MGL Avionics

Compass operation and calibration

Table of Contents

General

This document discusses use, installation and calibration of a magnetic compass system for MGL Avionics EFIS systems.

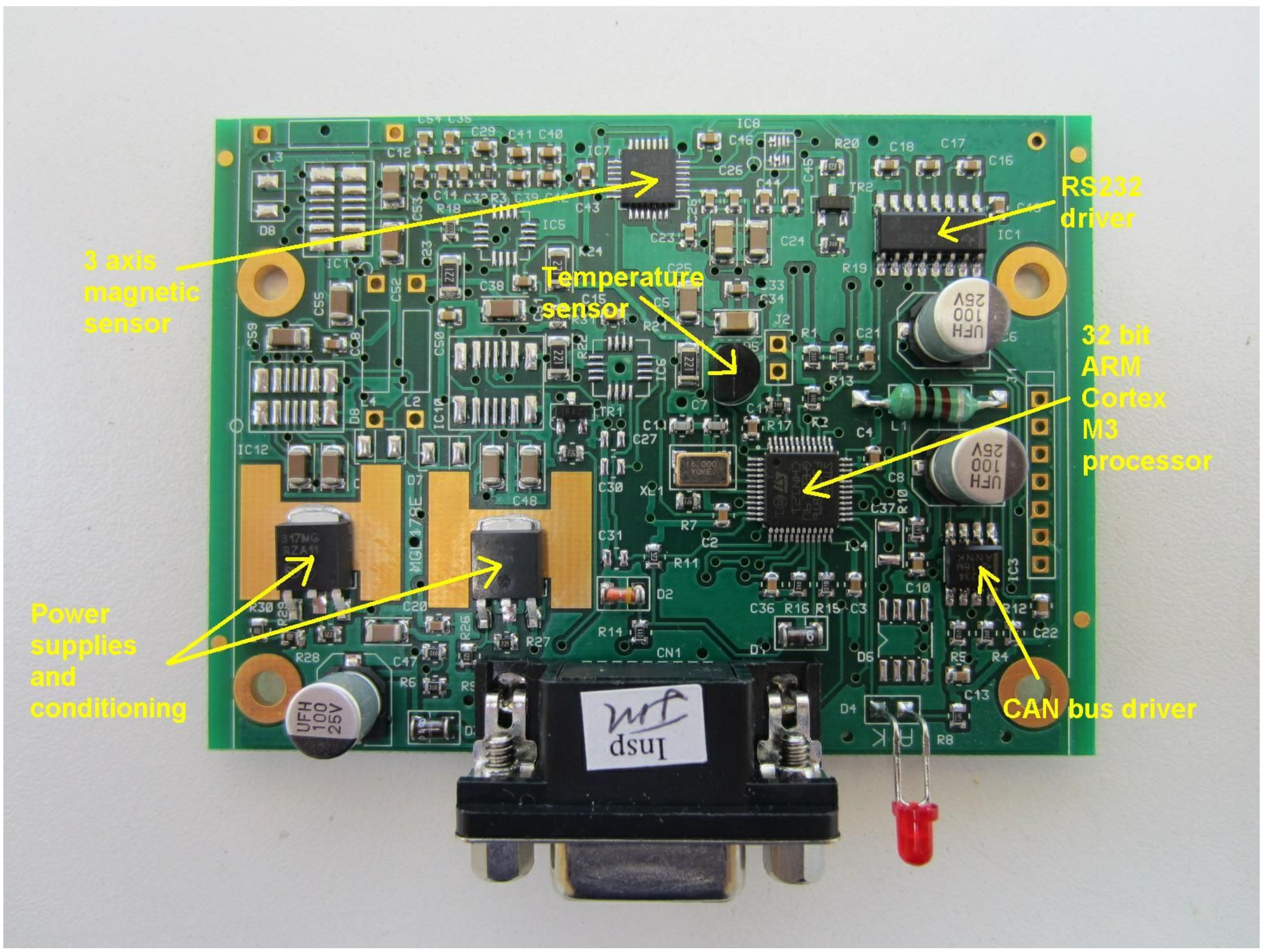
Applicability:

Compass systems SP-2, SP-2B, SP-6 and SP6B

EFIS versions supporting compass mode 2 (3D accel) and mode 4 (3D EFIS).

Inside a MGL SP-6 compass

This picture gives an overview of what goes into a modern electronic compass



Compass modes

MGL compasses support several operating mode that you can select depending on needs and available support systems in your installation.

Compass mode 2 (3D accel)

This compass mode is supported by all compass systems. This is the original compass system created for MGL systems and consists of a traditional 3 axis magnetoresistive field sensor and a accelerometer based tilt compensation system. SP-2 uses a two axis accelerometer while the SP-6 uses a three axis accelerometer sensor.

SP-2 systems can tilt compensate up to 60 degrees angles from the horizontal while SP-6 systems can tilt compensate any angle and can theoretically work even if upside down.

Accelerometer based tilt compensation does not work during accelerated flight such as balanced turns as the accelerometer cannot determine the angle of tilt relative to the Earths surface during such maneuvers. The magnitude of error introduced is highly dependent on the angle of inclination at the location where the compass is used. The error is less at the magnetic horizon and larger closer to the magnetic poles. The error is heading dependent and some headings to not have an error at all depending on the aircraft's attitude.

SP-2B and SP-6B retain this mode for compatibility reasons or for systems that do not have an artificial horizon system and cannot be operated in mode 4 for this reason.

Compass mode 4 (3D EFIS)

This is a new mode introduced in 2012 for MGL Avionics systems. The object is to provide a compass that can give a reasonable heading even during banked turns and also provide increased calibration functions to help cancel out magnetic effects found in the airframe.

With this mode the compass transmits basic, raw sensor information to the EFIS and the EFIS is responsible to calculate the heading from data available to the EFIS. In particular the EFIS has an artificial horizon system that can substitute the accelerometer based tilt compensation and thus provide a tilt compensated heading even in turns or other maneuvers.

In addition the EFIS has access to other information such as gyroscopic turn rates which may be further used to stabilize headings.

This mode is only available with SP-2B and SP-6B (SP-2 units upgraded at the factory, SP-2 are no longer in manufacture).

Other compass modes

Compass modes 2D and 3D gyro refer to first generation systems and are no longer supported.

Installation requirements for a compass system

A compass system is designed to show the angle of a magnetic field relative to the body of the compass.

In order for this to coincide with the true horizontal angle of the Earths magnetic field, correct installation of the compass is required.

Unsuitable position or incorrect installation can easily render the compass useless.

The most important initial step is to perform a magnetic survey of the aircraft. Do not simply choose a location that seems convenient. **<u>This is very important.</u>** You must locate an area in your aircraft that has as little magnetic deviation as possible. While small deviations can be calibrated out, keep in mind that any deviation caused by airframe and other influences will never be constant but will change over time (possibly quite rapidly) as the magnetic signature of your aircraft changes.

You must try and find a location where errors in the field are less than 10 degrees at any heading. It is not recommended to use a location where errors are larger than this.

Use a good quality hiking compass to perform a magnetic survey of your aircraft's possible magnetic sensor installation locations. This must be done while pointing the aircraft through as many different headings as possible. Only once you have located a suitable mounting point can you provisionally mount the electronic compass sensor.

Once you have done this, ensure that the sensor is placed in factory calibration mode so any corrections that may have been applied have been removed. Your EFIS compass setup provides a function to restore factory default. Now observe the headings given by the electronic compass on your EFIS as you point the aircraft in various directions. Do these headings agree within 10 degrees of your hiking compass ? If errors are larger than this but less than 20 degrees at the worst case you can consider performing a “deviation compensation” (described later in this document). This may assist in doing a rough calibration for external influences.

Do not mount your compass with steel or any other ferro-magnetic fastener. Consider brass screws (not plated, solid brass only) or even self adhesive velcro tape.

Ensure that the compass is correctly aligned with the aircraft. It is easy to introduce a couple of degrees of error by not aligning the compass. Remember – the compass measure the direction of the field related to the compass – not the aircraft.

Ensure that there are no ferro magnetic structures or parts close by. Aluminium, copper, brass is OK. Be aware of rivet mandrels remaining inside rivets. These are made from mild steel and magnetize.

Be aware that wires carrying currents will have magnetic fields around them. If these are close to the compass sensor they can cause significant heading errors.

Aircraft fuselages consisting out of steel tubing cannot contain a compass. Consider mounting the sensor in a wing tip.

Be aware of baggage areas. Baggage may contain magnets or metals that will cause deviation.

Do not mount the sensor close to the pilot or passenger. A bunch of keys in a passengers pocket can have significant effects on the heading if close to the sensor.

Mounting locations behind the panel are seldom successful due to many disturbing items. Many instruments contain magnets and there are likely to be many steel fasteners and parts.

Be aware of engines. Why they are mostly aluminium, engine mounts are steel and there are many steel parts on an engine. Mounting locations close to engines are never recommended.

Beware of temperature extremes. Electronic compass systems use magentoresistive sensors which are subject to temperature drift. This means that heading errors can be introduced if temperatures are very low or high. If a compass system is installed inside the fuselage temperatures tend to be fairly controlled while those installed in wing tips or similar places may be exposed to higher temperature fluctuations.

Additional requirements for Compass mode 4 (3D EFIS)

The EFIS will use bank and pitch angle from the AHRS as attitude source for the compass tilt compensation if bank angles are greater than 15 degrees. At zero degrees the EFIS will use the heading calculated by the compass itself which is based on the internal accelerometer based tilt compensation. At bank angles greater than zero but less than 15 degrees, the EFIS will show a composite of the two calculations, biased depending on the bank angle.

It is important that the compass has been mounted on the same plane as the AHRS as the compass uses the attitude from the AHRS to be the same as its own. If this is not the case, the tilt compensation will show errors.

Remove any bank or pitch angle corrections on the EFIS if you need to verify the angles reported by the AHRS. The compass will always use the actual angles reported by the AHRS before any correction has been applied in the EFIS. These are corrections that you can apply to cancel out installation or trim errors. Remove them before adjusting the mountings.

Calibrating the compass

Once you have located a suitable mounting location and have verified that the sensor returns reasonably good headings (less than 10 degrees error preferably on any heading) you can proceed with calibration.

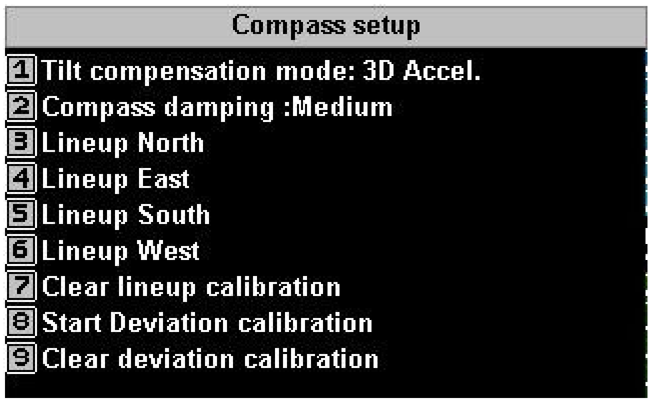
There are two calibration methods:

a) Deviation calibration (done only if heading errors on a compass set to factory settings are more than 10 degrees and less than 20).

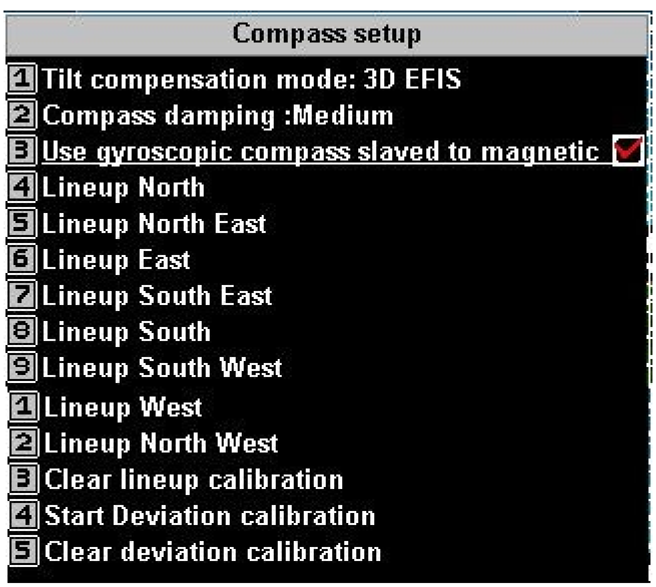
b) Lineup calibration.

The compass menu changes depending on the compass mode selected:

Here is the menu for mode 2:



The menu for mode 4:



Prerequisites:

For the compass calibration we recommend to switch compass damping “OFF” and **disable** gyroscopic slaving.

For MGL EFIS systems supporting mode 4 (3D EFIS) select this mode using the provided function (note: you need a SP-2B or SP-6B sensor for this), otherwise select mode 2 (3D accel).

Calibration must be performed at a suitable location. Generally this means away from hangers (steel structures) and concrete aprons that contain steel reinforcing. Often airports have a dedicated compass check area with a painted compass rose which can be very helpful.

Deviation calibration

This involves placing the compass into “deviation calibration mode” through the EFIS compass menu and then rotating the aircraft through at least one full 360 turn on the ground and then ending the “deviation calibration mode”.

This takes maximum field strength readings in all directions in the X and Y horizontal axis. Using this the compass can work out offsets that need to be added or subtracted to recenter the circle created by the measurements. This can provide you with an improvement if magnetic distortions at the compass mounting location are simplistic.

If this does not decrease the heading errors or increases them, return the compass to factory default and find another mounting location or try and identify the source of the error using a hand held hiking compass.

During deviation compensation you will see a set of numbers displayed. These are the current field readings and minimum and maximum values recorded during the turn.

To see the effect of various disturbances you can place the system in deviation mode and for example move a screw driver close to the sensor to see the effect on the current magnetic field measurement values. Cancel the deviation compensation so you do not change the existing one stored after you have finished (do not “end” it - “cancel” it).

Lineup calibration

Lineup calibration is similar to a compass deviation chart. Here we can tell the system what errors there are and the system will then subtract these errors from the reading.

This works differently depending on if you are using mode-2 or mode-4.

In mode 2 (3D accel), you are presented with 4 lineup calibrations – N, E, S, and W. The calibrations will be stored in the compass.

In mode 4 (3D EFIS), you are presented with 8 lineup calibrations – N,NE,E,SE,S,SW,W,NW. The calibrations are stored in the EFIS. If any direction is applying a correction, the lineup text in the menu shows the number of degrees added or subtracted from that heading.

For headings falling between the calibration points, the system works out a scaled correction factor based on the correction values at the calibration points.

Lineup calibration mode 2

If you are going to use mode 2, park or taxi the aircraft to a suitable location and point the aircraft in each of the 4 cardinal headings. Note: Magnetic headings, not true headings.

Use a hiking compass and verify the aircraft's heading from outside the aircraft by sighting along the compass from in front or behind the aircraft. View the magnetic heading displayed on the EFIS and if different to the compass select the corresponding lineup function to send a correction to the compass. Note: you may have to repeat this command as it may get lost on a busy communication bus. Repeat it until the heading changes as required.

Note: the system will refuse this command if the heading error is greater than 22 degrees.

Repeat the lineup for all 4 cardinal headings.

Note: you may need to repeat this procedure at intervals as the magnetic signature of your aircraft changes over time.

Lineup calibration mode 4

If you are going to use mode 4, park or taxi the aircraft to a suitable location and point the aircraft in each of the 8 major magnetic headings. Note: Magnetic headings, not true headings.

Use a hiking compass and verify the aircraft's heading from outside the aircraft by sighting along the compass from in front or behind the aircraft. View the magnetic heading displayed on the EFIS and if different to the compass select the corresponding lineup function to send a correction to the compass. Note: you may have to repeat this command as it may get lost on a busy communication bus. Repeat it until the heading changes as required.

Note: the system will refuse this command if the heading error is greater than 22 degrees.

Repeat the lineup for all 8 headings.

Note: you may need to repeat this procedure at intervals as the magnetic signature of your aircraft changes over time.

If you have more than one EFIS connected to one compass, perform the lineup command in the EFIS menu on all connected EFIS systems as the lineup correction is stored in the EFIS and not in the compass.

Operating the compass

You have two relevant compass settings in the compass setup menu:

Compass damping

This slows down the rate at which heading is allowed to change. A setting of medium is recommended. This prevents the compass from swinging wildly during turbulence as the nose of the aircraft yaws.

Use gyroscopic compass slaved to magnetic

If this is enabled the EFIS creates a gyroscopic compass based on information from the artificial horizon system (yaw rate referenced to Earth's surface). This is coupled to follow the heading from the magnetic compass system but you are presented with the heading output from the gyroscopic compass.

If the difference between the two headings is large, the gyro compass will accelerate its slaving so it catches up to the magnetic compass quite fast.

Note: If your magnetic headings are not accurate you will see the heading “pulling” as you turn out in a new direction. Consider this example:

You start with a heading of zero degrees and want to turn onto 90 degrees but your magnetic compass reads 80 degrees when you are at 90 degrees. However, for this example the heading is correct at 0 degrees.

You perform your 90 degree turn based on the gyroscopic system which is very accurate however as you turn out there is now a 10 degree error between margetic compass and gryo system. The gyro will now “catch up” to the magnetic compass and the heading will slowly change to 80 degrees as this is what the magnetic compass is reading.

If you would like to use the gyroscopic compass system, first ensure that your magnetic headings are reasonably accurate in flight and that a 90 degree turn in any direction at any heading results in a 90 degree change of the magnetic heading or at least reasonably close.

Returning the compass to factory settings

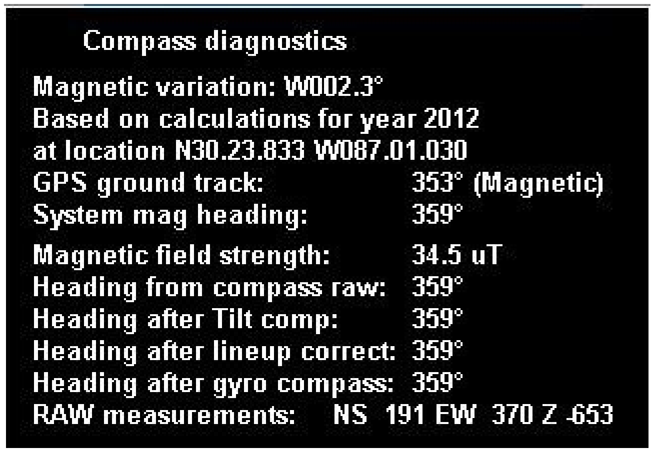
Select the “Clear deviation calibration” from the compass menu.

Please note that this also clears the lineup calibration stored in the compass for mode-2 operation.

You can clear the lineup calibration separately at any time by selecting “Clear lineup calibration”.

Compass diagnostics

The EFIS contains a diagnostics function that can provide useful information during flight and on the ground. This screen is mainly used for compass mode 4 (3D EFIS).



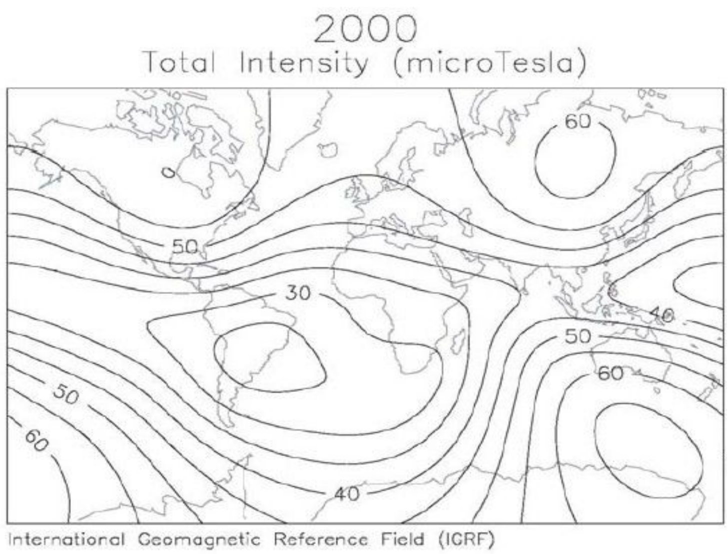
The compass diagnostics screen is found under the diagnostics menu in menu level 2.

It starts with showing the magnetic ground track from the GPS and also the data that was used to calculate the magnetic track. Ensure that your EFIS is at least set to the correct year so variation can be calculated correctly.

Note: GPS track is only valid if you are moving at least at 5 miles per hour. At speeds less than this the entry will show the heading from the compass.

The "System mag heading" is the value that is used by the system as magnetic heading from the compass sensor (this is what you would see on the screen).

Magnetic field strength is calculated from the three magnetic sensor readings that are also shown in the last line (NS, EW and Z axis sensor). The field strength shown should roughly equal what you can find in this map based on your location:



If your measured field strength differs you may have significant magnetic effects in your aircraft at the location of your compass.

Following this is the RAW heading as calculated by the compass itself, using its accelerometer based tilt compensation but excluding the mode-2 lineup correction.

This is followed by the result of the tilt compensation done in the EFIS. This is mixed with the original RAW heading depending on the bank angle according to the following rule:

The EFIS will use its own calculations based on attitude from the horizon at bank angles of 15 degrees or more. At lesser bank angles the EFIS's calculated heading is mixed with that obtained from the compass according to a factor based on the bank angle. At a bank angle of zero the original compass heading is used.

Next follows the heading calculated after the 8 lineup corrections have been applied.

Finally, if enabled, the heading output from the gyroscopic compass is shown.

Conditions that can damage a compass sensor

The SP-2 and SP-6 compass use magnetoresistive sensors made by Honeywell. These are robust sensors but environmental stress can degrade the performance of these sensors or cause issues with the circuitry around the compass itself.

To be avoided:

a) Large and rapid temperature fluctuations.

b) Over voltage or operating the compass with unsuitable power supplies containing A/C signals or power surges.

c) Exposure to strong magnetic fields.

d) Ingress of moisture including condensation.

f) Severe shocks or vibration.

What we have seen

Here are a few choice installation errors we have seen over the years:

a) Mounting the compass upside down

b) Mounting the compass backwards (it now shows north and south swapped)

c) Mounting the compass on a nice aluminium bracket with brass fasteners on the firewall (cockpit side) – with the steel engine mounting frame two inches away on the other side of the firewall.

d) Mounting the compass with steel screws (but they are so small – surely they can't do anything... - yes they do !)

f) Staring a deviation calibration but not finishing it – leaving the compass with incomplete measurements.

g) Mixing up true and magnetic headings (hey, it was not us that shifted the magnetic poles).

h) Comparing magnetic track from the GPS with that of the compass and it's not the same – True, track is what you're doing over the ground. Heading is where you are pointing (the compass is pointing !). If there is even a slight wind from the side, the two are not the same unless you are slipping into the wind, compensating exactly.

i) Mounting the compass under the passenger seat (guess what...).

j) Mounting the compass next to an electric trim motor (there are magnets in the thing).

k) Mounting the compass next to a set of steel rudder cables.

l) Mounting the compass at a location where a steel bearing moved towards as the flaps where deployed (heading changes dramatically as the flaps go out).

There is more of course, but this shows some of the things folks do. Give your compass installation a good thought before you start. This is not a trivial task and certainly one of the more involved ones related to an EFIS installation.

Calibration is never finished

Unless you mount the compass in a very good location (such as a glass fiber fuselage close to the tail with no magnetic interferences from anywhere), you will find the need to periodically recalibrate the compass.

With a normal Whiskey compass you would rotate two small magnets in the base of the compass in order to neutralize the biggest deviation offenders and then produce a compass deviation card showing the remaining errors at various headings so you can compensate for them when flying.

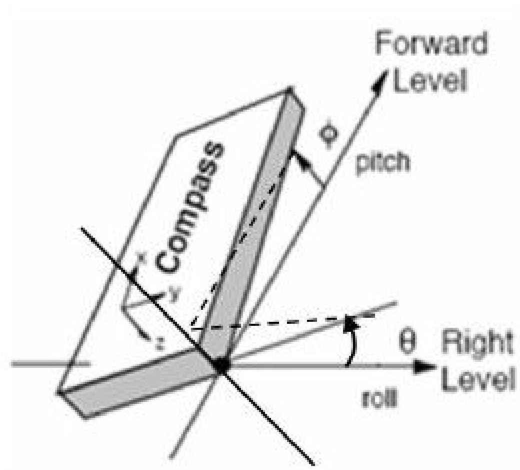
With a electronic compass things are no different, except the calibration has changed. In most cases you should be able to completely eliminate errors using the lineup procedure. In theory you should be able to get them to not worse than say three degrees worst case (provided you have a good compass location to start with) and in normal operation you will have a useful compass.

The headings will slowly drift out over time as your aircraft's magnetic signature changes. It may change due to fitting of new equipment or it may change because you are parking your aircraft always in the same orientation and the Earth's magnetic field is very slowly turning your aircraft into a big magnet.

Compass swings (or calibration) should be done once a year or whenever something on the aircraft has changed that could affect its magnetic profile. Also consider doing a quick lineup calibration before you do any flight where you need maximum accuracy from the compass – such as a navigation exercise in an air rally where your GPS is banned...

On the need for tilt compensation

This short text explains why we need to compensate a compass for “tilt”.



This graphics illustrates the problem. The X and Y sensor readings of the compass are used to calculate the heading. This is trivial but only gives you the heading you want if the compass is perfectly level to the Earths surface.

If we know the pitch and bank angles relative to the Earths surface and we know at what angle and strength (inclination and magnitude) the field is at your location – then we can mathematically rotate the magnetic sensor readings into the horizontal plane and can then extract the heading information.

Some compass systems work this way but these are not very practical for an aircraft that can cover great distances as inclination and field strength will change.
A better way would be to introduce a third sensor in the Z axis. This way the system knows the Z axis field strength and the rotation of the three sensor readings can proceed without further information required. This system would work anywhere on Earth. MGL's compass systems are based on three magnetic sensors like this.

In mode 2 of our compass systems, an accelerometer is used in the compass itself to derive pitch and bank angles – this works well but only if you are not turning or changing speed. Any form of acceleration will cause the accelerometer (which is similar to a pendulum) to give a false reading.

In mode 4 of our compass systems the accelerometer is used for small bank angles and the AHRS attitude is used for larger bank angles. This way the compass can return a good heading even in a turn. Of course, this method requires that an AHRS is available to the system.

Tilt compensation may fail in an aircraft at certain headings – consider for example a banked turn with the compass installed in a wing tip. Depending on the angle of dip (inclination) of the field at the location, at some point in the turn the fuselage of the aircraft with all its magnetic disturbances may be closely aligned with the compass and cause a deviation of the field. This effect does not last long so it can be bridged by using a magnetically slaved gyroscopic compass. This can be enabled in compass mode 4 in MGL EFIS systems.