AIRPORT GEOMAGNETIC SURVEYS IN THE UNITED STATES

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Abstract. The Federal Aviation Administration (FAA) and the United States military have requirements for design, location, and construction of compass calibration pads (compass roses), these having been developed through collaboration with US Geological Survey (USGS) personnel. These requirements are detailed in the FAA Advisory Circular AC 150/5300-13, Appendix 4, and in various military documents, such as Handbook 1021/1, but the major requirement is that the range of declination measured within 75 meters of the center of a compass rose be less than or equal to 30 minutes of arc. The USGS Geomagnetism Group has developed specific methods for conducting a magnetic survey so that existing compass roses can be judged in terms of the needed standards and also that new sites can be evaluated for their suitability as potentially new compass roses. First, a preliminary survey is performed with a total-field magnetometer, with differences over the site area of less than 75nT being sufficient to warrant additional, more detailed surveying. Next, a number of survey points are established over the compass rose area and nearby, where declination is to be measured with an instrument capable of measuring declination to within 1 minute of arc, such as a Gurley transit magnetometer, DI Flux theodolite magnetometer, or Wild T-0. The data are corrected for diurnal and irregular effects of the magnetic field and declination is determined for each survey point, as well as declination range and average of the entire compass rose site. Altogether, a typical survey takes about four days to complete.

Keywords: airport geomagnetic survey; compass rose survey; compass calibration pad

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1. Introduction

There are two primary objectives in performing airport geomagnetic surveys. The first is to determine the suitability of the site for a compass calibration pad (compass rose), and the second is to determine magnetic declination at a suitable site. Suitability is assessed using the standards outlined in FAA (Federal Aviation Administration) and DOD (Department of Defense) documents. Magnetic declination is determined using procedures developed by the US Geological Survey (USGS). Surveyors must have an understanding of geomagnetism and be trained to use several sophisticated magnetometers to acquire magnetic measurements. Personnel from geomagnetic observatories are especially suited to perform compass rose surveys. In the United States, the USGS and private companies provide airport geomagnetic surveys.

2. Requirements

The FAA and the DOD have specific requirements for design, location, and construction of a compass rose.

2.1. FAA REQUIREMENTS

FAA requirements for design, location and construction of a compass calibration pad are detailed in the FAA AC (advisory circular) 150/5300-13 Appendix 4. The advisory circular may be obtained at the following internet site: http://www.faa.gov/arp/pdf/5300-13p2.pdf. Highlights of sections 4 to 6 of the advisory circular are discussed below.

2.1.1. *Section 4 - Design of Compass Calibration Pad*

Design details from section 4 are to be used as guidelines. Variations in design are acceptable if the general requirements are met. Design requirements of a compass rose are:

- Radials must be painted every 30 degrees beginning at magnetic north. (Figure 127)
- The compass rose must be built with non-magnetic materials.
- The size of the compass rose must be compatible with the size of aircraft using it (15 meters for small airplanes to 33 meters for large jets).

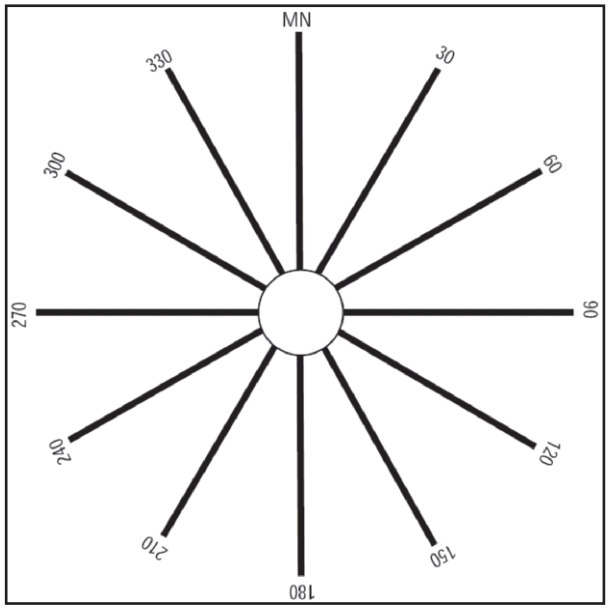

Figure 127. Compass rose radials.

2.1.2. *Section 5 - Location of compass calibration pad*

Section 5 of the FAA Advisory Circular provides guidelines for locating a suitable site for a compass rose. Section 5 also states the range of declination which is allowed over the compass rose area. Ideally, all criteria in the circular should be met. At many airports it is not possible to locate a compass rose following all the requirements. The general requirements for location of a compass rose are:

- Locate a compass rose 90 meters from power and communication cables and other aircraft.
- Locate a compass rose at least 180 meters from large magnetic objects, such as buildings, railroad tracks, high voltage transmission lines, or cables with direct current.
- Locate a compass rose off the side of a taxiway or runway to satisfy local clearances.

2.1.3. *Site location suitability*

To judge the suitability of a site a thorough magnetic declination survey must be made so that the criteria in 5d of the FAA AC are met. The criteria are:

- The difference between magnetic and true north must be uniform across the site.

- The range of declination must be less than one half degree (from 0.3 to 3 meters above the base and within 75 meters of the center).

To assess site suitability some subjectivity in judgment must be employed. For example, if a small magnetic object is located within 75 meters of the center of the compass rose, (but is not on the compass rose), and if the object will not affect compass calibration, the location is suitable, though a disclaimer should be included in the report. On the other hand, if a building is within 120 meters of the proposed site and has an effect on the compass rose (yet the pad still meets the one half degree criteria) the site should be deemed unsuitable because the natural magnetic field of the area is disturbed.

2.1.4. *Section 6 – Construction of compass calibration pad*

Compass roses must be constructed according to the exact requirements detailed in Section 6 of the FAA AC. The requirements are:

- Use only non-magnetic materials for construction of a compass rose. Reinforcing steel, ferrous aggregates, and steel or reinforced concrete drainage pipe cannot be used. Many non-magnetic materials are available. Suspect materials must be checked before use.
- The radials of the compass rose must be oriented to within one minute of its magnetic bearing.
- The date, declination value, and annual change must be marked near the center of the compass rose. A permanent monument marking geographic north should be established at a remote location.
- A second magnetic declination survey must be made after construction of the compass rose is complete to confirm it meets FAA standards and to determine the average declination in order to paint the radials.
- Another magnetic declination survey must be made if major construction occurs within 180 meters of the center of the compass rose.
- Declination surveys must be made at least every five years to recertify the compass rose.

2.2. MILITARY REQUIREMENTS

There are only a few minor differences between the FAA and DOD requirements. The US Air Force may use the FAA or DOD requirements. The DOD documents may be found at the following internet sites: http://www.hnd.usace.army.mil/techinfo/UFC/UFC%203-260-01.pdf (see Attachment 11) and http://www.fas.org/nuke/intro/aircraft/afman32-1123.pdf (see Attachment 11).

3. Compass rose site selection

The USGS has developed specific methods for conducting magnetic surveys so that existing or new compass rose sites can be judged in terms of the FAA and DOD standards. The steps used to select a compass rose site are:

- A preliminary site assessment must be made. Airport drawings should be reviewed and airport personnel queried about potential sites.
- Total field magnetic surveys of potential sites must be made in order to evaluate the sites.
- A declination survey of the most favorable site must be made to determine that the site meets FAA guidelines, to determine the average declination over the site, and to determine where to locate the compass rose radials.
- When a new compass rose has been constructed, a second declination survey must be made to be certain that the compass rose still meets the FAA criteria.

3.1. PRELIMINARY SITE CHECKS

The airport management personnel usually have one or more sites in mind on which to build a compass rose. Managers should be encouraged to consider as many locations as possible and to take into consideration the ease of access of a site by aircraft that will use the compass rose, and traffic flow around the compass rose. The most common locations for compass roses are a taxiway, ramp, or a separate pad built specifically for a compass rose.

When considering potential sites, airport drawings should be reviewed for pipelines, conduits, and drainage pipes. Potential sites should be checked visually to scan for drainage grates, manhole covers, and any evidence of buried ferrous metals. Also, the airport maintenance supervisor should be interviewed to see if he knows of any magnetic items which may compromise sites.

3.2. TOTAL FIELD SURVEY

A magnetic total field survey of an existing or new compass rose is essential to determine the suitability of the site because preliminary checks may not show buried ferrous metals which can impact the magnetic field. A total field survey of a site can be made in 1-2 hours.

3.2.1. *Equipment for a total field survey*

Two total field magnetometers in general use are a Geometrics G-856 portable total field magnetometer or a GEM Systems GSM-19 portable total field magnetometer. Both magnetometers consist of an electronics console, cable, sensor, 2 meter staff, and carrying harness. Both consoles are able to store data points for later download.

3.2.2. *Procedure for a total field survey*

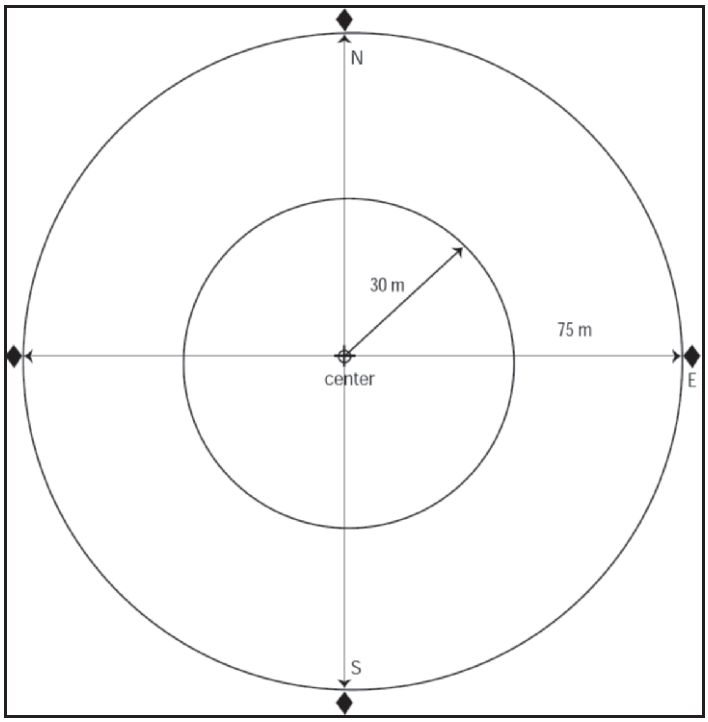

Figure 128. Total Field Magnetic Survey.

- Mark the center point and points 30 meters north, south, east, and west with temporary wooden stakes.
- Make total field readings at the center point and approximately every 3 meters along N-S and E-W lines. Exact locations are unnecessary. The distances between points may be approximated and established by simply pacing them.
- Where initial results look promising, make total field readings every 3 meters to cover a 30 meter radius area.
- From 30 meters out to 75 meters radius make total field readings every 10 meters. (Figure 128)

If the total field has a range of 75nT over a 75 meter area, it will meet the FAA and DOD requirements.

Experience and judgment must be employed to interpret the results of a total field survey. USGS interprets the FAA and DOD requirements to mean that if a slightly anomalous area (off the compass rose pad itself, but within 75meters of the center of the compass rose), does not affect declination on the compass rose pad, the pad may be certified (with a description of the anomaly included in the report).

3.3. SITE DECISION

Total field survey results are used to rank potential compass rose sites. Following the total field survey, a single site must be chosen for construction of the compass rose after which a detailed magnetic declination survey must be made to confirm the site meets the FAA requirements stated in 5d. The declination survey will take from one to three days to complete.

3.4. MAGNETIC DECLINATION SURVEY

The USGS has developed the procedure for performing a magnetic declination survey.

The steps for making a declination survey are:

- Set up test points in a grid pattern over the compass rose area.
- Determine geographic north.
- Measure magnetic declination at the test points.
- Apply diurnal and instrument corrections to the data.
- Create a final report for the airport.

3.4.1. *Equipment for a compass rose survey*

There are several declination magnetometers suitable for a compass rose survey. Discussed below are the Gurley transit, the DI Flux, and the Wild T0 magnetometers.

- The USGS uses a Gurley transit magnetometer to perform compass rose surveys as it is faster to use than the DI Flux and more accurate than the Wild T0. Since it is a mechanical compass, it has an instrument correction which must be determined. The Gurley has a unique reading eyepiece which allows compass readings to 15 seconds of arc. The Gurley is no longer manufactured.

- The DI Flux instrument is also suitable for compass rose surveys. The advantage in using a DI Flux is that it is an absolute instrument and has no instrument correction. A DI Flux theodolite reads to either 0.1 minute or 1 second of arc, depending on the model. The shortfall of the DI Flux is that it must be precisely leveled and four separate measurements are required to determine the magnetic meridian.
- Another suitable and reliable instrument is the Wild T0 Compass Theodolite. The T0 reads to 1 minute of arc. It is no longer manufactured.

3.4.2. *Test point and grid setup (Figure 129)*

To perform a declination survey over a compass rose area, many test points must be established. There are several ways to establish these points, but the best method is to use a grid pattern where the test points are spaced evenly over the compass rose. For example, a compass rose pad 36 meters in diameter should have main test points established in a grid pattern 6 meters apart. Grid spacing of 4 to 9 meters is also acceptable. The established grid is 7 lines by 7 lines. If the test points are on pavement, they should be marked with a 3 millimeter dot of marking paint. The paint marks should be labeled and broadly circled so that they are easily identified. When test points are on dirt or grass, they should be marked with a wooden stake which should have a 3 millimeter dot on top to mark the exact location of the test point. A theodolite or transit is suitable to set up the grid. The grid setup procedure follows:

- Mark the center of the compass rose with a wooden stake or paint mark. It should be labeled test point “D4”. Set an azimuth stake 120-180 meters south of D4 for convenience. The azimuth stake should have a heavy vertical line marked on it and be labeled “D”.
- Establish three test points north and three to the south on this line at 6 meters spacing. These test points are named D1 through D7. Establish auxiliary test points 75 meters along the same line north and south of D4. These points are named N75 and S75.
- Turn the transit exactly 90˚ east from the D azimuth and set an azimuth stake in this line 120-180 meters east of D4. Turn the transit 180˚ to the west and set an azimuth stake in this line 120-180 meters west of D4. The accuracy of the declination readings is dependant upon these azimuth stakes. Read and reset the azimuth stakes so that the final angle between them is 90˚, plus or minus one half minute of arc.

- Establish six grid test points at 6 meters spacing on this line. Label these points A4 through G4. Establish auxiliary test points along this line 75 meters east and west of D4. Label these points E75 and W75.
- Move the transit to the C4 test point. Level the instrument, sight on the azimuth mark to the west, turn exactly 90˚ to the south, and set the "C" azimuth stake at 120-180 meters in this line. Establish six test points north and south of C4 on this line at 6 meters spacing and label them C1 through C7.
- Continue in the same manner until all 7 lines are established. Points A1, A7, G1, and G7 may be left off the grid.

The time required to establish a grid of this size ranges from three to six hours. A field assistant is needed to set up the grid stakes in the locations pinpointed by the surveyor.

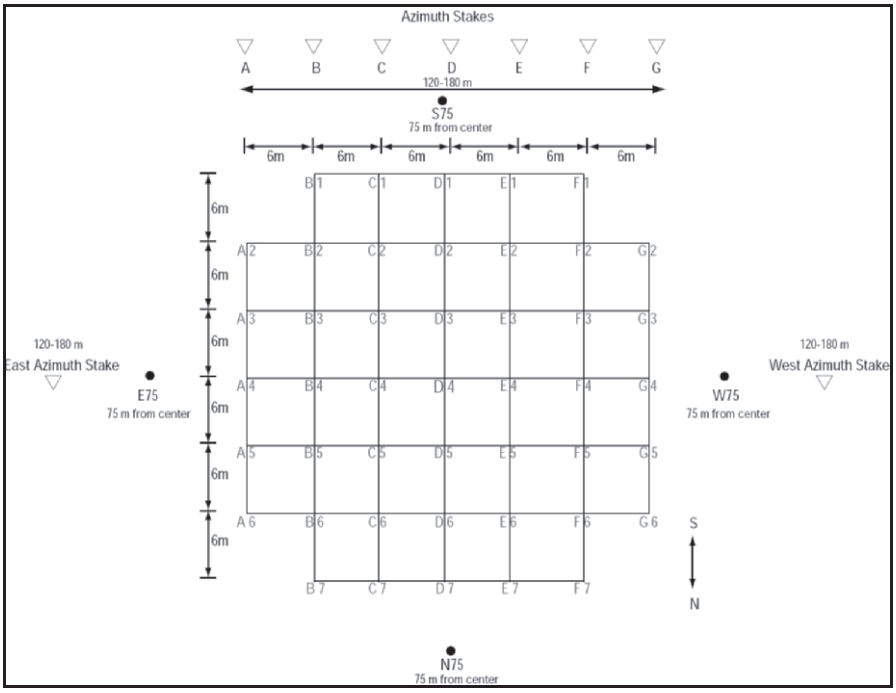

Figure 129. Typical grid layout.

3.4.3. *Determine geographic north*

Geographic north must be determined in order to convert the magnetic survey values to declination. The most common methods used to determine geographic north include:

- Astronomical (solar or star) observations. These are preferred as they are quick, easy, and accurate. A solar filter must be used for solar observations. A lighted mark and a light source are needed for star observations. Software is readily available for azimuth computations from solar or star observations. The drawback to using solar or star observations for locating geographic north is that the sun or stars must be visible.
- GPS. GPS is accurate, but the equipment is expensive.
- Gyrocompass. This equipment is heavy and lacks the accuracy of solar, stars, and GPS, but works in any weather.

A permanent geographic north azimuth marker should be established and azimuths to at least three equally spaced nearby prominent objects. A permanent azimuth marker and the prominent objects should be at least 75 meters from the center point of the compass rose. Prominent objects can be the airport beacon, the corners of nearby buildings, or any permanent, stationary object. The true azimuth of these objects is computed from the geographic north determination.

3.4.4. *Declination survey*

The declination survey must be done during quiet or unsettled magnetic conditions. Measurement procedure:

- Set the declinometer at station D4, the center point.
- Level the instrument.
- Set the horizontal circle to read 0° while sighted on the azimuth stake D. The azimuth mark should be set to 0° at each test point so the measurements are easily compared to each other. It will be evident if a reading at any test point is bad.
- Read the magnetic declination.
- Move declinometer to the next test point and repeat the measurement procedure.
- Continue in a methodical manner until the magnetic direction has been measured at all 45 test points and the 4 auxiliary test points.
- Make repeated measurements at the center point approximately every 30 minutes. These readings will allow the observer to apply diurnal corrections to each declination value.

The time required to make a survey of this size is 5-20 hours depending on size of the compass rose, observer's speed and instrument used.

3.4.5. *Apply diurnal and instrument corrections*

The diurnal (daily) variation of the magnetic field must be removed from the magnetic survey field data to negate the affect of the magnetic field changing during the measurement period. The diurnal variation may be determined either with data from a nearby observatory or by making repeated observations at the center point of the compass rose every 30 minutes. In either case, a chart is created with time on the horizontal scale and the declination on the vertical scale. The declination values measured at the center point every 30 minutes are plotted on the chart through the time of the survey. A straight line is drawn between each point. The times of the declination measurements at the other test points are plotted along the drawn line. The average declination during the measurement time is determined to the nearest minute of arc. The individual correction for each test point is determined by how many arc minutes above or below the average line is each test point measurement.

Instrument corrections must be applied to the data collected using the Gurley transit magnetometer and the Wild T0 Compass Theodolite. Instruments with a mechanical compass require an instrument calibration against a known standard to determine the instrument correction. DI Flux instruments are absolute and have no correction, but they must be compared to an instrument which has been compared to an international standard.

3.4.6. *Final report and recommendations*

Once the data have been collected, corrections applied, and azimuths determined, the compiled information is formatted into a report for the airport. The report includes:

- Airport name
- Date of the magnetic survey
- Geographic coordinates
- Description of the compass rose site
- Description of the grid layout
- True azimuths
- Diagram of the survey results
- Recommendations based on the magnetic measurements and professional judgment

4. Conclusions

The FAA and the DOD have requirements for design, location, construction, and recertification of compass roses, which have been developed through collaboration with USGS. These requirements are detailed in the FAA Advisory Circular AC 150/5300-13, Appendix 4, and in various military documents, such as Handbook 1021/1, but the major requirement is that the range of declination measured within 75 meters of the center of a compass rose be less than or equal to 30 minutes of arc. The USGS Geomagnetism Group has developed specific methods for conducting a magnetic survey so that existing compass roses can be judged in terms of the needed standards and also that new sites can be evaluated for their suitability as potentially new compass roses. First, a preliminary survey is performed with a total-field magnetometer. Differences of less than 75nT over the site area are sufficient to warrant additional, more detailed surveying. Next, a number of survey points are established over the compass rose and surrounding area, where declination is to be measured with an instrument capable of measuring declination to within 1 minute of arc, such as a Gurley transit, DI Flux theodolite, or Wild T-0 magnetometers. The data are corrected for diurnal and irregular effects of the magnetic field and declination is determined for each survey point, as well as declination range and average of the entire compass rose site. Once the data have been collected, corrections applied, and azimuths determined, the compiled information is formatted into a report for the airport.

DISCUSSION

Questions (Jurgen Matzka):
1. What is the reason that the compass instrument gives different readings than DI – flux (magnetic impurities or problem with needle)?
2. Why declination and not magnetic north at compass rose?
Answers (Alan Berarducci):
1. Most compass instruments have some ferrous parts in them, such as the pivot which the needle balances on. Also, many compass instruments are able to be adjusted so the correction is 0 or very small. Since the instrument can not be inverted and usually it is not read from either end of the needle such as with DI Flux measurements where the instrument is read in 4 positions, there are errors from the transit or theodolite.
2. Magnetic North is used on a compass rose.