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DGLR
Deutsche Gesellschaft für Luft- und Raumfahrt
Lilienthal-Oberth e.V.

The Opinions

From magnetic to true reference

De la référence magnétique à la référence géographique

Von der magnetischen zur rechtweisenden Referenz

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DE LA RÉFÉRENCE MAGNÉTIQUE À LA RÉFÉRENCE GÉOGRAPHIQUE

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1- DE LA RÉFÉRENCE MAGNÉTIQUE À LA RÉFÉRENCE GÉOGRAPHIQUE

1.1. Situation actuelle : la référence magnétique

Depuis les débuts de l'aviation, nous utilisons le Nord magnétique comme référence pour les caps et les trajectoires, sauf à proximité des pôles magnétiques[1]. Cela peut s'expliquer par des raisons historiques : jusqu'à la disponibilité des centrales à inertie et de la navigation par satellite, les compas magnétiques et les vannes de flux étaient les seuls instruments capables de fournir des informations de cap.

Les centrales inertielles (IRS) fournissent essentiellement un cap vrai et intègrent une base de données de déclinaison magnétique pour élaborer les informations de cap magnétique. Les IRS font désormais partie de l'équipement standard des avions de transport, mais les avions régionaux et d'aviation générale utilisent des compas magnétiques, des vannes de flux ou des magnétomètres pour obtenir le cap magnétique.

Pour le vol aux instruments (IFR), la navigation basée sur les performances (PBN) est désormais la norme : navigation entre des points définis par des coordonnées géographiques. La PBN repose sur l'utilisation de GNSS (*Global Navigation Satellite Systems*).

Le GNSS fournit la position de l'avion ainsi que le vecteur vitesse sol (vitesse sol et trajectoire), en référence géographique. Il est maintenant largement utilisé, des avions de transport aux avions légers.

1 *La référence au nord géographique est utilisée pour les vols polaires (au nord de 73°N ou au sud de 60°S), et dans les zones où l'intensité du champ magnétique est inférieure à 6 micro Tesla.*

Il faut noter que plusieurs technologies existantes peuvent afficher une information de cap vrai :

- Un AHRS (*Attitude and Heading Reference Systems*), qui utilise un magnétomètre et une base de données de déclinaison magnétique interne, ainsi que la position de l'avion provenant du GNSS, peut présenter le cap vrai.
- Les super AHRS, qui utilisent la technologie gyroscope laser, génèrent des informations de cap vrai.
- Les systèmes utilisant des récepteurs GNSS doubles sont capables de générer des informations de cap vrai à partir de la différence de phase des signaux. Ils sont utilisés pour des applications maritimes et devraient être disponibles commercialement pour l'aviation dans la seconde moitié de cette décennie.

Cependant, la référence magnétique est toujours utilisée : les trajectoires, les orientations des pistes, etc, sont toujours publiées en référence magnétique.

Dans ce contexte, l'utilisation de la référence magnétique a plusieurs conséquences négatives :

- Les ANSP (*Air Navigation Services Providers*) doivent régulièrement mettre à jour les cartes en raison de l'évolution régulière de la déclinaison magnétique. Les bases de données de déclinaison magnétique utilisées par les systèmes aéronautiques (IRS, FMS, récepteurs GNSS…) pour élaborer la route et le cap magnétique (dans le cas de l'IRS), doivent être régulièrement mises à jour par souci de cohérence.
- Les identifiants de piste, fonction de l'orientation magnétique de la piste, doivent également être modifiés, ce qui entraîne des coûts pour les exploitants d'aéroport (un changement d'identifiant de piste nécessite de modifier les marquages sur la piste et les panneaux à chaque intersection de piste).
- Les schémas d'émission VOR doivent être régulièrement modifiés afin de prendre en compte l'évolution de la déclinaison magnétique.
- Les divergences entre la déclinaison magnétique publiée et la déclinaison magnétique utilisée par les systèmes des avions (provenant de bases de données internes) introduisent une erreur systématique qui peut être considérée comme du “bruit”.
- Si cette divergence dépasse quelques degrés, elle induit une instabilité latérale pendant l'atterrissage automatique, ce qui peut entraîner des risques de sortie de piste.
- Pendant les approches ILS, cette divergence peut également entraîner un décalage entre le symbole de la piste

synthétique et la piste réelle (sur les affichages tête haute ou les systèmes de vision synthétique).

- La direction du vent est généralement indiquée en référence magnétique par le contrôle aérien et en référence géographique par les services météorologiques (messages TAF et METAR), ce qui est une source d'erreurs lorsque la déclinaison magnétique est importante.

Nous pouvons conclure que l'utilisation de la référence magnétique est la source d'erreurs systématiques, de complexité et de coûts récurrents qui seraient éliminés par l'utilisation de la référence géographique.

Il faut noter que la référence géographique est utilisée pour la navigation maritime depuis plusieurs décennies.

1.2. La transition vers la référence géographique d'ici 2030 est un objectif réalisable

De l'analyse de la situation actuelle, nous pouvons conclure que :

1. La transition de la référence magnétique à la référence géographique est souhaitable.
2. Elle nécessitera un investissement ponctuel pour les opérateurs et les ANSP, mais éliminera les coûts récurrents.
3. Puisque les technologies GNSS et IRS élaborent l'information sur la trajectoire (et le cap) à l'aide de la référence géographique, la plupart des avions sont en mesure de voler en utilisant la référence géographique sans modification importante.

Le Canada a décidé d'étendre la référence vraie à l'ensemble de son espace aérien d'ici 2030. Cette décision a été motivée par les arguments énumérés ci-dessus et par le fait que la référence géographique est déjà utilisée dans une partie de l'espace aérien canadien (le NDA, *Northern Domestic Airspace*). NAV Canada[2] élabore actuellement un concept d'opérations (CONOPS) pour la transition vers la référence géographique.

Comme il existe de solides arguments en faveur du passage de la référence magnétique à la référence géographique, il serait souhaitable que le plus grand nombre possible de pays se joignent au Canada pour un passage coordonné à la référence géographique impliquant au moins les États-Unis, l'espace aérien de l'Atlantique

2 *NAV Canada est une société privée sans but lucratif chargée de la prestation des services de navigation aérienne dans l'espace aérien intérieur du Canada et dans la FIR océanique de Gander.*

Nord ainsi que les États membres d'Eurocontrol.

Cela créerait une dynamique conduisant à une extension mondiale de la référence géographique.

1.3. Préparer la transition

Une des conditions du succès est de promouvoir la transition de la référence magnétique à la référence géographique en informant et en recherchant l'implication de toutes les parties prenantes : ANSP, compagnies aériennes, organisations de pilotes professionnels, aviation générale et opérateurs gouvernementaux, autorités de l'aviation civile, AESA, opérateurs aéroportuaires, fabricants d'avions et d'avionique, organisations internationales (OACI, IATA...).

L'Association internationale des instituts de navigation (l'AAE est membre de cette association) promeut activement la transition vers la référence géographique par le biais du groupe AHRTAG (*Aviation Heading Reference Transition Action group*).

Grâce à ses membres et à ses contacts avec les parties prenantes européennes, notre Académie pourrait jouer un rôle actif en promouvant la transition vers la référence géographique et en encourageant les parties prenantes à préparer la transition d'ici 2030.

Pour réussir cette transition, nous devrions encourager les actions concrètes des parties prenantes :

- Les représentants européens à l'OACI devraient promouvoir activement la transition vers la référence géographique, avec pour objectif une transition mondiale d'ici 2030.
- Eurocontrol et les ANSP européens devraient préparer un concept d'opérations avec la référence géographique (les CONOPS développés par Nav Canada devraient être examinés dans cette perspective ainsi que les opérations actuelles dans le NDA).
- Les ANSP européens devraient étendre les publications de cartes avec une double référence systématique pour les routes et les relèvements, comme l'a déjà fait l'ASECNA pour les cartes relatives aux procédures PBN.
- Les fabricants d'aéronefs et d'équipements devraient développer des outils permettant de passer de la référence magnétique à la référence géographique à un coût et une simplicité minimum. Airbus devrait être encouragé à prendre en compte cette exigence pour les futurs avions et à développer une interface spécifique pour les familles A320 et A220. Les fabricants

d'équipements pour l'aviation générale et les transports régionaux devraient développer des outils logiciels permettant de sélectionner la référence vraie (comme le fait déjà Garmin pour tous ses produits). Les fabricants d'aéronefs devraient inclure dans leurs manuels les opérations en référence géographique.

2- ANNEXES

ANNEX 1: EARTH'S MAGNETIC FIELD

A 1.1. Earth's magnetic field models

The main source of the Earth's magnetic field is the dynamo effect created by convection currents in the Earth's outer core, made up of 90 % liquid iron. The dynamo's movements are generated by a progressive cooling of the outer core and growth of the inner core (which is the solid metallic mass in the center of the Earth).

The result is a dipolar magnetic field, also called the core field. Its direction differs from that of the Earth's rotation axis by about 10°.

The Earth's magnetism has other sources. Magnetic minerals in the crust and upper mantle make a further contribution that can be locally significant. Electric currents induced by the flow of conducting sea water through the ambient magnetic field make a further, weaker contribution to the observed magnetic field.

Models, such as WMM (World Magnetic Model) produce magnetic field predictions taking into account the above-mentioned sources, extending over a five-year period. WMM20 is considered valid from 2020 to 2025.

The model validity according to time is monitored from ground and space: in France, the Institut de Physique du Globe uses 11 stations located on airports, distributed to cover continental France and Corsica, ESA Swarm mission uses a constellation of three satellites in low Earth orbit to monitor the Earth's magnetic field.

Earth's magnetic field models are used to update magnetic variation in the charts and data bases.

In addition, Earth's magnetic field is affected by solar activity: electric currents due to the interaction between the solar wind and the magnetosphere can also produce magnetic field variations visible from the ground. The contributions arising from electric currents in the upper atmosphere and near-Earth space are time-varying, and induce electric currents in the Earth and oceans, producing secondary internal magnetic fields. Earth magnetism models such as WMM do not take into account these contributions, also called disturbance fields.

During periods of high solar activity, solar flares may be ejected, causing a sudden rise of the speed of the solar wind and of the intensity of production of X-rays and UV radiations from the sun. Depending on orientation of the magnetic field carried by the solar wind, these phenomena may generate magnetic storms on Earth: fast and relatively strong variations of the near-Earth magnetic field affecting magnetic instruments.

During storms, the path of radio signals through the ionosphere may be modified due to higher electron density, inducing errors in the positioning information provided by GNSS and affecting HF radio transmissions. Geomagnetic induced currents may also affect the power grid and induce electric power outages in northern regions with potential consequences on airports and navaids. Increased particles density in the upper atmosphere may have consequences on satellites in low Earth orbits: an increase of drag may induce a premature reentry (a spectacular event occurred in February 2022, after the launch of 49 StarLink satellites: a geomagnetic storm occurred triggering the loss of 40 satellites).

A 1.2. Magnetic poles and magnetic variation

Magnetic poles are usually defined as the positions on the Earth's surface where the geomagnetic field is vertical. These positions are also called dip poles, and the north and south dip poles are not antipodal.

Another magnetic pole definition originates from the geomagnetic field model. The representation of the core field includes a magnetic dipole at the centre of the Earth. This dipole defines an axis that intersects the Earth's surface at two antipodal points. These points are called geomagnetic poles.

Earth's magnetic field is continuously changing. Among the consequences, changes in the position of magnetic poles are observed: according to the WMM2020, the magnetic North Pole is drifting 44 km each year while the magnetic South Pole is drifting 9 km each year. In 1900, the magnetic North Pole was located close to King William Island in North Canada (now, in

Nunavut Province), and should reach northern Siberia by the end of this century.

Compass needles point in the direction of the magnetic field lines, which is generally different from the geographic North Pole direction. The compass pointing direction can also differ from the direction to the magnetic North Pole since magnetic field lines are not just circles connecting magnetic poles: magnetic north represents the horizontal direction of magnetic field lines; it does not point in the direction of the magnetic North Pole (see Figure 1).

It is considered that magnetic compass indication is not reliable when the horizontal component of Earth's magnetic field is lower than six micro-Teslas. This is the case in the vicinity of magnetic poles and, as a consequence, magnetic navigation instruments are not usable in polar areas.

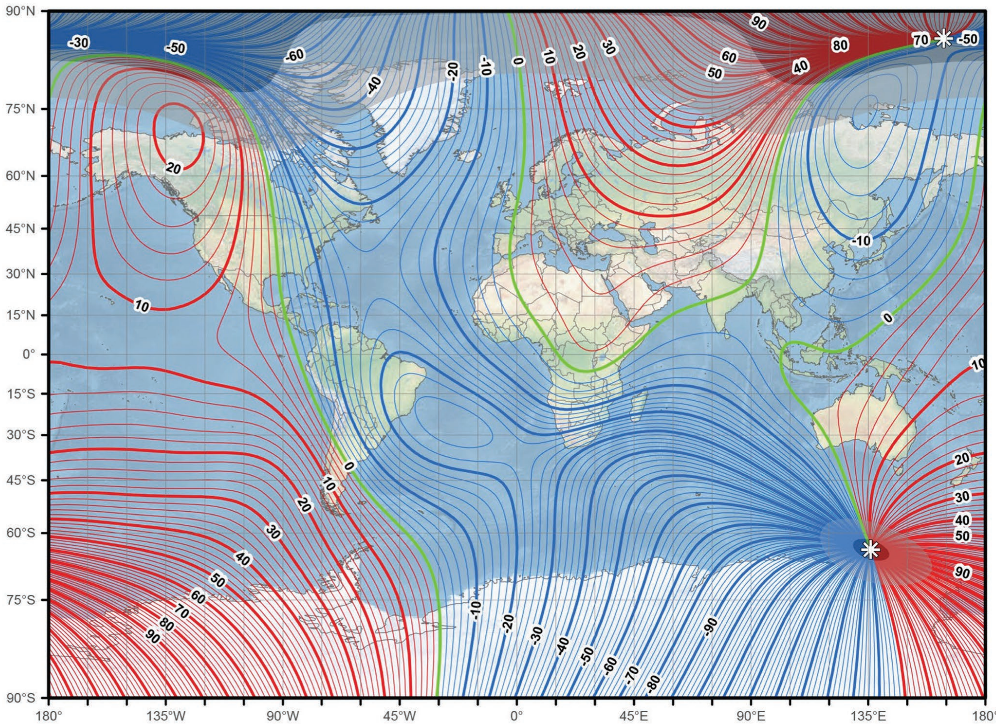

Figure 1: Constant magnetic variation lines from WMM 2020 model. Red contours positive (east); blue negative (west); green zero (agonic) line. Magnetic poles (dip poles) are represented by white star symbols. © NOAANCEI

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ANNEX 2: AIRCRAFT OPERATIONS

A 2.1. Heading and track information

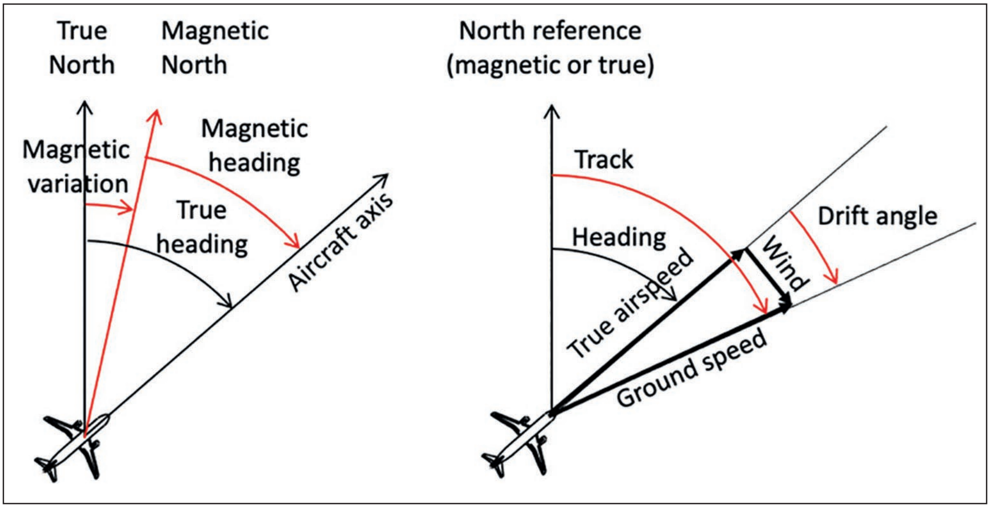

Figure 2: Heading and track information. *© Jacques Verrière*

Definitions

As shown on the figure above:

- Heading is the angle between north reference (magnetic or true) and the aircraft longitudinal axis.
- Magnetic variation (also called declination) is the angle between true north and magnetic north directions. Easterly variation corresponds to a magnetic north east of true north (it is considered as positive according to World Magnetic Model).
- Track is the angle between aircraft ground speed vector and north reference (magnetic or true).
- Drift angle is the angle between true airspeed vector and ground speed vector. Assuming zero sideslip, drift angle is the angle between aircraft heading and ground speed vector.

To obtain a magnetic heading (track) from true heading (track), westerly magnetic variation must be added and easterly variation must be subtracted.

Heading and track information are basic information used for navigation:

- Track is the primary information required to fly between waypoints (WPTs) defined by their geographical coordinates.
- Without track information on board, drift is estimated and heading is used as primary information. Heading is used by air traffic control for radar vectoring.
- Wind can be computed from heading, true airspeed and ground speed vectors. This computation requires combining heading and track information in the same reference (magnetic or true).

Wind information and north reference

Regarding the wind, under the current situation:

- Wind information (observed or forecast) is provided by meteorological services in true reference, this is the case for METAR and TAF messages.
- Wind information is usually provided by air traffic services in magnetic reference. When an air traffic controller issues a take-off or landing clearance, he/she indicates the latest wind in magnetic reference. However, in cruise, when a pilot requests the latest weather information, the controller reads the latest METAR with a wind indicated in true reference.
- On navigation displays, wind direction and speed are usually presented in true reference, but the wind vector is oriented according to the reference used for heading (magnetic or true). The wind vector computation requires air data (True Airspeed), true track (from IRS or GNSS) and true heading (from IRS or from magnetic heading and magnetic variation).

Use of multiple references for wind data is a source of errors in areas when magnetic variation is significant.

As an example, in St-Johns, Canada (CYYT), published magnetic variation is 19° west. To determine crosswind, we must determine the angle between runway orientation (QFU) and wind direction. If the wind indicated in the METAR is 130° at 30 kts, we would expect intuitively a crosswind component lower than 15 kt for runway 11 (105° magnetic). However, in this case, the angle between QFU and wind direction is not 25° but 44°, and the corresponding crosswind component is 21 kt.

Current technologies and evolution perspectives

Heading and track information can be provided by systems using three basic technologies:

- Inertial Reference Systems (IRS) provide ground speed vector (true track and ground speed) as well as true heading. True wind vector can be derived from TAS (True Airspeed) and ground speed vector. Magnetic variation data bases integrated in IRS are used to derive magnetic heading and track from true heading and track.
- GNSS receivers also provide ground speed vector (true track and ground speed), with no heading information. In some systems, magnetic track is computed using a magnetic variation data base.
- Magnetic flux valves, magnetometers and compasses provide magnetic heading information. In most recent systems, magnetic heading is provided by a 3D magnetometer which measures three dimensions of the Earth's magnetic field, instead of two.

Those three basic technologies have their own limitations and error sources:

- IRS are expensive systems, that is why they are used on commercial jets and military aircraft, while most regional transport and general aviation aircraft (GA) are not IRS equipped. IRS are also subject to drift associated with time. Some AHRS (Attitude and Heading Reference Systems) designed for GA and regional market, based on ring laser gyro technologies and called "Super AHRS", provide true heading information without use of magnetic sensors, at a fraction of the cost of IRS.
- GNSS are affordable systems, and the vast majority of aircraft flying in 2022 use GNSS for navigation: from certified GNSS receivers (required for IFR operations), tablets, smartphones or connected watches. GNSS accuracy is good compared to IRS, but may be subject to loss of continuity (when the number of visible satellites in the GNSS constellation does not ensure nominal accuracy) and to local jamming or spoofing. More details on GNSS accuracy, continuity and integrity are presented below.
- All aircraft are equipped with a magnetic compass, either as a primary source for magnetic heading (on light airplanes) or as a back-up instrument. Magnetic compasses are simple and inexpensive systems, but are sensitive to the magnetic anomalies due to aircraft magnetized parts, so they must be regularly calibrated. Magnetic heading information from a compass is only usable in straight and steady level flight, without significant turbulence. Some light air-

planes are equipped with directional gyros, which can display magnetic heading information usable in all flight phases, provided that the gyro is regularly aligned with the magnetic compass.

- To avoid regular alignment some directional gyros can be slaved to flux valves or magnetometers, providing a more accurate and stable magnetic heading information. Some AHRS (Attitude and Heading Reference Systems) used on regional and GA airplanes navigation systems incorporate a magnetometer to provide magnetic information, as well as a GNSS receiver and a magnetic variation data base (or model) and are able to generate true heading information.
- Magnetic instruments (compass, flux valves and magnetometers) require a minimum value for the horizontal component of the Earth's magnetic field in order to provide usable indication. It is considered that 6 Micro Tesla is the minimum value. As a consequence, magnetic instruments are not usable in regions close to magnetic poles (cf. Annex 1).

GNSS technology may be also used to provide true heading information: the system elaborates true heading information from the phase difference between two GNSS receptors, with antennas located at some distance. It may be associated with directional gyros to ensure continuity in case of temporary loss of GNSS signal. At the present time, this technology is used only for maritime applications but some avionics manufacturers plan to commercialize such equipment in the years to come.

IRS and so-called super AHRS provide true heading information with a 95 % accuracy less than 1°, this accuracy is also achieved by using GNSS technology. By comparison, when using magnetic technology, a 3° error is considered acceptable. Concerning the magnetic compass, CS 25 (Certification Specifications applicable to large transport airplanes) indicates that, after compensation, in normal level flight, the compass deviation must not be greater than ten degrees on any heading.

GNSS accuracy, continuity and integrity

As discussed above, GNSS are essential for navigation, which is why augmentation systems are used to improve accuracy, continuity and integrity.

ABAS (Aircraft Based Augmentation Systems) is an avionics implementation that processes core constellation signals with information available on board the aircraft. ABAS provide integrity monitoring (required for IFR flight) and may also improve GNSS signal continuity.

There are two general classes of integrity monitoring: Receiver Autonomous Integrity Monitoring (RAIM), which uses GNSS information exclusively, and Aircraft Autonomous Integrity Monitoring (AAIM), which also uses information from additional on-board sensors such as inertial reference systems (IRS).

RAIM requires redundant satellite range measurements (at least five satellites with good geometry) to detect a faulty signal and alert the aircrew; Fault Detection Exclusion (FDE) requires six satellites. A barometric altimeter may be used to provide an additional measurement that reduces by one the number of satellites in view required for RAIM and FDE.

GNSS signals may be affected by ionospheric scintillation and by magnetic storms (cf. Annex 1).

GNSS and IRS information may be combined to obtain a hybrid position, combining GNSS accuracy and IRS continuity. In the event of loss of GNSS signal, this hybrid position continues to be computed, using IRS data. The AAIM algorithm determines the validity of the hybrid position with regard to RNP (Required Navigation Precision). This function is usually implemented in IRS and, recent systems ensure RNP 0.3 availability H24 worldwide if there is a minimum number of operational satellites in the GNSS constellation.

GNSS signal reception may be affected by jamming or spoofing. The consequence of jamming is a loss of GNSS signal, while spoofing introduces a position bias. Jamming or spoofing are usually observed in conflict zones and their immediate vicinity[1].

When hybrid GNSS-IRS position from ABAS is available, AAIM is usually able to reject invalid GNSS signals and hybrid position may be used for FMS update if compatible with required RNP.

One member of the working group experienced GNSS jamming on several occasions: at cruising levels over eastern Turkey and Iraq, and in approach to Mexico City airport (in the latter case, the signal loss was limited to less than one minute). In all those cases, the loss of GPS signal was detected, but the FMS was still showing the message GPS PRIMARY, indicating that hybrid GPIRS position was still used by the FMS and that the estimated position uncertainty was compatible with required RNP for the flight phase.

1 *After the start of conflict between Russia and Ukraine in February 2022, GNSS jamming was observed in Romanian and Polish airspaces. In Western United States, GNSS jamming is frequent during military exercises.*

SBAS (Space Based Augmentation Systems) such as EGNOS in Europe and WAAS in North America improve accuracy as well as integrity. Satellites in geostationary orbit are connected to ground monitoring stations which validate signals from the GNSS constellation and determine GNSS position bias in the geographical zone. Some SBAS provide an additional GNSS signal in order to improve continuity (this is the case of WAAS in North America).

GBAS (Ground Based Augmentation Systems) are ground stations which are used to transmit GNSS position bias (comparing GNSS position with actual coordinates) as well as approach parameters.

The use of multiple GNSS constellations (GPS, GALILEO, GLONASS, Beidou…) increases GNSS signal availability but, at the present time, GNSS receivers certified for IFR navigation process signals from GPS constellation only. Some GNSS receivers used for recreational activities rely on multiple constellations. We may expect that, before the end of this decade, multi-constellations GNSS receivers, called DFMC by ICAO (Dual Frequency Multiple Constellations) will be available for PBN.

A 2.2. PBN (Performance Based Navigation) and magnetic/ true reference

Navigation between waypoints

The basic principle of PBN is to navigate using waypoints (WPT) defined by their geographical coordinates.

Aircraft flying under Instrument Flight Rules (IFR) use PBN most of the time. PBN capability is required to fly in upper airspace and in some terminal areas. ILS (Instrument Landing System), based on radio signals are still used for final approaches but RNP (Required Navigation Precision) approaches using GNSS are now widely used.

PBN requires a Flight Management System (FMS) or a stand-alone GNSS receiver, using a navigation data base (NDB) which include WPT coordinates, magnetic variation, procedures, airways, navaids, altitude and speed constraints…

FMS process signals from GNSS, IRS and radio navigation. In the event of loss of GNSS position (or hybrid GNSS-IRS position), position may be obtained from IRS (usually MIX IRS position established from several units) or radio navigation (DME-DME or VOR / DME). For RNP approaches, GNSS is usually required even when position accuracy obtained with DME-DME

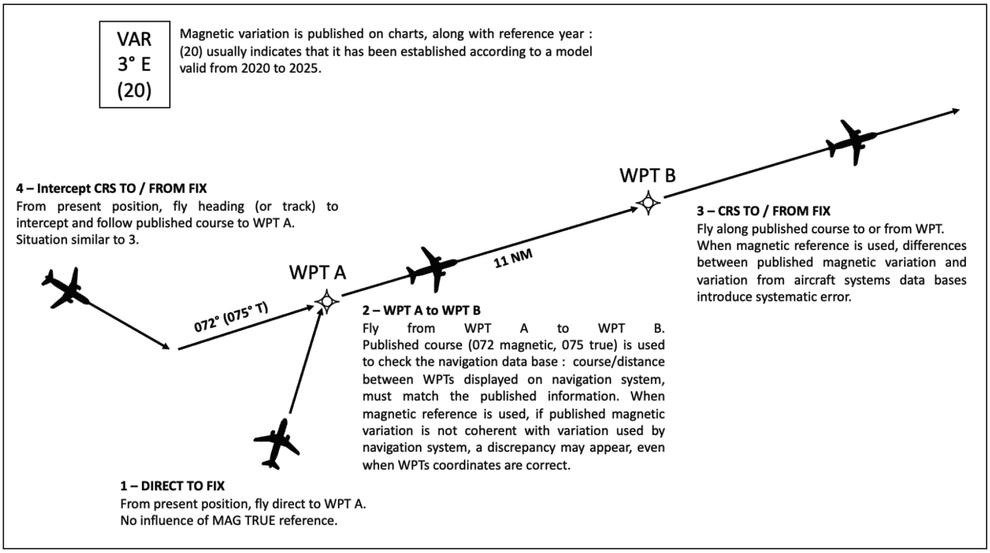

Figure 3: PNB procedures. *© Jacques Verrière*

(0.3 NM with a good geometry) is compatible with required RNP.

RNP (Required Navigation Precision) is function of accuracy and continuity of the navigation system.

PBN procedures: departures (SID), cruise (Airways), arrivals (STAR) and RNP approaches can be decomposed as a series of segments, which are summarized in the figure above (holding patterns and turns associated with procedures are not represented on this figure).

1. *Direct to Fix*

   This type of segment is used regularly: from present position fly direct to a WPT, and then follow the flight plan (F-PLN). The navigation system computes the route (in geographic reference) and distance from aircraft present position and WPT coordinates (from navigation data base).

   Flying from present position to a WPT defined by its geographical coordinates uses basically geographical reference: the system determines the true track to join the WPT. If magnetic reference is used, magnetic heading, track and bearing to the WPT are displayed after being computed using magnetic variation data bases from IRS and navigation system.

2. *WPT to WPT*

   The greatest part of a F-PLN can be defined by a string of WPTs. Flying between WPTs is similar to flying from present position to a WPT. The navigation system computes the route from

WPT A to WPT B and provides guidance to stay on this route, using present position, WPTs coordinates and aircraft track. This is similar to case 1.

As per standard procedures, pilots must check that courses and distances between WPTs in the F-PLN are consistent with published courses and distances. This is important to avoid navigation errors and to check the navigation data base, and is required before flying RNP approaches.

When true reference is used, if WPT coordinates are correct, there should be no mismatch between course as shown on the navigation system and published courses (there could be a potential 1° maximum mismatch if rounding methods differ).

When using magnetic refence, an additional discrepancy may occur. In the example shown in Figure 3, the published route between WPTs A and B is 072° magnetic and 075° true. Published magnetic variation is 3° east. If the magnetic variation data base is out of date and is 1° east, this will introduce a 2° discrepancy: the navigation system will show a 74° magnetic course between WPT A and B.

This systemic error increases with the annual rate of change of magnetic variation.

3. *CRS TO / FROM FIX*

   When following a course TO or FROM a WPT, if magnetic reference is used, this can introduce a systemic error if the magnetic variation data base from the navigation system has not been updated (cf. Figure 4).

   In the example shown on the Figure 3, with the values corresponding to the previous case (2), when flying track 72° magnetic, the aircraft will follow 73° true track instead of 075°.

4. *Intercept CRS T0 / FROM FIX*

   When using a track to intercept (ex. 120° track), the situation is similar to the previous paragraph.

   When using a heading to intercept (ex. 120° heading), the situation is different.

   When magnetic reference is used, if heading information is inertial, it is established in true, and magnetic variation from IRS data base is used to obtain magnetic heading. In this case, we introduce a systemic error if this data base is several years old. If heading information is magnetic, there is no systemic error.

   If true reference is used, the situation is reversed: if heading information is non-magnetic (inertial or from dual-GNSS), it is established in true and there is no systemic error. If heading information is magnetic, magnetic variation from the navigation system data

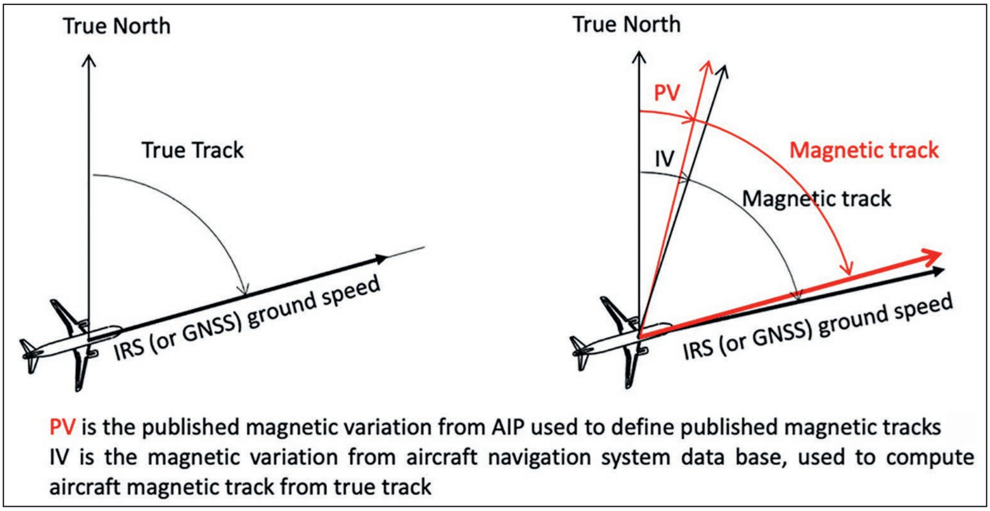

Figure 4: PV published magnetic variation. *© Jacques Verrière*

base must be added to obtain true heading and there may be a systemic error.

When true reference is used (left), to follow a published true track, IRS or GNSS ground speed vector is used. The only error factor (not presented on the figure) is the system accuracy.

When magnetic reference is used (right), a systemic error may occur when following a published magnetic track, established using published magnetic variation. To follow this magnetic track, the navigation system determines the true track and uses magnetic variation, from its internal data base table to determine magnetic track. Any difference between magnetic variations generates a difference between published track (in red) and aircraft track (in black).

Magnetic variation updates on aircraft systems

When magnetic reference is used for navigation, any discrepancy between published magnetic variation and magnetic variation used by aircraft systems introduces systemic error with consequences on PBN, and also on ILS approaches and Autoland, and on synthetic vision systems (cf. next paragraph).

FMS navigation data bases are updated at each AIRAC cycle (28 days) and data loading is a standard maintenance operation. FMS have two navigation data bases, one active and the other inactive. The data base for a new AIRAC cycle is loaded a few days before becoming effective, it is inactive initially and a data base swap is performed at the effective date. PBN operations require the use of a valid data base corresponding to AIRAC cycle effectivity.

There is no regulatory requirement concerning the update of IRS magnetic variation data bases: in 2022, it is legal to operate a Boeing 767 manufactured in 1985 without having updated the IRS magnetic variation data base since its entry into service. Usually, IRS magnetic variation data bases are based on a world magnetic model, projected five years in advance, in order to remain valid for ten years.

Updating an IRS magnetic variation data bases is a costly operation (some cost figures have been presented, ranging from 40,000 to 100,000 US Dollars per aircraft), requiring some time and logistical constraints: in most cases, this update must be done by the equipment manufacturer and implies a change of part number. That is why some operators are reluctant to perform such operations.

However, flying with out-of-date IRS magnetic variation data bases may impose some operational restrictions (cf. next paragraph concerning ILS CAT II and CAT III operations). Airworthiness Directives (AD) defining those restrictions are issued by the authority responsible for the oversight of type certificate holder (ex. EASA for Airbus, FAA for Boeing).

As a recent example, an AD proposal was issued in February 2022 by the UK CAA. It concerns Avro RJ-146 equipped with IRS with magnetic variation data bases dating from 1990 or 1995. To comply with this AD, operators have to determine if discrepancy between actual magnetic variation (according to WMM2020) and IRS magnetic variation data base exceeds two degrees in some part of the area of operation. If it is the case, the MEL should be amended to prohibit dispatch with unserviceable TAWS or TCAS.

Some GA or regional airplanes use a magnetic variation data base to combine magnetic heading information from AHRS with true track from GNSS. On some systems, such as Garmin 1000, a magnetic variation data base is contained in the navigation data base, updated at each AIRAC cycle. To obtain true heading, some AHRS incorporate world magnetic model equations, taking into account aircraft position and current date (from GNSS receiver).

As summarized in Table 1, use of true reference would eliminate the need to update magnetic variation data bases except for GA and regional airplanes using magnetic heading from AHRS associated with GNSS.

	Magnetic reference	True reference
Inertial Reference Systems (IRS)	Yes	No
FMS navigation data base	Yes	No
Systems combining magnetic AHRS and GNSS	Yes	Yes

Table 1: Aircraft systems requiring magnetic variation data according to magnetic or true reference.

Conclusion

PBN is best adapted to true reference since it is natural to use true reference to navigate between positions defined by geographical coordinates.

The use of magnetic reference for PBN generates systemic errors due to unavoidable discrepancies between published magnetic variation and magnetic variation data bases used by various aircraft systems. To minimize this bias, frequent updates are required, at some cost for ANSP and operators.

The use of true reference will eliminate this bias and limit the need to maintain and update a magnetic variation data base to aircraft using flux valves or magnetometers as heading source (on those aircraft, a magnetic variation data base is used to obtain the wind vector and for guidance purposes, since aircraft track from GNSS is determined in true reference).

The localizer beam is usually oriented along the runway centerline (some localizers are offset by a few degrees, restricted to CAT I and not usable for Autoland).

A 2.3. Radionavigation and magnetic/true reference

ILS approaches

The published course (088° magnetic or 091° true on the Figure 5) is used only as a reference for the guidance. To intercept and maintain the localizer axis, heading (or track) must be adjusted relative to the published course, taking into account the crosswind.

An ILS approach may be flown using magnetic or true reference, with no change in

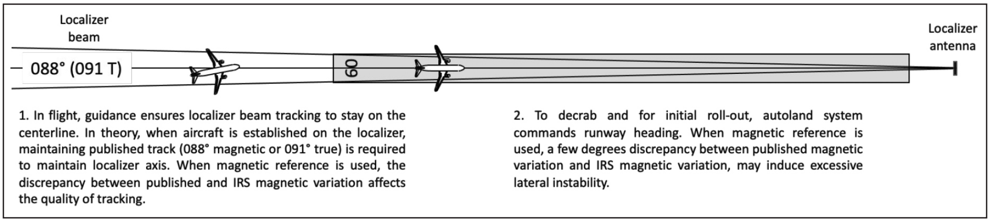

Figure 5: ILS approaches. © Jacques Verrière

the ground infrastructure or aircraft receiver. The only condition is to use the same reference (magnetic or true) for the localizer course and for heading.

If magnetic reference is used, discrepancies between published magnetic variation and variation used by navigation system (if the system uses track information coming from IRS or GNSS) or between published variation and actual variation (for aircraft using magnetic heading only), introduce some systemic error. When this error is small, it does not significantly affect localizer tracking, but if it becomes significant, it may induce some lateral instability.

This lateral instability may affect guidance during CAT II and CAT III operations, leading to unsafe conditions during Autoland and roll-out phases.

EASA has published an Airworthiness Directive applicable to A320 (AD 2003-270 B) family. It is stated that "a difference greater than 3° between the real magnetic deviation and the one implemented in the inertial reference system could lead to an unsafe situation during the phases of Cat 2 or Cat 3 automatic landing and roll out." This AD prohibits Autoland on a list of airports, until application of service bulletins corresponding to the update of IRS magnetic variation tables. A similar AD applicable to A330/340 aircraft has been published (AD 2006 – 0232).

In 2012, the FAA updated the magnetic variation of Anchorage airport (PANC) to reflect current values. This caused a mismatch between the magnetic variation used in various aircraft systems and the published magnetic variation. As a result, some Boeing aircraft experienced unacceptable lateral guidance when conducting CAT II and CAT III approaches. To rectify the problem, the FAA returned the magnetic variation to the incorrect (but aircraft usable) value, until the aircraft operators could update their IRS magnetic variation tables.

This latest example shows that when using magnetic reference, magnetic variation data used by aircraft systems do not need to reflect the reality, but they do need to be consistent with published magnetic variation used for procedure design.

Using magnetic reference, a discrepancy between published magnetic variation and IRS magnetic variation also affects HUD (Head Up display) symbology as well as synthetic vision. During ILS approaches, localizer deviation is used for synthetic runway symbol generation, since it is considered more accurate than a symbol generated from aircraft position determined by navigation system (FMS or GNSS stand-alone.

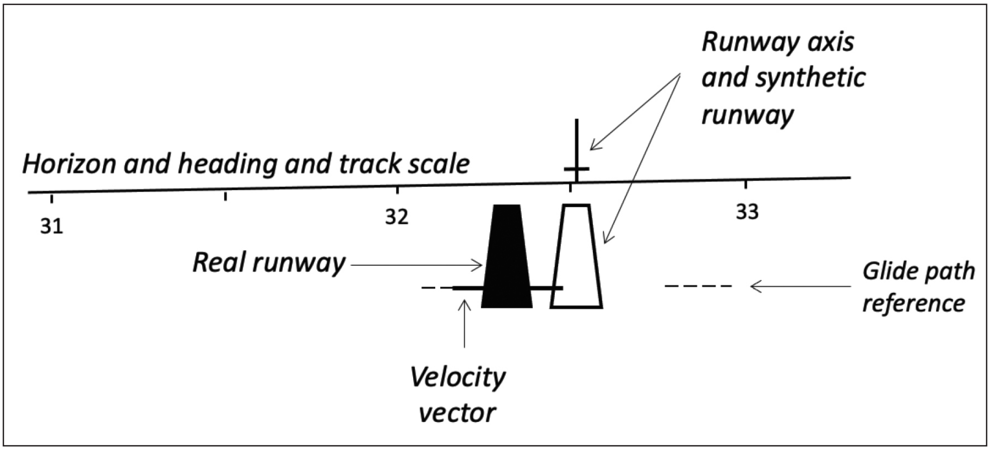

Figure 6: HUD symbology. *© Jacques Verrière*

Figure 6 presents HUD symbology in the case of a two degree discrepancy between IRS and published magnetic variations: when the aircraft is established on the localizer, in short final, the velocity vector is aligned with the real runway. However, the synthetic runway is aligned according to the published QFU (runway axis in magnetic reference) and a discrepancy introduces an offset between real runway and synthetic runway. As a consequence, the synthetic runway may be useless when transitioning from instruments to visual references and this may affect HUD symbology as well as synthetic vision systems (SVS).

Experience from use of HUD on Airbus A380: on ILS approaches, synthetic runway is presented with solid lines, while it is presented with dashed lines when a non-precision approach (NPA) is performed (established from aircraft position and runway coordinates). The logic is that without localizer information, position relative to runway centerline is less accurate. Experience has shown that it is not always the case: when performing ILS approaches, large offsets, representing several runway widths (larger than GNSS accuracy) were frequently observed (when performing NPA, some offset was frequently observed, but generally limited to half the runway width).

VOR (VHF Omni Range) navigation and approaches

A few decades ago, most airways were based on VORs and the latter were also used in terminal areas for approach guidance. Since PBN is now widely used, and RNP approaches offer better minima compared to VOR and VOR/DME approaches, VOR are used mainly as a back-up when GNSS signals are not available. VOR stations use VHF frequencies, and their range is in the order of a few hundred nautical miles, varying with the square root of altitude.

As shown on the Figure 7, the VOR signal allows for positioning of the aircraft on a radial relative to the station. This radial is defined in magnetic reference, except in the case of VOR located in regions where magnetic instruments are not usable, close to magnetic poles, as is the case in some areas of northern Canada.

VOR stations must be periodically calibrated and their signal aligned with magnetic north, due to magnetic variation evolution.

Use of VOR in true reference will require rotating their signals in order to be used in true reference (this will be a one-time operation, contrasting with periodic rotation required by magnetic variation evolution).

On board VOR receivers are usable regardless of the reference.

NDB (Non Directional Beacons)

NDB is an historic navigation system, invented in 1920. NDB ground stations, also called beacons, emit radio waves in MF band (from 190 to 1800 kHz). Aircraft receiver ADF (Automatic Direction Finder) provides a relative bearing to the beacon, which does not depend on the reference (magnetic or true).

The cost of NDB ground infrastructure is relatively low, but NDB suffers from relatively poor precision (errors in the order of 5°), high sensitivity to thunderstorm activity, ionospheric activity (also called night effect) and to static noise due to precipitations.

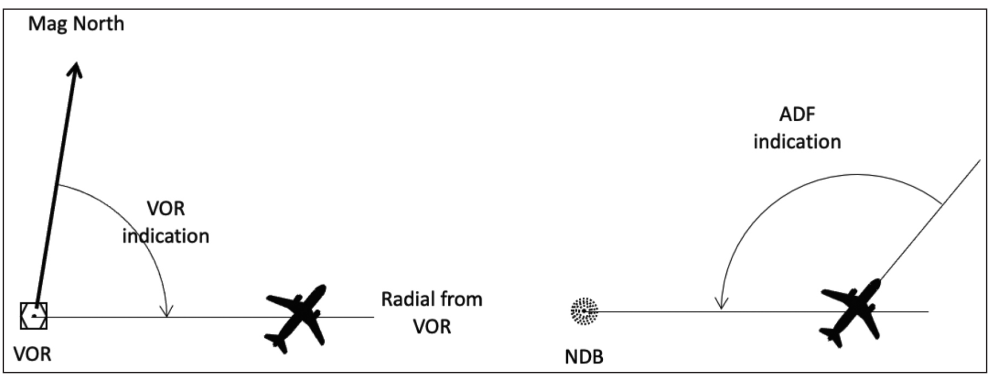

Figure 7: VOR receivers. © *Jacques Verrière*

From the iconic Douglas DC-3 to the Airbus A320 generation, ADF was a standard equipment for aircraft flying under IFR (Instrument Flight Rules). However, since GNSS receivers provide an accurate and affordable navigation system, most recent aircraft are not ADF equipped. However, NDB are still widely deployed in Europe (in the Single European Space Area, 806 NDBs were in service in 2021 but this number should decrease to 81 by end of 2030).

The use of NDB for navigation should decrease in the years to come due to lack of aircraft equipment (ADF) and decommissioning of NDBs. However, NDB are usable either using magnetic or true reference.

A 2.4. Flying with true reference

IRS equipped aircraft

As presented in paragraph 1 of this annex, IRS provides basically true heading and track information. However, in many aircraft, heading and track are presented in magnetic reference, using a magnetic reference data base embedded in IRS.

On most long-range airliners (examples: Airbus A330, 350, 380, Boeing 777, 787) and many current generation fighters, it is possible to switch from magnetic to true reference using a push button in the cockpit (switching from magnetic to true is automatic when latitude exceeds some predetermined value).

On most medium-range airplanes (examples: Airbus A320 and Boeing 737 families), there is no possibility to switch from magnetic to true.

For such airplanes, which constitute the majority of commercial airplanes, we can envision several technological solutions to fly with true reference:

- IRS and FMS software modifications can be developed in order to systematically display heading and track in true reference. Those modifications should be relatively straightforward for future versions of FMS and IRS, when true reference will be applied worldwide, since it is simpler to process heading and track data in true reference only, instead of introducing magnetic variation.
- For existing aircraft and equipment, we could obtain similar results by replacing IRS and FMS magnetic variation data bases by “empty” data bases considering 0° magnetic variation worldwide. However, modified airplanes would not be able to fly in magnetic reference. Concerning the IRS,as already mentioned, introducing a new data base (even containing only zeros) is a costly maintenance operation requiring some time

and logistic constraints, imposing a gradual retrofit which is not adapted to a fixed transition date for magnetic to true reference.

- Implementation of functions allowing to switch from magnetic to true and back, either through a push-button (similar to push-buttons used in long range airplanes) or by other interfaces such as multi function displays.

The last solution offers increased operational flexibility for the transition phase from magnetic to true reference:

- Aircraft may be modified before magnetic to true reference change is effective.
- Aircraft are able to switch from magnetic to true reference (and back) in flight, if the change of reference is not implemented at the same date in all airspaces.

AHRS equipped general aviation and regional aircraft

During the last decades, many general aviation (from light airplanes to business jets) and regional aircraft have been equipped with integrated avionics suites (examples: Garmin 1000, Collins Pro Line, Bendix King Aero Vue, Dynon Skyview…) using AHRS as the source for magnetic heading.

Without IRS, these systems rely on GNSS for position and track, and on magnetometers for heading. A magnetic variation data base is integrated in order to manipulate heading and track with the same reference (this is required to compute wind data).

Some systems are able to display heading and track in magnetic or true reference through system setup pages and are therefore compatible with true reference (that is the case for all Garmin systems). On other systems, this switch should be possible to implement through software modification.

Most recent AHRS, without magnetic sensors, basically provide true heading information. As a consequence, their situation is similar to IRS equipped aircraft.

Aircraft equipped with free or slaved directional gyros

Most recent GA and regional airplanes are equipped with integrated avionics suites but older airplanes and some light airplanes still in production are equipped with free or slaved gyros. Free gyros must be periodically aligned with magnetic compass indication (before take-off they may be aligned with the runway orientation).

The magnetic compass needs to be periodically calibrated and a compensation card

Figure 8: Compensation card. © Jacques Verrière

is presented with the compass to compensate compass errors (see photo, Figure 8).

To provide true heading indication, a simple solution for airplanes flying in a limited area of operation (such as France and neighbouring countries) would be to include the average magnetic variation in the area of operation in the compensation card (the systemic error introduced by the non-uniformity of magnetic variation would be acceptable considering the compass accuracy).

Slaved gyros are automatically aligned on magnetic north and to fly in true reference, gyro slaving must be disconnected and aligned with true heading.

As mentioned in the first paragraph of this chapter, compasses based on GNSS technology, providing an accurate true heading indication, are already available for marine applications. Similar systems could be developed for GA, at a relative low cost, replacing slaved gyros as they become obsolete and costly to maintain, the magnetic compass remaining the standby instrument in case of complete loss of electrical power.

VFR navigation

Basic VFR navigation method relies on the use of paper charts, dead-reckoning and visual identification of landmarks.

To navigate from point A to point B, the pilot draws a line on his chart to determine the course and distance and to identify landmarks (rivers, towns, highways, airports, railway tracks, ...). Since visual navigation charts are true north oriented, the course is obtained in true reference. It can be converted in magnetic reference using magnetic variation.

The pilot uses wind predictions (published in true reference) to compute its estimated ground speed and drift, to determine the magnetic heading from A to B, as well as the estimated flight time. That is the dead reckoning principle.

In flight, observing landmarks, it is possible to detect a deviation from the route and correct the heading.

This basic navigation method uses basically true north reference and magnetic variation is introduced to set the correct magnetic heading. A change of reference would not affect this method.

Pilots are still trained for basic VFR navigation, but GNSS systems are now widely used for VFR navigation: stand-alone VFR receivers with or without moving map, tablets with air navigation applications. Some applications are used also for flight preparation, providing courses, distances and estimated flight time.

GNSS provides true track information and, as for PBN, true reference is more adapted to its use.

A 2.5. Radar vectors, from magnetic heading to true track

Present situation

Under radar control, ATC may issue heading instructions as radar vectors. Heading instructions may be explicit or relative, a few examples are presented below:

- “Fly heading 090 degrees”.
- “Maintain present heading”.
- “Turn right 10 degrees”.
- “After departure, maintain runway heading”.

Most air traffic controllers issue radar heading instructions by multiples of ten degrees, sometimes with five degree precision (frequently in UK airspace but rarely used in other areas). This five to ten degree precision is compatible with the goal of radar vectoring: ensuring traffic separation and guide aircraft during initial and intermediate approach to intercept final approach course.

Magnetic heading instructions are issued for historical reasons: until 1990, track information was available only on IRS equipped aircraft, and track guidance was not available on autopilots and flight directors. However, air traffic control systems present track information (computed from radar data or transmitted by ADS-B) to air traffic controllers, usually in graphic form (ground speed vector).

Heading instruction is a substitute for ground track instruction: wind must be taken into account to compensate the drift, since the goal of radar vectoring is to impose a ground track (software based on wind models may provide some wind drift estimate to air traffic controllers). We must also note that wind varies with altitude and that drift is a function of aircraft speed.

After issuing heading instructions, air traffic controllers should check that airplane ground speed vector is coherent with expected trajectory.

Towards vectoring through ground track

In 2022, in the vast majority of aircraft, ground track information is available and presented to pilots. The logic would be to issue ground track vectors instead of heading vectors: if the air traffic controller wants the airplane to fly on a given track, logic dictates the issuing of a track instruction.

In most large airplanes, track guidance is available under autopilot and flight director (in Airbus airplanes, the flight director / autopilot TRACK mode ensures guidance to maintain a selected track).

In most light airplanes, a GNSS receiver provides a ground track information, which is more accurate and stable compared to the heading information from compass and directional gyro.

When considering the instructions listed above, with track vectors, they will become:

- “Fly track 090 degrees”.
- “Maintain present track”.
- “Turn right 10 degrees”.
- “After departure, maintain runway track”.

Loss of GNSS signal

We know that, in aircraft equipped with stand-alone GNSS equipment (without inertial reference), ground track information may not be available in case of GNSS signal outage or jamming. In the future, the use of DFMC receivers should limit the probability of GNSS signal outage.

Even if loss of GNSS signal has a relatively low probability, contingency procedures should be established in case of loss of GNSS track information, this could include:

- Estimation of drift by pilots, to fly on the desired track using heading information. This is the basic method used by VFR pilots to fly between airports without navaids and experience shows that this method is usually compatible with the usual vectoring precision (five to ten degrees).
- Heading guidance request by pilot.

ANNEX 3: AIR NAVIGATION SERVICES AND AIRPORT OPERATIONS

A 3.1. Charting

For the Air Navigation Service Providers (ANSPs), the first impact of changing the reference for the bearings, tracks and radials from magnetic north to true north concerns the published charts. Today all the published charts use magnetic north as reference. However, in the ICAO Annex 4 (Aeronautical Charts) it is indicated that it is possible to publish, on the PBN procedure charts, in addition to the magnetic values, the value referenced to true north. On the example presented on the attached chart, final approach course is published in magnetic and true reference (all other courses are published in magnetic reference).

In the current situation (magnetic reference), ANSPs must update regularly the published charts and procedures to cope with constant changes in the direction of magnetic north.

Presently, most approach charts published in France have been updated with the magnetic variation established in 2020: magnetic variation is not measured but

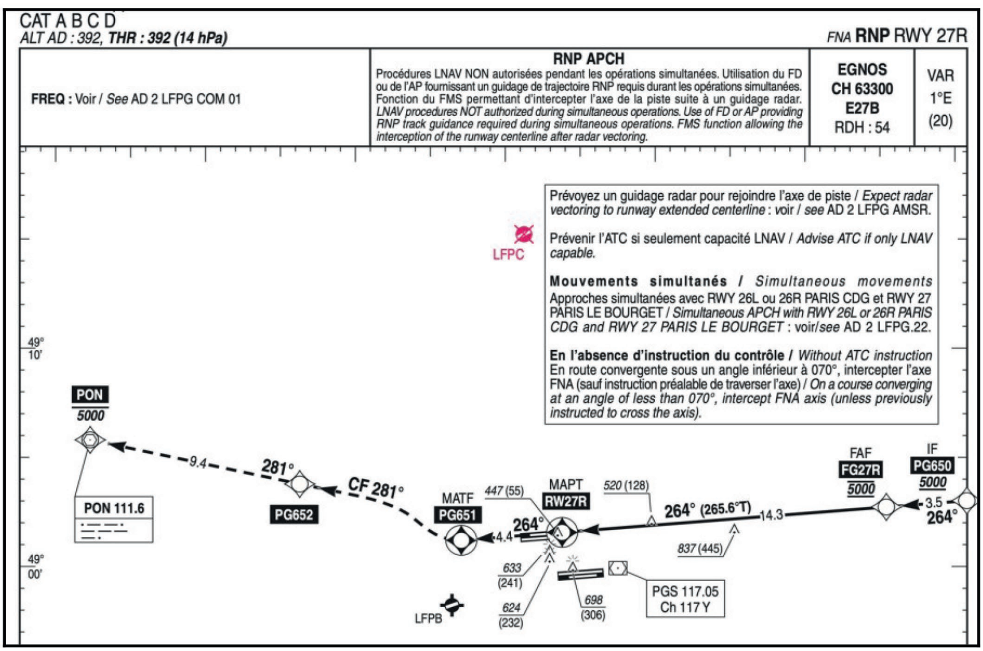

Figure 9: Final approach chart for RNP RWY 27R approach (LFPG - Paris CDG). © SIA France

established according to a model representing Earth's magnetic field (cf. Annex 1), the value which is presented, 1° E on the chart in Figure 9, is defined for a five year period (2020 to 2025). Some approach charts still present magnetic variations established according to the 2015 model, and a few visual charts for general aviation airports still give a value established in 2010.

In some countries, ANSPs do not update their magnetic variation data frequently. In the previous decade, one airline, when flying for the first time to an airport in Africa, observed a discrepancy exceeding 10° between published QFU and heading when the aircraft was lined up before take-off.

Using true north reference will eliminate the need to update the charts regularly due to the change of magnetic variation, reducing significantly the volume of documentation updates. However, ANSPs will have to anticipate the switch from magnetic to true reference. To anticipate the transition period, one solution would be to generalize the publication of courses and headings in dual reference (magnetic and true), since some ANSPs are already producing some charts with dual references as shown in Figure 10.

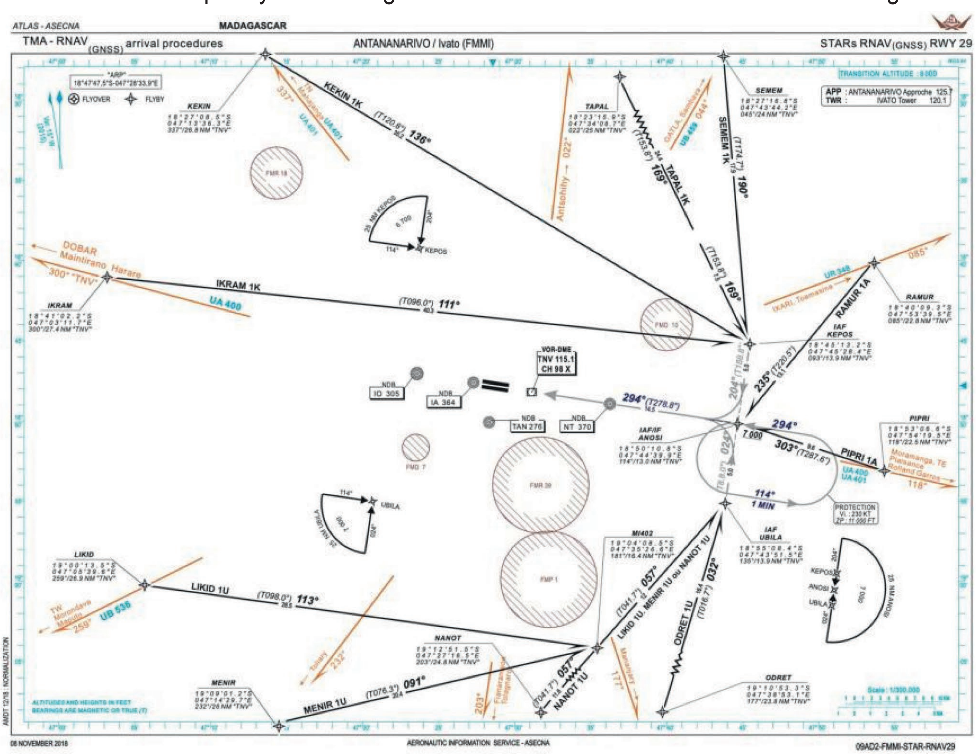

Figure 10: Arrival chart (RNAV STARS) for runway 29 in Antananarivo (FMMI), published by ASECNA: courses between WPTs are published in magnetic and true reference. *© ASECNA*

A 3.2. Ground infrastructures

VOR (VHF Omni Range) stations

VOR stations transmit radial information that is referenced to magnetic north: when the direction of magnetic north changes, it is necessary to realign VOR antennas (Nav Canada maintains VOR alignment within plus or minus 2° of magnetic north).

The switch to true north reference will eliminate the need for periodic realignment but, since it is not possible to realign all VOR stations simultaneously, the realignment of VOR with true north reference will have to be planned carefully in order to maintain a minimum number of VOR operative, in coordination with the decommissioning of VOR stations: more than half of VOR in service in 2021 should be decommissioned by end of 2030 to maintain a Minimal Operational Network (MON). According to the CNS Advisory Group Report in the Single European Space area, 586 VORs are in service in 2021 and this number should decrease to 273 by end of 2030.

In the transition period, we will need to clearly identify:

- The VORs usable only in magnetic reference;
- The VORs usable only in true reference;
- The VORs usable in both references.

The latest category depends on the allowable deviation. If we allow a 2° tolerance on VOR alignment, it will be possible to use VOR with both references in areas where magnetic variation is less than 4°, as is the case for a large part of Western Europe. If we consider a lower tolerance, the number of VORs usable in both references will be limited to regions where the variation is close to 0°.

One way to clearly identify the usable reference would be to add a letter to the VOR identification. For instance: PGS VOR (on the above chart) will become PGSM if only usable in magnetic reference, PGST if only usable in true reference or PGSB if usable with both references. However, this would require a modification of ICAO Annex 10.

Air traffic surveillance

Information from air traffic surveillance radars, displayed to air traffic controllers, is referenced to magnetic north and must be periodically realigned. Switching from magnetic to true north reference will require software changes.

ADS-B is used in regions with no reliable radar coverage such as oceanic areas (over North Atlantic, ADS-B data are transmitted via low Earth orbit satellites), in the United States, ADS-B is mandatory in class A, B and C airspaces and in class E airspace above FL 100, in Europe ADS-B is mandatory for airplanes with a maximum take-off weight greater or equal to 5.7 t or cruising speed higher than 250 kt (from December 2020 for new airplanes and from 2023 for airplanes produced before December 2020).

Aircraft position (from GNSS) is transmitted by ADS-B (Group 1: mandatory parameter), ATC may derive track information from successive positions or use ground track information transmitted by ADS-B (Group 2: desirable parameter), which is considered as more accurate. Ground track information is obtained in true reference through aircraft position or from GNSS, and magnetic variation must be taken into account to obtain ground track in magnetic reference.

Magnetic heading may also be transmitted by ADS-B, but this information is classified as optional (Group 3) and transmitted only when ground track vector (from GNSS) is not available. To be in accordance with transition from magnetic to true reference, this will require a parameter change from magnetic to true.

Airport operations: runway identifiers

Runways are identified by their magnetic orientation divided by ten: if magnetic orientation is 264°, the identifier is 26. In case of parallel runways, letters L (left), C (centre) and R (right) may be used. However, on airports such as Paris CDG or Atlanta, with more than three parallel runways, identifiers may not correspond exactly to runway orientation: in Figure 1, we see that magnetic orientation for runway 27 L (and 27 R) is 264°, the same as for runway 26 L and R.

Due to the evolution of magnetic variation, runway identifiers change periodically. This has some impact on charting but also on marks and signs on ground: runway identifiers are painted at runway thresholds and posted at all runway holding positions.

Switching from magnetic to true reference will eliminate the need to regularly change runway identifiers. In 2021, AHRTAG (Aviation Heading Reference Transition Action Group) conducted a survey of world runways. Using runway end and threshold coordinates, a geomagnetic model, and the published identifiers, it is possible to determine the identifiers that will need to be modified in case of transition to true reference, those which will need to be changed by 2030 if magnetic reference is still in use and those which are currently outdated.

Worldwide, 25,732 paved runways have been analyzed. Transition to true reference in 2030 would require modification of 14,416 runway identifiers (56 %).

Keeping magnetic reference until 2030 would mean modifying 8,044 runway identifiers (31 %), while 5,656 runway identifiers (22 %) are currently outdated.

Switching to true reference will increase the number of changes in runway identifiers, but we must keep in mind that it will be a one-time operation, compared to regular changes in the present situation.

In Western Europe, considering the present values of magnetic variation, switching from magnetic to true reference by 2030 would require changing only a limited number of runway identifiers. The survey identified 603 runways in France: 78 identifiers (13 %) are currently outdated, and by 2030, 154 (26 %) will need to be changed if magnetic reference is maintained, while only 31 (5 %) will require changing in the case of transition from magnetic to true.

An example in France: LFAQ (Albert Bray) runways orientation is 85.4 / 265.4 true, the present designation is 09/27, but it corresponds to magnetic variation 0° established according to 2015 model. We can consider that this designation is outdated since the present magnetic variation is 1° east and runways should be designated 08/26. If transition to true is decided by 2030, it would be preferable to keep the present designation 09/27.

Due to costs and logistics associated with runway identifiers, it will probably take several years to rename all runways to be in accordance with true reference. This should not be a major concern for safety, since, as mentioned above, in the present situation some identifiers do not reflect the magnetic orientation. As shown in the case of runway 27R at CDG presented on Figure 9, some runway identifiers are not exactly in accordance with runway orientation and there is no known incident associated with this situation.

As an example, Atlanta airport (KATL) has five parallel runways with magnetic orientation 95°/275° (08 - 26 L/R, 09 – 27 L/R and 10 – 28), and, in the case of runway 08 L(R) / 26 R(L), there is a 15° difference between runway identifier and magnetic orientation.

A 3.3. Transition from magnetic to true

In order to generalize the use of true north, it is better to work on a regional basis than country by country and transition from magnetic to true should be implemented in a coordinated way. ICAO is the best framework within which to set up this coordination, as was already done for the RVSM transition, in Europe with Eurocontrol support.

Procedures should be established to fly from a region where the reference is true north to a region where the reference is magnetic (or back), in particular if the magnetic variation is significant. Even if the Canadian experience is not directly applicable to other areas, it should be examined, since there are 39 airports in Canadian North Domestic Airspace (NDA), where true north reference is used, with flights operating daily between NDA and SDA (South Domestic Airspace), where magnetic reference used.

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