International Civil Aviation Organization

Eighth Meeting of the Performance Based Navigation Sub-Group (PBN SG/8)

(Doha, Qatar, 12 - 13 December 2023)

Agenda Item 4: PBN Planning and Implementation in the MID Region

VULNERABILITIES OF BARO-VNAV APPROACHES

(Presented by the secretariat)

SUMMARY

Recent incidents have highlighted that an erroneous altimeter setting can have serious consequences on flight safety during final approach operations. This working paper outlines the risks related to altimeter setting errors, in particular, during APV Baro-VNAV and non-precision approach operations and proposes a plan to mitigate altimeter setting errors.

Action by the meeting is at paragraph 2.

REFERENCES

- State letter Ref: ME 3/2.4 – 23/210
- State letter Ref.: ME 3/2.4 – 23/225
- Seventh meeting of the Navigation Systems Panel (NSP/7) report
- UK CAA SN–2023/003
- EASA SIB No.: 2023-03

1. INTRODUCTION

1.1 ICAO Assembly Resolution A37-11 urged that States include in their PBN implementation plan provisions for implementation of approach procedures with vertical guidance (APV) to all runway ends serving aircraft with a maximum certificated take-off mass of 5 700 kg or more, according to established timelines and intermediate milestones.

1.2 ICAO has also defined a specific strategy for approaches in its Annex 10 Volume I: “e) promote the use of Approach with Vertical Guidance (APV) operations, particularly those using Global Navigation Satellite System (GNSS) vertical guidance, to enhance safety and accessibility.”.

1.3 The definition of a vertical path and guidance along that path should minimize the possibility of the loss of situational awareness (SA) on the approach path. When a lateral and vertical path is defined, the pilot will fly the approach just like a precision approach and the APV is flown to a decision altitude/decision height (DA/DH). Positioning on the lateral path is using augmented GPS and on the vertical path using either barometric altimetry (an APV Baro) or geometric altimetry (an APV SBAS)

1.4 The use of Baro-VNAV to fly vertically guided PBN approaches is currently supported by the PBN Manual as RNP APCH down to LNAV or LNAV/VNAV minima and is included in GANP ASBU element NAVS-B03. The navigation technologies used for these approaches are GPS ABAS for lateral guidance, and a barometric system for vertical guidance. It is one of the enablers of PBN with vertical guidance approaches, and brings real safety benefits over LOC, NDB and VOR approaches.

1.5 Baro-VNAV based approaches are however significantly less robust than geometric PBN approaches enabled by GBAS (GANP ASBU element NAVS-B01) and SBAS (GANP ASBU element NAVS-B02).

1.6 Recent serious incidents have highlighted a concern on the effects of incorrect barometric altimeter settings when operating below the transition level. Operating with an incorrect altimeter setting could result in insufficient clearance with terrain and obstacles, or a loss of separation with other traffic, which may potentially lead to CFIT or mid-air collision.

1.7 This working paper outlines the risks related to altimeter setting errors, in particular, during APV Baro-VNAV and non-precision approach operations and proposes a plan to mitigate altimeter setting errors and raise awareness of the issues throughout the aviation community in MID Region.

2. DISCUSSION

2.1 Baro-VNAV is based on the combination of on-board Flight Management System (FMS) and GPS Airborne Based Augmentation System (ABAS) for lateral guidance with barometric vertical guidance. The barometric vertical guidance relies on the barometric-altimeter reference (QNH mostly) entered manually by the pilot. Approach procedures with vertical guidance (APVs) rely heavily on the accuracy of altitude information provided by the pressure altimeters.

2.2 Setting the correct barometric values involves several steps that may be subject to errors, including the following: the determination of the local barometric pressure by the meteorological service provider, the broadcasting of the local QNH (or QFE) through ATIS (where available), the radio transmission of the local QNH (or QFE) by Air Traffic Services to the flight crew, and, finally, the altimeter setting by the flight crew from 1013.2 hPa / 29.92 inHg to QNH (or QFE).

2.3 Incorrect barometric altimeter setting, however, could severely affect the safety margins protecting a variety of approach procedures that are based on the use of barometric altimetry for vertical navigation (e.g. RNP APCH to LNAV/VNAV minima, RNP AR APCH), or that are flown using the CDFA technique that rely on a BARO-VNAV equipment onboard to compute the vertical profile and to provide vertical guidance along the descent (e.g., NDB, VOR, LOC). In addition, it is highlighted that when using barometric altimetry for vertical navigation, altitude/distance cross checks in the Standard Operating Procedures do not detect an incorrect barometric altimeter setting.

2.4 On 23 May 2022, a serious incident occurred involving an Airbus A320 conducting an RNP BARO-VNAV approach to Runway 27R at Paris – Charles de Gaulle Airport (LFPG/CDG). During the approach, the aircraft encountered a 'near CFIT" event with incorrect QNH set and came within 6 feet of terrain approximately 1 NM from Runway 27R. The Preliminary Report has been issued by the Bureau d'Enquêtes et d'Analyses (BEA) and it is available at https://bea.aero/fileadmin/user_upload/BEA2022-0219_9H-EMU_preliminary_report_for_publication_EN_finalise.pdf

2.5 The subject has been brought forward to the seventh Navigation Systems Panel (NSP/7) (January, 2023), which supports the need to further promote awareness of BARO VNAV QNH setting errors, and current mitigations.

2.6 To raise awareness on the Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations, the Draft Guidance at **Appendix A** was developed for civil aviation regulators, Air Navigation Services Providers (ANSPs) to mitigate the risks related to altimeter setting errors, in particular during APV Baro-VNAV and non-precision approach operations.

2.7 Based on the above and with a view to sensitizing the MID aviation community to vulnerabilities of Baro-VNAV approaches, in particular their dependence on correct altimeter setting, the following Draft Conclusion is proposed:

> ***DRAFT CONCLUSION 8/1: Guidance related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations***
>
> *That, States and stakeholders be invited to review the Draft Guidance at* ***Appendix A****; and provide comments/inputs to the ICAO MID Office before 15 January, in order to consolidate the final version for endorsement by MIDANPIRG/21.*

3. ACTION BY THE MEETING

3.1. The meeting is invited to :

a) note the information provided;
b) review and amend as necessary, the Draft Guidance at **Appendix A**; and
c) endorse the Draft Conclusion at paragraph 2.9.

– END –

#

Guidance on Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations

Date: December 2023

Disclaimer

This document has been compiled by the MID Region civil aviation stakeholders to raise awareness on the Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations by providing guidance for civil aviation regulators, Air Navigation Services Providers (ANSPs) to mitigate the risks related to altimeter setting errors, in particular during APV baro-VNAV and non-precision approach operations.

It is not intended to supersede or replace existing materials produced by the National Regulator or in ICAO SARPs. The distribution or publication of this document does not prejudice the National Regulator's ability to enforce existing National regulations.

This guidance material should be thorough, accessible, and regularly updated to reflect changes in technology and regulations. It should serve as a valuable resource for aviation authorities, operators, and pilots to enhance safety during APV Baro-VNAV operations.

To the extent of any inconsistency between this document and the National/International regulations, standards, recommendations or advisory publications, the content of the National/International regulations, standards, recommendations and advisory publications shall prevail**.**

TABLE OF CONTENTS

Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations

1. BACKGROUND

1.1 Using an erroneous barometric reference setting during approach may cause the aircraft to fly lower than the published approach path, when the vertical guidance and trajectory deviations use the barometric reference. This can lead to a risk of controlled flight into terrain in poor visibility conditions or at night.

1.2 Recent incidents have highlighted that an erroneous altimeter setting can have serious consequences on flight safety during final approach operations.

1.3 This safety advisory explains the potential consequences of an erroneous barometric reference. It aims to draw renewed and refreshed attention to the risk of Controlled Flight into Terrain (CFIT) when flying instrument approach operations with the pressure altimeter sub-scale set to an incorrect pressure setting and provides a set of recommendations to mitigate altimeter setting errors.

2. RISKS

2.1 The technical characteristics of the altimeter induce two risks that could lead to the determination of an erroneous altitude:

a) The incorrect altimeter setting;
b) The temperature effect (difference between the real atmosphere and the standard atmosphere).

2.2 Barometric altimeter setting errors can lead to significant altimeter deviations. Each 1hPa error equates to 28 ft of height difference; therefore, an altimeter setting error of 10 hPa would result in an altitude error of about 280 ft. The diagram below highlights what the situation might look like :

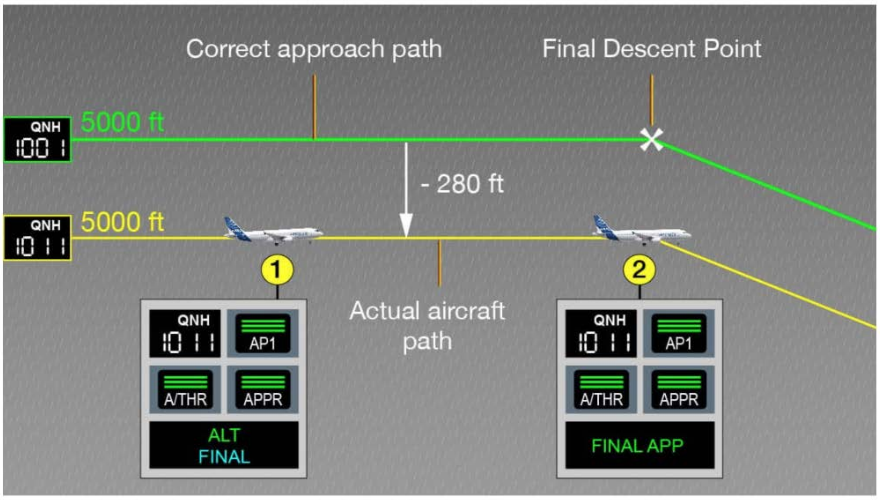

Figure 1 – Example of altitude deviation resulting from altimeter setting error

2.3 Temperature has an effect on the accuracy of barometric altimeters, indicated altitude, and true altitude. The standard temperature at sea level is 15 degrees Celsius. The temperature gradient from sea level is minus 2 degrees Celsius per 1,000 feet.

For example, if the OAT is - 40 °C then for a 2000 ft indicated altitude the true altitude is 1520 ft thus resulting in a lower than anticipated terrain separation and a potential obstacle-clearance hazard.

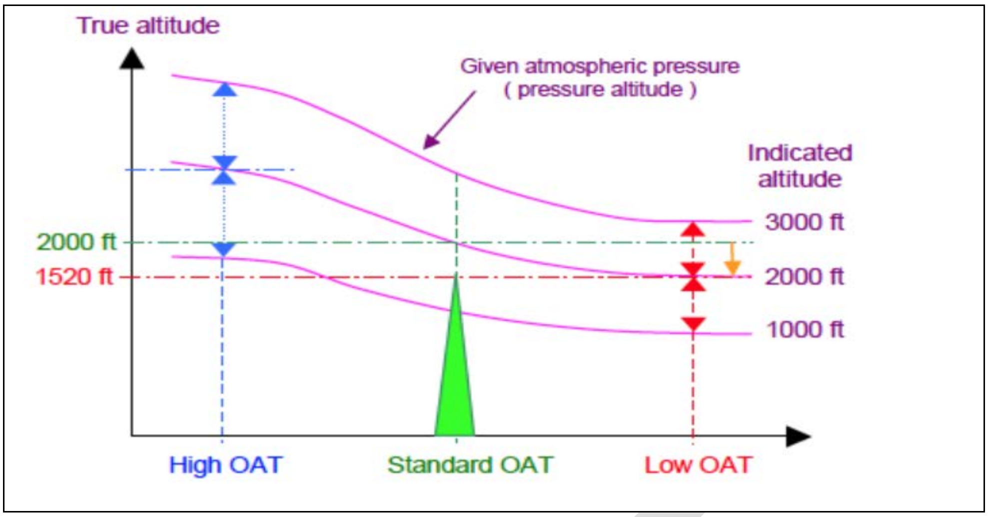

Figure 2 – Effect of Outside Air Temperature (OAT) on True Altitude

2.4 The effects of temperature can be anticipated because they are directly related to the deviation from the standard ISA temperature. They can lead to a reduction of safety margins, but technical solutions exist, as well as operational procedures, already in place, which allow to limit these effects, in particular by cold temperature corrections.

Note – Further guidance on the "RNP approach and RNP AR approach operations in non-standard temperature conditions" is available in the Performance-Based Navigation (PBN) Manual (Doc 9613), Fifth Edition, Volume II, Attachment B.

3. Final approach operations

3.1 The consequences of an erroneous altimeter setting will be more severe on the final segment of the approach for which the obstacle clearance margins are reduced. Most final approach operations can be affected by an erroneous altimeter setting. But they will not all be affected in the same manner.

3.2 ILS, SBAS (RNP APCH to LPV minima) or GBAS provide vertical guidance to the runway that is not dependent on barometric altitude. Once established on the glide path, an altimeter setting error will not affect the vertical profile. As a result, only the Decision Altitude (DA) based on barometric altitude, may still be subject to an error, such that the crew might make the decision either to land or go around higher or lower than expected, depending on the error of the altimeter setting.

3.3 On the other hand, non-precision approach procedures (NPAs) operated as either Dive & Drive (stepdown) or using a Continuous Final Descent Approach (CDFA) technique, as well as RNP APCH to LNAV or LNAV/VNAV minima and RNP AR operations rely heavily on the accuracy of altitude information provided by the pressure altimeters. If the appropriate pressure setting is set incorrectly on the altimeter sub-scale, the aircraft could be significantly above or below the safe vertical profile as determined by the procedure.

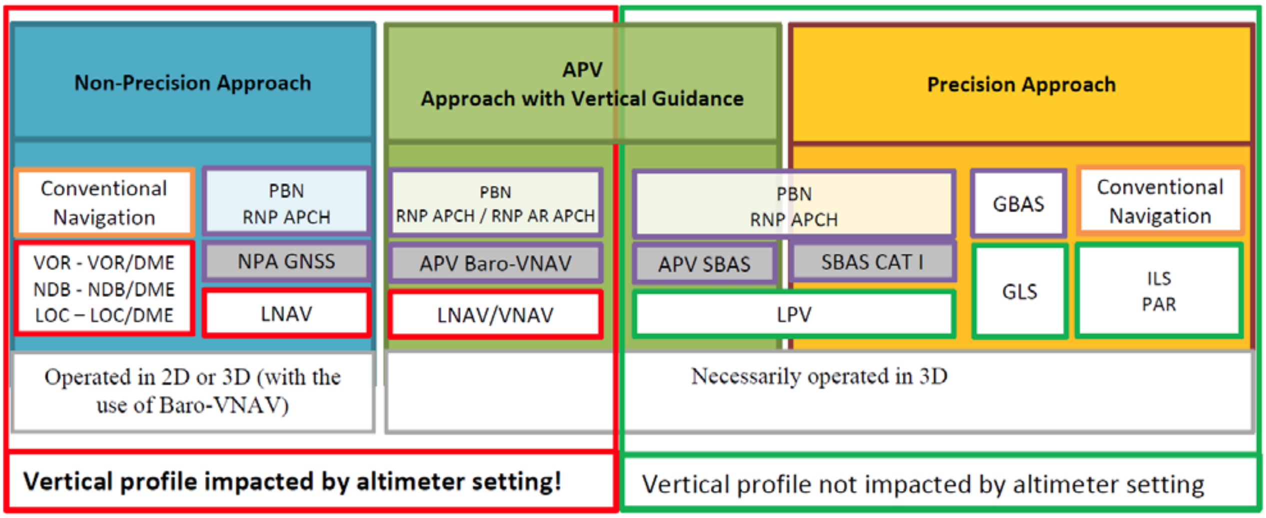

Figure 3 – Approach procedures and Altimeter setting

4. Approach Operations Utilizing Barometric Vertical Navigation (Baro-VNAV) Equipment

4.1 Baro-VNAV equipment can be used in two different scenarios to provide vertical guidance on a 3D approach operation:

a) Approach operations on APV procedures designed for 3D operations. In this case, the use of a baro-VNAV system is required.
b) Approach operations on non-precision approach procedures. In this case, the use of a baro-VNAV system is not required but auxiliary to facilitate the CDFA technique. This means that advisory VNAV guidance is being overlaid on a non-precision approach.

4.2 An undetected erroneous BARO setting can cause an aircraft to fly above or below the published final approach flight path when following approach guidance that uses a barometric reference. Vertical deviation indications are shown as correct, even if the aircraft is not on the correct flight path, with an incorrect BARO setting.

4.3 It is emphasised that a Terrain Awareness Warning System (TAWS) may not provide a ground proximity alert close to an aerodrome when the aircraft is in the landing configuration as shown the figure below.

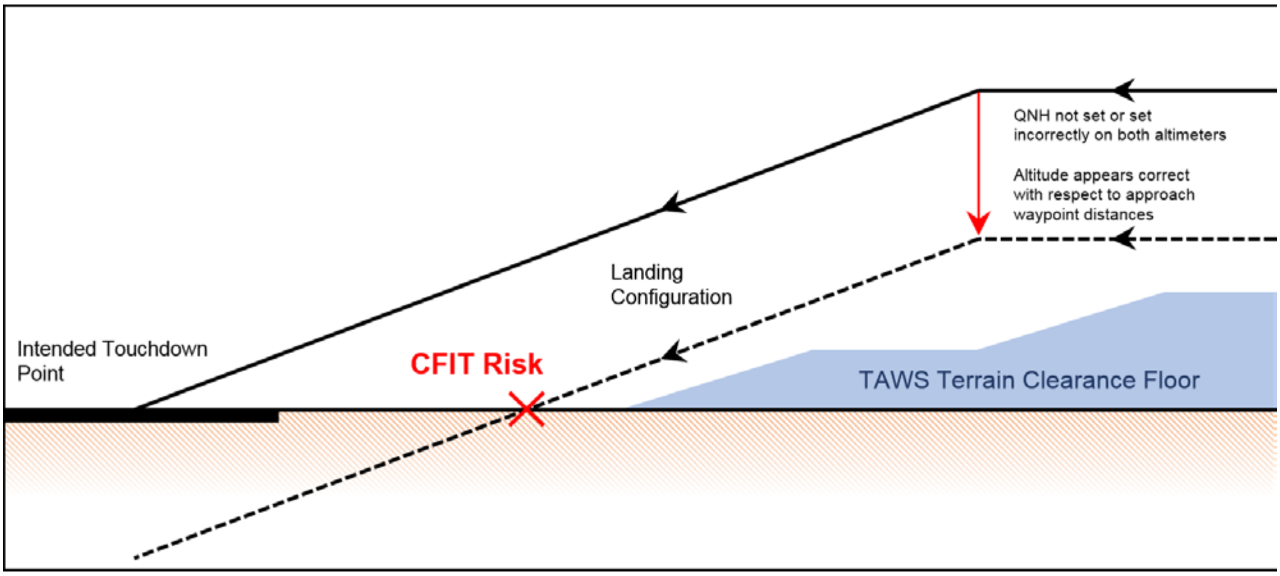

Figure 4 The TAWS may not detect a too low flight path

4.4 It is particularly worth highlighting that when using barometric altimetry for vertical navigation, altitude/distance cross checks in the standard operating procedures do not detect an incorrect barometric altimetry setting. Standard altitude-vs-distance checks will wrongly confirm that an aircraft is on the correct trajectory, because it uses the same erroneous barometric reference. If visual conditions are not sufficient, the flight crew may not be able to detect that their aircraft is on an incorrect flight path in time to adjust their trajectory or perform a go-around.

4.5 Baro-VNAV approach operations shall only be flown with a current local altimeter setting source available and the QNH/QFE, as appropriate, set on the aircraft’s altimeter. Baro-VNAV procedures shall not be authorized with a remote altimeter setting.

5. Operations at temperatures differing from ISA

5.1 Non-standard temperatures affect the measurement of pressure altitude by the aircraft’s barometric altimetry systems. The measured pressure altitude can then negatively impact the actual vertical flight path and the VNAV guidance an aircraft’s RNP system provides during RNP APCH and RNP AR APCH operations. During cold temperatures the aircraft’s vertical path can be lower than indicated and reduced enough to potentially compromise the vertical protection procedural barometric altitudes provide during an instrument approach. In contrast, during hot temperatures, the aircraft’s vertical path can be higher than indicated and result in aircraft VNAV guidance for a vertical path that is actually steeper than desired, potentially creating difficulties for energy management on the final approach segment.

5.2 Operations at temperatures differing from ISA will cause Barometric Temperature Error. Even a small difference from ISA temperatures can cause the approach flightpath to be steeper or shallower than published. Whilst this is allowed for in instrument procedure design within charted limits, it changes the relationship between indicated Barometric Altitude and Radio Altitude (RA) during the approach. This might make it more difficult to detect a mis-set QNH or could give the appearance of a mis-set QNH when in fact the flightpath error is caused by non-ISA temperatures. The diagram below refers.

5.3 The effects of temperature can be anticipated because they are directly related to the deviation from the standard ISA temperature. They can lead to a reduction of safety margins, but technical solutions exist, as well as operational procedures, already in place, which allow to limit these effects, in particular by cold temperature corrections.

Note – Further guidance on the “RNP approach and RNP AR approach operations in non-standard temperature conditions” is available in the Performance-Based Navigation (PBN) Manual (Doc 9613), Fifth Edition, Volume II, Attachment B.

6. Operational and Human Factors Involved in Altimeter-setting Errors

6.1 The following operational and human factors as causes of or contributing factors to altimeter-setting errors :

- Incorrect determination of the local barometric pressure, use of regional pressure instead of local barometric pressure values or transmission of a wrong value by the meteorological service provider,
- Provision of incorrect QNH through ATIS (where available)
- Ineffective ATC-Pilot communication, such as: wrong value given by ATC, incorrect read back not detected by ATC, radio/frequency issue, etc.
- Incorrect selection of the altimeter setting by the crew due to different factors such as: high workload during descent / approach, confusion in the unit of the barometric setting (Inch Hg instead of hPa), confusion between QNH and QFE, absence of effective crosscheck between crew members, flight deck system failure, etc.

7. Mitigation Actions

7.1 Aircraft operators and ANSPs are reminded of the importance of ensuring that the correct barometric altimetersetting is provided and entered in the aircraft’s systems.

7.2 Some mitigations are as follows:

<u>At aircraft operator’s level</u>

- Encourage the use of those 3D operations where final segment profiles cannot be impacted by wrong barometric altimeter setting (ILS, RNP APCH down to LPV minima, GLS).
- Establishment and strict adherence to the standard operating procedures for the use of the VNAV function.
- Consider adjusting the operating minima by taking into account the operational exposure and/or crew experience with approach procedures that are vulnerable to QNH errors.
- Apply Crew Resource Management techniques, such as cross-checking and monitoring.
- Consider altitude callouts, whereby the aircraft's radio altimeter can provide height callouts to the pilot when passing specific values (e.g. 500 ft and 1000 ft), which can be interpreted to assess whether the

aircraft is deviating from the intended vertical profile. This mitigation is more effective when the terrain is relatively flat.

- Configure correct QNH in all altimeters (main, standby) and FMS. The flight crew should pay attention to a barometric reference that significantly differs from the one used for approach preparation. That could be the symptom of a barometric reference error. The flight crew should consider cross-checking of the barometric references from all available sources (METAR, ATIS and ATS).
- Apply standard communication and phraseology between the pilot and air traffic services.
- Pilots should use effective Threat & Error Management (TEM) techniques to identify and mitigate against incorrect altimetry when preparing to fly an approach that relies directly on an accurate pressure altimeter sub-scale setting (e.g. use of Baro-VNAV, non-precision approaches).

<u>At ANSP level</u>

- Consider fixed and harmonized transition altitudes/levels which can harmonize the switch from 1013.2 hPa to QNH.
- Consider using the barometric pressure settings provided by Mode S EHS (Enhanced Surveillance) and ADS-B equipped aircraft, to enable the timely identification of aircraft operating with incorrect barometric altimeter setting.
- Consider introducing procedures to provide aircraft with the QNH at different phases of approach, including when clearing an aircraft for the approach or at first contact with the tower.
- Apply standard communication and phraseology between the pilot and air traffic services.

<u>Technical solutions</u>

- Consider using those 3D approach procedures where the final segment cannot be impacted by wrong QNH setting (ILS, RNP APCH down to LPV minima or GLS).
- Use of recovery safety nets, such as Minimum Safe Altitude Warning (MSAW) and Approach Path Monitor (APM) by ATC and Terrain Avoidance and Warning System (TAWS) by pilots, which can alert actors and thus lead to recovery actions associated with operational procedures.
  Note – these safety nets are not available in all aircraft or ATS units and their technology varies from one site to another. Their intrinsic characteristics, in particular resulting from choices intended to limit the false alarm rate, lead them, in certain cases, not to be triggered, without this being a malfunction. To get the most consistent alerts, aircraft operators should ensure that the latest available software version and the latest terrain and obstacle database are loaded in the TAWS.
- Consider the use of datalink for transmission of MET information, including QNH, to aircraft.
- Consider other emerging monitoring solutions that would offer comparison between barometric altitude with GNSS-driven altitude.

8. RECOMMENDATIONS

8.1 In order to better manage the risks related to altimeter setting errors, in particular during APV Baro-VNAVand non-precision approach operations, the followings are recommended:

a) General recommendations:

- to ensure that awareness of the risk of altimeter setting errors and their consequences is shared;
- to assess the robustness of the mitigation measures described in the previous point, and to consider implementing them, when relevant;
- to report all situations that have generated deviations in order to improve the visibility of this type of event, preferably with a perspective of the appropriate treatment in each case;
- to contribute collectively to training on this risk, to disseminate best practices and to promote exchanges between domains in order to better understand the limits of the systems;
- MET Service providers to ensure provision of quality-assured MET information to users;
- aircraft operators, to investigate methods to identify incorrect altimeter setting with the Flight Data Monitoring (FDM) Program; and

- Relevant ANC Panel(s), to assess the potential review of APV Baro-VNAV criteria concerning thelikelihood of QNH errors.

b) Recommendations on Training:

- Barometric altitude setting is largely dependent on human factors. Therefore, it is recommended to consider appropriate initial and recurrent training subjects to pilots and ATCOs, including the following:

  For pilots:

  - Initial and recurrent training should address the limits of barometric altimetry, and the impact of incorrect barometric pressure settings on vertical position including those factors outlined inthis bulletin.
  - Training and/or promotional initiatives on altimeter setting procedures, different impacts of QNH errors between geometric and barometric approaches and possible mitigation measures, use of standard phraseologies, adhering to read back and hear back, etc.
  - Training on 3D operations including the difference between 3D depending on Baro-VNAV and other 3D approach operations, highlighting the critical importance of Barometric setting for Baro-VNAV operations.
  - Training on 3D RNP operations highlighting the RNP chart layout where LNAV/VNAV and LPV minima co-exist.

  For ATCO:

  - Initial and recurrent training should address the limits of barometric altimetry, and the impact of incorrect barometric pressure settings on vertical position including those factors outlined inthis bulletin.
  - Training and/or promotional initiatives on altimeter setting procedures, different impacts of QNH errors between geometric and barometric approaches and possible ATC mitigation measures on erroneous setting of altimeter setting by flight crew, use of standard phraseologies for transmitting QNH information to pilots, paying attention to pilots' read back and hear back, etc.

- Flight Crew and Air Traffic Control Officer (ATCO) training should include how, why, and when MSAW (Minimum Safe Altitude Warning) alerts are generated as well as necessary actions and R/T calls as set out in PANS-ATM Doc 4444.

References

- ICAO Annex 3 – Meteorological Service for International Air navigation
- ICAO Annex 5 – Units of Measurement
- ICAO Annex 6 – Operations of Aircraft, Part I – International Commercial Air transport – Aeroplane,
- Procedures for Air Navigation Services – Rules of the Air and Air Traffic Services (PANS-ATM, Doc 4444).
- ICAO – Procedures for Air navigation Services – Aircraft Operations (PANS-OPS, Doc 8168), Volume I – Flight procedures
- EUR OPS Bulletin Serial Number: 2023_001
- EASA SIB No.: 2023-03
- UK Civil Aviation Authority SAFETY NOTICE Number: SN–2023/003
- Airbus Approach & Landing Briefing