The Use of Remote Sensing Technology with Flight Inspection to Improve the Accuracy of Obstacle Databases

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ABSTRACT

Although accurate vertical obstacle data has always been critical for designing safe Instrument Flight Procedures (IFPs), the implementation of Required Navigation Performance (RNP) has made the necessity for accurate obstacle data even more important. This paper will outline how the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), and Rapid Imaging Software, Inc. (RIS) are researching a new remote sensing technology called SmarTopo to validate and improve the accuracy of obstacles in a cost efficient manner. Under FAA's TERPs criteria and the soon to be published ICAO PANSOPs criteria for RNP, an accuracy tolerance must be applied to every RNP approach segment. Thereby, more accurate vertical obstacle data will directly result in lower RNP minimums.

This remote sensing technology could be incorporated into a flight inspection aircraft to provide a value-added service to traditional flight inspection operations. Initial research demonstrates that this technology achieved obstacle accuracies of one meter horizontally and two meters vertically. A comprehensive research study was conducted, and the results of this study will be presented in this paper. This technology is also key to the FAA's Obstacle Repository System (ORS) effort to meet the ICAO requirements for electronic Terrain and Obstacle Databases (eTOD).

INTRODUCTION

NASA's Johnson Space Center sponsored the development of the SmarTopo technology by Rapid Imaging Software, Inc. of Albuquerque, NM, under Small Business Innovation Research (SBIR) efforts. This new and innovative technology has been demonstrated to provide important capabilities for the FAA in the improvement of obstacle database accuracy.

SmarTopo technology consists of a desktop component and an airborne component. The desktop component incorporates geospatial technology including satellite imagery and digital terrain models that allow FAA personnel to examine and manage the databases. The airborne component could utilize existing FAA flight inspection missions to enhance these databases by verifying the location and size of obstacles each time an inspection mission is flown.

On April 6th 2007, SmarTopo was demonstrated as a proof of concept on a NASA research aircraft at Ellington Field in Houston, TX. The WB-57 had been equipped with a SmarTopo airborne component consisting of a computer with software, operator interface, and a gimbaled optical sensor. During the 1-hour flight the system was used to locate and measure known obstacles near the aerodrome to within 1 percent of the surveyed height, validating the proof of concept.

The FAA provided funding for further development and evaluation of the technology as a Phase III SBIR effort to be conducted by RIS under NASA management and partnership. It is expected that this technology may save vast quantities of aircraft fuel by creating more direct, fuel-efficient approach procedures for aerodromes in the United States and around the world.

Significant safety benefits for international civil aviation can be provided by in-flight and ground-based applications that rely on quality electronic Terrain and Obstacle Data (eTOD). The performance of these applications, which often make use of multiple data sources, may be degraded by data with inconsistent or inappropriate quality specifications. The increasing worldwide implementation of aircraft and air traffic control units with systems that make use of electronic terrain and obstacle data requires standardization in the supporting data.

The development of RNP approach procedures are needed for the growth of the US National Air Space System (NAS). The creation of highly accurate obstacle databases will not only be vital to RNP approaches but to all approaches in the NAS. New RNP capable aircraft that utilize Wide Area Augmentation System (WAAS) GPS may measure their position to within less than 2 meters (FAA WAAS Performance Analysis Report, August 2007). However, many obstacle locations in the database are not verified to this level of accuracy. In order to create the best RNP approaches, the accuracy of the obstacle database must be improved.

While other remote sensing technologies have been considered for construction of such a database, there are limitations in the accuracy that can be derived from these technologies or they are cost prohibitive on the scale required for the U.S. NAS. For example, the FAA has researched LiDAR, although accuracies of 15 meters horizontally and 6 meters vertically where achieved, the cost of the data collection necessary to achieve this accuracy is currently not practical. While satellite imagery can be useful in verifying the location of an obstacle previously reported, the resolution of this imagery is often too coarse to be useful in detecting the height of unreported obstacles. Consider that a radio tower may have a base that is several meters across, however the top of the tower may be only a few centimeters wide. Consequently, the base of the tower may be detectable, but the top is sometimes not.

The FAA also currently uses aerial stereo imagery for measuring obstacles. This technology can achieve accuracies of 15 meters horizontally and 6 meters vertically, but again the cost on the scale required for the U.S. NAS makes it of limited use. Another problem with satellite and stereo aerial imagery is that the measurement of greatest interest – obstacle height – is orthogonal to the camera view. Of course obstacle height can be verified to 6 meter horizontal and 1 meter vertical accuracy by ground survey, but these surveys are expensive and time-consuming and cannot be readily be combined with existing flight inspection missions.

Overhead imagery displays obstacles from the top where their vertical extent is hidden. As a result, overhead imagery method is not sufficient in detecting obstacles for applications involving public safety. By contrast, SmarTopo views obstacles from the perspective of an aircraft flying the actual approaches at the aerodromes. The analyst using SmarTopo sees the image from the side, where the full vertical extent of an obstacle is visible. Safe obstacle data requires flight inspection with a human in the loop. As aviation moves progressively toward synthetic vision systems, the accuracy of all aeronautical data - including obstacles - becomes absolutely critical to safety of flight.

FAA REQUIRED NAVIGATION PERFORMANCE - RNP

Required Navigation Performance is a rating system, defined in nautical miles, of an aircraft's ability to know its own position. The lower the aircraft's RNP number, the more airspace access, particularly in new or reduced minimums approaches will be available to it. (See reference 1 The Dawning of RNP, John Croft, Business & Commercial Aviation, April 2003). Safety benefits include smoother and more stable approaches into challenging aerodrome environments, and efficiency gains through tighter airspace buffers that currently widen the farther an aircraft is from a ground station.

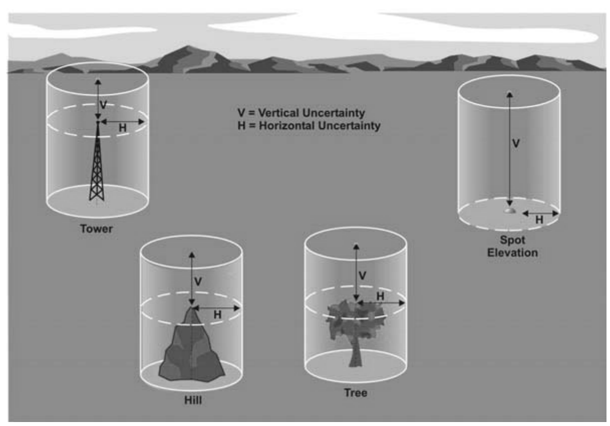


Figure 1 Application of Horizontal and Vertical Accuracy.

The development of RNP procedures requires that the uncertainty of the obstacles be considered in all phases of the approach and missed approach procedure, where the final approach segment is the most critical. The result is a cylinder of uncertainty that cannot violate the protected surface, which often results in high approach minimums for RNP procedures. A majority of the obstacles controlling an RNP approach to higher minimums are found in eTOD Area 2 as shown in Figure 2.

ICAO ETOD

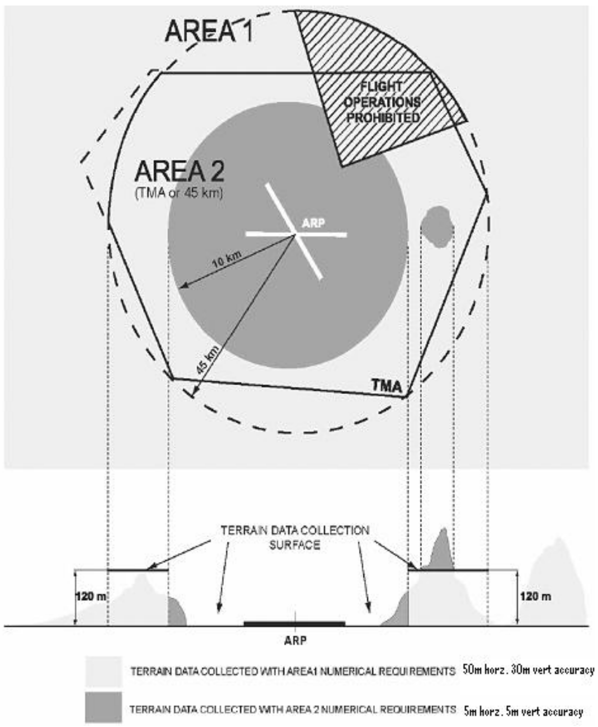


Figure 2 ETODs Area 1 and Area 2.

ICAO's Annex 15 Amendment 33 outlines the requirements for: Terrain and Obstacle Survey, Database structure and metadata, and data quality and integrity. The implementation of eTOD models will provide users with new levels of accuracy and reliability of the data as all data included within the model will have been assured to a given probability factor.

To satisfy identified user requirements for electronic terrain data, while taking into account cost-effectiveness, acquisition methods and data availability, it is proposed that eTOD data be provided according to four basic coverage areas. Proposed Area 1 has coverage over the whole territory of a State, including aerodromes/heliports. Proposed Area 2 covers the established terminal control areas, not exceeding a 45 km radius from the Aerodrome Reference Point (ARP), to coincide with the existing specification for the provision of topographical information on the Aerodrome Obstacle Chart — ICAO Type C (Annex 4, Paragraph 5.3.1 (c) refers). Proposed Area 3 covers the area which is within 50 m from the edges of a defined aerodrome or heliport surface movement area while the Proposed Area 4 should be restricted only to those runways where precision approach Category II or III operations have been established.

eTOD Area 2 poses a challenge to data stewards due to the large area requiring very accurate data. When faced with cataloging each aerodrome area that extends to over 6000 sq./km to a vertical accuracy of 3 meters and horizontal accuracy of 5 meters or better for all obstacles exceeding 120m, the need for innovative technologies and processes comes to light. Traditional ground based surveys become prohibitively expensive when faced with the numbers of obstacles found in each individual aerodrome's Area 2. Traditional LiDAR becomes a cost challenge due to the extensive time needed to illuminate an area with sufficient laser energy in an effort to paint the required obstacles and the vast amount of data that must be processed in order to harvest the obstacles and identify the false returns. Even in best case scenarios, LiDAR's ability to identify the highest fidelity obstacles, such as the apex of small transmission towers, cannot be assured.

The FAA currently has over 275,000 obstacles in its Obstacle Repository System (ORS) database. When eTOD requirements are implemented, the need for improved accuracy becomes mission and time critical. Area 2 of eTOD currently has the largest gap between current in use capabilities, and the requirements set in ICAO Annex 15.

THE SMARTOPO SYSTEM

SmarTopo is a collection of technologies designed to facilitate the creation of a unified database of obstacle information. This collection of technologies, as envisioned, would allow for:

1. Rapidly identifying new obstacles using flight inspection aircraft and remote sensing products.

2. Improving the accuracy codes of identified obstacles.

3. Identifying and removing phantom obstacles from the database. (e.g. cell phone towers that were taken down or never built).

4. Providing integrated handling of terrain and man-made obstacles from many different sources.

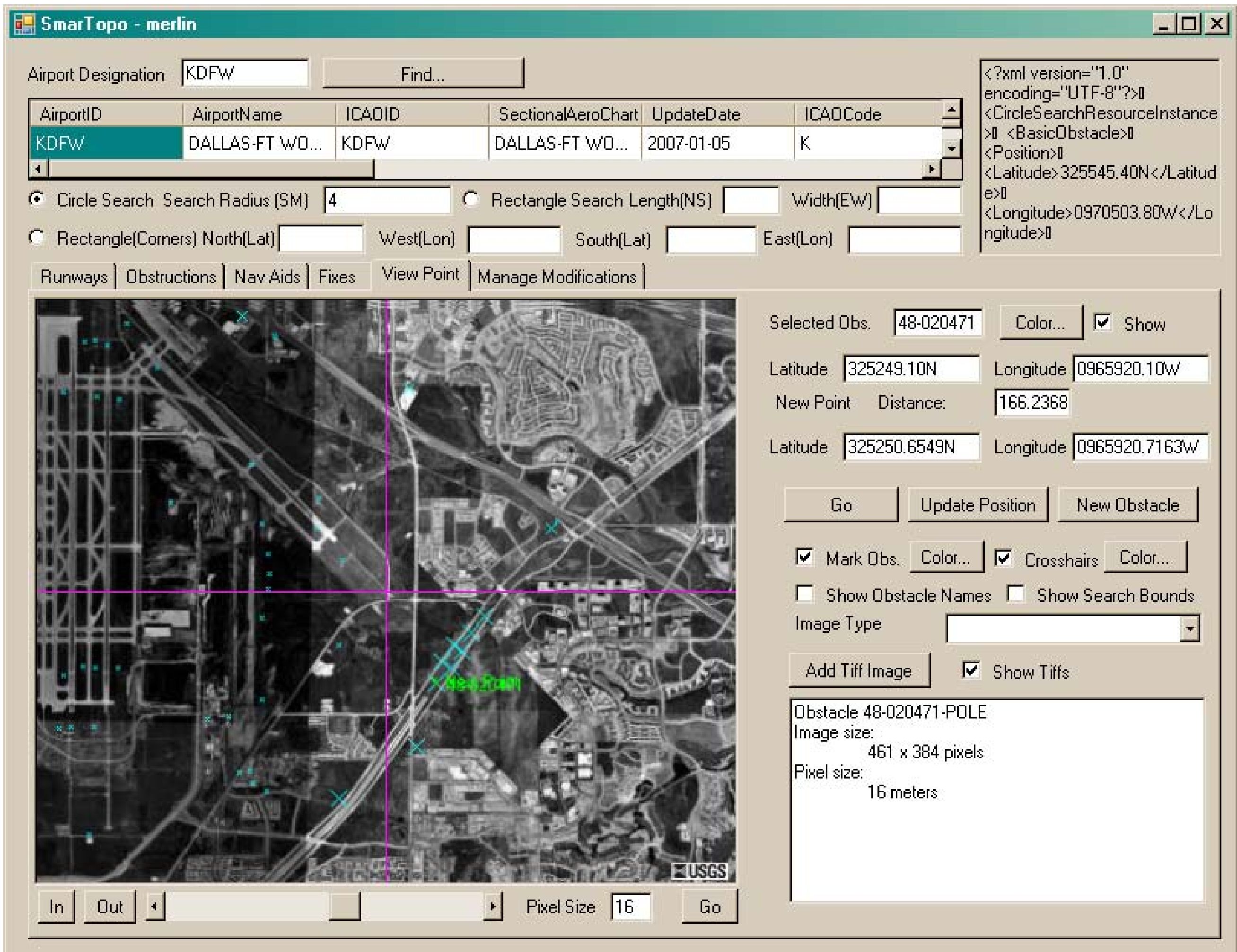
5. Visualizing the databases in three dimensions.

The SmarTopo system consists of an airborne and desktop component. The desktop component is software that allows analysts to verify and locate obstacles through calculations based on highly accurate digital elevation models and high resolution satellite imagery, and

SmarTopo airborne component measurements. Obstacles measured with the desktop component are usually found in eTOD Area 2. The SmarTopo airborne component is made up of a high fidelity optical and attitude/position sensor that allows precise measurements of obstacles. Typical obstacles obtained through the aerial segment are those that are the controlling obstacles for an approach. These obstacles require 3 meter or better accuracy.

DFW FLIGHT DEMONSTRATION

The Dallas/Fort Worth International Airport (DFW) in Texas, is one of the busiest commercial hubs in North America. It was chosen for this test because the existing RNP Z31R approach is a good example of how approach minima are impacted by obstacles. Figure 3 depicts the obstacles near the approach end of DFW 31R; a short distance from the runway threshold is a toll road, and near the extended runway centerline is the toll booth along with more than a dozen light poles that are approximately 38 meters tall.



Not all of these light poles were entered in the AirNav database, but those that were had a vertical accuracy of 76 meters horizontally and 15 meters vertically. Because their position was not precisely known, the approach minima had to be increased accordingly. It was thought that this would be a practical test for the real-world utility of SmarTopo. Could SmarTopo be used to lower the approach minima for DFW RNP Z31R?

An estimated 80% of SmarTopo's obstacle database enhancement can be done with the desktop component software running on a desktop PC. However, the verification of height above ground level for an obstacle must be done using a side-looking system. Methods which attempt to use sensors looking down on obstacles from above are normally looking at exactly the smallest and least informative profile of an object. The top of a 300 meter radio tower might be a single light fixture that is 0.2 meters across. Finding such an object for purposes of stereographic reconstruction of obstacle height is challenging at very best.

As seen in figure 4, the SmarTopo airborne component uses instruments placed on inspection aircraft to view the image from a side perspective, not from the top. As a result, it is easier to examine obstacles and find their true height. In this figure an obstacle has been imaged with an optical system under the control of the SmarTopo airborne component, which allows us to overlay a height scale on the object.

Figure 4 SmarTopo Aerial Segment measurement of light pole at DFW.

The first step in upgrading the obstacle database is to obtain the appropriate resolution aerial imagery. In this case commercially available aerial photographic ortho imagery with 6 inch resolution was obtained. The aerial photography meets National Map Accuracy Standards at a map scale of 1 inch = 200 feet (1:2400). The photo scale is 1 inch = 1500 feet (1:18000). Figure 5 shows such an image.

Figure 5 SmarTopo view of light pole obstacle using aerial survey imagery.

The user locates the obstacle record of interest in SmarTopo and then zooms in for examination. SmarTopo can utilize Open Geospatial Consortium (OGS) Web Map Servers (WMS). This allows access to a wide variety of geographic data and the user can import properly geo-referenced aerial imagery as well. SmarTopo then provides the necessary data for the user to adjust the recorded location of the obstacle, and the obstacle data accuracies. SmarTopo is designed to facilitate rapid, efficient processing of obstacles. It can also be used to obtain base obstacle elevations from properly qualified Digital Elevation Models (DEMs), from LIDAR, and other data sources. Figure 6 shows an example LiDAR map.

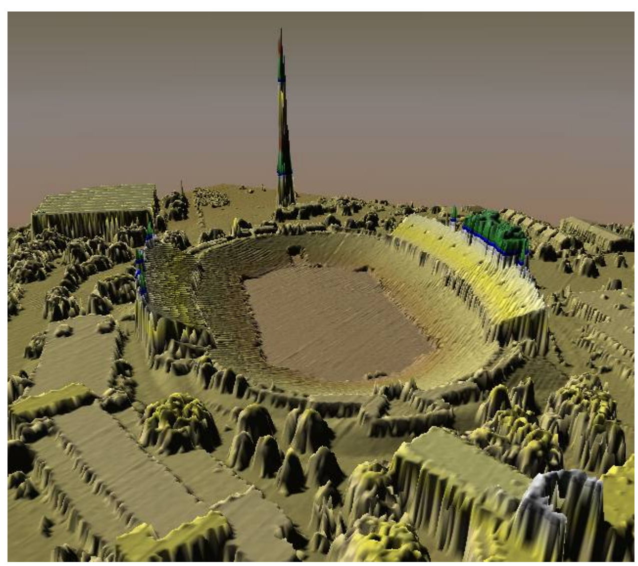


Figure 6 LiDAR image of the Cotton Bowl.

SmarTopo Measurement - Actual Height	
Average	0.2177 meters
Standard Deviation	1.07671 meters
Minimum	-0.792441 meters
Maximum	1.92 meters
Sample Size	14

Table 1 Results from SmarTopo Flight Test

There are really three measurements required for obstacle data. The horizontal location (latitude and longitude in NAD83/WGS84), the height of object above ground level (AGL), and finally the base elevation of the object (required to compute an object MSL height). The horizontal measurement can be confirmed using overhead ortho imagery in the SmarTopo desktop component. The SmarTopo airborne component aids in the collection of AGL height measurement. The base elevation of the obstacle is then obtained from LIDAR survey data. Current LIDAR topographic survey instruments routinely achieve accuracies of 15 to 20 cm.

The National Geospatial Agency (NGA) has collected such data for certain areas of the U.S. Figure 6 shows a LiDAR map of the area near the Cotton Bowl, in Dallas, Texas.. To date, NGA has analyzed data in 76 U.S. cities to a vertical accuracy of 20 cm. While this LiDAR data does have a resolution of 20 cm or better, it should not be used for the purpose of obstacle detection, rather only for bare Earth base elevations. This LIDAR effort is aimed at providing the best possible geospatial data to federal, state, and local governments. NGA is contracted to provide another 57 cities over the next two years and may consider additional data collection if requested.

For the purposes of the DFW flight test, an appropriate flight test platform was selected. In this case a DA-42 Diamond TwinStar equipped with a FLIR systems turret and the SmarTopo airborne component shown in Figure 7. On March 1, 2008, the aircraft flown by pilot Paul Pefley, of Mohawk Technologies, flew an example flight inspection mission at the DFW airport. The mission was highly successful and captured several dozen measurements during the allotted one hour flying time. The measurement of the light poles that control the RNP Z31R approach were collected within a 20 minute window in the busy departure airspace 4 km southeast of the DFW airport, indicating excellent potential process efficiency.

Figure 7 Mohawk Tech DA-42 used in flight test

One hundred percent of these measurements correctly measured the light pole height at 38.1meters high AGL to better than 2 meter accuracy. Though most were 1 meter accuracy or better, there can be no doubt that better than 2 meter accuracy was achieved on all obstacles. This conservative criterion was therefore adopted. Other known obstacles were also measured and showed similar performance accuracy except in the case of one measurement of the Dallas Love Field control tower. The control tower had a base obscured by surrounding buildings that did not allow an accurate obstacle base point to be recorded. Upon post analysis of this measurement, it was discovered that a successful measurement could have been obtained if the aircraft was positioned on the opposite side of the obstacle from where the original measurement was obtained. This scenario does point out that a small number of obstacles maybe in environments that make obtaining accurate obstacle base points difficult, warranting additional research or adaption of new processes.

A statistical analysis of the measurement performance was undertaken by Dr. Janis White of Statistical Consulting. Two statistical techniques are applied to the data. The first technique is to formally test the hypothesis that, on average, SmarTopo measurements for the light poles meet the 3 meter standard using a one-sided test based on the sample average difference. The second technique tests the hypothesis that the proportion of SmarTopo measurements exceeding the 3 meter standard is less than 0.01.

As a result of this analysis we have achieved a level of confidence in this range of performance for the SmarTopo airborne component. More detail, especially on taller obstacles, is currently being collected. However, SmarTopo has clearly demonstrated 3 meter vertical measurement performance on the controlling obstacles for DFW Z31R RNP approach.

At the completion of the effort, all of the controlling obstacles accuracies were improved from 76 meters to 6 meters horizontally, using the SmarTopo desktop component. Combined with the results of the airborne component, all controlling obstacles were improved from 15 meters to 3 meters vertically.

The compiled SmarTopo data from the KDFW flight test could allow the FAA to lower the RNP minimums for RWY 31R. Reductions in the Height Above Touchdown (HAT), visibility, and minimums were all realized following the test.

CONCLUSIONS

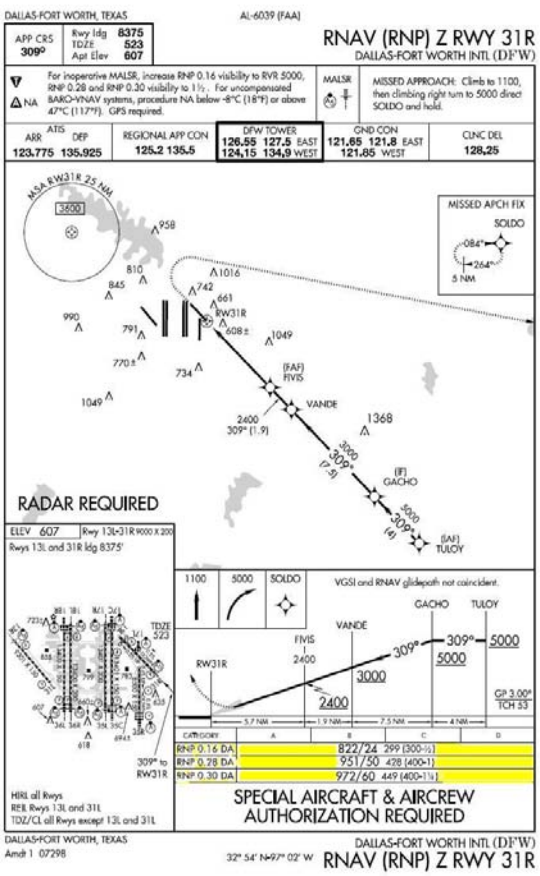


Figure 8 Approach Plate for RNAV Z RWY 31R

The potential impacts for KDFW ZRNAV 31R were substantial. This approach has three RNP value approaches – a 0.16, 0.28 and 0.30. Based on the results the RNP 0.16 was unaffected but the 0.28 could be replaced with a more desirable 0.29 with both lower HAT and lower visibility minima. The minima for the RNP 0.30 approach could also be improved as seen in table 2.

RNP	HAT	Visibility	Weather Minimum
0.16	299	½ mile	300 – ½ No change
0.28	428	1	400 – 1
Replaced with improved RNP 0.29 minimum			
0. 30	449 **402**	1 ¼ **1**	400 – 1 ¼ **400 – 1**
0.29	**367**	**3/4**	**300 – ¾ Replaces old 0.28 RNP**

Table 2 SmarTopo improves DFW Z31R. SmarTopo impact in Blue

FUTURE APPLICATIONS

The flight test at DFW 31R provides concrete evidence that the SmarTopo technologies can accurately and reliably improve the horizontal and vertical accuracy of obstacle data. This has profound implications for the future in that new RNP approaches can be designed with lower minima and more possible routes.

The FAA is currently planning to use technologies like SmarTopo to provide the best data available to the ORS. This will result in a more efficient NAS, saving vast quantities of jet fuel, reducing the carbon emissions of aircraft measurably, and maintaining the highest standards of flight safety.

This technology also offers a possible solution to the eTODS requirements. A SmarTopo system would have the advantage of being deployable worldwide onboard aircraft as a modular installation and be able to measure obstacles while a flight inspection aircraft conducts routine mission runs.

Area 2 of eTOD, which runs from 50 meters beyond the movement surface of an aerodrome to 45 km, would be the prime target area of the SmarTopo system. The location of the DFW controlling obstacles were all found in the purposed eTOD Area 2. The SmarTopo airborne component captured the data inside the Class B airspace with minimum impact to DFW Air Traffic Control. The successful integration of this flight test into crowded Class B airspace was due to the high resolution optics of the FLIR turret and the human interface of the SmarTopo system. Targets were captured from an altitude of 500 meters above ground level (AGL) and from a slant range of between 2000 and 4000 meters. The ultimate estimated operational envelope of SmarTopo system performance for eTOD Area 2 are 300-3000 meters AGL, 500-6000 meters slant range.

The SmarTopo desktop component may be utilized to improve the horizontal accuracy of most obstacles not already meeting Area 1 criteria, while the most critical obstacles in Area 2 could also be brought up to 3 meters vertical accuracy, if needed, with the SmarTopo airborne component.

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