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Cuestión 8 del Orden del Día: **Implementación de la navegación aérea CAR/SAM**

SEGURIDAD EN LOS ATERRIZAJES PBN

(Presentada por Francia)

RESUMEN EJECUTIVO

En GREPECAS/21, Francia presentó la NE 09 "Implementación de PBN en Francia: un retorno de experiencia" y en GREPECAS/22 la NE 42 " Recomendaciones de seguridad para aterrizajes PBN". Estos documentos destacaron que Francia se beneficia de un importante retorno de experiencia en aproximaciones PBN operadas mediante Sistema de Aumentación Basado en Satélites (SBAS) y Guía de Navegación Vertical Barométrica (BaroVNAV), e identificaron impactos potenciales en la seguridad operacional relacionados con operaciones BaroVNAV y errores de QNH.

Tras la publicación por parte de la Oficina de Investigación y Accidentes francesa, Bureau d'Enquêtes et d'Analyses (BEA), en junio de 2024, del informe final sobre uno de los incidentes de seguridad operacional más graves ocurridos dentro del espacio aéreo francés en los últimos 10 años, este documento proporciona una actualización sobre los estudios realizados en Francia y en Europa respecto a errores de QNH y las modificaciones a las mínimas adoptadas en Francia como medidas de mitigación de riesgo para garantizar mayor resiliencia ante estos errores.

Acción:	Se invita al GREPECAS a: a) Tomar nota del contenido de esta nota de estudio, b) Considerar el informe final de BEA sobre el "Incidente grave del AIRBUS A320 con matrícula 9H-EMU operado por Airhub Airlines el lunes 23 de mayo de 2022 en aproximación al aeropuerto de París-Charles de Gaulle", c) Considerar los estudios del ANSP francés DSNA y Eurocontrol que demuestran que el valor de integridad nominal establecido por la OACI (2.10-7/aproximación) no se cumple en las aproximaciones PBN con guía barométrica, con un factor de 1.000 a 10.000 veces superior, d) Considerar las capacidades de integridad y precisión de SBAS y los problemas latentes de seguridad de BaroVNAV en la implementación y operaciones de aproximaciones PBN en la región CAR/SAM.

Metas Estratégicas 2026-2050:	• Todos los vuelos son seguros y protegidos • La Aviación es sostenible en términos medioambientales • Movilidad fluida, accesible y confiable • Ningún país se queda atrás • Marco jurídico integral • Desarrollo económico
Referencias:	• Anexo 10 de la OACI, Volumen I • Manual PBN • Elemento NAVS de ASBU del GANP

1. Introducción

1.1 La implementación de la Navegación Basada en la Performance (PBN) es de gran interés para respaldar trayectorias precisas y avanzadas dentro de los espacios aéreos. La OACI ha definido una estrategia específica para aproximaciones en su Anexo 10 Volumen I: "*e) promover el uso de operaciones de Aproximación con Guía Vertical (APV), particularmente aquellas que utilizan guía vertical del Sistema Mundial de Navegación por Satélite (GNSS), para mejorar la seguridad operacional y la accesibilidad*".

1.2 Francia suscribe plenamente la estrategia específica de la OACI para aproximaciones en la implementación de PBN y ha publicado aproximaciones PBN para la mayoría de sus extremos de pista IFR siguiendo la normativa de la UE. Francia tiene el mayor número de extremos de pista IFR en Europa. En consecuencia, Francia se beneficia de una amplia experiencia en el uso tanto de SBAS como de BaroVNAV en operaciones de aproximación PBN.

1.3 Uno de los principales riesgos conocidos en las aproximaciones BaroVNAV es el error en el ajuste del altímetro. Algunos pilotos se refieren a esto como "el elemento mortal en los procedimientos BaroVNAV". El perfil de vuelo se ve significativamente afectado y puede causar un CFIT (Control Flight Into Terrain) cuando el error reduce la altitud real de la aeronave.

1.4 En 2021 en Nantes y en 2022 en París CDG, dos aproximaciones BaroVNAV llevaron a aeronaves por debajo de la altitud mínima del procedimiento. En el incidente de CDG, la altura de la aeronave en el momento de la aproximación frustrada se registró como 2 metros sobre el suelo. La tripulación y los pasajeros deben su supervivencia a un aumento de 50 pies en los mínimos realizado por la compañía encargada de los procedimientos de vuelo por instrumentos para esta aerolínea.

1.5 Se tomaron varias acciones como elevar el mínimo, recordar a la tripulación el QNH en aproximación final para evitar otro incidente, y se realizó un taller nacional en Francia con un gran número de operadores para implementar medidas efectivas para prevenir el riesgo de error. Al mismo tiempo, la DSNA, el ANSP francés, decidió realizar un estudio sobre errores de ajuste de altímetro durante la aproximación.

2. Estudios realizados por el ANSP francés DSNA y Eurocontrol

2.1. Datos y metodología de DSNA

2.1.1 El primer paso fue estudiar los datos disponibles y utilizarlos para validar un método de análisis. La solución elegida fue recopilar datos de altitud proporcionados por aeronaves que utilizan el Modo S, en particular el "QNH seleccionado", y comparar este valor con el QNH disponible en los sistemas ATC.

2.1.2 Posteriormente, este método se implementó recopilando datos de seis importantes aeropuertos franceses durante el período 2019-2023 para obtener una muestra representativa y proporcionar resultados concluyentes.

2.1.3 La muestra recopilada comprende aproximadamente 1,7 millones de aterrizajes (1.694.266) para el período seleccionado. Esta muestra representa todas las aproximaciones en los aeropuertos seleccionados, independientemente del tipo de aproximación final realizada por la tripulación. La "no distinción" del tipo de aproximación final no afecta los resultados obtenidos en el contexto del estudio.

2.2. Resultados de los estudios

2.2.1 Según los datos recopilados por DSNA, los resultados iniciales muestran que:
- Existe una probabilidad de error de 10-3 por aproximación para un error de QNH igual o superior a 2 hPa; y
- Existe una probabilidad de error de 10-4 por aproximación para un error igual o superior a 10 hPa.

2.2.2 El análisis de la información por parte de DSNA a través de los datos recopilados permitió cuantificar los dos tipos más comunes de error relacionados con el QNH.

2.2.3 El primer tipo de error es olvidar cambiar al QNH local en la altitud de transición. Este error tiene consecuencias variables y depende de la diferencia entre 1013,25 hPa y el QNH local.

2.2.4 El segundo es el error de 10 hPa. En casos desfavorables (+10 hPa), este error provoca que la aeronave se desvíe 280 pies del perfil vertical publicado, y actualmente es imposible detectar este error a bordo. Este error corresponde al incidente de CDG en 2022.

2.2.5 Además, el efecto de estos errores se midió reproduciendo las trayectorias de varias aeronaves del estudio. Las trayectorias mostraron un desplazamiento vertical en la aproximación antes de interceptar la trayectoria de descenso o durante toda la aproximación final.

2.2.6 Finalmente, el estudio de DSNA muestra que los errores de ajuste del altímetro ocurren tanto en aproximaciones ILS/LPV como en aproximaciones PBN con una fuente de guía barométrica. Se ha identificado claramente que el impacto es mayor en las aproximaciones PBN con una fuente de guía barométrica que en las aproximaciones ILS/LPV, ya que se ve afectada toda la geometría de la trayectoria de descenso. El valor de integridad nominal establecido por la OACI (2.10-7/aproximación) no se cumple, con un factor de 1.000 a 10.000 veces superior.

2.2.7 Estos resultados son confirmados por un estudio de Eurocontrol[1] que analizó operaciones de aterrizaje en 378 aeropuertos de la UE durante 31 días, representando 747.353 vuelos. El estudio encontró 196 ocurrencias de errores de ajuste de QNH superiores a 5 hPa, sobre 747.353 vuelos, por lo tanto, un riesgo de integridad superior a 5 hPa del orden de 10-4 por aproximación.

2.2.8 Para SBAS/GBAS, el riesgo de integridad es por diseño de aproximadamente 10-7 por aproximación, para cumplir con el Nivel de Seguridad Objetivo (TLS) definido por la OACI de 10-8 por aproximación.

[1] An Algorithm for Identifying Altimeter Setting Errors from ADS-B Data by Nikolaos Mourousias, Emilien Robert; David De Smedt (Eurocontrol)

2.2.9 Para BaroVNAV, el riesgo de integridad se mide alrededor de 10-3 por aproximación, lo que significa que el TLS se ve afectado por un factor de 10.000.

2.3. Elevación de los mínimos como medida adoptada por la autoridad supervisora francesa

2.3.1 En Francia, la autoridad supervisora aprueba los mínimos publicados y el regulador requiere que las oficinas de diseño de procedimientos proporcionen mínimos además de las OCHs (Altura de Franqueamiento de Obstáculos). Esto no es obligatorio en muchos países y la OACI solo requiere la determinación de una OCH para cada procedimiento publicado.

2.3.2 Para limitar el riesgo de incidentes o accidentes causados por errores de ajuste del altímetro, la autoridad supervisora francesa ha adoptado las siguientes medidas de mitigación de riesgos que serán implementadas en 2026 por DSNA:

- Las Alturas de Decisión (DH) para los procedimientos de aproximación LNAV/VNAV se incrementarán en 100 pies, sin exceder el valor de la Altura Mínima de Decisión (MDH) para un procedimiento LNAV en el mismo QFU
- El valor mínimo de DH para procedimientos RNP AR se establecerá en 350 pies
- Los valores de Alcance Visual en Pista (RVR) para procedimientos LNAV/VNAV se actualizarán en base a los nuevos valores de DH.

2.3.3 Estas medidas se definieron tras el resultado de estudios realizados por la autoridad supervisora francesa analizando las OCHs publicadas en otros países como los Estados Unidos de América.

2.3.4 Las principales diferencias con los Estados Unidos son:

- El ajuste del altímetro se da en pulgadas de mercurio (inHg), no en hectopascales (hPa)
- El nivel de transición es FL180
- El idioma utilizado, el inglés, es la lengua materna de los controladores de tránsito aéreo y de una gran proporción de pilotos
- Los procedimientos de aproximación PBN están diseñados con criterios de Procedimientos de Instrumentos Terminales (TERPS), más conservadores en términos de mínimos LNAV/VNAV, como alternativa a PANS-OPS.

2.3.5 Los Estados Unidos han estado utilizando procedimientos BaroVNAV durante años. Ya han identificado inconsistencias en los ajustes de altímetro a bordo, pero los efectos de estos errores se mitigan por su unidad de ajuste de altímetro (pulgadas de mercurio) y valores de OCH que son más altos que los encontrados en Francia.

3. Conclusión

3.1 Los errores de ajuste de altitud pueden tener consecuencias dramáticas, particularmente cuando se utilizan procedimientos BaroVNAV. El incidente en París CDG debe recordarnos que no existe el riesgo cero y que deben implementarse medidas para mitigar este riesgo a fin de que tal situación no vuelva a ocurrir.

3.2 Algunos ANSP han implementado herramientas como Barometric Pressure Setting Advisory Tool (BAT) para alertar a los controladores de tránsito aéreo sobre errores de ajuste de altímetro. Alternativamente, podría incluirse un margen adicional en la definición de los mínimos.

3.3 Los fabricantes de aeronaves están desarrollando actualmente soluciones a bordo para alertar a los pilotos sobre errores de ajuste de altímetro.

3.4 El documento publicado por la autoridad supervisora francesa, proporcionado en el **Apéndice (disponible en inglés solamente),** detalla los resultados del estudio realizado por el ANSP francés DSNA.

3.5 Podría ser interesante evaluar el impacto de los posibles errores de ajuste de altímetro en la región CAR/SAM.

4. Acciones sugeridas

4.1 Se invita al GREPECAS a:

a) Tomar nota del contenido de esta nota de estudio;

b) Considerar el informe final de BEA sobre el "Incidente grave del AIRBUS A320 con matrícula 9H-EMU operado por Airhub Airlines el lunes 23 de mayo de 2022 en aproximación al aeropuerto de París-Charles de Gaulle";

c) Considerar los estudios del ANSP francés DSNA y Eurocontrol que demuestran que el valor de integridad nominal establecido por la OACI (2.10-7/aproximación) no se cumple en las aproximaciones PBN con guía barométrica, con un factor de 1.000 a 10.000 veces superior; y

d) Considerar las capacidades de integridad y precisión de SBAS y los problemas latentes de seguridad de BaroVNAV en la implementación y operaciones de aproximaciones PBN en la región CAR/SAM.

— FIN —

MINISTÈRE CHARGÉ DES TRANSPORTS

Liberté
Égalité
Fraternité

direction générale de l'Aviation civile
DSAC

ANALYSIS OF QNH INCONSISTENCIES IN APPROACH

IMPACT ON THE INTEGRITY OF NAVIGATION SYSTEMS WITH BAROMETRIC VERTICAL GUIDANCE

Data 2019 - 2024

TLP GREEN

Direction de la Sécurité de l'aviation civile (safety directorate)
Mission Evaluation et Amélioration de la sécurité (State Safety Programme implementation unit)

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Introduction

After the serious incidents in Nantes (October 2021)[1] and CDG (May 2022)[2] during which errors in the selection of altimeter settings brought aircraft to heights well below the required minimums, the DSAC led a working group within the France Aviation Safety Network (RSAF, for Réseau Sécurité Aérienne France), the main lessons of which are described in the 2022 safety report.

In addition, a number of actions have been launched, both on the DSAC side[3] and on the DSNA and EASA sides, and avenues still to be explored have been identified.

The following may be mentioned:

- An analysis of safety occurrence reports (see below)
- Publication of a safety info leaflet https://www.ecologie.gouv.fr/sites/default/files/documents/Safety_information_Leaflet_2023-02.pdf
- A publication in the 2022 safety report https://www.ecologie.gouv.fr/sites/default/files/publications/rapport_securite_aerienne_2022.pdf developed on page 44 et seq.
- A contribution to the EASA SIB https://ad.easa.europa.eu/ad/2023-03
- An incentive for aircraft operators to measure these deviations through flight data monitoring (FDM)
- On the DSNA side, an instruction to controllers to remind the QNH at the first contact with aerodrome control (see details below)
- An educational publication on TCAS and MSAW https://www.ecologie.gouv.fr/sites/default/files/documents/Note_TAWS-MSAW.pdf
- The decision to dedicate the DSAC 2025 symposium in part to this topic
- Contributions to a reflection launched within EASA on PBN-IR.

The present study seeks to quantify the frequency of altimeter setting errors in approach using the down-link information from the Mode S frames and the QNH information provided to controllers.

1) Data in reports

The analysis of the safety occurrence reports described in section 1.18.1.2 of the BEA report revealed that altimeter setting errors for aircraft in approach were regularly reported. This analysis has identified some 150 cases in a few years. These cases have several notable characteristics: most of the errors were detected once on the ground and then reported, mainly after an ILS approach, and therefore without consequence on the trajectory[4].

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[1] https://bea.aero/fileadmin/user_upload/F-HMLD_EN.pdf

[2] https://bea.aero/fileadmin/uploads/9HEMU/9H-EMU_EN.pdf

[3] DSAC: Direction de la Sécurité de l’Aviation Civile, (Civil Aviation Safety Directorate), competent authority in France

DSNA: Direction des Services de la navigation aérienne, Air navigation service provider in France

[4] These errors had consequences for the decision altitude and could have had consequences in the event of a go-around, with no effect on safety due to favourable weather conditions

The two most frequently encountered factors (but not exclusively) were a failure to change from 1013 to the local QNH and a representation error with error peaks at +10 and -10 hPa in particular. The count of such errors or omissions was previously based only on the notification under Regulation (EU) 376/2014. This point was developed in Part 5 of the 2022 safety report[5].

2) Data and methodology of the study conducted by the DSNA

To measure the objective frequency of these discrepancies, an exhaustive analysis of all available data was undertaken by the Directorate of Air Navigation Services (DSNA), using the data transmitted by the aircraft (and recorded) by mode S, in particular the parameter "selected QNH", and comparing it to the available ground QNH on the control positions.

After validation of the technical feasibility of identifying a discrepancy between on-board and ground-based QNH, in particular by comparing the measured deviation with the deviation obtained by other means (comparison with a sample of safety occurrence reports notified by the DSNA and operators to DSAC), the study set out to quantify the frequency of inconsistencies between the on-board barometric setting and the "ground" QNH.

The study collected adequate data regarding its objectives for six major French airports (Paris CDG, Paris Orly, Paris Le Bourget, Nice, Marseille and Toulouse) over a period covering 5 years from 2019 to 2023.

The aeroplane barometric setting is measured from the down-link aeroplane parameters transmitted by the aircraft's S Mode transponders, detected and collected (when recorded) by the secondary radars of the air navigation services. This is assumed to be the barometric setting selected by a crew as part of the aircraft trajectory management.

The “ground” QNH setting is obtained through ATC systems data and corresponds to the QNH information as presented on the dedicated control position displays.

In total, over the perimeter of the 6 airports and over the 5-year period for which adequate data are available, the measurements are usable for 1,694,266 landings. It should be noted, however, that the study does not allow to know directly what types of approaches were flown (ILS or RNP 2D or 3D) in the identified cases or which minima (LNAV, LNAV/VNAV or LPV) were applied, but this uncertainty does not affect the ability to measure the object of the study.

For each identified approach path, the deviation between the on-board setting and the "ground" QNH is measured, in particular when the aircraft flies over the runway threshold.

3) Study results

The study conducted by the DSNA on a wide basis of observations makes it possible to estimate that the average probability of significant inconsistency (greater than or equal to 2 hPa) on the on-board QNH setting at the time of landing is of the magnitude of 10^{-3} per approach, and that the probability of occurrence of very significant inconsistency (greater than or equal to 10 hPa) is of the magnitude of 10^{-4} per approach.

The study shows that out of 7328 inconsistencies detected in the vicinity of the transition altitude, about 31% of these inconsistencies are still observed up to heights of 1000 ft, or even until touchdown, (resp. 2312 then 2269 cases).

[5] https://www.ecologie.gouv.fr/sites/default/files/publications/rapport_securite_aerienne_2022.pdf

More precisely, these 2269 inconsistencies detected at runway threshold greater than or equal to 2hPa contain 387 inconsistencies greater than or equal to 10 hPa. The singular value of 10 hPa is found in 202 cases.

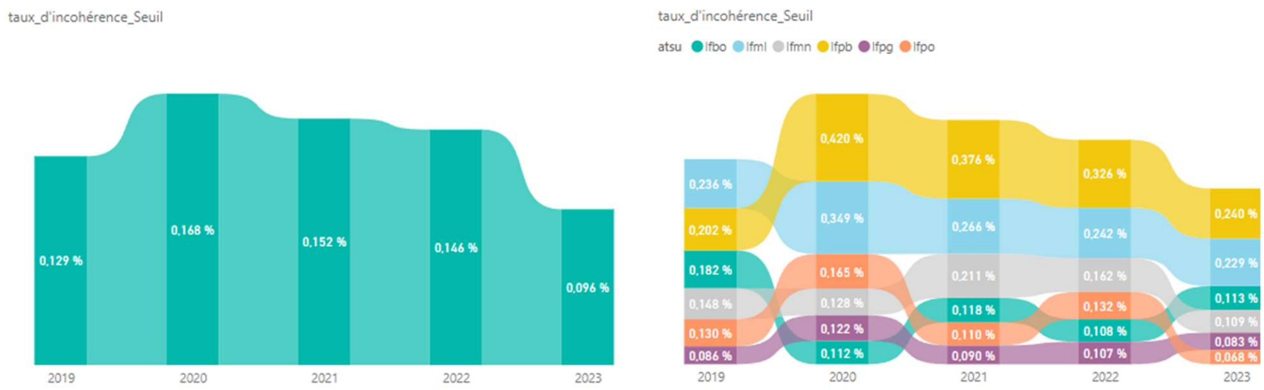

Figure 1. Barometric ground-board inconsistency rate greater than 2 hPa.
On the left, the overall rate by year, on the right, the overall rate by year and by airport.

Beyond this general result, disparities between the inconsistency rates by aerodrome appear. There is a factor of 3 between Paris Le Bourget and Paris CDG, which are very close geographically, but in which very different fleets[6] operate. These differences could be analysed in more detail to understand their origin, but as the level of inconsistency remains statistically high, it is important to note that the most serious incident known to date occurred during approach to Paris-Charles de Gaulle airport, even though it is the airport for which the frequency of inconsistencies found is the lowest among the 6 airports in the study.

The study also analyzed the statistical distribution of inconsistencies and quantified the occurrence of two most common types of errors.

- The lack of transition from the standard 1013.25 hPa setting to the QNH during the approach: Figure 2 shows that nearly 27% of the inconsistencies correspond to cases where the on-board setting is at 1013.25. Of these cases, in 85% of occurrences, there was no change in the BPS (Barometric Pressure Setting) during the approach. The latter cases (therefore about a quarter of the cases of inconsistencies) result a priori from a omission to change the altimeter setting when passing the transition level.

The effect of these "1013 omission" on the vertical offset of the trajectory is random: it depends on the local atmospheric pressure with respect to the standard setting.

- The 10 hPa error: Figure 3 shows the distribution of inconsistencies values. It is notable that:

A clear peak appears for values of +/- 10 hPa of inconsistency, this peak alone representing about 10% of the inconsistency values.
The cumulative inconsistencies of at least +/- 10 hPa represent almost a quarter of the cases recorded.
These cases correspond to high risk situations where an inconsistency of at least 10 hPa results in an vertical error of 280 ft or more – the case of the serious incident that led to the present study.

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[6] The inconsistency rate between the on-board BPS and the ground QNH at the time of the landing threshold overflight is 1×10^{-3} for the approaches at Paris CDG and 3×10^{-3} for those at Paris Le Bourget.

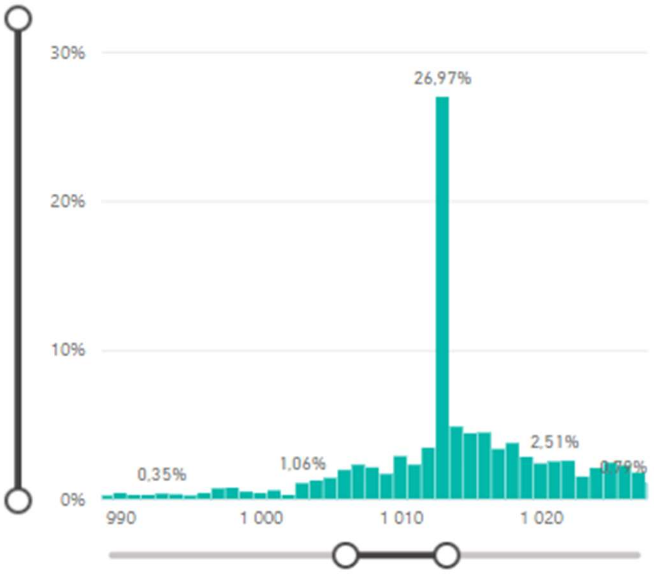

Figure 2. Share of inconsistencies as a function of the value of the on-board BPS. Nearly 27% of the inconsistencies noted in the study are the result of a failure to change the altimeter setting from the standard setting to the QNH during the approach

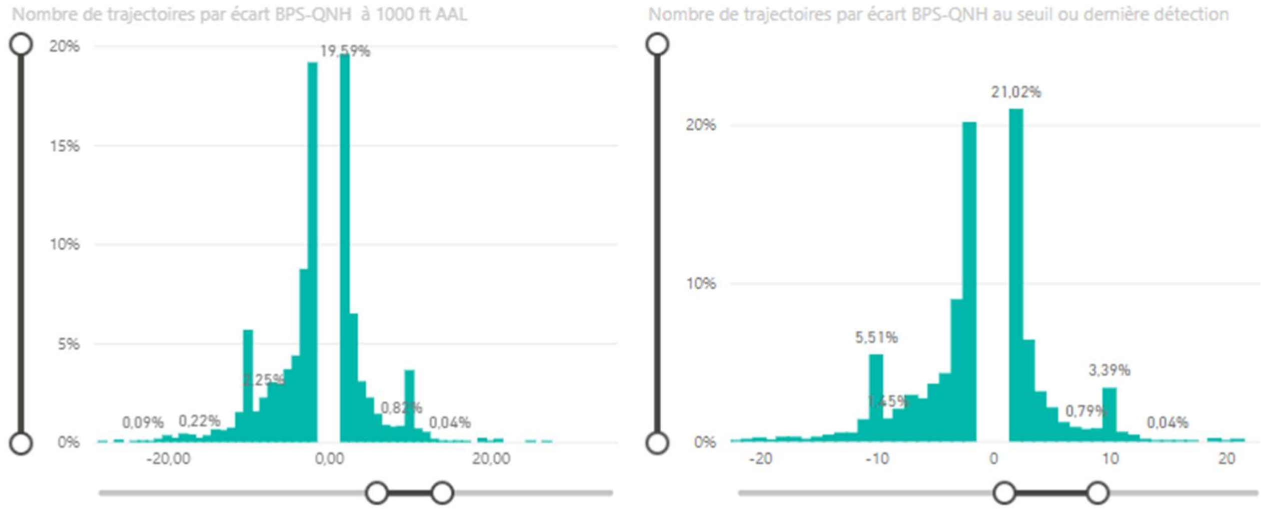

Figure 3. Distribution of the on-board BPS – QNH ground inconsistencies as a function of the value of the latter, at 1000 ft AGL and at the runway threshold resp. Approximately 17% of inconsistencies have an error of 10 hPa or higher

Finally, the study focused on highlighting the measured effect on trajectories of the identified inconsistencies. Thus, for a few cases listed, the replay of the radar trajectories confirmed that the inconsistencies resulted in vertical shifts in the final approach path.

In some cases, the entire final approach path was offset above or below the expected slope, with a return to the nominal path only in the short final phase. In these cases, it is likely that the aircraft were following barometric guidance approach procedures. In others, the intermediate approach segment (interception of the plane before the final) is shifted above or below the desired altitude, before the plane follows the nominal final approach path. In these cases, it is inferred that the aircraft are following procedures with geometric vertical guidance (ILS or LPV).

4) Lessons learned from the study.

This study confirms that QNH inconsistencies occur on both ILS and RNP approaches, but for ILS approaches the safety impact[7] for the conduct of the approach is greatly mitigated by the following of a geometric path. Only the operational minima dependant on the baro-altimeter are really affected, and for ILS approaches, there are also operational procedures such as the comparison of altitude vs remaining distance at 1000 ft AGL that make it possible to detect barometric errors at the time of the start of the final descent.

On the other hand, for an RNP approach guided by barometric reference, any error in the altimeter setting results in a systematic geometric error in the descent path actually flown. What is more, no confirmation point of the follow-up of the correct descent plan is possible, unlike the ILS procedures.

These orders of magnitude make it possible to confirm experimentally laboratory studies that had already estimated [Ref. 3] the error rate related to the memorization then restitution by the crews of messages delivered by the controllers.

These data show an integrity deficit of a factor of 1,000 (10^3) to 10,000 (10^4) with respect to what ICAO considers to be the nominal integrity value (2.10^{-7}/approach) to meet the target level of safety (TLS) of approaches, which represents a very significant differential. In concrete terms, this means that if the BaroVNAV technology were used systematically, the other assumptions for the geometric guidance remaining unchanged (incident/accident ratio, risk mitigation by crew actions, etc.) the safety objective of the approaches could be reduced by a factor of 1000 to 10,000, due to the direct relationship between the integrity of the navigation system and the TLS, explained in Table 1 of the Appendix.

Finally, it should be noted that the risk of accidents will increase with the increase in the use of RNP approaches (mainly based on barometric guidance, due to the equipment of aircraft fleets) instead of ILS approaches as a result of the current European PBN strategy.

5) Additional mitigation measures put in place by DSNA

Following the quasi-CFIT of AirHub at CDG, on July 11, 2022, the Direction of Operations took a precautionary measure requesting, during RNP approaches among other things, on first contact with the LOC controller, that the latter recall the value of the QNH in force. This instruction was intended to reduce the occurrence of barometric inconsistencies by announcing the QNH in addition to the announcement that had already been made during the approach.

This temporary instruction has been made permanent and extended, so that since 15 September 2023, for all approach control centres and aerodrome control towers:

"On first contact with the LOC controller, the latter recalls the QNH value by direct reading on the dedicated HMI for all approach procedures except ILS and LPVs.
With a view to harmonising working methods, the control centres have the possibility of extending this principle to all instrument approach procedures. »

Conclusion

The precise quantification of the cases of barometric setting inconsistencies between the airplane and the ground revealed by this data collected by the DSNA, relating to a large base of observations (almost 1,700,000 landings) and which owes its robustness in particular to the original on-board source, represents a very important advance in the understanding and objectification of the level of risk provided by vertical barometric guidance.

The study confirms that the barometric integrity risk in the context of the operational implementation of these approaches in France (and in Europe) prior to the AirHub near-CFIT in CDG is very high, leading to a level of safety of approaches with barometric vertical guidance reduced by 3 to 4 orders of magnitude compared to the safety objective of approaches sought by ICAO.

In Europe, France is probably the country most exposed to the risk to date due to the large number of aerodromes that have published RNP approaches with barometric vertical guidance.

The effect of the announcement of the QNH on first contact with the aerodrome control set up by the DSNA after the serious incident of the AirHub at CDG cannot be quantified at this stage.

It should be noted that the barometric setting risk discussed in this note affects in the same way, and to the best of our knowledge most likely with a quantitative level of the same magnitude as that discussed here, special procedures of the RNP AR type that use barometric vertical guidance.

It is planned to continue the measurement of inconsistencies in 2024 and subsequent years in order to further expand the statistical basis for measuring inconsistencies, and with the aim of quantifying the effect of specific mitigation measures.

In addition, DSAC is studying the interest of raising the minima of the Baro-VNAV approaches as a risk mitigation measure.

Finally, these orders of magnitude are confirmed by two other independent sources: a French airline as part of its flight data monitoring program (FDM) on the one hand, and a study conducted by Eurocontrol to validate an error detection algorithm on the other hand. This last study is available on Researchgate [Ref. 4].

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[Ref 3] Flight Safety Foundation, Airport Operations, "Studies investigate the Role of Memory in the interaction between pilots and air traffic controllers, January- February 1998.
[Ref 4] Mourousias, Nikolaos & Robert, Emilien & Smedt, D. (2025). An Algorithm for Identifying Altimeter Setting Errors from ADS-B Data. 1-12. 10.1109/ICNS65417.2025.10976916.

[7] Only the safety impact with regard to the vertical obstacle clearance margin is considered, deviations in the event of a go-around or losses of vertical separation from other aircraft are not taken into account in the risk assessment.

Appendix

Reminder on the risk of integrity of navigation systems

Navigation systems are standardized by ICAO in Annex 10 to the Chicago Convention, Aeronautical Telecommunications, through a set of specifications for the quality of navigational information critical to flight safety.

For the landing phase which is the subject of this note, the following table gives the minimum performance of satellite navigation systems for approach and landing operations, taken from Annex 10.

Table 3.7.2.4-1 Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I) (Note 8)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II) (Note 8)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

Table 1. Annex 10 ICAO Vil 1 Table 3.7.2.4-1, Performance Requirements for Navigation Information Generated on Board by Navigation Satellite Systems.

Of particular note in this table, outlined in red, is the requirement on the integrity risk of vertically guided approaches. Integrity is defined in Annex 10 as: "A measure of the level of confidence in the accuracy of information provided by the system as a whole. The concept of integrity encompasses the ability of a system to provide valid warnings (alarms) in a timely manner."

In concrete terms, this means that for approaches with vertical guidance, the navigation system on board the aircraft must not provide guidance error above a predefined threshold that is a function of the phase of flight, without alerting the crew in less than 6 seconds, more than twice every 10 million landings.

These performance requirements should be understood (see Figure 1) as measured on the navigational information transmitted to the crew and/or aircraft systems at the exit of a flawless "black *box". This "black box" represents the on-board navigation system the aircraft and the information sent to it (navigation signals affected by atmospheric propagation, multi-paths, satellite failures, etc.).[8.]*

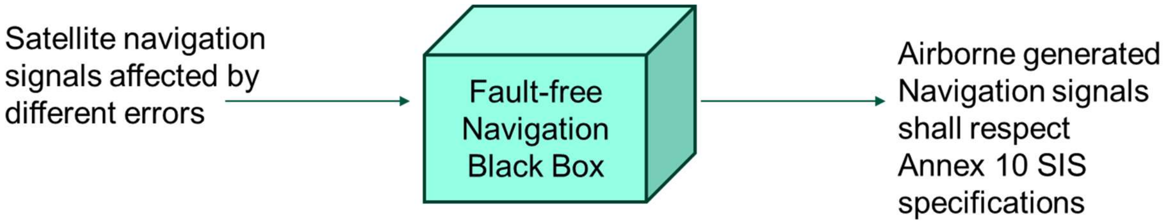

Figure 1. To specify the required performance on the navigation information generated on board the aircraft (from external information), a fault-free navigation system on board the aircraft is assumed.

The integrity requirement of Annex 10 is the result of work carried out by the All Weather Operation Panel (AWOP) in the 1990s. Starting from the overall safety objective for the approach and landing phases (Target Level of Safety – TLS, accident risk less than 10^{-8}/approach) AWOP's work has resulted in precise performance specifications on safety-critical parameters, such as integrity, as shown in Figure 2 below [Ref 1].

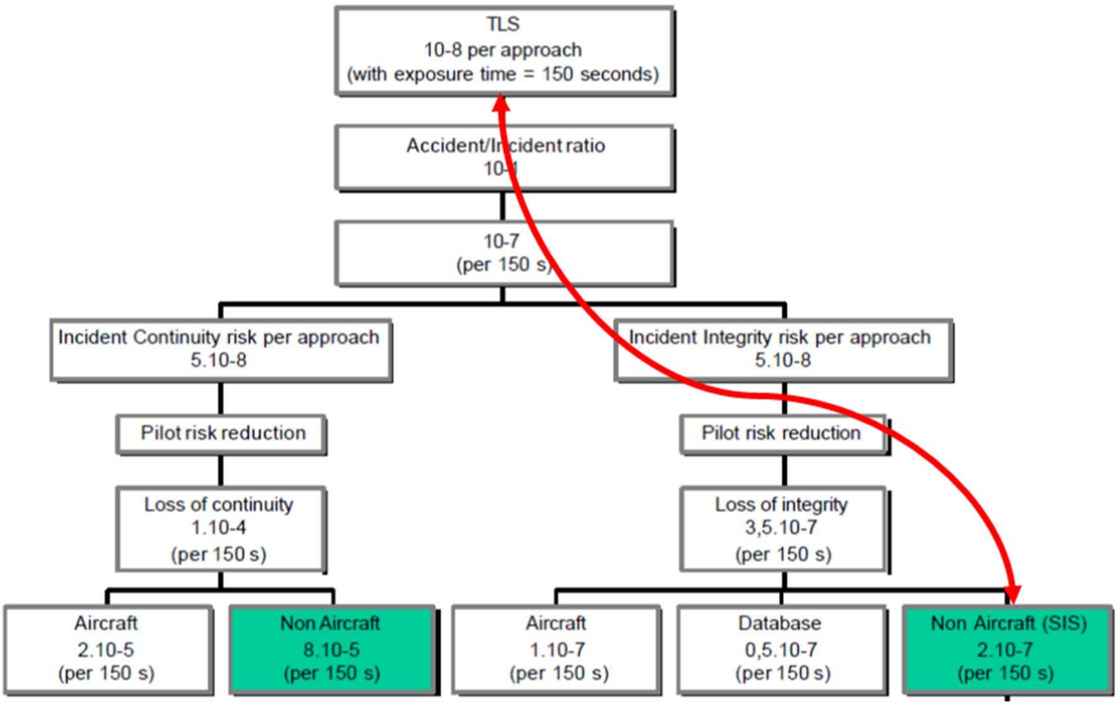

Figure 2. Allocation tree deriving the performance requirements necessary to meet the overall approach safety objective. The red arrow describes how a failure in the integrity of the navigation information generated on board the aircraft impacts the level of safety of approaches.

The requirement for integrity on the navigation information generated on board the aircraft could be deduced from the overall safety objective (TLS), and conversely, an out-of-tolerance integrity of navigation signals, regardless of its origin, can seriously affect the safety objective of approaches. It is on this reasoning that the impact of the frequency of occurrence of the error on the probability of an accident is based.

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[8] The requirements to protect against possible failures of the on-board navigation system of the aircraft and also against database corruption are defined elsewhere (see Figure 2).

In this regard, four factors that can significantly affect the integrity risk of BaroVNAV operations can be cited:

- *The frequency of use of barometric guidance vs. geometric guidance,*
  NB: there has been a sharp increase in Europe since 2018 with the PBN regulation, as a result of the absence of a mandate to carry SBAS avionics.

- *The criteria for the design of procedures influencing the BaroVNAV operational minima,*
  NB: more conservative in the United States

- *The Transition Level*
  NB: the lower it is, as in Europe, the more the risk that the 1013 to local QNH change will be made during a phase with a high workload increases, which negatively impacts the risk of QNH error.

- *The choice of unit for local atmospheric pressure, two different units being available on-board commercial aircraft, hectopascals (hPa) or inches of mercury (in Hg)*
  NB: there is a ratio of 1 to 3 between an error of one unit of in Hg and one unit of hPa, and consequently the most frequent human error of 10 units generates a vertical error of the order of 300 ft with the hPa unit, while it is limited to 100 ft in Hg, used in North America.

Each of these factors leads to an increased risk of error in the QNH setting.