casey of the Corps of Engineers. Casey's determination of the height of 597 feet, 3 inches was related to the local mean low water vertical datum (a national vertical datum did not exist at that time). Research by NGS using the tidal series of 1891-1901 derived from observations at the MERIDIAN STONE (PID. HV1846) compares with a value of 597 feet, 2.9 inches.

#### Difficulty in Finding an Apples-to-Apples Vertical Datum

While this would appear to confirm the 1885 determination, it is still not clear if the tidal series of 1891-1901 is similar to or significantly different from the series used in 1885 by Casey. Research continues on this issue. It is hoped that the review of data in the National Archives will reveal the information required to assure this comparison as well. Completion of the least squares adjustment of the final NAD 83 coordinates and NAVD 88 height data for all stations in this project, along with the associated meta-data elements for inclusion in NSRS will be completed following the review of information available from the National Archives. (For more information, visit [www.ngs.noaa.gov](http://www.ngs.noaa.gov))

One additional interesting aspect of this survey will be the determination and monumentation of the point that marks the actual intersection of the meridian of the White House and the latitude through the center Capitol. The position of the center Capitol (FREEDOM; PID UA0016) was previously determined using GPS by NGS in 1993 (see "Where Freedom Stands," *Pro-*

Maryland. All receivers worked perfectly during the entire survey program. On Friday, August 20, the final day of operations, each manufacturer's antenna and receiver was taken to the top for a brief 45-minute session and photo opportunity.

GPS vector processing was performed using precise orbits and the vector reduction programs OMNI and PAGES, developed by the NGS Geosciences Research Division. Final coordinates and heights relative to NSRS will be solved with the NGS ADJUST network adjustment software package.

#### Complex Historical Data

The assumption that the determination of the height of the Monument is very straightforward does not address the complexities of understanding the relationship of historical data, similar to the research that would be required for a 114-year-old boundary survey. Before the currently published height of 555 feet, 5 inches can be challenged or confirmed, every effort must be made to ensure that the same reference points used in the 1884 measurements by the Corps of Engineers are used in the current survey. The top of the Monument is without question. However, this is not true for the control points used on the ground or at the base of the monument. Evidence seems to indicate that measurements were originally taken from points on the base floor at the entrance to the Monument and

Press conference at the Ellipse. Left to right: Steve Lorenzetti (National Park Service), Captain Ted Lillestolen (NOS), Dr. James Baker (NOAA Administrator) and Charles Challstrom (NGS Director)





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Originally the Jefferson Pier was supposed to mark the location of this intersection. However, due to the limitations of the original surveyors' equipment, and an obstructed line of sight from the Jefferson Pier to the Capitol, the point actually falls approximately 0.680 meter (2.23 feet) north of the center of the Jefferson Pier. To determine a more precise location of the intersection point, the survey monument used by NPS to locate the meridian of the White House, 868 H 90002 was also positioned in this campaign. Subsequent to the completion of the final adjustment and in cooperation with NPS, NGS will set a new monument at the intersection of these celebrated lines with a precision of approximately 1-2 cm. On behalf of NGS, I would like to take this opportunity to thank the many talented and dedicated people who helped make this survey a success. The cooperation between Federal agencies—NGS,



Ashtech choke ring antenna in position.

NPS, NIST, the Park Police, and the Smithsonian Institution; the construction contractors—Alpha, Grunley-Walsh Joint Venture, and UBS; and the GPS Manufacturers—Ashtech-Magellan, Javad, Leica Geosystems, Spectra Precision, and Trimble Navigation; led to the successful completion of this once-in-a-lifetime opportunity. One final note: A very special thanks is extended to Marc Cheves, editor of *Professional Surveyor* Magazine. Marc supported this program by taking hundreds of photographs to document and commemorate these activities. His photographic expertise is evident in the pictures attached to this article and in a contributing article in the July/August 1999, *ACSM Bulletin*. ▼

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ABOVE Author Dave Doyle commands an aerial view of Washington, D.C..

LEFT NGS employee David Crockett with Leica choke ring antenna.