International Civil Aviation Organization
ICAO South American Regional Office
Seventeenth Meeting of the Civil Aviation Authorities of the SAM Region (RAAC/17)
(Santiago, Chile, 10 to 14 April 2023)

Agenda Item 4A: **Initiatives for the Development and sustainability of air transport in the Region**

PBN implementation in France: a return of experience

(Presented by France)

SUMMARY

In recent years, France has implemented on a wide scale PBN procedures within Metropolitan France airspaces, in particular for approach and landing operations. These projects are in line with the EU regulation which aims at an exclusive use of Performance Based Navigation (PBN) in the airspace of EU Member States for all operations, including Cat I landings, by June 2030
In this context, France benefits from an important return of experience in PBN approach operated through Satellite Based Augmentation System (SBAS) and Barometric Vertical Guidance Navigation (BaroVNAV).
The integrity and precision of the SBAS signal used both in lateral and vertical guidance ensure a high level of safety of SBAS PBN approaches within a wide geographical area. SBAS also has the capability to support Cat I operations when conventional navigation systems such as ILS are not available.
The barometric vertical guidance in BaroVNAV relies on the barometric-altimeter reference manually entered by the pilot. Recently, France has seen an increase in the occurrence of serious BaroVNAV approach incidents due to human errors.
Based on a working paper presented by France on the BaroVNAV incidents, the ICAO EURNAT Europe Aviation System Planning Group (EASPG) has decided to draft an ICAO EUR OPS Bulletin on the vulnerabilities of BaroVNAV approaches.
The RAAC is invited to:
a) Note the content of this working paper;
b) Consider the ICAO EUR OPS Bulletin regarding the vulnerabilities of BaroVNAV when it is published;
c) Consider the integrity and precision capabilities of SBAS and the safety issues of BaroVNAV in the implementation and operations of PBN approaches in the SAM region.

References:
- ICAO Annex 10 Volume I
- PBN Manual
- GANP ASBU element NAVS

***ICAO Strategic Objectives*:**	- Safety - Air Navigation Capacity and Efficiency

1. Introduction

1.1 The implementation of Performance Based Navigation (PBN) is of great interest to support precise and advanced trajectories within airspaces. ICAO has 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*".

1.2 France fully subscribes to the ICAO specific strategy for approaches in the implementation of PBN and has published PBN approaches for a majority of its IFR runway-ends following EU regulation.

1.3 In the European Union, the regulation (EU) 2018/1048 on Airspace usage requirements and operating procedures concerning PBN requires Members States to:

i. deploy PBN for all phases of flight in approach and en-route by 25 January 2024,
ii. reduce conventional navigation infrastructure,
iii. implement the "*exclusive use of PBN*" rule for all operations, including Cat I landings, by June 2030.

1.4 The last requirement means that, by June 2030, EU Members States will ensure Cat I landings with SBAS and no longer with ILS[1].

1.5 In recent years, under the EU regulation, France has developed and implemented on a wide scale PBN procedures within Metropolitan France airspaces, in particular for approach and landing operations.

1.6 The implementation of PBN approach operations is supported by the publication of Required Navigation Performance Approach (RNP APCH) charts on aerodromes with LNAV (Lateral Navigation) or LNAV/VNAV (Lateral/Vertical Navigation) minima. Two technical solutions, the Satellite Based Augmentation System (SBAS) and Barometric Vertical Guidance Navigation (BaroVNAV), are used to meet the requirements for PBN approach operations.

1.7 France has the largest number of IFR runway-ends in Europe and has seen recently an increase in the number of airspace users flying PBN landings. Consequently, France benefits from a wide return of experience on the use of both SBAS and BaroVNAV in PBN approach operations.

2. Discussion

<u>Satellite Based Augmentation System (SBAS)</u>

2.1 SBAS is a wide area differential GNSS signal augmentation system, which uses geostationary satellites. It can broadcast on vast areas primary GNSS data, provided by a network of ground stations with ranging, integrity, and correction information.

2.2 The SBAS signal is designed with a very high level of integrity requirements as defined in ICAO Annex 10 Volume I. The integrity and precision of the SBAS signal both in lateral and vertical guidance ensures a high level of safety for SBAS PBN approaches within wide area airspaces.

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[1] The European Union Aviation Safety Agency (EASA) has recently warned aircraft operators of the risk of losing Cat I landings capability in Europe after June 2030 unless they upgrade their aircrafts avionics (https://www.easa.europa.eu/en/newsroom-and-events/news/easa-publishes-communication-aircraft-operators-pbn-implementation).

SBAS has the capability to support Cat I operations, which is very useful when conventional navigation systems, such as ILS, are not available. For secondary runways and secondary aerodromes, SBAS brings a high level of improvement in terms of safety of landing operations and aerodrome accessibility, without requiring local infrastructures.

2.3 Outside of the aviation field, SBAS usage can be extended to e.g., the maritime field, road and rail transports, precision farming. Being a multimodal infrastructure with wide-range benefits for citizens, experience has shown that SBAS signals are provided free of direct user charges to all users, including in aviation. This feature makes SBAS more cost-effective compared to other satellite-based landing technologies, such as the Ground Based augmentation System (GBAS) for which aviation users have to cover the costs of procurement, installation, and certification of the ground stations.

Barometric Vertical Guidance Navigation (BaroVNAV)

2.4 BaroVNAV 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.

2.5 Recently, several serious BaroVNAV approach incidents have occurred in France. These incidents on major French aerodromes are due to human errors when entering the local barometric altimeter reference (QNH) in the aircraft avionics.

2.6 Following the analysis of these incidents, France presented a working paper (see Appendix A) during ICAO EURNAT Europe Aviation System Planning Group meeting (EASPG/4) at the end of November 2022. This working paper summarizes the main facts and findings from these quasi-Controlled Flight Into Terrain (CFIT) in the use of BaroVNAV PBN approaches. As a conclusion to the meeting, EASPG has decided to draft an ICAO EUR OPS Bulletin on the vulnerabilities of BaroVNAV approaches. A working paper "*Issue with PBN implementation in France*" was also presented to ICAO Navigation System Panel meeting (NSP/7) in January 2023.The NSP concluded that communication around specific PBN technologies issues, such as BaroVNAV, was key and that it should be put under consideration to the ICAO Air Navigation Commission.

2.7 Furthermore, BaroVNAV PBN approach does not meet the requirements in precision to ensure Cat I landings.

3. **Suggested action**

3.1 The RAAC is invited to:

a) Note the content of this working paper,
b) Consider the ICAO EUR OPS Bulletin regarding the vulnerabilities of BaroVNAV when it is published,
c) Consider the integrity and precision capabilities of SBAS and the safety issues of BaroVNAV in the implementation and operations of PBN approaches in the SAM region.

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European and North Atlantic Office

EUROPEAN AVIATION SYSTEM PLANNING GROUP

FOURTH MEETING

(Paris, France, 29 November - 1 December 2022)

Agenda Item 3: Safety

Agenda Item 4: Air Navigation Planning and Implementation

BARO-VNAV APPROACHES

(Presented by France)

SUMMARY

Baro-VNAV approaches provide significant safety benefits over legacy LOC, NDB and VOR approaches. They can also enhance safety at unequipped runway ends.

Baro-VNAV approaches are however significantly less robust than geometric PBN approaches enabled by SBAS, and GBAS, as evidenced by several Baro-VNAV related issues in France.

The main vulnerability of baro-VNAV approaches lies in their dependence on correct altimeter setting, which involves multiple human interventions. Other vulnerabilities exist, such as the risk of overestimating the precision of the vertical guidance.

It is proposed that an ICAO EUR bulletin be published, and also sent to States and international organizations, with a view to sensitizing the EUR aviation community to vulnerabilities of baro-VNAV approaches, in particular their dependence on correct altimeter setting.

1. Introduction

1.1 The use of baroVNAV 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.

1.2 This approach and landing capability is available over a large segment of the transport category aircraft (mostly Airbus/Boeing).

1.3 It is one of the enablers of PBN with vertical guidance approaches, and brings real safety benefits over LOC, NDB and VOR approaches.

1.4 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).

2. Discussion

2.1 Barometric vertical guidance was initially designed to fly continuous descents within TMAs. It was later promoted as an advisory system during laterally guided approaches, and eventually a final approach landing PBN system, in the mid-2000, as an opportunity to address some pressing safety shortcomings (such as suboptimal vertical situational awareness along LOC, NDB, VOR approaches, and unequipped runway ends).

2.2 Baro-VNAV was not designed as a self-standing approach and landing system, by contrast to geometric vertical guidance systems such as ILS, GBAS and SBAS.

2.3 In the same way that VOR and NDB in their time brought progress at runway ends with no landing aids, barometric guidance represents another step of progress at this point in aviation history.

2.4 As evidenced by several serious incidents, baro-VNAV approaches are however significantly less robust than ILS approaches and geometric PBN approaches enabled by GBAS and SBAS.

2.5 The main vulnerability of baro-VNAV approaches lies in their dependence on correct altimeter setting.

2.6 Correct altimeter setting involves multiple human interventions (e.g. determination of the local QNH by the meteorological service provider, publication of the local QNH in ATIS, transmission of the local QNH by ATC to the flight crew, altimeter setting by the flight crew, correction for the effects of temperature on the atmospheric pressure at aircraft altitude).

2.7 It is noteworthy that ILS, GBAS and SBAS are required by ICAO Standards to be designed and certified to meet an integrity risk lower than 10^-7 per approach (which means that these systems should not create an out of tolerance positioning error, without alerting the air crew, more frequently than once every 10 million approaches). The inherent integrity risk of baro-VNAV approaches is certainly on a much lower level. For instance, a 1998 study (Judith Bürki-Cohen https://flightsafety.org/ao/ao_jan_feb98.pdf) published by the Flight Safety Foundation showed that the altimeter setting error rate was on the order of a few percentage points, depending on factors such as the complexity of the clearance.

3. Examples of baro-VNAV related issues experienced in France.

3.1 Example 1:

On June 25th, 2021 a Vueling flight crew to Nantes Atlantique Airport miscopied as 1017 mb the 1007 mb ATIS QNH. The flight crew stated having experienced adverse weather conditions, with cumulonimbus clouds, during descent and approach, and been very focused on weather avoidance. The flight crew correctly readback 1007 QNH to the air traffic controller, without correcting the altimeter setting. The MSAW system alarmed. The air traffic controller used the emergency MSAW phraseology. The flight crew, who was in VMC conditions by then, immediately corrected the altimeter setting and was able to stabilize the approach.

3.2 Example 2:

In 2013, the French meteorological service provider misset the QNH measuring unit at Biarritz Pays Basque airport during a routine maintenance operation. As a result, the local ATC broadcast, during half a day, QNH with a 7 mb error up. The weather conditions were good on that particular day, and the error was detected by airspace users who were too low on approach (NB: 7 mb error = 196 ft error). No incidents/accidents occurred.

3.3 Example 3 :

On October 10, 2021, before starting the RNP approach to runway 21 at Nantes Atlantique Airport, the air traffic control unit cleared the crew of an Air France Hop CRJ 1000 aircraft to descend to 3 000 ft QNH 1002. The flight crew read back QNH 1021. During the final approach, the MSAW alarmed, and an investigation by the French Civil Aviation Safety Investigation and Analysis Bureau (BEA) into this serious incident is underway.

3.4 Example 4 :

a) An Air Hub Airbus A320 flight performed on May 23, 2022 a baro-VNAV approach to Paris CDG Runway 27R. The air traffic controller erroneously advised the flight crew that the QNH was 1011, while it was correctly broadcast 1001 on the ATIS. The aircraft performed its approach about 280 ft below the nominal descent profile, in clouds according to the flight crew.

b) At an indicated altitude of 891 ft QNH 1011 (617 ft actual altitude QNH 1001), 1.53 NM from the runway threshold, the MSAW system alarmed.

c) At 1.2 NM from the runway threshold, and with a vertical speed of -717 ft/min, the aircraft passed the indicated altitude of 802 ft QNH 1011 (537 ft QNH 1001, 122 ft RA), which corresponded to the Decision Altitude (DA) for the crew (Point 2 Figure 1).

d) The flight crew stated that arriving at the minima, they did not acquire visual references and consequently performed a go-around.

e) At an indicated altitude of 735 ft QNH 1011 (461 ft QNH 1001, 52 ft Radio Altimeter), and at 1 NM from the runway threshold, the autopilot was disengaged, and the captain pitched up.

f) Three seconds later, at an indicated altitude of 679 ft QNH 1011 (405 ft QNH 1001), and 0.8 NM from the runway threshold, the minimum radio-altimeter height was recorded at 6 ft above the ground, and an investigation by the French Civil Aviation Safety Investigation and Analysis Bureau (BEA) into this serious incident is underway:

BEA

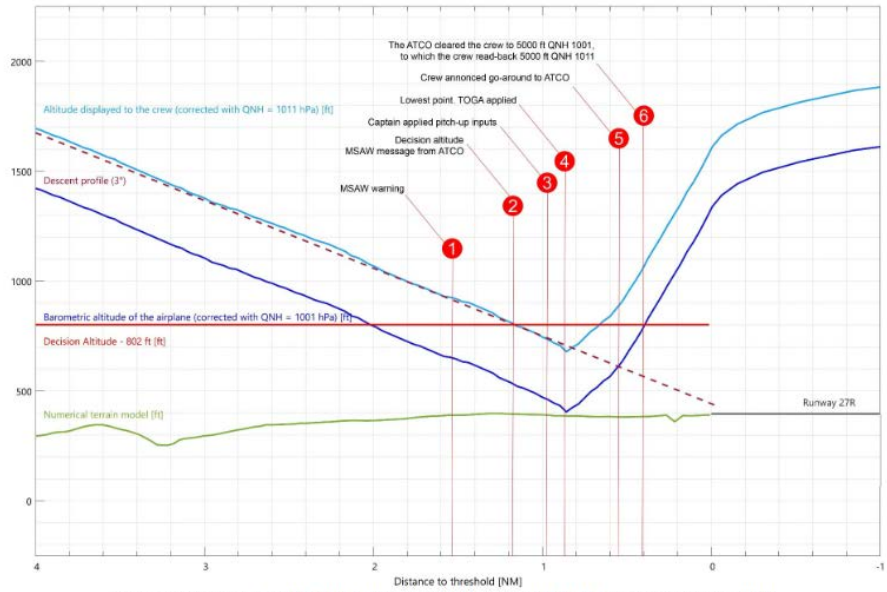

Figure 1: First approach profile, flight path computed from recorded flight parameters (source: BEA)

4. Conclusion

4.1 The safety of baro-VNAV approaches is dependent on correct altimeter setting, a process which requires multiple human interventions, and can lead to serious incidents as stated above.

4.2 Other vulnerabilities of the baro-VNAV technology, such as the risk that flight crews overestimate the precision of the baro-VNAV vertical guidance and conduct an unstabilized approach path, exist.

4.3 By contrast, ILS, SBAS and GBAS geometric approaches are not dependent on altimeter setting, are designed and certified to meet a 10^-7 integrity risk, and have logically proven safer in operations, by eliminating the type of errors involved in the above mentioned incidents, than baro-VNAV approaches.

4.4 In Europe, and other regions of the world, a non-exhaustive search through databases (BEA, Skybrary, NASA ASR, …) reveal occurrences of altimeter setting related incidents/accidents such as reported here for France.

4.5 Proactive safety management is about looking for safety weaknesses and preventing accidents before they occur.

4.6 France is of the view that in the mid/long terms only geometric vertical guidance enabled by ILS, GBAS and SBAS can provide the needed level of safety for the expected traffic growth and increased use of PBN approaches.

4.7 Based on the foregoing, the following is proposed:

Why	Avoid baro-VNAV incidents and accidents
What	Publish, and send to States and international organizations, an ICAO regional bulletin with a view to sensitizing the EUR aviation community to vulnerabilities of the baro-VNAV technology, in particular its dependence on correct altimeter setting.
Who	The Regional Director
When	In 2023

Draft EAPSG Decision 4/#_easpg04wp22/1 – Publication of a Regional Bulletin on baro-VNAV approaches

That the ICAO Regional Director, Europe and North Atlantic:

Publish, and send to States and international organizations, an ICAO EUR bulletin with a view to sensitizing the EUR aviation community to vulnerabilities of baro-VNAV approaches, in particular their dependence on correct altimeter setting.

5. Action by the Meeting

5.1 The meeting is invited to:

a) note the information provided;

b) amend as necessary and endorse the Decision in paragraph 4.7; and

c) provide direction as deemed necessary.

— END —

APPENDIX B

PBN implementation in France: return of experience

Mitigation measures implemented following serious incidents in BaroVNAV operations

1.1 It should be noted that APPENDIX A documents a few examples only of the three main types of categories of incidents with significant impact in the operations of BaroVNAV PBN approaches: error within the ATC system, error transmitted by ATC, error made by the aircrew.

1.2 Many other less severe incidents are also documented by the French civil aviation authority and in other incident databases.

1.3 Given the EU regulation requirements on PBN implementation and in particular the exclusive use of PBN phase from June 2030, aircrafts that are not equipped with SBAS will have to rely on BaroVNAV as an alternative to ILS. It is expected that more and more operators will use BaroVNAV PBN operations in Europe, and possibly in other regions as well. Consequently, an increase in the occurrence of such incidents is to be foreseen in the future.

1.4 From what is observed in France, BaroVNAV may be useful in the first phase of introduction of vertical guidance at runway-ends where it was not available previously. Nonetheless, the return of experience shows that the latent failures of BaroVNAV will require significant additional operational mitigation measures which make it difficult to identify BaroVNAV as a long-term primary landing aid.

1.5 In the same time, the European Union Aviation Safety Agency (EASA) has recently warned aircraft operators of the risk of losing Cat I landings capability in Europe after June 2030 unless they upgrade their aircrafts avionics (https://www.easa.europa.eu/en/newsroom-and-events/news/easa-publishes-communication-aircraft-operators-pbn-implementation).

Additional operational mitigation measures are implemented for BaroVNAV operations in France

1.6 Following the analysis of the serious incidents in the use of BaroVNAV PBN approaches, France decided to implement additional operational mitigation measures to increase the level of safety in operating PBN LNAV and LNAV/VNAV approaches.

1.7 While determining the mitigation measures, several significant issues were raised and pointed out in the working paper "*Issue with PBN implementation in France*" proposed to the ICAO Navigation System Panel in the NSP/7 meeting in January 2023:

i. the absence of ICAO standards describing the failure modes of BaroVNAV,
ii. the absence of guidance material for States on the appropriate mitigation measures to implement in relation to the limitations in performance of a technology.

1.8 In the absence of ICAO standards, France defined additional mitigation measures:

i. Reinforcement of QNH information exchanges at all aerodromes between ATCOs and Aircrews

QNH is now announced 3 times by Air Traffic Control (ATC): 1- ATIS, 2- approach ATCO (ITM), 3- tower ATCO (LOC),

ii. Additional operational requirements at aerodromes using a Minimum Safe Altitude Warning (MSAW) safety net
ATC is now required to issue a go around instruction in case of MSAW alert, whatever its cause.

1.9 In addition to the above, the most frequently observed QNH error being a confusion of 10 millibars equivalent to 280 ft, the decision has been made to increase by 300 ft the operational minima of Nantes airport runway 21, subject to several MSAW alerts recently as the approach trajectory overflies the city of Nantes. This specific mitigation measure is implemented only at Nantes airport for the time being[1].

1.10 It is still too early to confirm whether these operational mitigation measures need to be maintained, reinforced, or alleviated as their implementation also has an operational impact.

1.11 In addition, France currently:

i. investigates other technologies to mitigate the safety issues raised by BaroVNAV such as the mode S downlink of the on-board QNH. This will enable the ATC system to compare its value with the QNH known by ATC, and possibly to alert the ATCO in case of divergence.
ii. monitors evolutions in new generation aircrafts that are not yet widely available, where on-board QNH errors are automatically detected.

- END -

[1] It may be noted within the BEA AirHub CDG report that the involved airline had a policy of an “add-on” of 50 ft over the published LNAV/VNAV minima. Since at the lowest point of its vertical trajectory the aircraft was only 6 ft above the ground ahead of the runway, this minima add-on probably saved the aircraft that day. Increasing LNAV/VNAV or LNAV minima is a potentially useful safety mitigation.