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The use of three-dimensional analysis of GPR data in evaluation of operational safety of airfield pavements

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Abstract

Diagnosis of airfield pavements is an important component of airport managing. Proper diagnosis makes possible to take optimal decisions in terms of ongoing maintenance and repairs, which in the case of airfields is of particular importance, among others, in the context of seasonal changes in the intensity of air traffic. The completeness and accuracy of gathered data is important in the diagnostic activities, what means that the entire airfield road network should be measured and identification of all relevant pavement construction parameters at regular intervals should be done. These capabilities give the Ground Penetrating Radar technique (GPR), which enables the evaluation of the pavement structure in different ways and outlining different aspects of construction.

GPR application as a tool supporting the process of state assessment gives a wider and better understanding of the potential damage of pavement. Properly prepared methodology of measurement, configuration and selection of the measurement system creates the possibility of observation of the investigated object, not only in a single plane of a typical radar profiling, but also in the three-dimensional image. Spatial representation obtained on the basis of synchronized profiling allows precise localization of interlayer boundaries in longitudinal and transverse directions. An important advantage of three-dimensional analysis is the ability of imaging data by the use of horizontal cuts (slices). This makes it possible to identify plane direction and depth of the cracks and crevices of concrete slabs covered with layers of asphalt or concrete. An additional element of the GPR data analysis can be quantitative assessment of dowels in concrete slabs, reinforcement of prefabricated elements supporting pavement structure, as well as location of pipes, cables, tie bars and other.

The paper presents the series of examples illustrating the use of GPR technique as supporting in the process airfield pavement assessment.

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1. Introduction

Safe operation of airports is closely related to the technical condition of aircraft-use pavements. Appropriate diagnostic procedures form an important element of assessing the technical condition of the pavements, facilitating optimal decisions regarding the ongoing maintenance and repairs. In the case of airport pavements this issue is of particular importance in the air traffic safety.

As air traffic in Poland is now dynamically growing, the implementation of airport pavement management systems should be particularly important. Only such approach can ensure appropriate level of safety of operation as well as economic management and harmonious and sustainable planning of development of the airport in the long term.

Airfield pavements diagnostic tests are necessary for:

- managing pavement maintenance and repairs,
- determining the scope and duration of airport pavements repairs,
- checking the quality of new and upgraded pavements,
- creating databases of pavement condition assessment systems.

Completeness and accuracy is crucial in diagnostic activities, this means that tests should cover the entire network of airport pavement and identify all relevant parameters of the technical condition at regular intervals. The parameters that should be included in such a comprehensive diagnosis are: the identification of surface characteristics and evaluation of bearing capacity of the pavement. Examining the structure of the pavement by geo-radar test (GPR - Ground Radar Pentrating) is becoming ever more important and more often used. This test enables attaining a lot of important information on the current technical condition of the entire structure and pavement subgrade. GPR allows to test the entire airport pavement structure including the subgrade, this enables reviewing the individual structural layers and assessing their condition in a non-invasive and non-destructive way. The use of this technique makes it easier to anticipate destructive processes that are still undisclosed at the surface but already taking place in the deeper layers of the structure and subgrade. This technique is particularly applicable in preventing the occurrence of serious structural damages and allows to quickly assess the technical condition of the entire airport pavement.

2. Description of the radar method

Mobile GPR systems enable a detailed evaluation of the structure in terms of both quantity and quality. This measurement technique is also used to assess the condition of concrete of pavement slabs and bridges as well as the condition of reinforcement and dowelling. Geo-radars allow performing more sophisticated tasks such as identifying pavement moistness, identifying type and status of interlayer connections, identifying and examining cracks, assessing layers electrical vulnerability, identifying the ground water level and the level of ground frost-free depth, locating vacuums in concrete pavements, locating pipes and culverts or assessing the reinforcement corrosion degree (Maser at al. (1991), Sudyka (2006), Forest and Utsi (2004), Saarenketo and Scullion (2000), Sudyka and Krysiński (2013), Sudyka and Krysiński (2012a)).

GPR measurement technique uses the principle of electromagnetic waves propagation. When the electromagnetic wave penetrates a border between two layers of different dielectric properties, its part is reflected while the rest goes to the next layer, and also is subject to refraction. The phenomenon of reflection is the basis of the most common measurement method called reflective GPR. Refraction methods, aimed at measuring the wave transition time through the medium and, in this way, estimating the wave velocity are used much less frequently, as they entail the need of inserting antennas into the medium (D-Cubed (1983), Annan (2001), Daniels (2000)) or using sets of antennas with a distance between them.

The below article presents the results of measurements of the two geo-radar systems based on:

- a pulse antenna with a frequency of 2.2 GHz enabling a detailed insight into the construction of the pavement by means of vertical cross-sections along profiles corresponding to the routes of travel and
- a 3D antenna of a variable frequency, allowing to map the surface and thereby correlating the measurements results with the identifiable objects of the linear extension, such as pipes, expansion joints, cracks and repairs carried out in the past.

2.1. Measurement devices

The GSSI measurement system used in the tests is equipped with a pulse air coupled antenna of a center frequency of 2.2 GHz which allows a detailed recognition of pavement structure up to a depth of about 30 to 50 cm, depending on the properties of the medium. It usually helps to distinguish the reflection horizons that are located not less than about 2 cm from each other. The estimate precision of their depth corresponds to 10% of the marked depth and may be improved by using specific interpretation methods. The system mounted on a measurement vehicle (Fig. 1) is adapted to perform pavement surface profile measurements.

Echogram is a graphical comparison of time waveforms of feedback signals recorded in subsequent profile measurement points, which provides an approximate image of the structure of the tested medium. It is therefore a pseudo 2D method, as it only collates return signals and, during the interpretation process, it ignores the waveform deflection that is usually insignificant in the case of simple layer systems.

The system produced by 3D Radar AS (Fig. 1) is adapted to road GPR measurements and consists of a step frequency antenna assembly equipped with 15 pairs of transceiver antennas, a central unit managing the operation of antennas and data collection, a distance meter, a GPS signal receiving antenna and a power supply system. A 3d geo-radar is a new generation of equipment. In contrast to the commonly used impulse geo-radars it is based on step setting technology (Sudyka and Krysiński (2012b)). It enables simultaneous collection of data along several profiles in a single travel. The ability of spatial synchronization of measurement results, taken at many travels, with decimetre accuracy using GPS signal is an extremely valuable property of this model. Synchronized measurement results make it possible to obtain the spatial (pseudo 3D) image of the construction of the medium and can be further presented by the means of vertical and horizontal cross-cuts.

Fig. 1. The GSSI system with a high-frequency 2.2 GHz antenna (right); 3D system from Radar AS.

3. Selected applications of GPR in the diagnosis and assessment of airport pavements

GPR allows to test the entire airport pavement structure including the subgrade, this enables reviewing its technical condition in a non-invasive way. The use of this technique makes it easier to observe destructive processes that are still undisclosed at the surface and already taking place in the deeper layers of the construction and subgrade. Thanks of its advantages, this technique is widely used. This is confirmed, among others, by research conducted by the authors of this article in the scope of:

- measurement of the thickness of individual layers of construction and the entire pavement,
- assessment of the interlayer connection,
- identifying the direction of cracks in the structure of the pavement at different depths,
- subgrade condition and pavement structure support assessment,
- locating structural gaps in the concrete slabs covered with asphalt or concrete layers,
- locating dowels and anchors in the concrete surfaces,

The further part of the article contains several examples that illustrate the use of GPR in a quick assessment of airfield pavements that influence the airport safety.

3.1. Package thickness and layer arrangement examination

Estimating changes in the reflectivity of the upper layer and the speed of wave propagation in subsequent layers is one of the basic elements of the road structure thickness examination and layer arrangement assessment process. Single reflectivity measurements are subject to electromagnetic noise which, in case of an airport has a significant value (between 4 and 8% and even up to several % in signal probe amplitude units). Hence only local averaging of individual measurements enables deducing the dielectric properties of the wearing course (Fig. 2).

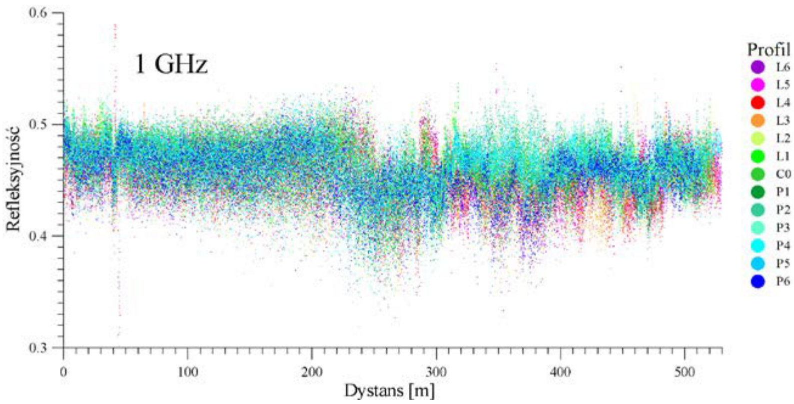

Fig. 2. An example of a summary of reflectivity changes observed along the profiles.

Wearing course reflectivity that confirms its homogeneity supports using its dielectric characteristics for calibration of calculating the return time to the depth. However, due to differences in wearing course material, using set parameters as the estimation of speed in deeper layers carries the risk of introducing calculation errors of even 10%. This issue is usually solved by using a limited number of calibration wells or other type of data that support both the process of identifying the reflection horizons and corresponding layers of package on geo-radar cross-sections.

In the case of very complicated pavement structures, geodetic data defining the actual thickness of the package of new layers basing on a precise measurement can be used in the process of identifying the sequence of new layers. In the discussed example, such data were confronted with five geo-radar cross-sections (Fig. 3) which are the closest to the available geodetic profiles. This summary shows that the geodetic data perfectly correlate with the geo-radar results and the adopted depth converter requires no changes.

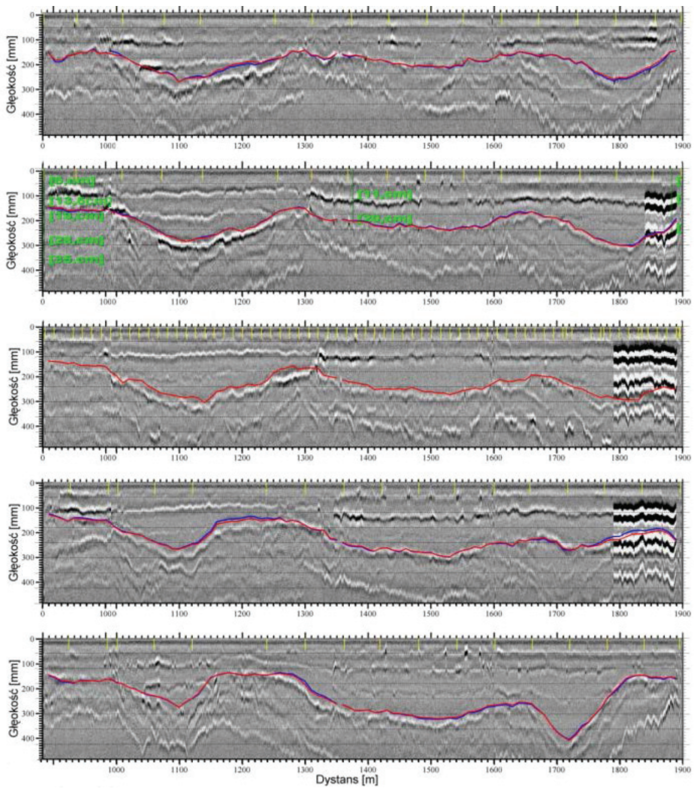

Fig. 3. Correlation of geo-radar cross-sections and the results of geodetic measurements of the thickness of the new asphalt package: blue lines correspond to the geodetic profiles located 20, 10, 0, 10 or 20 meters from the axis of the runway and to the lines that are the closest to a given geo-radar profile, and the red lines show the depth of those profiles that is corrected by interpolation using the other neighboring geo-radar profile.

It is worth noting that the examined pavement has a very complex structure because, apart from high volatility of the structure, it also contains a multitude of built-in infrastructure and nets. This causes serious interpretation difficulties, as without a detailed catalog of the earlier damage, infrastructure inventory and construction techniques used along with a well-defined location (chainage and distance from the axis) potential defects (cracks, delamination) of built-in components (cables, nets, generous spraying) cannot be clearly and unambiguously distinguished.

3.2. Identification of cracks and structural gaps direction

Due to the vastness of information posed by data collected during the tests the use of radar technique for identifying the course of cracks can be very helpful. An example illustrating the method of recognizing the condition of the airport runway pavement structure in a location where cracks in the new asphalt package occurred is shown in Figure 4. It is a summary of cross-cuts in horizontal planes along the 3D geo-radar travel profiles.

Horizontal cut at a depth of z = 3 cm (new asphalt package) shows only a weak reflection of the milling filled with a mass in the top part of the gap. No deeper display of a crack means that it is not opened yet or it does not continue into the foundation. This crack occurred away from nearby structural gaps and has an irregular, non-linear run. A deeper cut (z=34 cm) shows the system of expansion joints in the concrete layer and proves that a crack is located inside the slab (distant from the nearby expansion joints). A well made in the area has confirmed that a crack has cut through the old and the new asphalt package and that there was no crack in a concrete foundation.

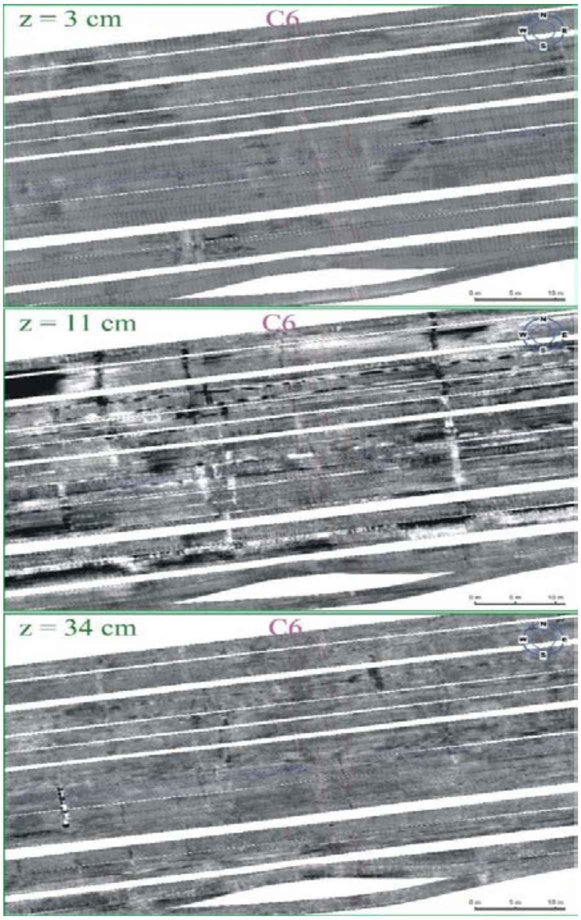

Fig. 4. Horizontal cuts at 3, 11 and 34 cm below the surface under the C6 crack.

Another example illustrating the method of recognizing the structure condition , the airport taxiway in this case, is shown in Figure 5. In the 3D geo-radar image, the area along the road curve is particularly interesting; it provides a lot of information on the structural layers system and its origin. There are three groups of vertical slots in a series of horizontal cuts:

- cracks (or technology cuts) transverse to the axis of the runway, located in the asphalt package,
- rectangular network expansion gaps on the north side oblique in relation to the main geographical directions and
- rectangular network expansion on the south side in line with the main geographical directions.

Both expansion gap networks correspond to square concrete slabs (5 by 5 meters). While it seems that occurrence of transverse cracks is limited to asphalt package, the signs of expansion joint cracking are particularly strong in the alleged concrete segment, but they are also visible in cuts on the depths specific to the asphalt package what would mean that these gaps cause its cracking over the expansion joints.

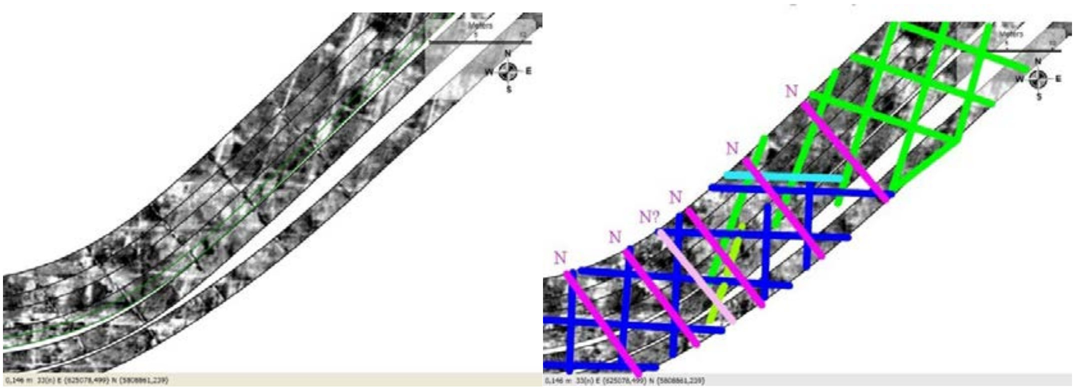

Fig. 5. A summary of 3D radar surveys routes along with interpretation (right) of vertical cracks and expansion joints.

3.3. Location of the system of dowels and anchors in the concrete surfaces

The speed and precision is an important advantage of using the 3D technology in locating structural joints, dowels and anchors in concrete pavements. Thanks to a large width of the antenna it is possible to scan large surfaces or their selected sections. On one of geo-radar horizontal cross-cuts of the airport concrete pavement structure (Figure 6) you can see densely distributed steel dowels and less densely distributed anchors that join the individual slabs of concrete pavement. The image confirms the possibility of locating this type of elements in the facilities' structures mentioned in Bęben study, et al. (2011). On the basis of the recorded data the depth, orthogonality in relation to slab walls, spacing and length of individual dowels and anchors. Therefore the geometric conditions of a correct cooperation of adjacent slabs can be assessed and thus the weakened places across the whole airport pavement structure can be indicated. On the basis of the tests it can be also determined where the dowels and anchors are located and the places where they are not present.

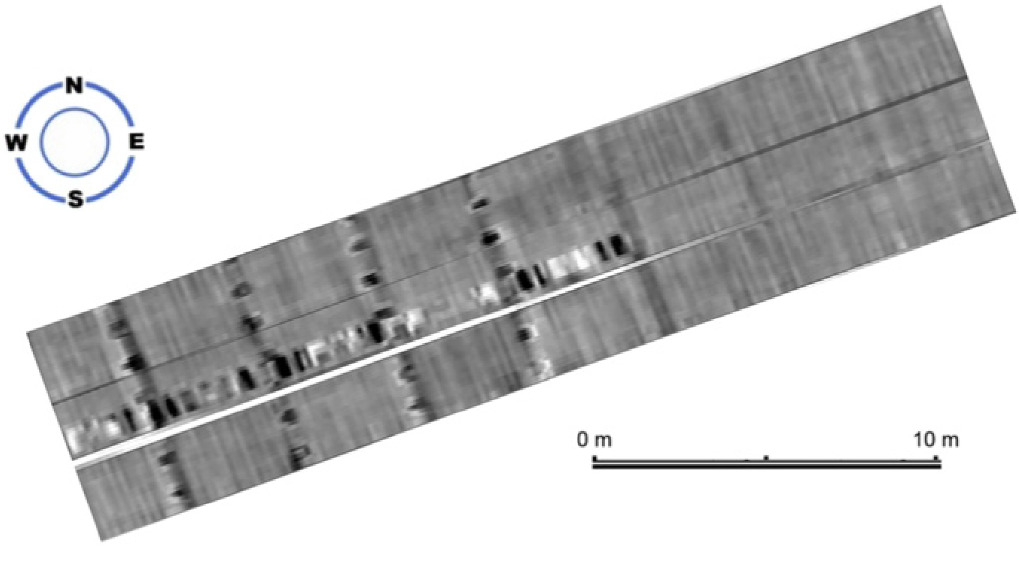

Fig. 6. A measurement of aircraft parking positions made using a 3D set (a horizontal cut to a depth of 16 cm) - a part of the pavement with dowels (left) and an area without dowels at the connections of concrete slabs (right).

Geo-radar surveys allow to precisely locate the infrastructure within the pavement structure. It is particularly useful in the case of old pavement structures in case of which sometimes there is a lack of proper documentation or inventory of technical installations in and beneath the surface. An example of such inventory is shown in Fig. 7. Infrastructure in the form of culverts located directly under the concrete pavement slab is visible on the GPR image.

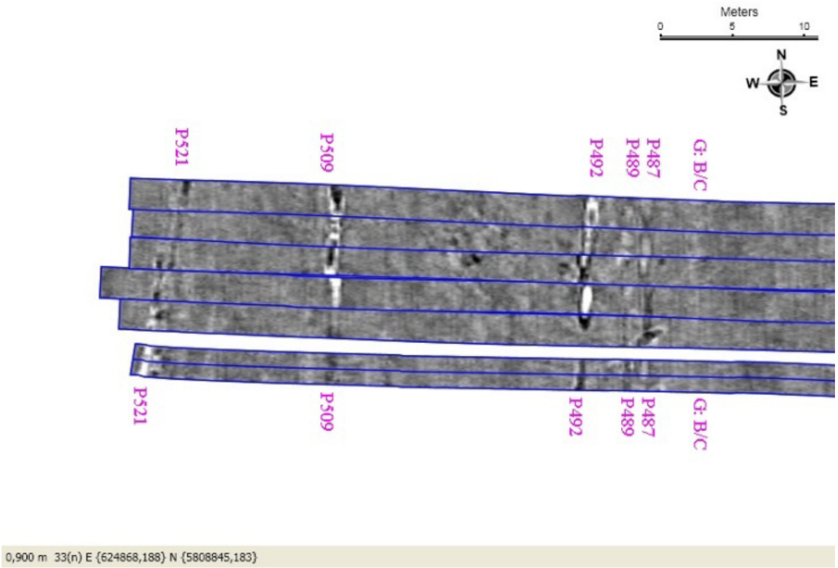

Fig. 7. A group of clearly visible culverts underneath the surface of apron.

4. Conclusions

The technical condition of airport pavement directly affects the safe operation of airports. GPR allows to review the airport pavement structure including the subgrade. This enables performing a non-invasive, non-destructive and quick assessment of the technical condition and detecting early signs of potential damage of the structure and subgrade. Fault detection at a very early stage also applies to destructive processes that are still undisclosed at the surface but already taking place in the deeper layers of the construction and subgrade. This is why the geo-radar method is particularly applicable in preventing the occurrence of serious structural damages and it enables a quick assessment of the technical condition of the entire airport pavement network of the landing area.

The presented examples of airport pavements tests executed at several airports in Poland illustrate the efficiency of the radar method in increasing the operational safety of airports. One of the basic areas of a particularly efficient use of the method is a measurement of a thickness of individual layers of construction and the entire pavement, The layered structure of asphalt packages is usually well visualized on echograms. Horizons between the upper and the lower layer are distinguishable, particularly at the border between new and old layers; other structural elements such as mesh reinforcement can be easily identified between the layers.

Thanks to horizontal cuts it is possible to identify the course of cracks in the pavement structure at different depths and locate structural gaps in the concrete slabs covered with asphalt or concrete layers. If these objects are horizontal then usually you can see their upper surface as a scattering line; the diffraction afterglow usually does not hinder the identification. In case of objects of a shape similar to the vertical half-plane with a horizontal edge (e.g. expansion gaps), the edge is the most dispersing element. Is not currently known why a weak signal corresponding to a depth continuation of the gap is possible to be observed, that is whether it is the result of heterogeneity of examined objects or is it a specific property of Fourier signal transformation method. Experience proves, however, that the GPR can efficiently identify the subsurface continuation of such a vertical discontinuity and often enables assessing the penetration depth of cracks or expansion joints.

GPR tests allow the precise location of infrastructure in the pavement structure, infrastructure can be identified horizontally and vertically. The test is particularly useful in the case of old pavement structures in case of which sometimes there is a lack of proper documentation or inventory of technical installations in and beneath the surface. Dowels and anchors can be such additional elements of the concrete pavement structures. With high speed and precision a 3D GPR method enables locating them and a relatively large width of the antenna enables scanning entire surfaces or their selected sections. On the basis of the obtained images you can evaluate the accuracy of the location (e.g. the depth , orthogonality to the slab wall and spacing) and length of individual dowels and anchors, i.e. geometric conditions of a proper cooperation of adjacent slabs can be assessed. In case of the absence of appropriate links the weakened places across the pavement structure of the airport can be identified.

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