

26 March 2015
F500-L15-018

Lic. Manuel Ángel Núñez
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México, D.F.,
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**Subject: Technical Letter—Parametric Analysis of Runway Threshold Elevations
(REVISION)**

Dear Lic. Núñez:

As you are aware, The MITRE Corporation (MITRE) works as an independent advisor, within its areas of expertise, on aeronautical matters pertaining to the Nuevo Aeropuerto Internacional de la Ciudad de México (NAICM). Therefore, following your request, a MITRE team spent a significant amount of time diligently working to prepare a parametric analysis of runway threshold elevations that consider terrain at the hills denominated Chiconautla and Chimalhuachi (hereinafter referred to, because of its location, as Chimalhuacán). In some MITRE documents, the two hills are referred to as the “northern hill” and the “southern hill”, respectively. As always, MITRE copies appropriate principal project stakeholders that may have an interest in the analysis and results.

The hills at Chiconautla and Chimalhuacán penetrate important United States (U.S.) Federal Aviation Administration (FAA) Standards for Terminal Instrument Procedures (TERPS) obstacle clearance surfaces and International Civil Aviation Organization (ICAO) Annex 14 Obstacle Limitation Surfaces (OLS). Penetrations to these surfaces can affect aeronautical feasibility and safety. Therefore, the objective of this document is to provide information about terrain penetrations to TERPS obstacle clearance surfaces and Annex 14 OLS by Chiconautla and Chimalhuacán to ensure that GACM, Mexican aviation authorities, and other stakeholders have the necessary data to make important decisions. The decisions will ultimately be based on cost/benefit analyses regarding potential runway threshold elevations and grading (including its extent) of Chiconautla and Chimalhuacán.

It is important to note that hill penetration is affected by two parameters:

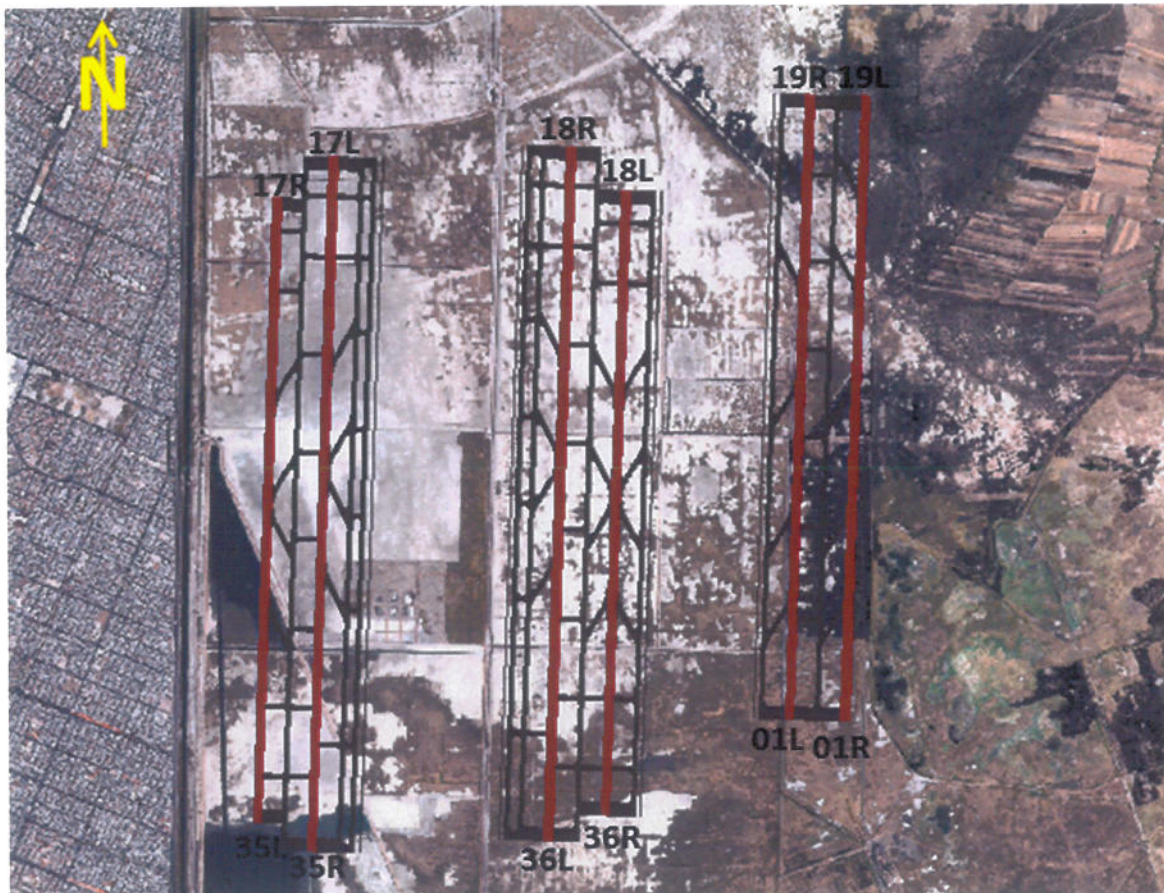
1. Runway threshold elevation
2. Terrain elevation at Chiconautla and Chimalhuacán

In order to get a more comprehensive understanding of how runway threshold elevations affect hill penetrations, MITRE evaluated the terrain at Chiconautla and Chimalhuacán in terms of TERPS obstacle clearance surfaces and Annex 14 OLS, using six different runway threshold elevations in 4 m intervals (i.e., 2223 m, 2227 m, 2231 m, 2235 m, 2239 m, and 2243 m). The results of these analyses are provided with respect to maximum penetration amounts per affected TERPS obstacle clearance surface and Annex 14 OLS per relevant runway, and with respect to approximate penetration volume.

Additionally, on 19 January 2015, Aeropuertos y Servicios Auxiliares (ASA) sent to MITRE an e-mail with a suggested maximum sinkage rate of 20 cm per year. ASA also sent with that e-mail a portion of a report conducted by the Instituto de Ingeniería of the Universidad Nacional Autónoma de México (UNAM) named *“Revisión y Evaluación en Geotecnia y Estructuras para Resolver la Problemática del Transporte Aéreo en el Centro del País, Convenio de Colaboración No. ASA-UNAM-13-002, Informe Final”*, dated 18 November 2014, that includes information on soil types/conditions and the sinkage situation at the NAICM site. Soil types/conditions, sinkage issues, hydrological considerations, and civil engineering/construction matters, which could affect runway threshold elevations, are all areas outside of MITRE’s area of expertise. Nevertheless, the MITRE team reviewed the above-mentioned report to better understand the overall situation. It was apparent to MITRE that the sinkage information in the report, such as the maximum sinkage rate, was consistent with the information that ASA provided to MITRE in the above-mentioned e-mail.

Methodology and Data

MITRE conducted its parametric analysis based on the runway threshold locations of the MITRE-Recommended Runway Configuration (July 2012) depicted in Figure 1, and terrain data acquired in late 2014 through a photogrammetric survey. A constant elevation was applied at each runway threshold (i.e., MITRE assumed a level airport). Finally, the TERPS surfaces referenced in this document are based on MITRE’s previously conducted procedure development work, which was used to prove the feasibility of the MITRE-Recommended Runway Configuration (July 2012).



Source Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 1. MITRE-Recommended Runway Configuration (July 2012)

MITRE examined TERPS Category (CAT) I Instrument Landing System (ILS) approaches, missed approaches, and instrument departure procedure obstacle clearance surfaces. Additionally, MITRE examined Annex 14 approach and take-off climb OLS. The results provided are limited to only surfaces associated with runways that are impacted by the terrain at Chiconautla and Chimalhuacán, which are:

- Final Approach Surface (TERPS) – Runways 19L and 19R
- Departure Surface (TERPS) – Runways 36L and 36R
- Approach Surface (Annex 14) – Runways 18L, 18R, 19L, 19R, 01L, and 01R
- Take-off Climb Surface (Annex 14) – Runways 36L and 36R

MITRE utilized TERPS design criteria due to the fact that this criteria is accepted in Mexico and, more importantly, because ICAO does not have criteria for conducting triple independent operations, which are being planned for NAICM. Per TERPS criteria and

guidance (FAA Order 8260.3B), each segment of an instrument procedure has a defined set of complex surfaces that must be evaluated for obstacles.

As mentioned above, MITRE evaluated CAT I ILS approach procedures. The CAT I ILS final approach surface is comprised of three sloping surfaces (denoted by W, X and Y). Obstacle penetrations are not permitted to the final approach surface. The center surface is called the W surface. The W surface slope is determined by dividing 102 by the glidepath angle. MITRE assumed a 3° glidepath angle, which is typical for most ILS procedures. Therefore, the W surface slope equals 34:1. It slopes upward (1 ft rise for every 34 ft of horizontal distance) starting 60 m beyond the landing threshold. The starting elevation of the surface is the same as the elevation of the landing threshold. Figure 2 shows a notional W surface. At NAICM, Chiconautla penetrates the W surfaces for Runways 19L and 19R. The X and Y surfaces are not affected.

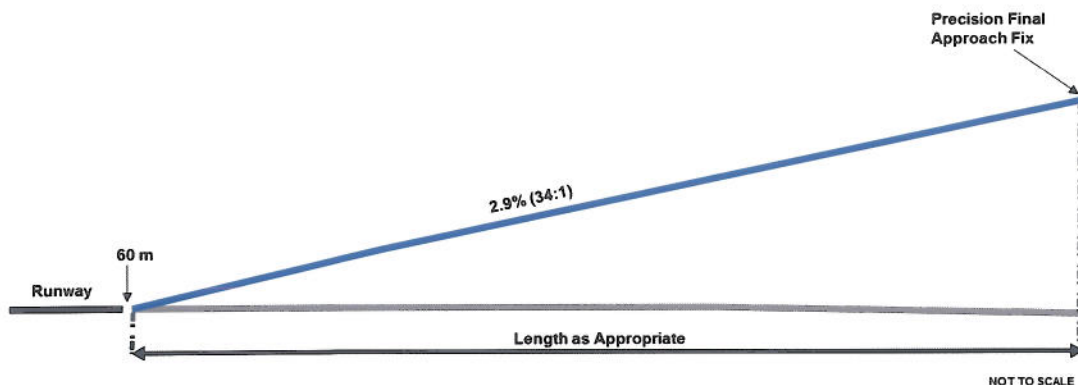


Figure 2. TERPS CAT I ILS Final Approach (W Surface)

MITRE also evaluated TERPS instrument departure procedures. A notional diagram of a TERPS instrument departure surface is depicted in Figure 3. Departing aircraft are expected to climb at a minimum climb gradient of 200 feet (ft) per nautical mile (NM). However, the underlying obstacle clearance surface rises at a climb gradient of 152 ft/NM (40:1 slope). The airspace between the aircraft and the surface is known as the amount of required obstacle clearance. When a penetration to the obstacle clearance surface exists, a climb gradient greater than 200 ft/NM is required. Instrument departure procedures are designed so that no aircraft is required to make a turn until reaching at least 400 ft above the departure end runway elevation.

Instrument departure procedures for Runways 36L and 36R (previously developed by MITRE) have climb gradients greater (i.e., ~ 250 ft/NM) than the minimum climb gradient of 200 ft/NM to maintain required obstacle clearance over terrain at Chiconautla. For the purposes of this parametric analysis, MITRE assumed a minimum climb gradient of 200 ft/NM for the above-mentioned instrument departure procedures to obtain a better understanding of the terrain impact of Chiconautla.

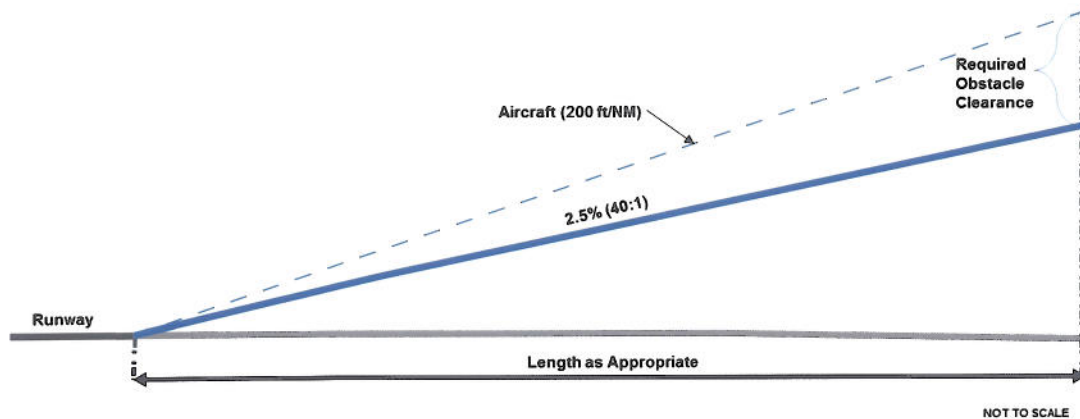


Figure 3. TERPS Instrument Departure Surface

MITRE analyzed the relevant Annex 14 OLS impacted by terrain at Chiconautla and Chimalhuacán. The Annex 14 approach surface is an inclined plane preceding the threshold that defines the volume of airspace that should be kept free from obstacles to protect an airplane in the final phase of the approach-to-land maneuver. As per ICAO Annex 14 Sections 4.2.16 and 4.2.17, the Annex 14 approach surface has a slope of 2% (50:1) for the first 3000 m, and then the slope increases to 2.5% (40:1) until it intersects either a horizontal plane 150 m above the threshold elevation or the horizontal plane passing through the top of any object that governs the obstacle clearance limit, whichever is higher. The total length of the approach surface is 15,000 m. The approach surface has an inner edge of 300 m starting 60 m from the threshold and extending at 15% divergence rate on both sides to 4800 m at the outer edge. A notional diagram of the Annex 14 approach surface is depicted in Figure 4, below.

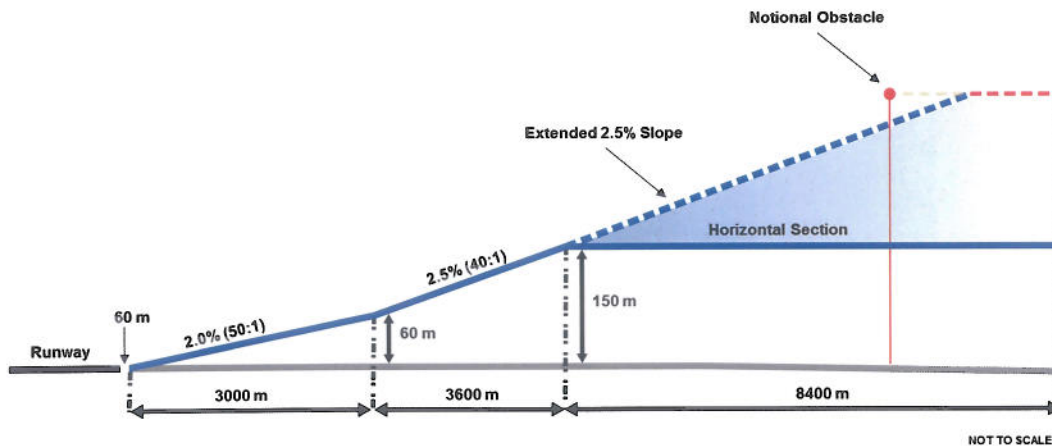


Figure 4. Annex 14 Approach Surface

ICAO Annex 14 Section 4.2.21 recommends that existing objects above an approach surface should, as far as practicable, be removed except when, in the opinion of the

appropriate authority, an object is shielded by an existing immovable object, or after aeronautical study it is determined that the object would not adversely affect the safety or significantly affect the regularity of operations of aircraft.

MITRE also evaluated the Annex 14 take-off climb surfaces, which are defined as volumes of airspace designed to protect aircraft on take-off by indicating which obstacles should be removed, if possible, and marked or lighted if removal is impossible. As per ICAO Annex 14 Section 4.2.23, the take-off climb surface, as shown in Figure 5, is an inclined plane starting at 60 m from the runway end or at the end of the clearway, if provided (MITRE's analysis did not consider any clearways), with a slope of 2% (50:1). The surface has an inner edge of 180 m and diverges on each side at a rate 12.5%. The final width for a straight-out take-off path is 1200 m, or 1800 m if the intended flight track includes changes of heading greater than 15° or greater in instrument meteorological conditions, or visual meteorological conditions at night. The total length of the approach surface is 15,000 m. Note that MITRE used a final width of 1200 m for the straight-out take-off paths from Runways 36L and 36R. However, if either of the take-off paths for Runways 36L or 36R are modified to include changes of heading greater than 15°, then a final width of 1800 m is required. If such a change occurs within approximately 3.4 km north of Chiconautla, it is important to note that additional grading of the hill would be required. Close coordination with MITRE is recommended regarding this matter.

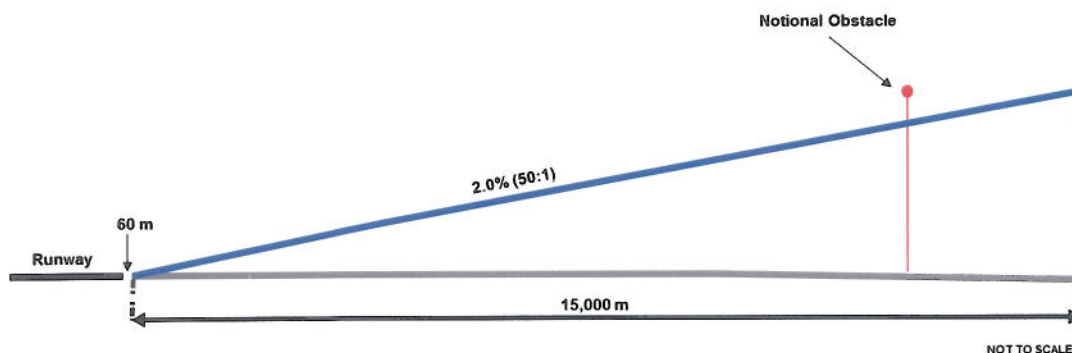


Figure 5. Annex 14 Take-off Climb Surface

ICAO Annex 14 Section 4.2.27 recommends that existing objects that extend above a take-off climb surface should, as far as practicable, be removed except when, in the opinion of the appropriate authority, an object is shielded by an existing immovable object, or after an aeronautical study determines that the object would not adversely affect the safety or significantly affect the regularity of operations of aircraft.

Results

The results provided in this document are limited to terrain penetrations to TERPS obstacle clearance surfaces and Annex 14 OLS by the Chiconautla and Chimalhuacán hills. It is assumed that man-made obstacles, such as the antennas on the top of

Chiconautla, and vegetation (e.g., trees) will be removed. That is, no man-made obstacles or vegetation were considered in this parametric analysis.

MITRE evaluated the penetrations to TERPS obstacle clearance surfaces and Annex 14 OLS using six different runway threshold elevations (i.e., 2223 m, 2227 m, 2231 m, 2235 m, 2239 m, and 2243 m). MITRE originally used an elevation of 2223 m to determine the feasibility of the MITRE-Recommended Runway Configuration (July 2012). Based on the recently acquired 2014 photogrammetric survey, 2227 m represents the average surveyed elevation of the runway construction area at NAICM, and 2231 m represents the highest surveyed elevation of the runway construction area at NAICM. MITRE considered additional runway threshold elevations, as mentioned above. It is important to note that the runway threshold elevations in this parametric analysis are representative of potential runway threshold elevations at NAICM. However, other runway threshold elevations may be considered by other stakeholders.

Maximum Hill Penetration

There are several useful ways to look at the hills' penetration data. MITRE analyzed maximum terrain penetrations to both the relevant TERPS obstacle clearance surfaces and Annex 14 OLS. It is important to note, however, that the point at which the maximum penetration occurs does not necessarily coincide with the highest elevation of the terrain.

This maximum penetration data should assist GACM to compare the impact of each relevant TERPS obstacle clearance surface and Annex 14 OLS as the runway threshold elevation varies. The results from this analysis are provided in Tables 1 through 3 below.

Table 1. Maximum Penetration by Chiconautla to TERPS Obstacle Clearance Surfaces

Runway Elevation	Final Approach Surface (TERPS)		Departure Surface (TERPS)	
	Runway 19L	Runway 19R	Runway 36L	Runway 36R
2223 m	19.1	19.1	68.4	61.3
2227 m	15.1	15.1	64.4	57.3
2231 m	11.1	11.1	60.4	53.3
2235 m	7.1	7.1	56.4	49.3
2239 m	3.1	3.1	52.4	45.3
2243 m	0.0	0.0	48.4	41.3

Notes:

1. Penetration results are provided in meters
2. Vertical and horizontal accuracy for terrain is 3 m and 2 m, respectively (not reflected in the penetration results)
3. Man-made obstacles and vegetation (e.g., trees) were not considered
4. For departures, a minimum climb gradient of 200 ft/NM was assumed

The maximum penetrations by Chiconautla to the TERPS final approach surfaces and TERPS departure surfaces, as shown in Table 1 above, are 19.1 m and 68.4 m, respectively.

Table 2. Maximum Penetration by Chiconautla to Annex 14 OLS

Runway Elevation	Approach Surface (Annex 14)				Take-off Climb Surface (Annex 14)	
	Runway 18L	Runway 18R	Runway 19L	Runway 19R	Runway 36L	Runway 36R
2223 m	77.9	85.5	85.5	85.5	16.0	48.5
2227 m	73.9	81.5	81.5	81.5	12.0	44.5
2231 m	69.9	77.5	77.5	77.5	8.0	40.5
2235 m	65.9	73.5	73.5	73.5	4.0	36.5
2239 m	61.9	69.5	69.5	69.5	0.0	32.5
2243 m	57.9	65.5	65.5	65.5	0.0	28.5

Notes:

1. Penetration results are provided in meters
2. Vertical and horizontal accuracy for terrain is 3 m and 2 m, respectively (not reflected in the penetration results)
3. Man-made obstacles and vegetation (e.g., trees) were not considered

The maximum penetrations by Chiconautla to the Annex 14 approach surfaces and take-off climb surfaces, as shown in Table 2 above, are 85.5 m and 48.5 m, respectively.

Table 3. Maximum Penetration by Chimalhuacán to Annex 14 OLS

Runway Elevation	Approach Surface (Annex 14)	
	Runway 01L	Runway 01R
2223 m	12.3	27.8
2227 m	8.3	23.8
2231 m	4.3	19.8
2235 m	0.3	15.8
2239 m	0.0	11.8
2243 m	0.0	7.8

Notes:

1. Penetration results are provided in meters
2. Vertical and horizontal accuracy for terrain is 3 m and 2 m, respectively (not reflected in the penetration results)
3. Man-made obstacles and vegetation (e.g., trees) were not considered

Chimalhuacán does not penetrate TERPS surfaces. On the other hand, the maximum penetration by Chimalhuacán to the Annex 14 approach surfaces, as shown in Table 3 above, is 27.8 m.

Volume Calculations

Another useful way to look at the penetration data is by looking at the relative volume of soil (“dirt”) required to be removed to avoid a penetration. In order to do this, MITRE created surfaces from survey contour information in AutoCAD Civil 3D. This matter is outside MITRE’s area of expertise. Therefore, it is being provided as an initial estimate only and should be verified by the Mexican authorities.

MITRE calculated the volumes in AutoCAD Civil 3D and validated these estimates in ArcGIS ArcMap and ArcScene. The volumes were calculated in a way to eliminate double-counting volume in areas where surfaces overlap. For example, in the case of Chiconautla, MITRE combined all of the Annex 14 OLS approach surfaces (18L, 18R, 19L, and 19R) to calculate a combined penetration volume. Likewise, MITRE combined all of the take-off climb surfaces (36L and 36R) to calculate a combined penetration volume. To take it one step further, since there is some overlap with the combined approach surfaces and combined take-off climb surfaces, MITRE calculated a single volume for all OLS. The same process was used at each of the runway threshold elevations and for the TERPS surfaces. Since TERPS penetration removal is a requirement and Annex 14 OLS penetration removal is only a recommendation, MITRE did not combine the TERPS and OLS volume calculations.

Tables 4 through 8 show the results of MITRE’s volume calculations.

Table 4. Chiconautla Volume Calculations for Combined TERPS

Runway Elevation	Combined Final Approach Surfaces (TERPS)	Combined Departure Surfaces (TERPS)
2223 m	458,739.0	9,271,588.3
2227 m	285,818.2	7,879,260.9
2231 m	153,576.9	6,650,445.6
2235 m	60,268.7	5,568,010.2
2239 m	7923.6	4,617,827.3
2243 m	0.0	3,786,587.2

Notes:

1. Results are provided in cubic meters
2. Volume calculations are approximate
3. Total volume calculations account for overlapping surfaces to avoid double-counting

Table 5. Chiconautla Total Volume Calculations for Combined TERPS

Runway Elevation	Combined Approaches and Departures Surfaces (TERPS)
2223 m	9,271,588.3
2227 m	7,879,260.9
2231 m	6,650,445.6
2235 m	5,568,010.2
2239 m	4,617,827.3
2243 m	3,786,587.2

Notes:

1. Results are provided in cubic meters
2. Volume calculations are approximate
3. Total volume calculations account for overlapping surfaces to avoid double-counting

It is important to note that the results shown in Table 5 are the same as those shown in Table 4 for the combined TERPS departure surfaces. This is because the departure surfaces wholly encompass the terrain penetration by Chiconautla and are lower than TERPS final approach surfaces.

Table 6. Chiconautla Volume Calculations for Combined Annex 14 OLS

Runway Elevation	Combined Approach Surfaces (Annex 14)	Combined Take-off Climb Surfaces (Annex 14)
2223 m	18,042,938.1	7,251,850.64
2227 m	15,364,756.5	6,211,682.53
2231 m	13,097,461.7	5,229,119.53
2235 m	11,215,228.4	4,305,609.09
2239 m	9,569,456.3	3,447,098.06
2243 m	8,130,818.7	2,654,450.74

Notes:

1. Results are provided in cubic meters
2. Volume calculations are approximate
3. Total volume calculations account for overlapping surfaces to avoid double-counting

Table 7. Chiconautla Total Volume Calculations for Combined Annex 14 OLS

Runway Elevation	Combined Approach and Take-off Climb Surfaces (Annex 14)
2223 m	25,140,719.55
2227 m	21,561,911.61
2231 m	18,326,581.18
2235 m	15,520,837.45
2239 m	13,016,554.37
2243 m	10,785,269.42

Notes:

1. Results are provided in cubic meters
2. Volume calculations are approximate
3. Total volume calculations account for overlapping surfaces to avoid double-counting

In the case of Chimalhuacán only the Annex 14 OLS approach surfaces affect the volume calculations.

Table 8. Chimalhuacán Total Volume Calculations for Combined Annex 14 OLS

Runway Elevation	Combined Approach Surfaces (Annex 14)
2223 m	2,013,215.1
2227 m	1,437,940.7
2231 m	947,208.2
2235 m	553,120.2
2239 m	253,806.9
2243 m	65,505.4

Notes:

1. Results are provided in cubic meters
2. Volume calculations are approximate
3. Total volume calculations account for overlapping surfaces to avoid double-counting

Visualizations

One additional way to look at the penetration data is to visualize the surface penetration depth amounts. In order to illustrate the worst-case penetration depth amounts, the figures in this section are based on a runway threshold elevation of 2223 m. Figures 6 and 7 depict the penetrations to the TERPS surfaces. Figures 8 through 11 depict the penetrations to the Annex 14 OLS.

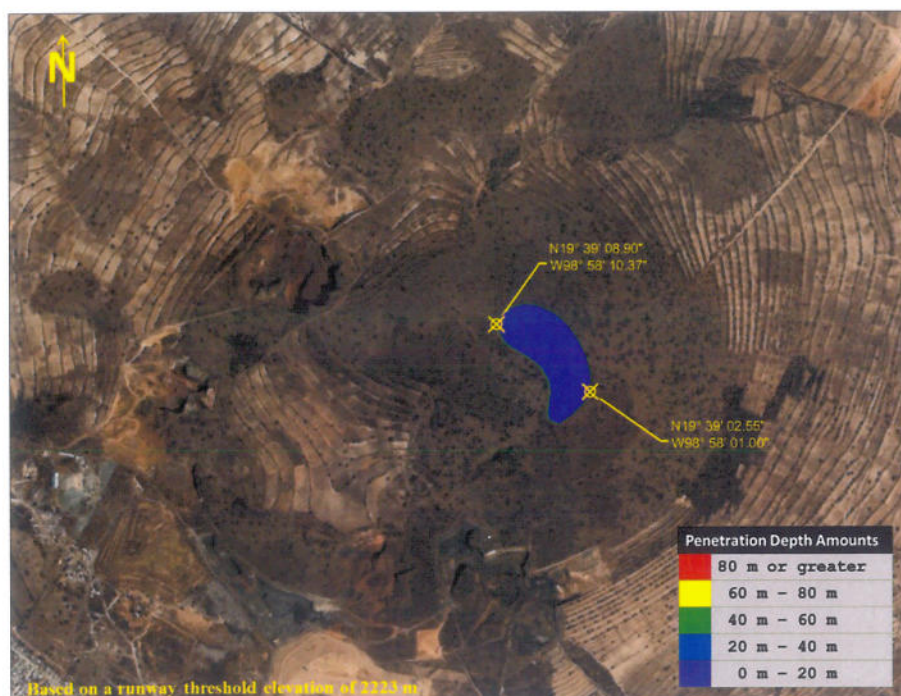


Figure 6. Chiconautla Penetrations to Combined Final Approach Surfaces (TERPS)

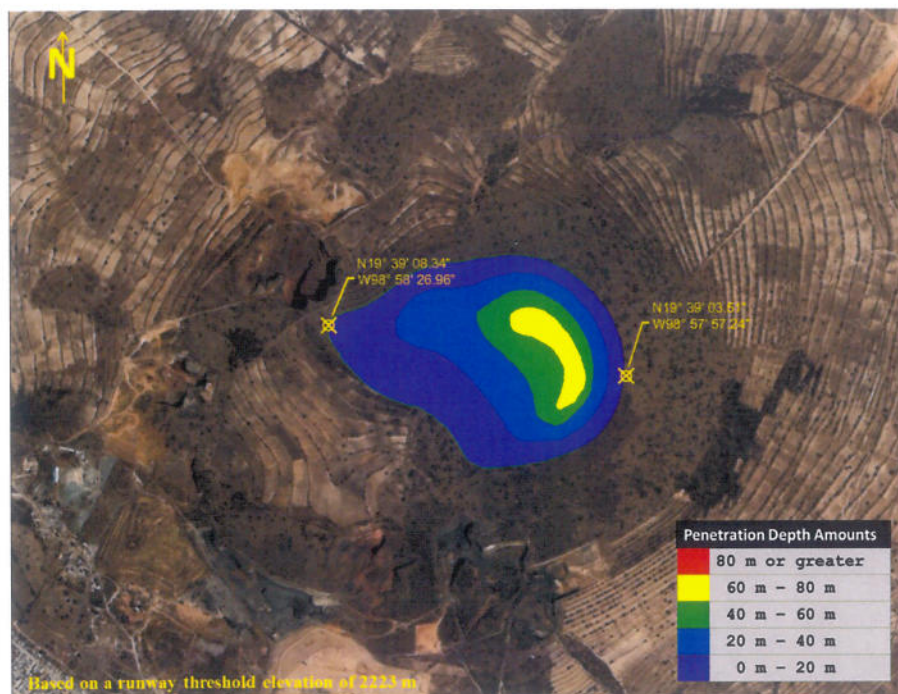
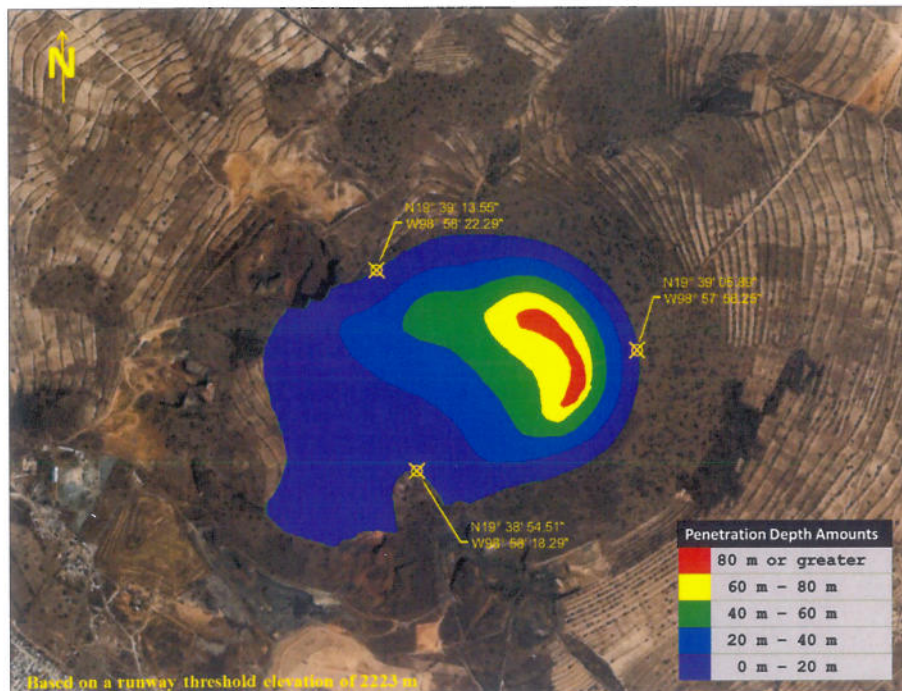
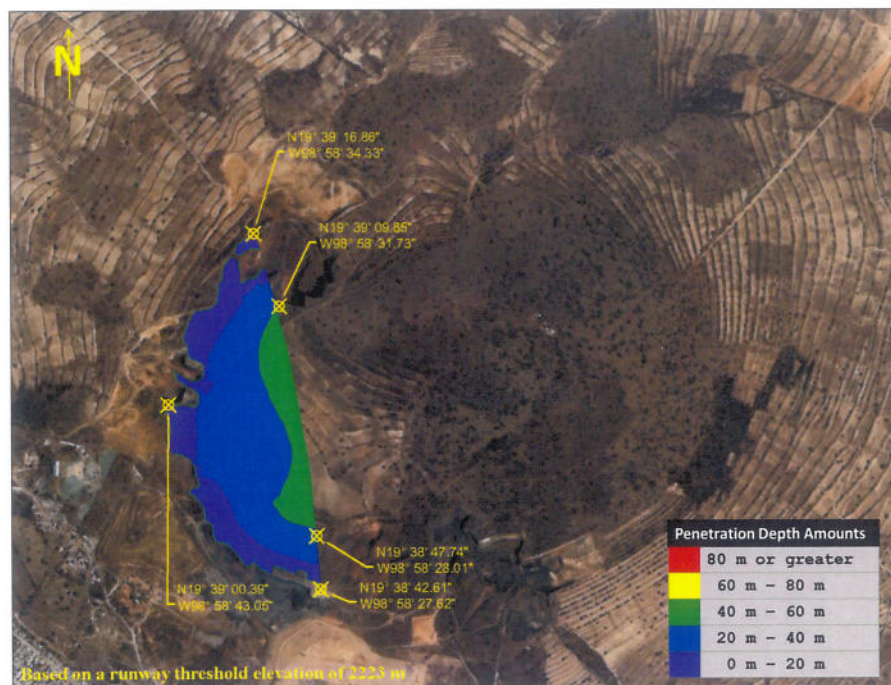


Figure 7. Chiconautla Penetrations to Combined Departure Surfaces (TERPS)



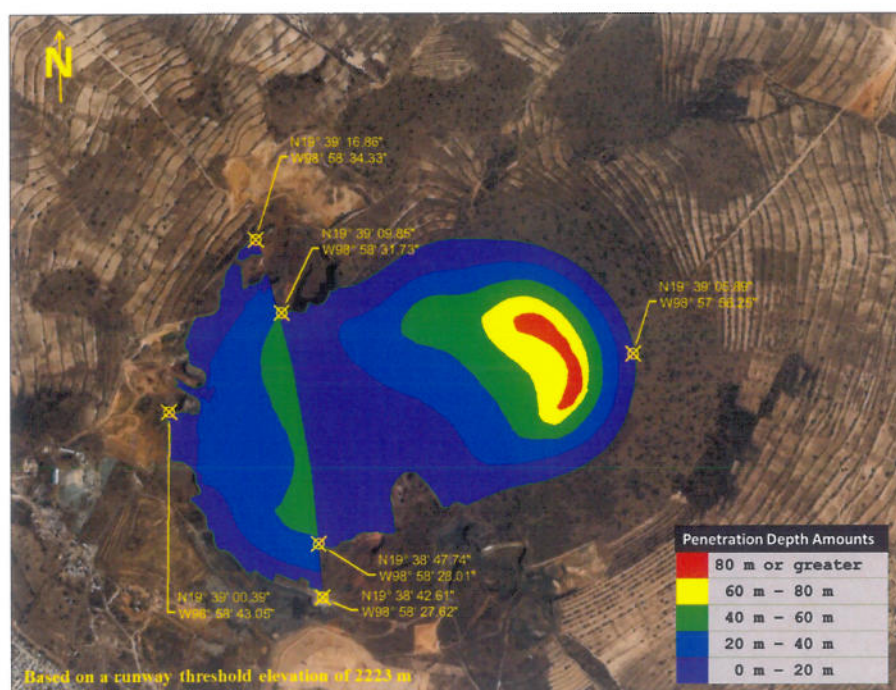
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Figure 8. Chiconautla Penetrations to Combined Approach Surfaces (Annex 14)



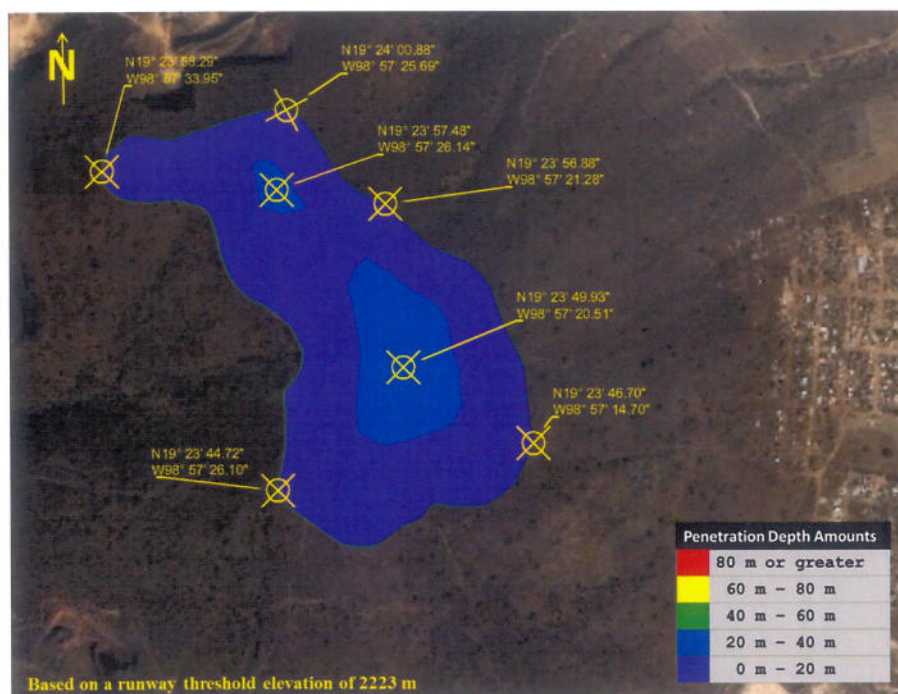
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Figure 9. Chiconautla Penetrations to Combined Take-off Climb Surfaces (Annex 14)



Source Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 10. Chiconautla Penetrations to Combined Approach and Take-off Climb Surfaces (Annex 14)



Source Imagery: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 11. Chimalhuacán Penetrations to Combined Approach Surfaces (Annex 14)

Closing Remarks

As stated previously, the intent of this document is to provide GACM, Mexican aviation authorities, and other stakeholders with important information about the terrain penetrations to TERPS obstacle clearance surfaces and Annex 14 OLS by the hills at Chiconautla and Chimalhuacán. The information can assist GACM in making key preliminary decisions regarding potential runway threshold elevations, grading (and its extent) of Chiconautla and Chimalhuacán, and the preparation of cost/benefit analyses. Once the authorities make a decision on the extent of grading, MITRE recommends that consideration be given to providing a “buffer” (i.e., grading more than what was decided) to provide an added margin of safety and to account for vegetation growth, trees in particular.

Importantly, this type of analysis is conducted after flight inspections have been completed, which can identify new or unknown man-made obstacles that could affect procedure designs. New or unknown man-made obstacles identified during flight inspections may need to be removed. MITRE recommends that flight inspections be conducted prior to starting runway construction.

It is important to note that the impact of terrain penetrations, as described in this document may, in some cases, be mitigated and/or alleviated through measures such as modification of runway lengths, displacement of thresholds, and other means. However, these measures need to be carefully considered with the airlines and various other stakeholders to ensure a safe and efficient operational environment for arriving and departing aircraft.

Please do not hesitate to contact me if you need any clarification or any other assistance.

Sincerely,



Ing. Robert W. Kleinhans
Project Technical Coordinator

cc – Alphabetically:

Ing. Claudio Arellano
Lic. y P.A. Gilberto López Meyer
Ing. Jorge Nevárez
Arq. Fernando Romero
Lic. Alfonso Sarabia