GEOMETRICS technical report

MA-TR 15

A GUIDE TO PASSIVE MAGNETIC COMPENSATION OF AIRCRAFT

A fixed installation of a total field magnetometer sensor on an aircraft is much more desirable than the towed bird configuration. Fixed installations can be made on the aircraft wingtip or tail stinger and even other locations provided that the site occupied by the magnetometer sensor is sufficiently well compensated for the varying magnetic effects of the aircraft from changes in pitch, yaw and roll and from the effects of electric currents, eddy currents and other such noise sources on the plane. The installation and compensation efforts required are usually somewhat greater than the efforts of installing a winch and towed bird system. The fixed installation, however, once achieved, usually provides a better signal-to-noise ratio, freedom from the effects of bird swing, greater maneuverability and flight safety, and in general a more satisfactory configuration.

Several types of disturbing "noise" must first be eliminated, altered or compensated to achieve a magnetically and electrically clean installation. The types of noise which are most significant include 1) Permanent magnetic effects; 2) Induced magnetic effects; 3) Eddy currents; and 4) Magnetic effects of electric currents. The permanent and induced magnetic effects will be discussed herein. Eddy currents are caused by the rotation of electrical conductors such as large metal sheets or loops which change their attitude while moving through the earth's magnetic field (rate of change of flux) thus generating electric currents with their associated magnetic fields. These can be eliminated by placing a sensor one or two feet away from such sources (compensation for such effects is extremely difficult). The effects of electric currents from instrumentation, generators and avionics requires attention to the routing of electrical cables and to the final configuration of grounding and shielding signal cables. The skin of the aircraft, for example, should not be used as a ground return if possible. The magnetometer signal cables should also not be placed near a source of varying currents nor should the sensor be placed near a source of DC currents.

CONSIDERATIONS FOR PASSIVE MAGNETIC COMPENSATION

The permanent and induced magnetic effects of the aircraft as seen at the magnetometer sensor can be largely reduced or removed through the use of passive magnetic compensation. Passive magnetic compensation refers to the use of permanent magnets and high permeability iron straps for compensation of magnetically disturbing sources on the aircraft. (Electronic systems and power supplies with non-variable currents can also be described as passive magnetic systems.)

Prior to installation or any quantitative measurements, the selected compensation site for the magnetometer sensor should be examined for possible sources of ferromagnetic disturbance. A portable magnetometer can be moved about the proposed compensation site for a radius of several feet to locate bolts, cables, structures, or other localized objects which would be serious contributors to magnetic heading errors and which may even degrade the signal. (The airborne magnetometer and sensor can also be used to check the compensation site, however, it must be removed from the aircraft.) A small magnet should also be used to see what parts are ferromagnetic. Use such a magnet carefully so as not to magnetize objects which cannot be removed or which may not lend themselves to degaussing.

If possible, ferromagnetic parts on the aircraft near the sensor should be replaced by aluminum or magnetically checked brass or non-magnetic stainless steel. Parts which cannot be replaced may be degaussed (demagnetized) to remove the permanent magnetism (degaussing will not remove or affect induced magnetic properties). In some cases, entire wing sections can be degaussed. Tens or hundreds of amperes of alternating current through several turns of wire can be used for degaussing if the coil is slowly removed, or if the current is slowly decreased to zero. Do not turn off the AC source as this will magnetize all ferromagnetic parts.

The object of this magnetic cleaning procedure is to eliminate local sources of magnetism. It will be considerably easier to compensate for the distant sources in subsequent procedures if they appear to the sensor as one assemblage, i.e., the disturbing sources should as much as possible behave as a dipole.

AIRCRAFT COMPENSATION GUIDELINES

The first step in magnetic compensation is to determine the magnetic effects of the aircraft as a function of heading (yaw) with all equipment operating and in-place. These magnetic effects pertain to the variations of total intensity as would be observed by a wingtip or tail stinger sensor as the aircraft changes its horizontal position (yaw angle). In all these discussions, it is assumed that all measurements are made with the aircraft in flight attitude (even if measurements are made on the ground) with all equipment on, all control surfaces oriented as though in flight, and with measurements made at exactly the point of proposed installation and over a fixed point on the ground.

There are two means of making the magnetic measurements to determine how much compensation is required. The aircraft can be flown in a " clover leaf" pattern both north, south, east and west over a fixed point on the ground in an area which exhibits a low magnetic gradient in all directions **(see** Figure 1). The sensor has to be installed in its final position in order to use this method. A second means of making these measurements involves " taxiing " or pushing the aircraft on the ground. The ground location must also be in a low magnetic gradient area so as to minimize the necessity of having to position the aircraft precisely over the same point which is often difficult both on the ground as well as in the air. Keep in mind that most concrete runways contain steel reinforcing rods which are highly magnetic, making them very poor areas in which to work. The grass apron or the " compass rose" areas are often acceptable just off the runway.

If the flying method is preferred to acquire these measurements, they must be carefully made at the same altitude and over the same point on the ground to ensure that the measurements are valid. If the measurements are made on the ground, simply place the portable magnetometer sensor at the proper elevation over a marked point on the ground and bring the aircraft in, for example, at a north heading. Then rotate the aircraft about, say, a wingtip position at 45 degree increments returning once again to the north heading. Then make one more measurement in the north heading with the aircraft removed. Two measurements both at the north heading (or several times during the procedure at some remote point) will assure one that there was no serious time variation during this measurement process. The measurement of the field with the aircraft removed from the vicinity will determine how much permanent and induced magnetic effects remain in the aircraft which have vertical symmetry and which must later be removed to prevent serious pitch and roll effects.

Assuming that the local vicinity of the airborne sensor described above was previously checked to be free of small objects such as steel bolts, control cables and even the bulb from a landing light, then the measurements made at each 45 degree rotation of the aircraft are probably from large sources on the aircraft such as the engine, instrumentation and the fuselage and irremovable hardware from the wing or tail sections. As stated earlier, there are three objectives involved in the procedure for passive magnetic compensation: 1) removal of the permanent magnetic effects which exist in the horizontal plane (transverse and longitudinal to the fuselage) and which appear as a single cycle sine wave as the aircraft is rotated about the vertical axis. 2) The induced magnetic effects which can occur as the first harmonic or two cycle sine wave as the aircraft is rotated through its vertical axis. 3) The combined effects of the vertically symmetric, induced and permanent magnetic effects which are not observed at all as the aircraft is rotated about the vertical axis, but is seen as the aircraft is removed from the vicinity of the magnetometer. The latter effects would eventually be seen as the aircraft undergoes pitch and roll changes in attitude which will certainly happen during the course of a survey.

AIRCRAFT COMPENSATION PROCEDURES Permanent Magnetic Effects

Permanent magnetic effects (1 above) are removed through the use of an orthogonal pair of magnets securely affixed to some rigid member of the aircraft at least several feet from the sensor. The magnetic correction required is that which will remove the fundamental or single cycle sine wave by creation of an identical effect 180 degrees out-of-phase. Recognition of the effects of permanent magnetism out of the observed total error can be aided by referring to Figure 3. A general rule-of-thumb, however, is that the permanent magnetic effect is one-half the perturbation of any pair of opposed headings, e.g. , one-half the N-S error or one-half the E-W error.

The amount or distance of the magnet required to compensate for a given heading error can be determined as follows. Determine the compensation amount required for each of the two orthogonal headings. At a distance of 3 - 10 feet from the sensor location and with sensor in place, temporarily affix a small bar magnet horizontal and exactly in a N - S direction at a convenient point on the stinger or wing. Either the size of the magnet or distance from the sensor should be varied to obtain a disturbance equal and opposite to one-half of the error required for that particular orientation of the aircraft. Regardless of whether the E - W or N - S error is being compensated, always place the magnet exactly horizontal and exactly N - S. The magnets end up exactly at right angles, of course. Following these instructions, one magnet should be placed with the aircraft in the north heading to compensate for one-half of the magnitude of the north-south heading error. The aircraft should then be positioned east and the second magnet used similarly to compensate for that error. (Ensure that all electronic systems and the aircraft engines are operating as they were during the initial measurements.) The aircraft should then be rotated through N - F - S - W headings to assure that there are no remanents of the fundamental due to permanent magnet sources. The above two compensating magnets could in theory be replaced by one permanent magnet which would give the same components (but that is not, of course, necessary). Remember that these permanent magnets must be fixed securely and that they must be in the horizontal plane and should be examined periodically if one suspects that a heading error has re-occurred.

Induced Magnetic Effects

Correction for the induced magnetic effects (2 above) can be accomplished by careful placement of high permeability iron materials such as permalloy or supermalloy or mu-metal placed very carefully near the sensor so as to compensate for induced effects of the aircraft. The principal by which this compensation achieves cancellation of the induced effects is based upon the fact that the field off the side of a dipole has exactly the opposite direction as the field off the end of a dipole. Assume that the induced effects of material on the aircraft have a given orientation, a point can be found near the sensor on a line, generally speaking, more-or-less normal to the direction between the induced sources and the sensor such that this compensation can be achieved (see Figure 2). This can be a difficult procedure because the effect of an induced mass is more complicated than that of a fixed permanent magnet. The moment of an induced magnet is a function not only of distance and orientation but also orientation in the earth's field and the length-to-width ratio of the mass. A small amount of metal, perhaps **less** than a few millimeters in diameter, may be all that is required when placed less than one foot from the center of the sensor. Furthermore, this material if too large may also degrade the signal of the sensor by causing a large magnetic gradient. In any event, placement of the high permeability material is almost an "art" and a simple procedure for placement of this material is difficult to describe. Moreover, if the aircraft is moved to a location where the dip of the earth's field is considerably different (more than 40 degrees) the procedure for compensation of the induced magnetic effects must be repeated. It should be noted, however, that the permanent magnetic effects described previously are usually the most serious and fortunately are much easier to compensate than the effects of induced magnetism.

Combined Vertical Magnetic Effects

Compensation for the vertically symmetric permanent and induced magnetic sources (3 above) is the easiest of all. A small permanent magnet is placed vertically so as to produce the same anomaly but opposite to that which is observed as a difference between a reading at the sensor installation location (at any heading if the above compensation procedures are successful) and the reading observed when the aircraft is removed from the location. Obviously, this requires that the sensor be free of the aircraft so that the sensor can be left in the measurement position as the aircraft is removed, say, 100 feet away. If the sensor cannot be removed conveniently, another measurement can be used to determine the correction required. The difference between the average value of the maximum peak-to-peak error observed before any compensation and the value with the aircraft removed, as described earlier in these procedures, is the value to be compensated.

These procedures are described only in general and will depend to a great extent upon the experience of the individual and some degree of knowledge of the behavior of a magnetic dipole and total field magnetometers. Remember that a total field magnetometer acts as a component magnetometer whose direction is determined by the direction of the earth's magnetic field.

Figure 1 Cloverleaf Flight Pattern

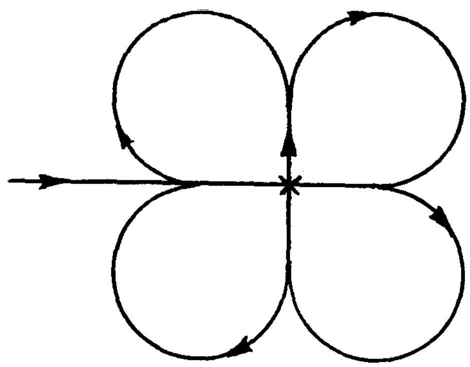
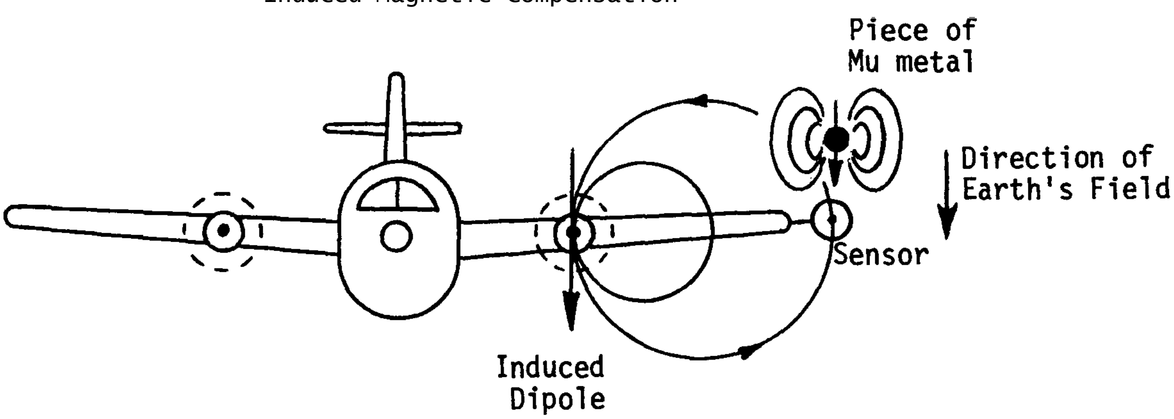


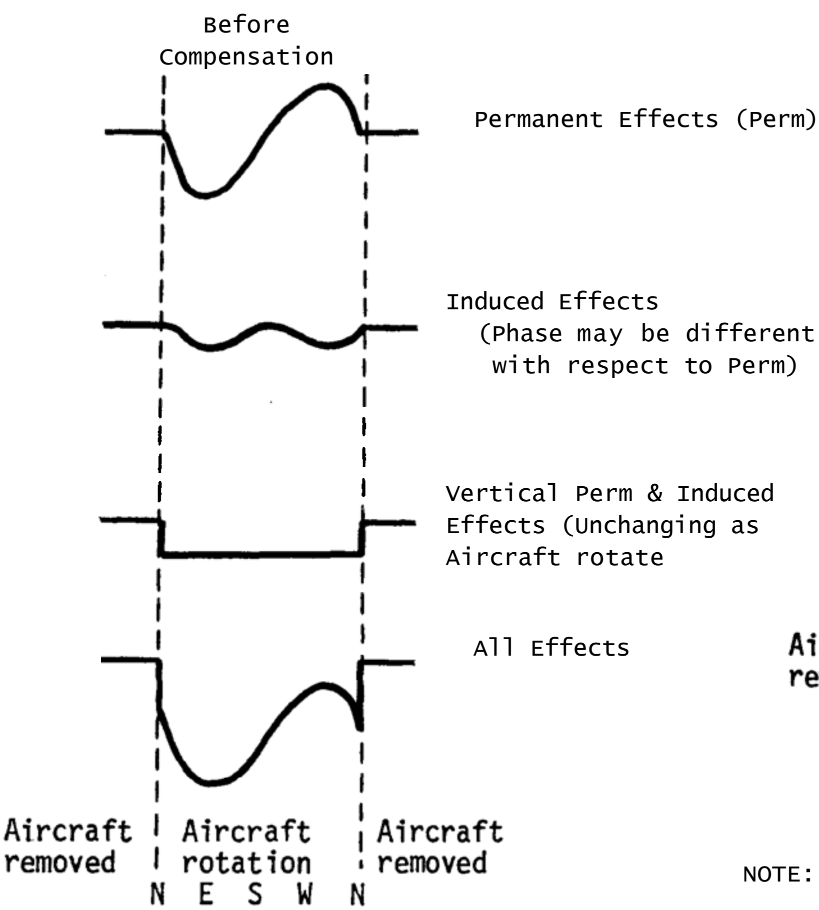
Figure 2

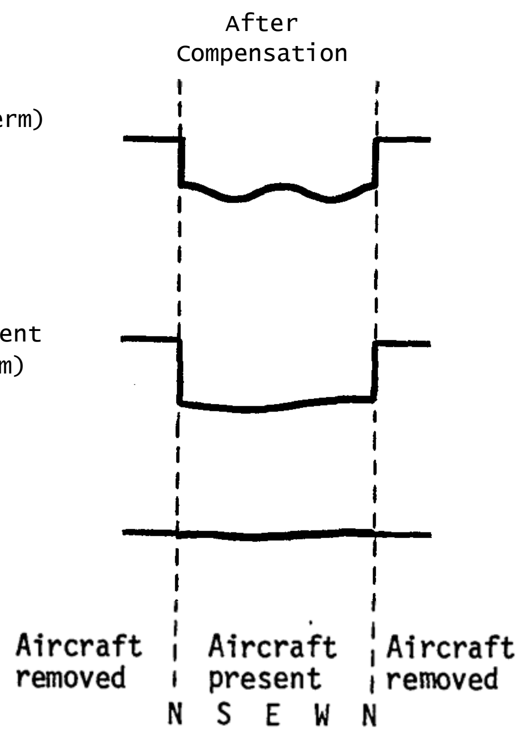
Induced Magnetic Compensation



<u>Figure 3</u>

The Effects of Magnetic Compensation





NOTE: The Perm compensation will generally remove 60% to 90% of all observed effects. Perm compensation can be accomplished in 1 day by a qualified technician. Induced compensation may require 2-3 days.