GEOMAGNETIC MEASUREMENTS AND MAPPING FOR AERONAUTICS IN GERMANY

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Abstract. This report is about activities of the Geophysical Observatory Fürstenfeldbruck in providing aeronautics in Germany with the infrastructure to use magnetic compass navigation accurately in aircrafts. Three prerequisites are important to accurately use the geomagnetic field for aircraft navigation purposes. First, the compass or magnetic field sensor employed on an aircraft has to work properly. Second, the direction of the horizontal component of the magnetic field and its temporal and spatial changes have to be known for all points of a given area. Third, the magnetic influence of the aircraft on the field sensor has to be known for all headings. This report deals mainly with the second and the third requirements described above. It specifically addresses the practical and technical details of magnetic measurements for aeronautics.

Keywords: geomagnetism; aeronautics; calibration pad; compass navigation; Fürstenfeldbruck; FUR

1. Magnetic declination in Germany

In Germany, maps with magnetic declination, isogonic charts, are a scientific product (e.g. Korte and Fredow, 2001) that can be used by air safety authorities. These maps are not derived from declination measurements at airports or along major air traffic routes but from declination measurements made at German geomagnetic repeat station sites that were set up for scientific research. After the reunification of Germany, a magnetic survey was conducted in 1992.5 (e.g. Beblo et al., 1995). Previous surveys were carried out separately for the German Democratic

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Republic (e.g. Bolz et al., 1969) and the Federal Republic of Germany (e.g. Schulz et al., 1997). Today, repeat station surveys are carried out by the Observatory Niemegk which is run by the GeoForschungsZentrum Potsdam. Approximately 40 repeat stations are occupied every 2 years. In general, the quality of repeat station data is more limited by the ability to separate external and internal field components than by the accuracy of the actual measurements. For the best possible separation of the internal and external field, the repeat station data is reduced to either one of the observatories (Fürstenfeldbruck (IAGA code: FUR), Niemegk (NGK), Wingst (WNG)) or to a temporary variometer station near the repeat station. The details of the data reduction can be found in Korte and Fredow (2001). The distribution of repeat stations, geomagnetic observatories, and temporary variometer stations is shown in Figure 122.

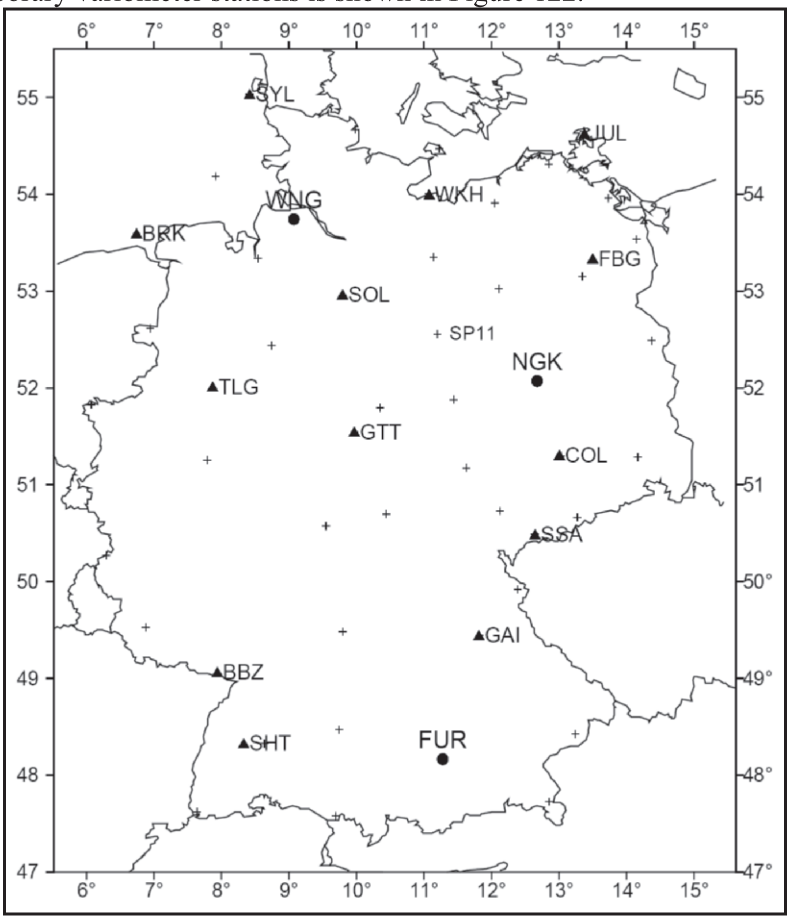

Figure 122. Repeat stations (crosses), temporary variometer stations (triangles), and geomagnetic observatories (dots) in Germany (from Korte and Fredow, 2001), with permission of Monika Korte, GeoForschungsZentrum Postdam.

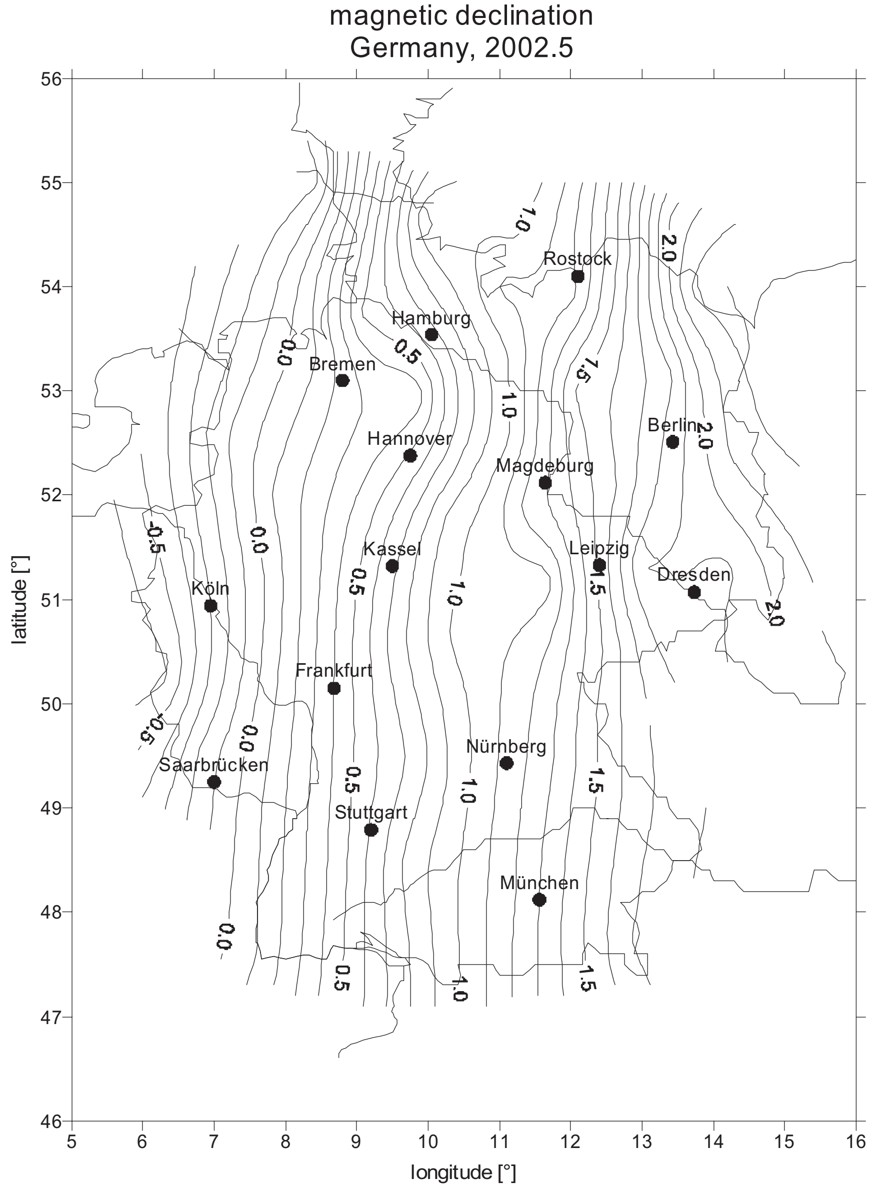

Figure 123. Magnetic declination map for Germany for the year 2002 (reduced to 2002.5) by M. Beblo. For details see text.

Two different approaches to calculating declination maps for Germany are discussed in the following. A declination map for the year 2002.5, established by Martin Beblo (see Figure 123, published on http://obsfur.-geophysik.uni-muenchen.de/images/2002d.gif), was obtained by combining the results of earlier, 3-component ground surveys of high spatial resolution (to quantify regional magnetic anomalies) with repeat station and observatory data of less spatial resolution (to quantify the change by secular variation). The ground surveys are described by Weingärtner (1991). A software package (Erhardt, 1991) is used to combine the ground survey data with the latest German repeat station data and a global magnetic field model. The magnetic declination is calculated on a 0.1° latitude / 0.1° longitude grid for the territory of Germany by Kriging.

The second approach to creating a declination map is to determine the difference between repeat station data, for one year and global, magnetic field model data. Then, using the secular variation information of that magnetic field model, the declination value expected at the repeat station for a subsequent year is derived. The magnetic declination map in Figure 124 is an example of a map hat was derived using this method. The magnetic field model used was the comprehensive model CM4 (Sabaka et al., 2004). The map was calculated during the year 2004, at a time when no annual observatory mean values for the year were available yet. Again, the magnetic declination was calculated on a 0.1° latitude / 0.1° longitude grid by Kriging.

The declination map for 2004.5 is smoother than the map for 2002.5. The method of combining repeat station data with a global magnetic field model has the advantage of extrapolating to a future epoch. Neither method described takes into account local magnetic anomalies that are potentially important at individual airports. Nevertheless, both methods give good approximations of the geomagnetic declination at altitude relevant for air traffic, since the increased distance to magnetic anomalies acts like a spatial low-pass filter.

2. Correcting for the magnetic influence of the aircraft on the onboard magnetic field sensor

The magnetic field sensor on board can be either a compass in the cockpit or a magnetic field sensor mounted somewhere in the aircraft. The sensor should be mounted on the wingtips or on the tail fin as far as possible from the most magnetic parts of the aircraft. The sensor consists of at least two magnetic field probes mounted perpendicular to each other in the horizontal plane. The aircraft's magnetic influence on the compass or the sensor (in the following, both the compass and the magnetic field sensor will be referred to as ‘sensor’) is tested on the ground on a compass calibration pad. The calibration pad must be in an area with a homogenous magnetic field and large enough to accommodate the entire aircraft at all possible headings. As a general rule, the homogeneity of the magnetic North direction at the

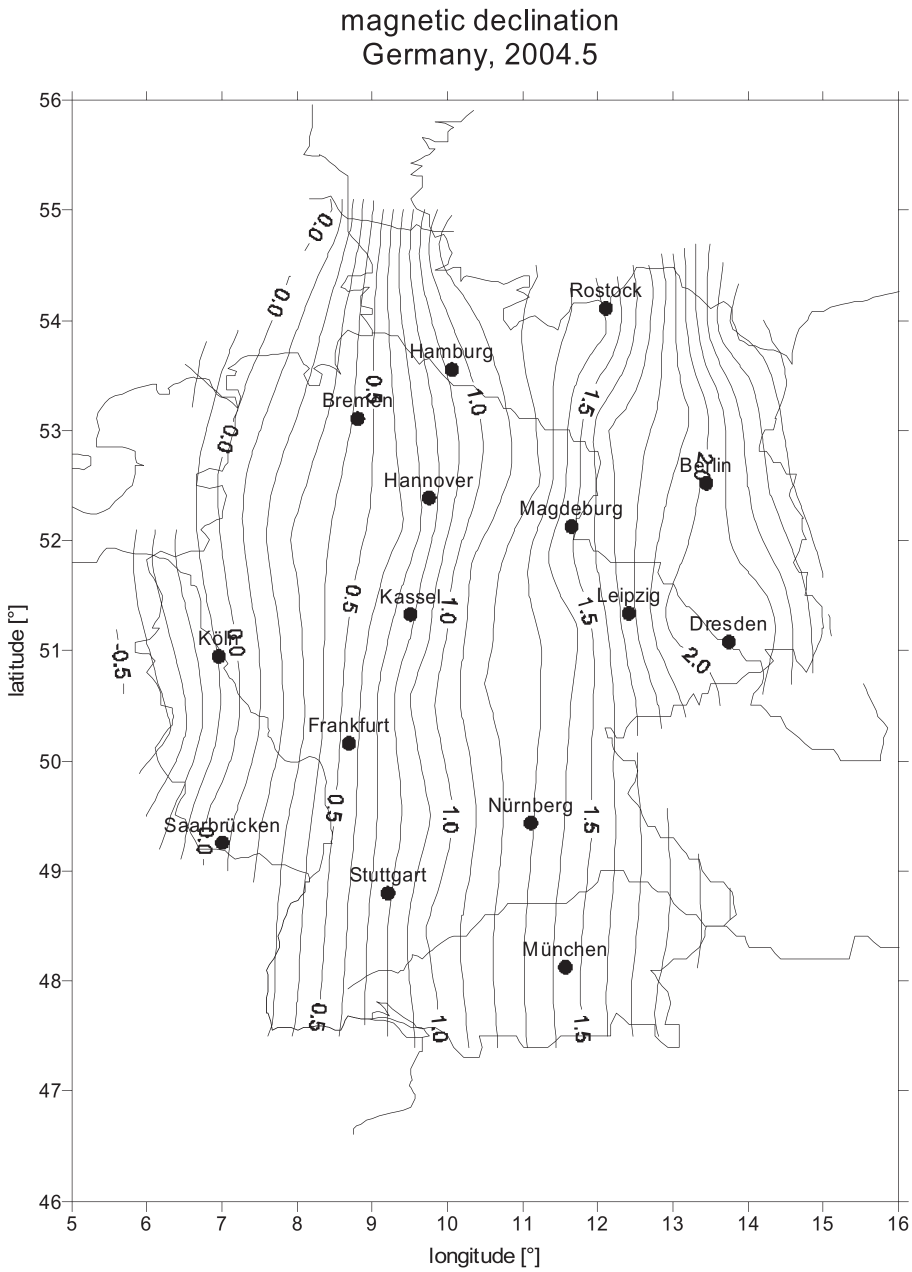

Figure 124. Magnetic declination map for Germany for the year 2004. Calculated by M. Korte. For details see text.

calibration pad should be within 1° for civil aviation and within 0.1° for military aviation. The aircraft is first aligned with magnetic North, which is indicated on the calibration pad by painted marks. Then, the offset between the sensor reading and magnetic North is determined. Next, the aircraft is rotated by a certain angle and the procedure is repeated. For example, if the angle of rotation is 15° , the aircraft is rotated by 15° from magnetic North. This subsequent direction is usually indicated by a painted mark on the calibration pad as well. Then, the difference between the sensor reading and the expected 15° is determined. For a full calibration, this procedure is done for each 15° heading for which an individual offset is determined. The individual offsets will be used to correct the sensor for each of the respective 15° headings.

3. Updating magnetic North at a calibration pad

Depending on the secular variation of the declination and the aimed for accuracy of the calibration procedure, the magnetic North direction has to be updated for each calibration pad at regular intervals. In Germany, the expected secular variation of the declination is +0.1° per year. Typically, the calibration pads are marked with a new magnetic North direction every year or two. The measurement of the North direction is performed with a DI-flux instrument, a non-magnetic theodolite with a fluxgate probe mounted on the telescope. The measurements are performed in the four positions (Kring Lauridsen, 1985; Jankowski and Sucksdorf, 1996) with at least 2 readings in each position. The theodolite can measure horizontal angles with an accuracy of 0.2 minutes of arc. The time of each measurement is noted using a GPS or radio controlled clock accurate to within 1 minute. The theodolite has to be leveled and the optical plummet centered above the mark. A non-magnetic umbrella provides shadow for the instrument during the leveling, since direct sunlight makes leveling difficult (due to the thermal expansion of both the level liquid and the instrument). Moreover, the fluxgate's sensor offset depends on temperature, so it is critical that temperature remain constant during measurement. The danger involved in using an umbrella close to the theodolite under windy conditions should not be underestimated.

Magnetic North is determined in the center of the calibration pad, at an external point, or at both points. The advantage of measuring magnetic North at the center of the calibration pad is that its direction can be indicated directly with the theodolite. If there is a small magnetic anomaly in the center of the calibration pad, due to iron parts in its structure, it is preferable to measure the magnetic North direction at an external point off the pad. This point has to be accurately defined and marked on the ground.

To transfer magnetic North from the external point to the center of the calibration pad, the angle between magnetic North and the center must be measured with the theodolite from the external point. Then, the angle, X, at the center of the pad between magnetic North and the external point, is calculated. The theodolite is set up at the center of the pad and magnetic North can be determined by measuring the angle towards the external point and adding this to the angle X. Let us assume that the distance between the center and the external point is approximately 10 meters. To achieve an accuracy of 0.01° when transferring the magnetic North direction from the external point to the center, both points have to be known with an accuracy of 1 mm. To mark the points, screws are fixed in the concrete of the calibration pad. These screws are made from brass and have a thin cross carved into the head.

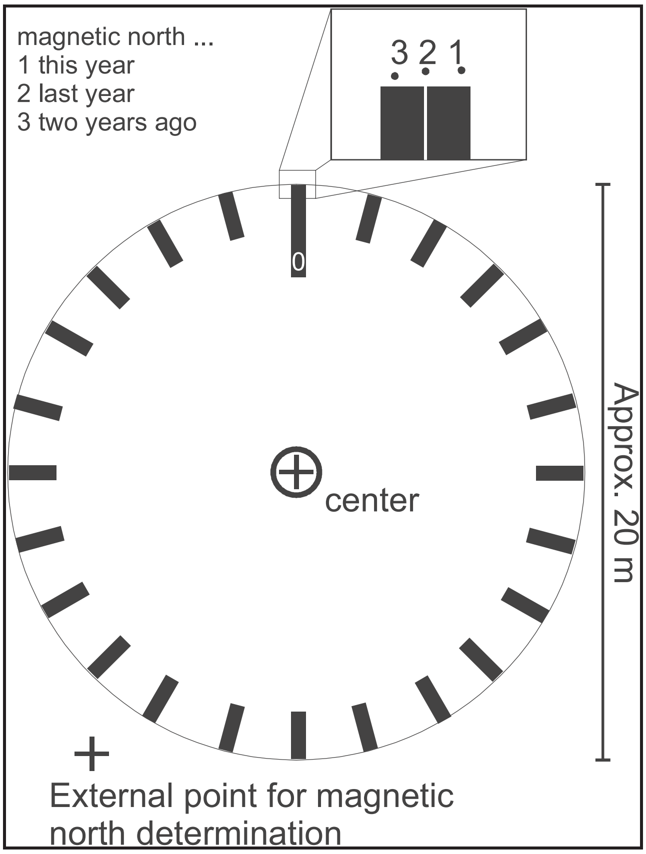

Figure 125. Sketch of a typical compass calibration pad. Two positions for magnetic measurements are indicated: the center and an external point. The inset shows an enlarged view of the painted mark (black with white central stripe) for magnetic North. Drill holes are used to mark magnetic North before the marks are repainted. The numbers 1, 2 and 3 indicate the magnetic North direction (with respect to the center) of this year, last year and two years ago, respectively. Paint marks are not to scale.

In the ideal case magnetic measurements are performed both in the center of the pad and at the external point. Then, the magnetic North directions at both points can be compared, after reduction of the temporal variation of the declination, with data from the nearest geomagnetic observatory. The two magnetic North determinations are usually the same, within 0.01°. The magnetic North direction has to be properly marked on the calibration pad. The magnetic North direction is usually marked by a drill hole of 6 mm diameter at a distance of approximately 10 meters from the center of the pad. The drill is positioned so that it is seen exactly in the cross hairs of the theodolite telescope bearing towards magnetic North. Usually, the drill holes are accurate to within 0.02°. Each 15° heading is marked by a drill hole. Figure 125 shows a calibration pad with the features described above.

4. Accounting for temporal variation of the magnetic field

Knowing the variation of the magnetic declination from the nearest observatory during the magnetic North measurements is advantageous for several reasons. First, if multiple measurements were performed, they can be compared with each other after reducing the temporal variation. Second, if the declination measurement was anomalous due to external fields, (e.g. during disturbed days, magnetic storms), it can be reduced to a value corresponding to the mean value of the nearest magnetically quiet day before or after the measurement. Figure 126 shows the quiet daily variation, Sq, of the declination in Fürstenfeldbruck for each month, calculated (for the year 2002) using the model of Campbell (2003). Note that this quiet daily variation of the declination is qualitatively quite similar throughout the year and that the amplitude of the quiet variation is highest in the summer months. During the usual working hours, even during the quietest possible magnetic conditions, declination changes can be on the order of plus or minus 0.1° (or 6'). The daily mean value of the declination is close to the mean value of the minimum and the maximum of the declination variations. It is therefore advisable to reduce the magnetic North direction measured at the calibration pad to a daily mean value at the calibration pad by using the recordings of the nearest geomagnetic observatory and assuming that the variations are similar in both places. The difference between the marked magnetic North direction and the daily mean value are reported to the airport staff who can take this difference into account when painting the marks. To keep this difference low waiting for a magnetically quiet day to perform the measurements and carrying them out close to local midday, when the declination has a value close to its daily mean value is recommended (Figure 126).

Before calibrating an aircraft's sensor, it is important that airport staff checks with geomagnetic observatory personnel to make sure that the geomagnetic conditions are not too disturbed for accurate calibration.

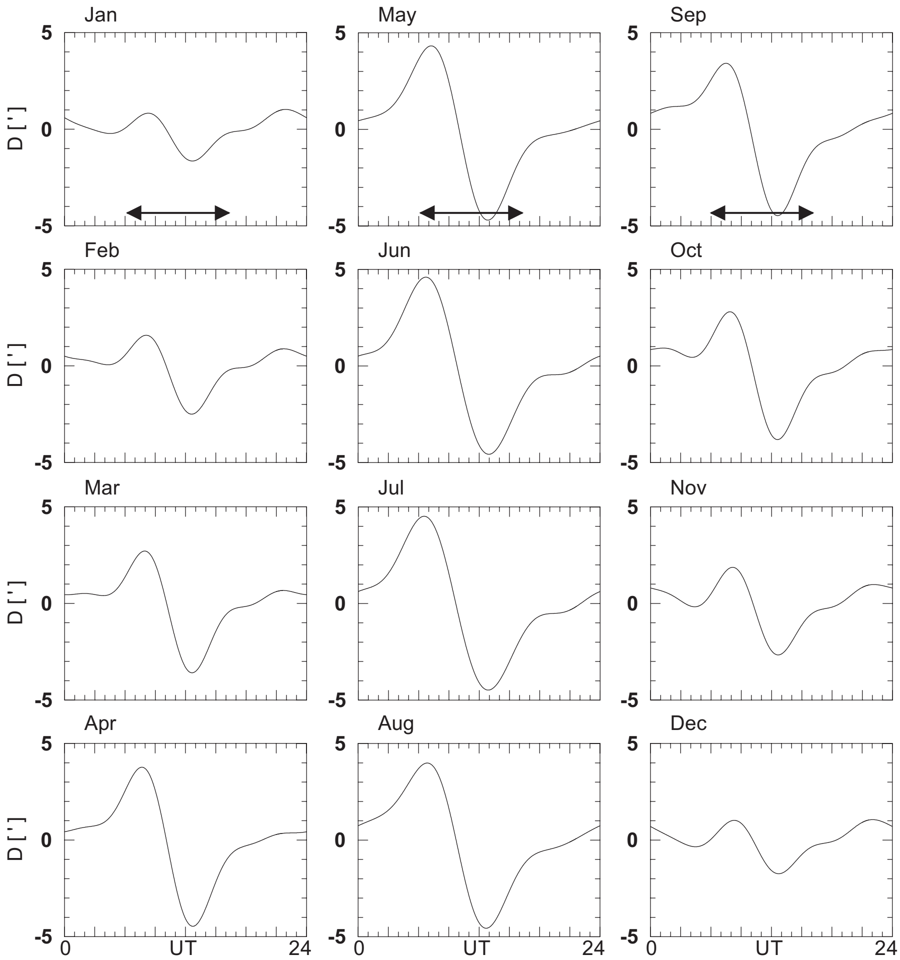

Figure 126. Daily variation of the magnetic declination in minutes of arc at Fürstenfeldbruck for magnetically quiet days. The variation is calculated for each month from the Sq model distributed with Campbell (2003). The double headed arrows indicate working hours, corresponding to the most likely time during the day when magnetic North measurements or compass calibrations are performed.

5. Calibration pad report

The calibration pad report should include a description of the measurement procedure (e.g. 4 position DI-flux), the exact location of the measurement points, the height of the instrument, the names and affiliation of the persons performing the measurements, and an estimate of the accuracy of the results. For the magnetic North determination and marking, typically an accuracy of 0.03° can be attained for a reasonably sized calibration pad.

If two or more magnetic North directions were measured, they should be compared to each other in order to check for measurement errors and spatial inhomogeneities of the magnetic North direction. The angles between the magnetic North direction and fixed objects like church towers or airport towers should be reported and compared to the angles measured in previous years. The results should also be compared with the expected secular variation for the region. A visual inspection of the calibration pad and the surrounding area should be made to be sure that no magnetic objects were introduced.

As noted above, the report should also give the difference in declination (observatory data) for the time of the measurements at the calibration pad and the daily mean value at the observatory.

6. Homogeneity of the magnetic North direction

When establishing a new calibration pad, or if changes were made at or near an existing calibration pad, not only the magnetic North direction, but also its homogeneity has to be checked. The area of homogenous magnetic North direction is a circle with a radius corresponding to the largest distance between the aircraft sensor and the calibration pad center. Since positioning and leveling the theodolite exactly above a given point and making a measurement of magnetic North with a theodolite is time consuming, the number of magnetic North measurements can be reduced by choosing appropriate points where to measure magnetic North and by a complimentary use of total field measurements with a proton precession magnetometer (PPM).Two different types of magnetic anomalies have to be considered when assessing the inhomogeneity of the magnetic North direction:

The first type of magnetic anomaly is a magnetic object built some distance from the calibration pad, such as a building with steel construction material. In this case, it is advisable to measure the magnetic field in the center of the calibration pad, and at four positions around the edge of the calibration pad. The four positions at the edge should be 90° apart. These four positions should be chosen so that one of the points is closest to the building (or at the point where the strongest influence on the magnetic North direction is expected). Since the source of the magnetic anomaly is at some distance, it is likely that the magnetic North direction measured with the theodolite, at a height of approx. 1.3 meters, is similar to the magnetic North direction measured by the aircraft sensor. The influence of such an anomaly on the magnetic North direction is difficult to discern from total field measurements. If the anomaly changes the magnetic field in the east component, then it would also have a significant influence on the magnetic North direction. However, vector sum of the Earth's magnetic field and the anomaly field might be insignificantly different from the total field of the Earth's magnetic field alone, provided that the anomaly field is small.

The second type of magnetic anomaly is a small magnetic object buried in the ground on the calibration pad, such as a piece of steel rebar. If its dimension is very small compared to the calibration pad and its magnetic moment is not too strong, it can easily remain undetected when performing the 5 magnetic North determinations as described above. However, this anomaly could have an adverse influence on the aircraft sensor compensation procedure. To detect such anomalies with a wavelength small compared to the dimension of the calibration pad, a total field survey should be carried out. Measurements with a total field magnetometer are quick, taking only a few seconds each. A grid with a spacing of 1 or 2 meters should be established to cover the area where homogeneity is to be checked. The grid should be oriented with the four magnetic North measurement points at the edge of the calibration pad. Ideally, the total field magnetometer would be a gradiometer and can measure the vertical gradient as well. If possible, the total field values should be reduced with data from the nearest observatory to account for temporal variations. Local magnetic anomalies can easily be detected by plotting isoline maps of the total field or its vertical gradient for the investigated area. Should an anomaly be detected, then magnetic North measurements should be performed at its location. Since the object causing the magnetic anomaly is buried in the ground, it is likely that the magnetic North directions measured at the height of the theodolite are more inhomogeneous than those expected at greater height, where an aircraft’s magnetic sensor is located.

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