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FINAL REPORT

Magnetic Anomaly Survey of San Antonio International Airport:
Aircraft Compass Calibration Site

Submitted to

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PROJECT SUMMARY

A major aircraft maintenance and repair center is planned for the San Antonio International Airport. Complete re-calibration of an aircraft's geomagnetic compass system is required following all major overhaul, refurbishment or modification work. A special taxiway pad area constructed of non-magnetic materials will be used for the calibration procedure. The proposed pad area (Figure 1) is located at an airport site remote from known magnetic objects that may cause local magnetic anomalies sufficiently large to disturb the normal direction of the earth's geomagnetic field. These anomalies can be caused by commonly buried objects including steel pipelines and cable conduits, electric current carrying power cables and abandoned waste dump items such as automobiles, household appliances, steel barrel caches etc. Also, nearby lighting/communications facilities, buildings, and radar installations with their associated electric

powerline circuitry as well as passing vehicles and aircraft may cause intermittent, unexpectedly large magnetic anomalies over the course of a day.

This report presents the results of a high resolution, total magnetic intensity (TMI) field survey of the compass calibration site (Figure 2) and short-term geomagnetic TMI base station monitoring at San Antonio International Airport . An interpretation of the surveyed TMI anomalies that are likely to disturb the normal horizontal component direction (declination) of the local geomagnetic field near the calibration pad site and the temporal geomagnetic base station observations is also included.

PROJECT DESCRIPTION

Introduction

A major aircraft maintenance and repair center is planned for the San Antonio International Airport. Complete re-calibration of an aircraft's geomagnetic compass system is required following all major overhaul, refurbishment or modification work. A special taxiway pad area constructed of non-magnetic materials will be used for the calibration procedure. The proposed pad area (Figure 1) is located at an airport site remote (>90 m) from known magnetic objects such as steel buildings, runways and powerlines that may cause local magnetic anomalies sufficiently large to disturb the normal direction (declination) of the earth's magnetic field in accordance with FAA guidelines. However, the proposed calibration pad site is located approximately 200 meters south of a known, abandoned landfill disposal area near the present SAIA firehouse (Figure 1). The precise limits of this disposal area, which was last active following WW II, are unclear. Also the location archive for airport underground utilities such as drainage pipelines and powerlines for runway lighting, communications, navigation that have been installed over the last 40-50 years may not be complete. Accordingly, a detailed geophysical survey investigation of the local magnetic environment was deemed prudent before precise location of the calibration pad site is finalized. Also, the survey results can be used to guide site remediation for relocating and/or removing magnetic objects that may disturb the normal declination of the earth's magnetic field.

Background

Engineering geophysics is playing an increasingly important role in the design and construction of structures that are highly sensitive to local environmental conditions. For example, earthquake hazard and stress analyses for buildings to be located in regions of high seismic risk is a widely used application. Another, perhaps less well-known, geophysical application is the use of electromagnetic and geomagnetic anomaly detection techniques for locating buried man-made (pipelines, waste dumps, etc) as well as natural geologic structures (sink holes, caves, faults, etc) that might pose building/facility design and/or construction problems or enviromental hazards.

Geomagnetic surveying is particularly well-suited for measuring lateral variations (anomalies) of the earth's normal magnetic field vector direction and its strength or intensity that are caused by fixed magnetic sources such as steel pipelines, barrels, drums, cable conduits and abandoned waste dump items such as automobiles, household appliances as well as electric current carrying powerline cables.

The normal geomagnetic field vector direction (declination, dip) and its total intensity (nanotesla, nT) expected at the San Antonio International Airport is approximately 10^{o} East, $+60^{o}$ down and 50,000 nT, respectively. The maximum lateral gradient of the total intensity is about +0.05 nT/m in the NNE direction. For the purpose of compass calibration, the FAA requires that the angular direction of the horizontal component of the geomagnetic (declination) not change by more than 0.5^{o} at any point relative to any other point within a space 0.6 and 3.0 m above the compass calibration pad and extending over an area within a 75 m radius of its center.

The current method used to determine if a site meets these angular declination change requirements is to conduct a closely-spaced station, vector magnetometer grid survey to measure directly the compass declination changes across the site. At each station the vector magnetometer axes are carefully oriented and leveled with accuracy much better than 0.5^{o} using optical geodetic survey methods. Unfortunately, this can be a very time consuming task depending on the density of the station grid spacing and the skill of the field surveyor. Also, periodic re-occupation of a fixed station location with the same magnetometer instrument used for the vector grid survey is required to correct for temporal, geomagnetic field direction changes during the survey operations period. In any event, many minutes would be required to make the vector measurements at each grid station. Ultimately, the site may fail to meet the 0.5^{o} FAA guideline everywhere after such an elaborate declination survey effort because of unknown magnetic objects!

Another Approach

Alternatively, a much faster total magnetic intensity (TMI) geomagnetic survey can be done to determine if sufficiently large anomalies are present at a site which could cause angular declination changes greater than the FAA-established 0.5^{o} limit before the more time-consuming vector declination survey is undertaken. Significantly, the measurement time required for each TMI station is on the order of seconds as compared to many minutes for a vector survey. In fact, for the new dual sensor, cesium magnetic gradiometer system used in this survey and described below, 5 measurements per second can be digitally recorded automatically as the field operator simply walks along each survey data line. No elaborate instrument leveling/orienting procedure is required. Also gradient measurements require no corrections for temporal changes of the Earth's geomagnetic field since both sensors are equally affected by such changes. The 0.01 nT resolution of cesium magnetometer systems is more than adequate to map TMI anomalies that may cause local disturbances of the normal declination of the Earth's field. The vector declination survey would only be done if the proposed site area showed only weak TMI anomalies.

To demonstrate that TMI geomagnetic anomaly survey methods can be used to infer angular geomagnetic field direction changes as small as 0.5^o, consider the following hypothetical configuration of magnetic field vectors:

1) Local magnetic field anomalies generally result from the superposition of dipole-shaped fields caused by small, nearby magnetic sources (i. e. steel barrels, electric currents, natural magnetic mineral bodies, etc) with the nearly uniform earth's magnetic field. For example, a single steel 55 gallon barrel typically shows a peak amplitude, total intensity anomaly of about 1000 nT at a distance of 1 m directly above the barrel. Such steel objects can typically exhibit strong permanent magnetization (remanence) with their dipole axes oriented away from the earth's field direction.

2) Near the earth's equator the total intensity (magnitude) of the earth's magnetic field is about 20,000 nT and its declination and dip directions are N-S (0^oE) and horizontal (0^o). A 0.01 percent change (2 nT anomaly) in the observed total geomagnetic field intensity could indicate a maximum angular horizontal field direction (declination) change of 0.8^o, if the horizontal component of magnetic field caused by a local disturbance is oriented horizontal and E-W. That is, the disturbing dipole field axis is perpendicular to the 20,000 nT N-S horizontal component of geomagnetic field vector (i.e. arcCos [20,000nT/20,002 nT]$\simeq 0.8^o$). The vertical component of the geomagnetic field here would be zero. Note that the dipole magnetic field vectors are not oriented perpendicular to the uniform geomagnetic field vector everywhere in the vicinity of a local magnetic source. Accordingly, the angular direction change will be less away from the dipole field axis. In fact, where dipole field directions are co-parallel with the uniform geomagnetic field vector, no angular disturbance of the total intensity geomagnetic field direction occurs.

3) Therefore, in a worst case configuration at the SAIA site, where the geomagnetic field dip is $+60^o$ and the horizontal component of the geomagnetic field is 25,000 nT (=50,000 nT x Cos 60^o), a total intensity anomaly of 0.01 percent or 5.0 nT could result in a 1.1^o angular change for a horizontal and E-W oriented, local disturbing magnetic field (arcCos [25,000nT/25,005 nT]$\simeq 1.1^o$). In fact, the maximum 0.5^o angular declination change specified by the FAA (Attachment 1) could result from a total intensity anomaly as small as 1.0 nT at SAIA!. This is indeed a small anomaly, but easily resolvable with current total intensity magnetometer survey systems which typically have resolutions on the order of 0.1 nT or better. Clearly, if the proposed site shows no anomalies greater than 1.0 nT, it can be expected to have no angular declination changes greater than 0.5^o. On the other hand if the site shows total intensity anomalies much greater than 1.0 nT, it could be expected to have angular declination changes greater than 0.5^o in the immediate vicinity of the

anomaly location. In fact, the 1000 nT anomaly seen 1 m above a single steel barrel, as mentioned above, could cause a declination change of 15.9° (arcCos [25,000nT/26,000 nT]≃15.9°), depending on the orientation of the dipole field anomaly caused by the barrel!

Objectives

Given the high resolution and ready availability of the Geometrics (Model 858) dual sensor, cesium magnetic gradiometer system and the speed with which it can be deployed, we undertook a TMI survey of the planned SAIA aircraft compass calibration site (Figure 1). The primary technical objective of this survey was to detect and map TMI geomagnetic anomalies that may be sufficiently large to disturb the normal, approximately 10° East, horizontal direction (declination) of the geomagnetic field. Detailed FAA information about compass calibration pad construction and site selection criteria is contained in Attachment 1. Figure 2 shows the location of the proposed calibration pad site near Taxiway "A" at SAIA. This site location appears to meet all FAA-established distance criteria in terms of being remote from buildings and other stationary structures that typically cause magnetic field disturbances. However, the site is near a likely center for airport ground traffic and aircraft activity, where daily, intermittent magnetic field changes can be expected to occur.

Field Work

Site Grid Survey LAN Inc. provided a land engineer XY-coordinate grid survey of the 180 m square calibration pad area prior to the commencement of the geomagnetic survey field operations. Known, buried electrical and storm drain utility lines in the survey area were also located (Figure 2). The X axis, survey traverse lines extended positively SW>NE (Figure 3). The Y axis, survey tie lines extended positively NW>SE (Figure 4). This survey work included positioning clearly visible, wood flag markers at 3 m station intervals along the NE and SW perimeters lines of the 180 m square survey area . In addition, three intermediate, parallel lines of 3 m interval flag markers were spaced 45 m from each other and their respective NE and SW perimeter lines. These 3m interval flag markers were positioned at station locations corresponding to the 3 m positions of the NE and SW perimeter lines flag locations. Steel markers (0.5 m long, rebar rod) were buried at the corners of the 180 m square survey area to allow exact reoccupation of the survey stations in the future.

Magnetic Survey A high resolution total magnetic intensity (TMI) geomagnetic survey of the SAIA compass calibration site was conducted during the period 8-10 May 1995. The 180 m square area centered on the proposed calibration pad location was surveyed using sixty, 3 m spaced traverse data lines oriented approximately NE-SW (Figure 3). Five, 45 m spaced tie data lines were surveyed NW-SE, pependicular to the traverse lines (Figure 4). Two types of magnetometers were used for the field work: 1) The primary survey was conducted using the high resolution Geometrics Model 858 dual sensor, cesium vertical gradient magnetometer system (0.01 nanoTesla or gamma resolution). The dual sensors were spaced 1 m apart with the bottom (lower) sensor positioned 0.6 m above ground level; 2) For the purpose of a separate student training excercise, a small independent survey was also conducted over the circular part of the calibration pad area with a lower resolution Geometrics Model 856 proton precession magnetometer (0.1 nanoTesla or gamma resolution). The results of this latter survey are not included here.

Geomagnetic Field Monitoring. The total magnetic intensity of the earth's geomagnetic field was continuously monitored during the survey operations using fixed station magnetometers. For these observations two Geometrics Model 856 proton precession magnetometer systems (0.1 nT resolution) were located at Base Stations 1 and 2 (Figure 1). These stations were positioned along a line 40 m southeast of the primary survey area and spaced 20 m apart . The primary purpose of these station observations was to measure possible temporal changes of horizontal geomagnetic gradient between the stations. Significant temporal changes differences between the two stations would indicate that local magnetic field disturbances are caused by nearby passing vehicles/aircraft or electric current-carrying cables and radar activity during the course of daily airport operations. The fixed base station data was also used to help level the tie and traverse line crossovers of the Geometrics 858 magnetic survey data.

Participants in the field work phase of the project included the following:

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Data Processing

Various commercial computer software systems running on UTIG's Sun, PC and Macintosh workstation were used for the laboratory data processing work. These included GEOSOFT, ERmapper, GMT, and GeoGraphix software systems. Also, the MAGPAC computer software, packaged with the Geometrics 858/856 magnetometer systems, was used for the field data acquisition/formatting phases work.

1) The initial data processing included development of four, XY coordinate-merged datasets of geomagnetic field measurements for the top and bottom cesium sensors, respectively, each using the traverse and tie datalines, separately.

2) First-order corrections for temporal geomagnetic field changes were then applied by subtracting the magnetic field changes observed at Base Station 1 from each of the four XY coordinate-merged survey datasets.

3) Next, traverse line/tie line cross-over leveling techniques were then applied to remove residual temporal geomagnetic changes from the respective traverse and tie lines datasets for each repective top and bottom sensor dataset.

4) A vertical magnetic gradient dataset was then calculated by taking the difference between the bottom and top sensor values and dividing by the 1.0 m sensor separation distance.

5) The leveled traverse line datasets for the observed top and bottom sensor readings and calculated vertical gradient were then gridded . The X and Y coordinate grid spacing interval was 1.0 m.

6) Color and line contoured maps of the TMI and vertical magnetic gradient intensity field across the survey area were then computed from the gridded datasets.

Results

Magnetic Survey. Amplitude profile plots of the leveled TMI values observed along each of the survey traverse lines are shown in Figure 5. Amplitude profile plots of the vertical magnetic gradient values along each of the survey traverse and tie lines are shown in Figures 6 and 7, respectively. Color contoured maps of the gridded TMI field for the top and bottom magnetometers are shown in Figures 8 and 9, respectively. A color contoured map of the vertical gradient of the TMI is shown in Figure 10. This map better emphasize the short wavelength anomaly features caused by shallow buried magnetic sources. A large black dot marks the location of the proposed compass calibration pad center for each map. The center line of the access ramp to the pad from Taxiway "A" is oriented horizontal across the map along the +90 m Y coordinate grid line.

Geomagnetic Field Monitoring. Temporal changes in the earth's geomagnetic were recorded at two fixed Geometrics 856 magnetometer base stations (1 and 2) during the field survey operations. In addition to their use for applying first order corrections to the survey data line observations, as discussed above, these stations served as a horizontal magnetic gradiometer to determine if significant local magnetic field changes are caused by nearby passing vehicles/aircraft or load changes in the electric current-carrying cables and radar activity during the course of daily airport operations. A comparison of the observations for base stations 1 and 2 recorded during a typical 12-18 hour overnight period is shown in Figure 11.

Interpretation

FAA Tower Powerline. Inspection of the TMI amplitude profiles shown in Figures 5, 6 and 7 clearly shows that large magnetic anomalies are caused by the known, buried electric power cable crossing the southern portion of the survey area to the nearby FAA tower. A continuous anomaly trend with amplitudes typically exceeding hundreds of gammas (nT) are seen along this powerline and its steel conduit access covers, especially near the southeast corner of the survey area, as depicted in the color and line contoured TMI maps shown in Figures 8, 9, 10 and 12, 13, 14, respectively. The vertical gradient maps best demonstrate the continuous nature of this anomaly trend (Figures 6, 7, 10, 14 and 15).

Storm Drainage Lines. Equally large amplitude anomalies are also seen along two previously unknown, storm drainage lines that appear to parallel the two main SAIA runways (Figure 1). However, note the discontinuous nature of the anomalies here as compared to FAA powerline anomaly trend. The vertical gradient amplitude profile plots, especially, show intermittent anomaly peaks separated by several smooth anomaly profiles across this drainage line (Figures 6, 7 and 16). In fact, field inspection of this drain line anomaly trend revealed concrete grate covers beneath some of the anomaly peaks here. This suggests that the grate covers may be constructed of steel reinforced concrete and that the main body of the drainage line may be non-magnetic material. A similar drainage line may parallel Taxiway "A". However, from examination of the five, tie line vertical gradient amplitude profile plots shown in Figure 7, it appears that none of these profiles passed over any of its concrete grate covers.

Proposed Calibration Pad Area. Careful inspection of the color and line contoured TMI top and bottom sensor anomaly maps of Figures 8, 9 and 12, 13, respectively, shows that the central part of the survey area over the circular 25 m (80') radius part of the proposed calibration pad is nearly devoid of magnetic anomalies. Anomaly amplitudes here are only on the order of 2-5 gammas (nT) over distance of a few meters. These anomaly trends may not be real but could result from imperfect removal of temporal geomagnetic field changes during the survey, despite the application of base station and line cross-over leveling corrections. In fact, the nearly smooth, vertical magnetic gradient field here as shown in Figures 14 and 15 suggests this is probably the case, since vertical gradient measurements are unaffected by temporal geomagnetic field changes.

Daily Magnetic Field Changes. In regard to the possible intermittent local magnetic field changes caused by passing vehicles/aircraft and powerline loading/radar fluctuations during the course of daily airport operations, careful comparison of the base station 1 and 2 recordings (Figure 11) show the reading to be nearly identical, suggesting that no horizontal gradient changes occurred during the observation period. Significantly, during this period several passes were made with the UTIG 2.3 ton field survey vehicle around the complete perimeter of the survey area along the runway/taxiway safety zone line. Also several airport vehicles and large aircraft passed along Taxiways "A" and "R" with no apparent effect on base stations 1 or 2. The pad site area would appear to be sufficiently remote from magnetic field fluctuations that might be related to daily airport activity.

Conclusions

Clearly, the proposed SAIA calibration pad site location is affected by large magnetic anomalies on the order of hundreds of gammas (nT) that are likely to cause compass declination changes greater than 0.5^{o} within the 75 m radius area around the pad center. Both the FAA tower powerline and the storm drainage lines present strong anomaly trends (Figures 12, 13 15). Even for the area directly over the circular 25 m (80') radius part of the proposed calibration pad weak 2-5 gammas (nT) anomalies may be present, especially near the southwest edge of the proposed pad adjacent to the FAA tower powerline, that may cause declination changes.

Remediation Suggestions

The most prudent course for remediation of the proposed compass calibration site as located would be to relocate the FAA tower powerline and the runway storm drainage lines to meet the 0.5^{o}/75 m radius, FAA guideline criteria. Less drastic action might consider replacing only the steel reinforced, concrete grate covers of the storm drainage lines, if indeed the main body of the drainage line is made non-magnetic materials, but still relocating the FAA tower powerline.

To meet the FAA guideline criteria for only the circular 25 m (80') part of the proposed pad, relocation of the pad site might also be considered, Simply moving the circular part of the pad 10 to 20 m to the northwest along the axis of the access taxiway from Taxiway "A" may be sufficent to avoid the 2-5 gamma TMI anomaly field currently seen along the sowthwest edge of the pad near the FAA tower powerline. However, care must be taken not to impinge too closely to the known 8" storm drainage line paralleling Taxiway "A". This drainage line is likely to have strongly magnetic, concrete grate covers similar to the drainage lines paralleling the main SAIA runways. Of course, these covers might also replaced as part of any remediation work.

Figure 1. Location map showing San Antonio International Airport (SAIA) runways/taxiways and magnetic survey area over proposed compass calibration pad site. Numbered crosses show positions of the geomagnetic base stations (1 and 2) used to monitor temporal changes of the earth's geomagnetic field during the field operations period, 8-10 May 1995.