Changing from Magnetic to True Tracks in Aviation

Bart Banning[*], Anthony MacKay, Paul Hickley[***]**

[*]International Association of Institutes of Navigation
Amsterdam, The Netherlands
email: bart.banning@lvnl.nl

[**]NAV Canada
Ottawa, Canada
email: anthony.mackay@navcanada.ca

[**]Royal Institute of Navigation
London, United Kingdom
email: iain@rin.org.uk

Abstract: *The use of the magnetic compass and magnetic North as the main reference in aircraft navigation in this era leads to avoidable costs and possible safety issues. A proposal is presented to change to GNSS based true tracks and headings, including a way forward for an internationally aligned transition strategy. Latest results of research in this field and of coordinating actions with international bodies are presented.*

1. Introduction

The International Association of Institutes of Navigation has taken up the initiative to transition to true tracks in aviation, as was done in the maritime world already in the previous century. Although it will take a worldwide effort to make the transition from magnetic to true reference, it is believed that this one time exercise will make aviation safer and much more efficient.

This paper will be updated for the ENC conference in Dresden in order to represent the latest advances and insights. At the ICAO conference in 2019, it was agreed that ICAO would take up this subject in its work programme. A date in the future and an accompanying roadmap for the transition to true tracks are still to be established.

2. Background

If history were different, and we had invented gyroscopes hundreds of years ago, but had only invented the magnetic compass recently, and were now offering it as an alternative means of indicating heading, the aviation world would reject it.

True direction can be established by measuring the spin of the Earth, offers operating accuracy of the order of one tenth of a degree and remains constant with time. By contrast, the instantaneous accuracy of a magnetic compass (that is, a snapshot at any random instant) is probably of the order of two degrees. When integrated over a period of tens of minutes or longer, this reduces to about half a degree. More importantly, magnetic declination (or variation, as it is commonly called by aviators) changes with location and time, necessitating

978-3-944976-28-0

constant updating of published procedures.

Earth Magnetism. The usual simple model used to visualise the Earth's magnetic field is to imagine a straight bar magnet running through the Earth, but this is a gross simplification. The majority of the Earth's magnetism is caused because the outer core of the Earth is a mass of molten metal containing a significant amount of ferrous ores. The combination of the rotation of the Earth and the convection currents within this liquid creates the geo-dynamo that makes up the main component of the field. The remainder comes from local magnetic anomalies caused by deposits of solid mineral, mainly magnetite, nearer the surface of the Earth.

Declination, often called magnetic variation, is the angle between true north and local magnetic north. Declination charts of the world are issued regularly by several geodetic organizations..

As can be seen, few parts of the world experience zero variation, so the challenge of managing both correcting for it now and the rate at which it is changing is an international issue. Nobody knows what causes variation to change and attempts to model the changing pattern break down after a certain point because of the complexity of the equations. All that can be done is to observe what has happened in the past and extrapolate into the near future. As with weather modelling, the further ahead we attempt to predict, the less accurate the model becomes.

The North and South magnetic poles are not co-located with the True poles, as defined by the extremities of the Earth's spin axis, nor are they antipodal. For instance, in 2015 the North magnetic pole was at approximately 87°N 150°W, whilst the South magnetic pole was at around 65°S 137°E – so far away from the True pole that it is not even on the continent of Antarctica.

More importantly, these magnetic poles are constantly moving. At Oxford Airport, for instance, the variation in 1942 was 11°W. In 2015 it was about 1°W. So, it has changed 10° in approximately 73 years, giving an overall rate over that period of one degree every 7.3 years. In other parts of the world, the rates of change are different and how fast these rates of change are speeding up or slowing down is also different.

On the internet we can find animations of how the isogonals have changed over the period 1590 to 1990.

Even though we can see that the motion is hugely speeded up, it makes a good general point. Trying to base a structure as complicated as our modern international airways network on this is like trying to build a cathedral on shifting sand.

There are also parts of the world where it is impossible to use a magnetic compass at all. Near the poles, the lines of flux of the earth's magnetic field lie at a very steep angle to the earth's surface. The scientific term for this is *inclination*, but it is normally called the 'angle of dip' by aviators. Close to the poles, the horizontal component drops to less than 6 microteslas, which is the generally accepted figure for the threshold below which a magnetic compass can no longer be used. The northern zone with values below 6 microteslas is quite extensive. The zone in the southern hemisphere is even larger.

There are also unpredictable changes to variation. Solar flares can be radiated towards the Earth, particularly at times of peak sunspot activity. The time that they take to pass through the Earth's magnetosphere is short – but their effects are noticeable. During the last 11-year sunspot cycle peak, variation anomalies of up to 7° lasting several hours were observed.

Current Practice – and Exceptions. Nevertheless, despite these limitations, magnetic direction is used as the datum for instructions, procedures and control in aviation, including airways tracks, approach procedure tracks and runway centrelines. When the variation alters by more than one degree, it becomes necessary to republish any printed runway and approach documentation. However, runway directions are defined by rounding the magnetic centreline, upwards or downwards, to the nearest ten degrees, then expressing them as a 2-digit figure. 195°, for instance, rounded upwards, becomes 200°, or Runway 20, whilst 194° is rounded downwards to 190°, or Runway 19. This necessitates re-painting the large white numerals on the main runways, and closing the airfield whilst the work is in progress. Consider the situation at Tampa, Florida, when the runways were re- designated in January 2011. The North/South parallel runways' centrelines are orientated 006.0°T and changed from 36 to 01. According to the FAA, variation at Tampa in 2005 was 4.3°W, with an annual change of about 0.1°W. They should have changed as soon as the magnetic variation was 3.5°W or more, which occurred in 1998. So, even then, the runways should have been designated 01 and 19, but up 2011, they were 36 and 18. In January 2011 the airport finally remarked not only the runways but some 100 sign panels and 40 other signs!

So why did the airport take 13 years to get around to conforming to what is established statutory practice? One can only surmise, but one of the reasons may be that it had to close for a week in order to re-paint the runways. This would have represented a significant loss of income for such a large airport and they may have put off biting the bullet until they could really leave it no longer.

The other main application in which magnetic north is used as a datum are those navigation aids where the bearing information is put in at the ground station, that is: VDF, VOR and the military TACAN.

Having decided on this convention, by usage and custom, we then depart from it when it becomes unworkable. At latitudes above about 60° tracks and routes published on charts are given in True because of the weakness of the horizontal component of the magnetic field and because it changes so rapidly with both location and time. It is simply assumed that any aircraft operating at high and polar latitudes will be equipped with a navigation system that gives it the ability to operate in True or Grid. Some high-latitude VORs are orientated to True North. Near Resolute Bay, Canada, the variation changes from 10°W to 90°W within about 200 nautical miles. A straight-line track on this chart would change magnetic track by 80° in that distance. Everyone using this VOR has to work in True.

3. Changing to True.

Now let us examine how to tidy up this situation. The obvious way is to convert all directions for aviation instructions, procedures and control to True, since we have to use it near polar regions anyway. Let's examine what effect it would have on:

- Airliners;
- Aircraft with a gyro-magnetic compass – that is, a good gyro slaved to a magnetic flux valve;
- Aircraft with Directional Gyro Indicators (DGI), manually reset to a Direct Reading Compass;
- Aircraft with a Direct Reading Compass only.

Airliners. Any airliner introduced into service less than 45 years ago uses an inertial navigation gyro-based system for navigation. Two, or sometimes 3, inertial reference systems determine True heading by measuring the direction of the Earth's spin. In the modern Flight Management System, all the navigation computations of spherical trigonometry to calculate desired tracks and all the computations of position data in latitude and longitude are carried out in True, so, for purely navigational purposes, there is no requirement for magnetic direction. Therefore, no magnetic sensor, or flux valve, is incorporated into the system.

However, for compatibility with Air Traffic Control procedures, the aircraft have to be capable of operating in Magnetic. Thus, the Inertial Reference System contains a database with values of variation against latitude and longitude. Note that this is the reverse of the traditional situation, in which Magnetic heading was sensed and variation was used to convert it to True for navigation. Here, True is sensed, and variation is used in reverse to convert it to a computed Magnetic heading for Air Traffic procedures.

The problem is that variation changes with time. The database is calculated for the half decade in which the IRS was built, i.e: built in 1981, set for 1985; built in 1992, set for 1995, and so on. Unless the database is updated, the information goes out of date. Unfortunately, updating is expensive and there is no strong incentive for the airline to carry it out.

It is difficult to establish how often these databases actually do get updated and, clearly, those airlines that allow the data to get out of date will be reluctant to give details of their 'in-house processes'. However, one airline pilot was so concerned that he took a series of readings over a period of 20 months between 2006 and 2008 in order to confirm what was otherwise merely anecdotal – that the heading showed by the EFIS in his fleet was nearly always a larger figure than the published runway centreline. He was operating in Western Europe and there, with westerly variation reducing with time, the indicated magnetic heading would be too great if the correction database was out of date.

This is his data. 364 is quite a reasonable number of observations. The mean is +2.854°, but the mode is more significant, at 4°, especially as he was reading to only the nearest degree. There must be some explanation of why this sample is skewed so well to the positive side of zero and by far the most probable one is that the variation databases were out of date.

Does this matter? Does it make a difference to safety? For ILS and VOR approaches, probably not, because the aircraft is following a deviation signal against the ILS centreline or the VOR radial, which are paths over the ground and do not change. However, in the ADF, it is the aircraft heading which positions the needle, or its modern electronic equivalent. For an NDB let down, it is a well-established procedure that the descent should not be commenced unless within 5° of the centreline because the Minimum Descent Altitude is based on terrain within that domain. If the datum heading is 4° out, because of the false artificial value of variation, before we start considering any other source of error, it seems possible that safety margins are being eroded.

Additionally, the variation correction system in IRS and FMS is not available at high latitudes. The manufacturers accept that, near the poles, the value of variation is so high and the rate of change so great, that it would be unsafe to make it available. Therefore, at latitudes north of 73°N and south of 60°S, only True headings and tracks are displayed. The magnetic database is inhibited at these latitudes and everyone flies in True.

These regions are becoming more and more important to routine passenger aviation. Thirty five years ago, if you needed to fly from Moscow to Vancouver, you would have followed a path at temperate latitudes.Today it would look distinctly different.

Today's aircraft can fly for 12 or 13 hours at a time, giving ranges of around 5000 miles, or even further, in a single leg. They are exceptionally reliable and the chances of an unplanned landing in inhospitable climates are very low. But, more importantly, gyro-based navigation systems allow us to navigate across the pole, saving thousands of miles on some journeys.

Aircraft with a gyro-magnetic compass. Let's now turn to those aircraft that use a traditional gyro-magnetic compass, in other words, one with a flux valve, such as might be found in an air-taxi aircraft. In fact, this problem of operating gyro-magnetic compasses in True has been dealt with before. During the '50s and '60s, compasses were magnetic, but automatic dead reckoning systems using Doppler needed their input to be in True to be compatible with a latitude and longitude graticule. Most compasses for large aircraft of that period had a facility for manual entry of variation to give a true read-out to the navigation equipment and, in many cases, to the actual compass dial, so that the pilot could fly true headings off the compass.

This facility tended to die out in gyro-magnetic compasses produced after about 1970 because the Doppler Ground Position Indicators had become digital by then and it was simpler to adjust the variation in the display computer itself, rather than in the compass. However, if we switched to True, the demand would revive, and it would be an easy matter for manufacturers to reinstate a well-established fifty-year old technology into modern gyro-magnetic compasses.

Aircraft with Directional Gyro Indicators (DGI). We now turn to those aircraft using a combination of Direct Reading Magnetic Compass and a Direction Gyro Indicator. These present the least problem of all. The DGI has no direct magnetic input and is simply set by the pilot to whatever datum is required. Normally, this is magnetic direction. All that would be required would be that the pilot would have to apply the local variation every time that he reset the DGI, which is normally every fifteen minutes or so. The light aircraft community has nothing at all to fear from such a change.

Aircraft with a Direct Reading Compass only. For aircraft that have nothing but a magnetic compass, which is mainly the microlight community, the only real option would be to mentally apply variation. Generally, these aircraft tend not to fly much more than, say, 100 miles from their home bases and it is a simple matter to remember just one value of variation and apply it every time.

VORs. The variation at a VOR is set at the ground station. It can be altered easily by changing the reference signal and, in fact, at present it has to be adjusted every time there is a variation change. So, the facility is already there to change it from Magnetic to True North. Once set, unlike the present situation, it would not need to be moved again.

In fact, within the UK, any change to the VORs will require less work than it would have done previously. NATS propose to reduce the number of VORs within the UK from 46 to 19 over the next 5 years. Clearly, they believe that all commercial traffic is now fitted with some form of area navigation equipment and that a large number of private pilots have GPS.

GNSS. A GNSS receiver establishes its position in latitude and longitude, which is based on True north. Because of the system's extreme accuracy, the receiver can, by integrating successive fixes over a short time interval, calculate its True track, which can either be displayed in numerical form or as a track marker on a moving-map display.

A particular GNSS receiver could cost about the same as one hour's light aircraft flying. It would actually be cheaper than a simple Direct Reading Compass. Given that True track is now available at this sort of price, why would anybody want magnetic heading, except possibly as a standby in the event of a power failure?

4. The Case for Converting to True.

The case for converting to True as the datum for aviation instructions, procedures and control is clear, and the only problems would be those of practically implementing it. Whilst it would be a huge and costly undertaking, it would also be a one-off operation which, once completed, would be final, unlike the present situation which is also costly, but is constantly with us.

The biggest single problem in trying to implement this change worldwide would be inertia – the large number of countries involved and the difficulty of finding the will to all change at once. Some of these countries do not have a sophisticated aviation environment that could deal with this easily, and in others, such as the United States, the sheer extent of the change would be formidable and might meet opposition from a conservative general aviation lobby. A foreseeable way that it could happen would be if a single country were to file a difference with ICAO and change unilaterally. Once they had proved that it worked without problems, we might then expect others to follow progressively.

This is not as unprecedented as it sounds. Some countries use feet as the unit for altitude others use metres. Some use hectopascals as the unit for atmospheric pressure, others use inches of mercury and so on. There is no difference in principle if some were to use Magnetic and others to use True.

In fact, one country has already taken a lead. The rate of variation change, both with time and position, is so great in parts of Canada that, at the 12th ICAO Conference, held in Montreal in November 2012, NAV CANADA, the agency that owns and operates Canada's civil air navigation system submitted a working paper which reported as follows:

> ***4.3.5 Navigation with reference to True North only***. *NAV CANADA continues to investigate only the use of navigation referencing true north for aircraft operations. A significant effort is expended to update current aeronautical information with changing*

magnetic variation (MAGVAR). Modern avionics carry out navigation calculations with reference to true north, and then convert the information for pilot displays to Magnetic (by applying a magnetic variation based on a magnetic model), or True heading or true Track, depending on aircraft capability. Safety activity in recent months included the emergency re- painting of runways as a result of "lapsed MAGVAR data" and the cancellation of all CAT 1 through III approach because of a changing MAGVAR, and out of date MAGVAR reference tables on board the aircraft (as old as 2005) in some states. NAV CANADA believes all operations referenced to true north would enhance the overall safety floor and save considerable effort in maintaining MAGVAR tables.

The paper concluded with the following recommendation (some other recommendations, not relevant to this topic, are omitted from the quote below):

> ***6.2*** *The Conference is invited to agree to the following recommendation:.......*
>
> *That the Conference request ICAO to:.........*
>
> *........consider employing navigation with reference to True North as the standard reference.*

IAIN takes the view that the case for converting to True North as the datum for aviation instructions, procedures and control is clear. The only problems would be the practical ones involved in implementing such a change. While it would be a huge and costly undertaking, it would also be a one-off operation, which, once completed, would be final, unlike the present situation, which is also costly, but is constantly with us.

5. Recent Developments.

IAIN has established a working group in order to coordinate work on the subject and to gain worldwide exposure. They are now working together with CANSO and individual ANSP's. They are also working with IATA and ICAO. The goal is to pick a date in the future, e.g. 2035, and progress towards it in a harmonized fashion.

Several ANSPs have conducted studies in the previous years. Those have also included live test flights. The results have all been in favour of the change.

Recently the magnetic field of the world has been in the news as it has been moving in a different, faster way then before. This has urged an extra interim update of the World Magnetic Model. The attention this received by the general public may aid to present the message.

Modern aircraft, surveillance systems and instrument flight procedures are all designed using True tracks. Abandoning the practice of converting all of them to Magnetic all the time for no practical reason seems long overdue.

References

[1] X. Mustermann, Y. Wellknown, and Z. Pfiffig, “New research in magnetic field”, *Proc. of 2010 Very Important Radar Conference*, Bigcity, Incountry, June 2010, vol. 3, pp. 210-214.

(Times New Roman, 11 pt)

[2] H. R. Hertz, “Ueber sehr schnelle magnetische Schwingungen“, *Annalen der Physik*, May 1887, vol. 267, no. 7, pp. 421-448.

[3] J. C. Maxwell, A Treatise on Magnetism and Electric Youth, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp. 68–73.