# Got Mountains? Challenges of Modeling SRTM and Other Terrain Data to Suit Aviation Applications

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## Abstract

Jeppesen, the leading supplier of aeronautical aviation data and charts, has produced a terrain database suitable for use in Terrain Awareness Warning Systems (TAWS) in the evolving aviation industry. Advances in terrain data captured from space-based platforms, like the Shuttle Radar Topography Mission (SRTM), have provided the opportunity for Jeppesen to significantly enhance topographically derived legacy terrain databases with more accurate terrain data models. The data used in aviation must be of the highest quality, and the systems based on sound development principles. This paper will explore the challenges, limitations, and benefits of incorporating the SRTM and other data sources into a new generation terrain database for use in the aviation industry.

## Past, Present, and Future for Terrain Databases

Jeppesen has provided terrain data to the commercial aviation industry since the early 1990's for in-cockpit Terrain Awareness and Warning System (TAWS) developed from the TSO-151b performance specification. TSO-151b resulted from the aviation industry initiating measures to enhance aviation safety through improvement of pilot situational awareness for the reduction of controlled flight into terrain (CFIT) incidents. Several incidents in preceding years brought attention to this problem.

The basis for Jeppesen's early TAWS models were multiple generations of commercially available terrain datasets. Jeppesen's 1$^{st}$ generation TAWS datasets were derived from independent 30 arc-second (1000 meter post spacing) global terrain datasets. The 2$^{nd}$ generation TAWS models combined NOAA's GLOBE 30 arc-second model with 1, 2, 3 arc-second terrain data into global TAWS models with the higher quality data available for the US only. Over 24 discreet sources of terrain data comprised these early TAWS models with each data source possessing unique quality characteristics. In some areas these legacy terrain models have uncertainty errors exceeding 650m (1800ft) vertically based on the original data source. With adequate data analysis and additive surface buffering these TAWS models were useful in earlier generations of in-cockpit TAWS systems.

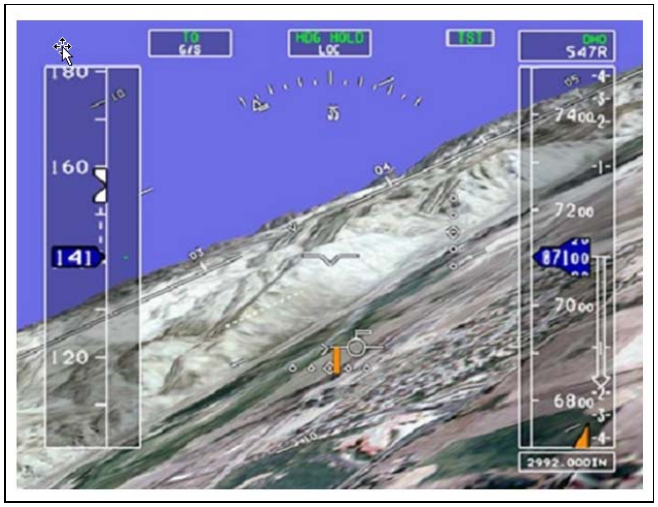

Figure 1 Synthetic Vision Display

As new styles of on-board systems, such as Synthetic Vision (SVS) (Figure 1), and as new international data standards, such as DO-276 (Figure 2) have been introduced, the inherit quality weaknesses of the legacy terrain data sources have limited their use requiring replacement with terrain data sources capable of supporting newer system requirements. For this task, the SRTM dataset was selected to upgrade Jeppesen's terrain database.

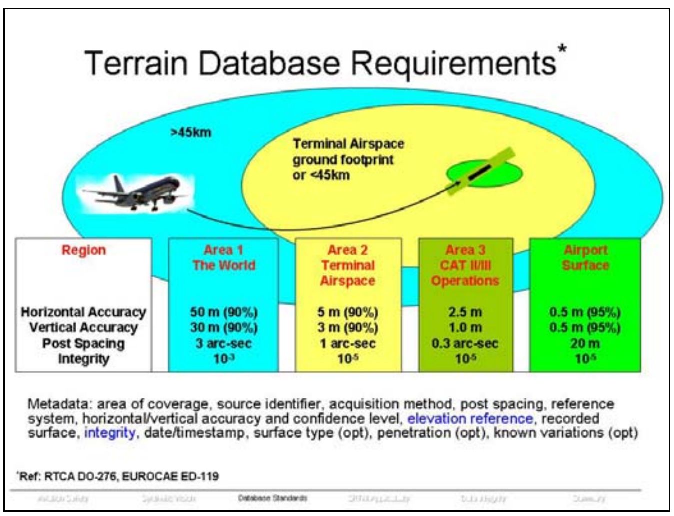

Figure 2 DO-276 Requirements

During the last three years, Jeppesen has developed a 3$^{rd}$ generation terrain model based upon the near global SRTM 3 arc-second (100m) first reflector terrain dataset acquired by NASA and NGA during a shuttle mission in 2000 and released to the public in 2005 as the 'Finished' SRTM dataset. The SRTM model provides several compelling characteristics for use in aviation some of which are indicated in the following list.

- Single data source covering majority (80%) of Earth surface

- Coverage of 95% of world's commercial airports
- Absolute vertical accuracies ranging from 3 m (~10 ft) – 15 m (49 ft)
- Absolute horizontal accuracies ranging from 4 m (~13 ft) – 13 m (~43 ft)
- Satisfies TSO-151b Terrain Awareness and Warning System requirements
- Satisfies DO-276 Area 1 requirements for a worldwide terrain model

The coverage and data source contrast between Jeppesen's legacy and 3rd generation terrain models can be seen in Figure 3. The current version of the terrain model does retain some legacy data in areas not covered by SRTM. These areas include the polar areas above 60 degrees north and below 56 south and SRTM void areas. Over time, these legacy data sources will be replaced with SRTM-like or better quality terrain data.

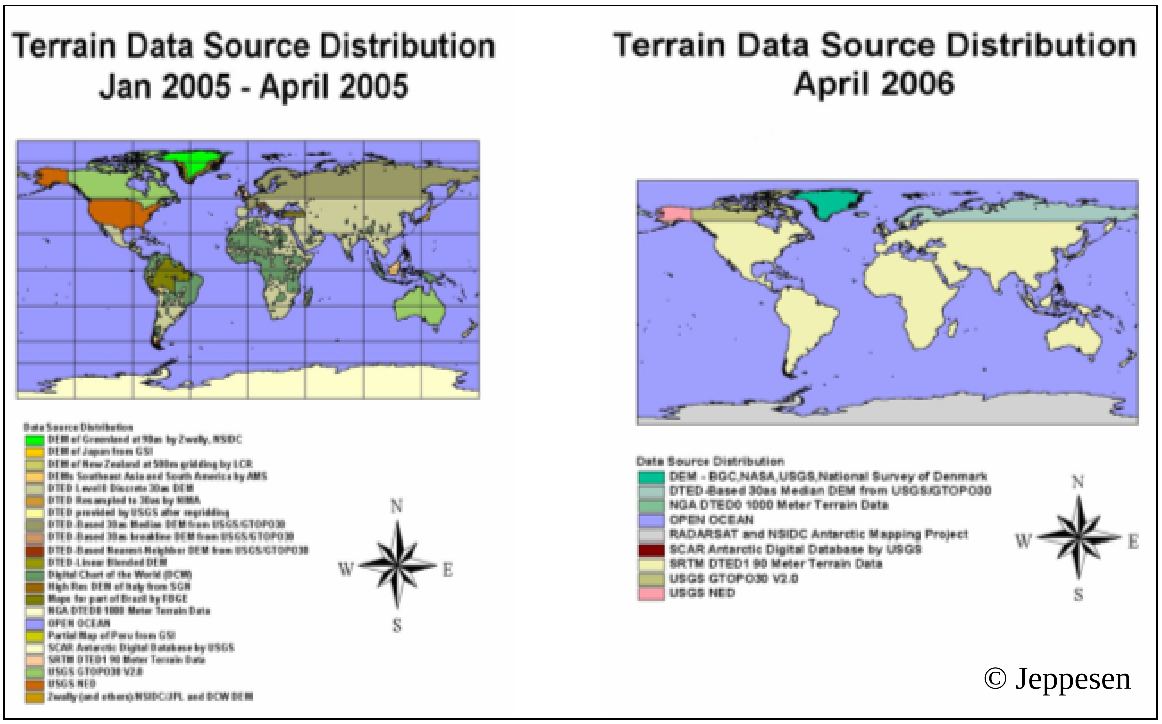


Figure 3 Legacy and Latest Terrain Model Comparison

While the SRTM dataset contributes substantial advantages to aviation, it does provide many challenges as well. The primary challenges using SRTM data are void (no data) areas within the dataset caused by C-Band acquisition signal loss and surface peak shadowing situations. These were caused by certain earth surface conditions attenuating the C-Band signal return and some areas of the earth having minimal number of 'looks' from the shuttle due to orbit dynamics and the short acquisition period contributing to creation of shadow zones on the back side of ridges. These surface conditions are affected by snow-capped mountain peaks, desert areas, water bodies, and marshlands. The red areas shown in

Figure 4 illustrate the geographic distribution of SRTM void areas. In addition to the voids, water and shorelines are not modeled and captured properly. Jeppesen has addressed these challenges by filling voids and modeling shorelines with methods suitable to aviation.

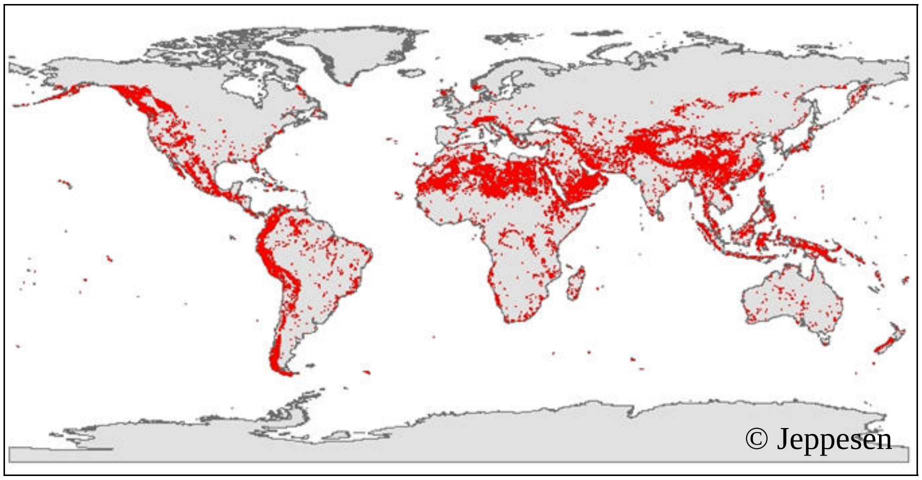


Figure 4 SRTM Void Area Distributions

There are roughly 3,316,753 voids covering nearly 1,005,933 sq km (388,390 sq miles) in the SRTM dataset. Jeppesen analyzed the characteristics of the void population and the available terrain data to fill the voids. Several methods for void filling have been developed that are unique to the extent of the void and the quality characteristics of available terrain data sources used to fill the void areas. The void fill operations prefer infill data of like or better quality than SRTM. However, in many areas, legacy terrain data of 6, 15, and 30 arc-seconds were used for the void fill process when the void extent exceeded a defined area threshold suitable for interpolation. This processing resulted in the creation of Jeppesen's seamless base level 0 terrain model.

Jeppesen utilized the base level 0 model, knowledge obtained from extensive data source accuracy analysis, error distribution analysis and terrain surface classifications in developing buffered terrain model surfaces that comply with aviation specific confidence levels of Routine ($10^{-3}$), Essential ($10^{-5}$) and Critical ($10^{-8}$) shown in Figure 5. Each confidence level is related to specific types of aviation operations. Confidence level processing ensures that no more than the indicated number of elevation posts in the terrain dataset may possibly be lower than the actual terrain surface. As an example, for an Essential Confidence Level ($10^{-5}$) model, 1 in every 100,000 elevations within a 3 arc-second 1X1 degree terrain tile composed of 1,442,401 elevation posts may be lower than the actual surface elevation. The result is 14 elevation posts potentially being lower than the actual terrain surface contrasted with 144,240 elevations potentially being lower than the actual terrain surface in the unbuffered base level 0 surface at a 90% confidence level.

To accomplish the calculation of the confidence surfaces, each base level 0 elevation post is analyzed for the accuracy of the source data, the terrain classification characteristics of the area, confidence level for the designated model and proximity to airports in calculating the confidence buffer amount added to the base layer elevation. This dynamic method of calculating confidence buffers is preferred by Jeppesen instead of a single elevation amount added uniformly across the model, which historically has been the most common approach. Jeppesen's dynamic calculation method is applied whenever terrain data changes occur in the base level model and the new terrain data issued through Jeppesen's Terrain Data Service to our clients.

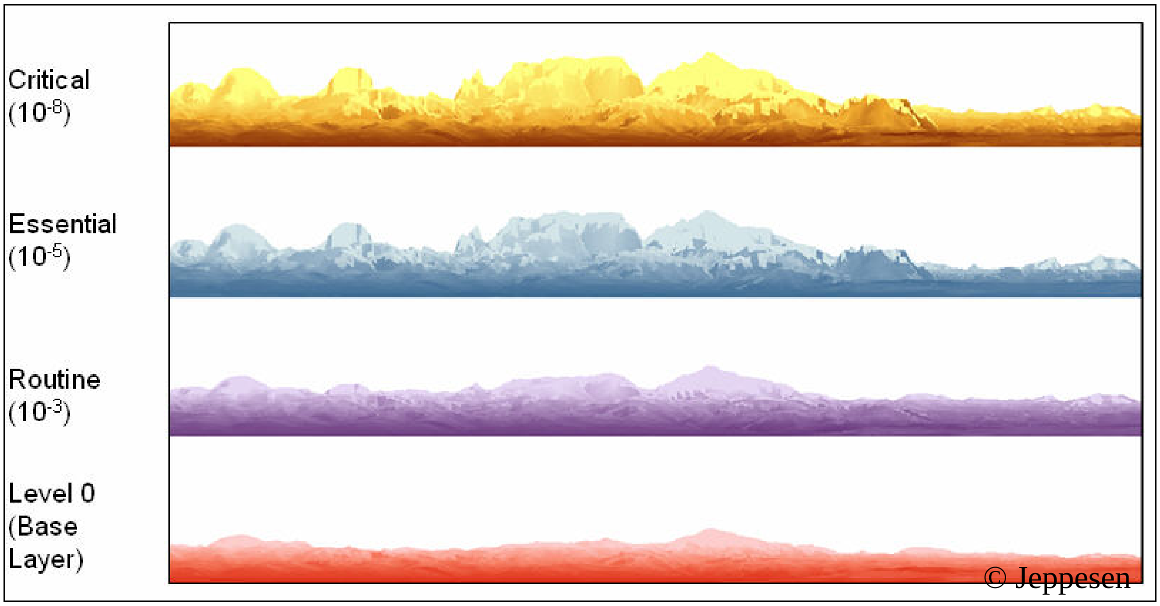


Figure 5 Jeppesen Terrain Model Surfaces

Figure 5 illustrates each model's surface in cross-section. As can be seen in the illustration, the surface of the unbuffered Base Layer can be raised as the confidence level increases. Some areas are raised more than others due to the processing criteria mentioned above while others remain lower due to the higher quality of the original terrain data.

As a result of this extensive development effort, Jeppesen has built a worldwide terrain database based on SRTM to provide a quality database for use in a broader range of civil aviation applications.

## Terrain System Software Development

Jeppesen developed a software suite of applications to create the worldwide seamless terrain database and address the unique characteristics of terrain data. This suite of applications is predominantly based on ESRI products, in particular the Spatial Analyst extension and the ArcObjects GIS framework. ESRI ArcSDE is used as the underlying database.

The Jeppesen applications also integrated several other third-party tools in order meet our requirements. This application suite is used to process the main SRTM data source and to integrate other terrain data sources in the SRTM base where appropriate. The terrain envelopes or buffers were also created using these applications.

The interesting facet of integrating ESRI and other third party tools into a Jeppesen application suite was the opportunity to use "best of breed" software from non-aviation related industries. The GIS industry encompasses many disparate industry and academic segments. Jeppesen unified several disparate GIS tools in order to create our terrain data.

**Tool characteristics**:

- Programming language(s) - Predominantly Java 1.4.2 with some 1.5, some Visual Basic 6 for COTS GUI functionality. ESRI 9.0 and 9.2 ArcGIS Engine and ArcObjects GIS framework. Some XML for configuration, build, and metadata templates. Third party tools to aid in bias correction (correlation of different data sources) and interpolation.
- Underlying database technology/technologies - ESRI ArcSDE on Oracle Spatial 10g

ArcGIS Engine 9.0 is used to manage the workflow and invoke specialized processes to prepare the terrain database. ArcGIS Engine 9.2 is employed for extraction and packaging processes for the finished datasets. Spatial Analyst is used to compare SRTM data with other data sources to analyze "like" quality characteristics.

## Aviation Products Incorporating Terrain

Advances in digital terrain databases, like SRTM, have improved quality and availability of terrain data worldwide. The upgraded databases are a marked improvement over traditional paper charts and manual compilation methods. The aviation industry is rife with products integrating digital terrain data. Paper and electronic charts have terrain data depicted for the enroute and approach phases of flight. Color-shaded depictions of terrain heights are required on instrument approach charts. The shading allows pilots to easily identify elevations that may influence the approach path of the aircraft. This paper will highlight three popular and important areas where quality terrain data improves the situational awareness of the flight crew and the procedures designed for them. Terrain Awareness Warning Systems (TAWS), procedure design, and grid MORAs are the focus.

### TAWS

Controlled Flight Into Terrain (CFIT) has long been a problem on the watch list of the FAA and other organizations concerned with preventing accidents. CFIT occurs when an airworthy aircraft is flown unintentionally into terrain, obstacles, or water without crew awareness. This type of accident is routinely associated with the approach and landing phase of flight. In 1999, the International Civil Aviation Organization (ICAO) passed requirements that Ground Proximity Warning Systems (GPWS) and TAWS provide predictive terrain hazard warning functions. Turbine-powered airplanes registered in the United States and authorized to carry six or more passengers must be equipped with this technology for use in flight [1]. At a minimum, the system must meet the requirements for Class B equipment in TSO-C151b [2] and be FAA approved. All newer aircraft have a TAWS loaded at the time of production.

A TAWS product incorporates hardware, software, and data to provide visual and aural warnings to the flight crew of impending terrain in the flight path. These systems compare the geographical location of the aircraft with the terrain elevation and vertical obstacles in the forefront of the route. The terrain and obstacle databases are loaded in the system to interact with the software that provides the notification. TAWS are an improvement on the earlier GPWS by generating earlier warnings, forward looking capabilities, and continued operation during landing. The more notice the flight crew has, the better their ability to make gradual corrective actions.

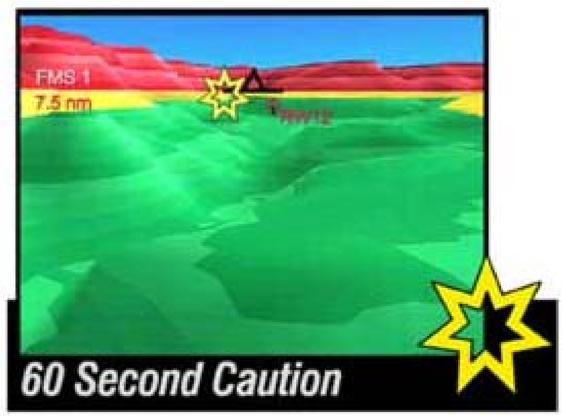


Figure 6 Universal Avionics TAWS 60 Second Caution

Basic functions of these systems include Forward Looking Terrain Avoidance, Premature Descent Alerts, and appropriate signals for caution and warning alerts. As displayed in the following screenshots, Figures 6 and 7, the TAWS provide cautions and warnings depending on the time prior to intercepting the impending terrain or obstacle.


Figure 7 Universal Avionics TAWS 30 Second Warning

**Procedure Design**

Required Navigation Procedures (RNP) are the new buzz words in aviation. Exciting advances in technology have improved aircraft capabilities to implement RNP into airline operations. RNP has proven benefits that reduce flight time and emissions and increase fuel savings. Fuel savings are realized through shorter, more accurate 3D flight paths that are effective in all types of weather. RNP relieves congestion at airports by allowing more aircraft to land in a timely manner. These procedures allow Instrument Flight Rules (IFR) access to more airports and runways via destinations, landing alternates, and Extended-range Twin-engine Operational Performance Standards (ETOPS) alternates.

RNP involves the use of GPS and onboard monitoring equipment to fly narrow corridors of airspace on approach and departure. These procedures allow aircraft to fly a more direct path to the landing zone, in contrast to conventional radar vectors. The new routes can save upwards of 10 nautical miles on each track, which equates to less fuel and schedule reliability.

Figure 8 shows a comparison of the compact corridor defined for an RNP in yellow and the traditional radar-based approach to a runway in gray. The satellites symbolized in the RNP approach illustrate how GPS signals received in the flight deck provide continuous feedback on aircraft position. The precise flight track allows for more efficient operations at congested airports.

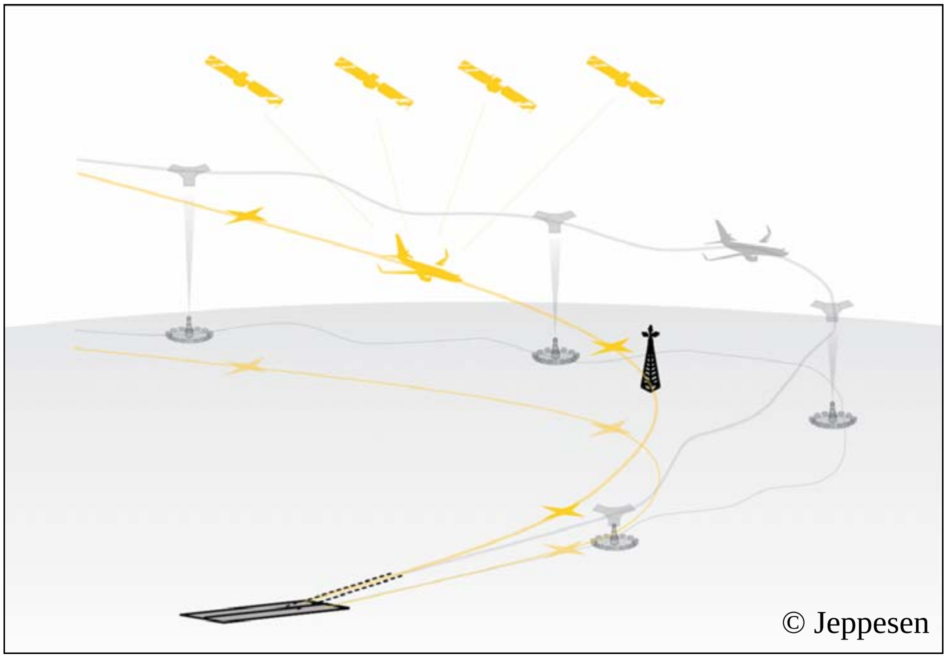


Figure 8 RNP Procedure compared to traditional approach

The chart in Figure 9 highlights an RNP procedure created for Palm Springs, California. Required Navigation Procedures are designed for arrivals and departures through a variety of inputs to a procedure design system, including terrain, obstacles, and ground surveys. The design accounts for obstacle clearance by incorporating Navigation System Error, Flight Technical Error, and any applicable buffers. The SRTM data reduces the need for expensive terrain surveys of an airport, its facilities, and neighboring areas, where there is a lack of consistent high-quality terrain data. The terrain surrounding an airport is modeled to give the aircraft the ability to climb and return to the airport in the event of engine failure. Minimum safe altitudes are derived from government-published source and quality terrain databases. The finalized procedure allows the RNP-capable aircraft to operate in all weather conditions and at terrain-challenged airports.

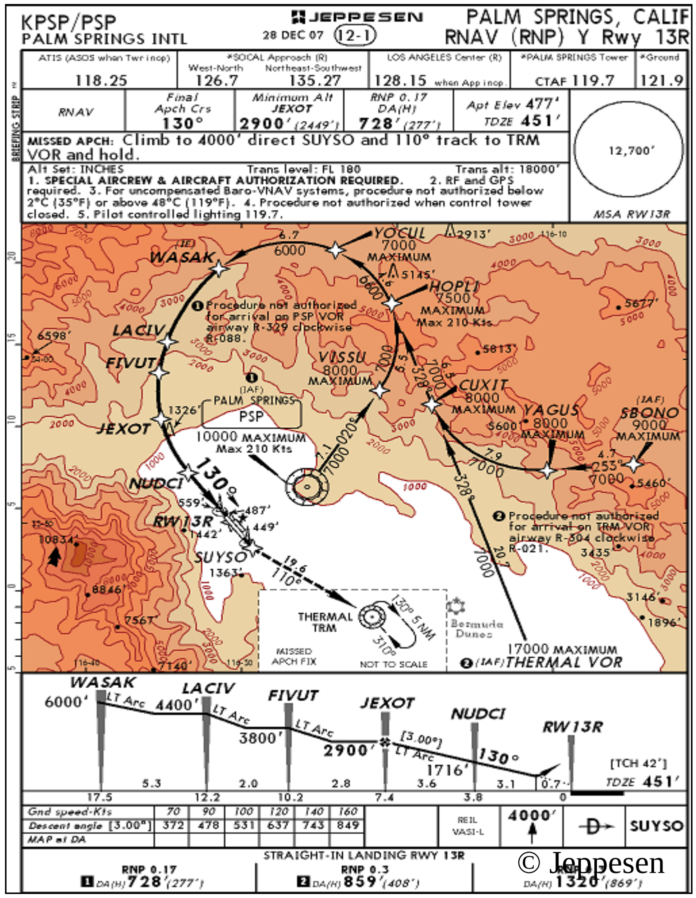


Figure 9 RNP Approach Chart

## Grid MORAs

The Grid Minimum Off-Route Altitude (MORA) provides terrain and man-made structure clearance within the section outlined by latitude and longitude lines, typically in one degree by one degree cells. Grid MORAs derived by Jeppesen clear all terrain and man-made structures by 1000 feet in areas where the highest elevations are 5000 feet Mean Sea Level (MSL) or lower. Grid MORA clearance is 2000 feet in areas where the highest elevations are 5001 feet or higher. Some countries apply different criteria. Grid MORAs are usually found on the enroute and area charts.

Jeppesen previously used topographical charts as a basis for determining grid MORA values. South America was an example of a region that had incomplete or unsurveyed terrain information available on charts. The new SRTM database provides more accurate elevation values that have been used to refine the grid MORA values in South America and enable more productive flight plans.

Oxygen and pressurization requirements are imposed on flights conducted at certain altitudes beyond a certain period of time. These requirements are found in the ETOPS rule published by International Civil Aviation Organization (ICAO). Commercial airlines use grid MORAs to keep a safe distance from mountains in case of decompression. When the altitudes are derived from accurate terrain data, the flight planners can create routes over the terrain instead of around it. The lower altitudes add up to less time in flight, fewer miles, and reduce fuel consumption.

## Conclusion

Jeppesen has incorporated the new SRTM terrain data into an aviation-quality terrain database. The finished terrain data significantly enhances the awareness of end users on a global scale. An extensible production system has been developed to maintain the current data as well as ingest new digital data as it becomes available. While the terrain does not change much in our lifetime, new sources to capture the terrain continue to come online with better accuracy, resolution, and quality characteristics. Jeppesen will continue to monitor advances in the technology to acquire the latest terrain data available.

## References

[1] "Controlled Flight Into Terrain And Approach-and-landing Accident Reduction." Flight Safety Foundation, Alexandria, Virginia, 2001.

[2] FAA TSO-C151b, Terrain Awareness and Warning System Requirements, 2002, FAA, Washington D.C.

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