IFATCA INTERNATIONAL FEDERATION OF AIR TRAFFIC CONTROLLERS' ASSOCIATIONS
64th ANNUAL CONFERENCE
28 April – 2 May 2025, Abu Dhabi, United Arab Emirates

Agenda Item: B.5.3 | WORKING PAPER | WP No: 95
IFATCA'25

Pressure Setting Monitoring

Presented by TOC

SUMMARY

Barometric Pressure Setting (BPS) error has led to various serious incidents in recent years especially during Baro-VNAV approaches. Ways to mitigate such errors are explored in this paper, including better pressure setting monitoring making use of BPS information available in Mode S Downlink Aircraft Parameters (DAPs). Other approach procedures without referring to BPS are also reviewed.

1. INTRODUCTION

1.1. In 1928, Paul Kollsman invented the Barometric Altimeter, which responds to changes in barometric pressure and displays the altitude to flight crews accurately. It works with reference to the barometric setting which is adjusted through a display called "Kollsman Window". Since then, the Barometric Altimeter has become one of the most important pieces of instrument in the cockpit. The invention has been the cornerstone of modern aviation which enabled pilots to "fly on the gauges".

1.2. Nowadays, "*aircraft altitude has been universally determined by comparing the air pressure outside the aircraft to a standard model of the atmosphere with a correction based on a local or standard altimeter setting.*"[1] The modern Air Traffic Management System (ATMS) has also been developed and adapted to display aircraft altitude with reference to local and/or standard barometric altimeter setting, providing essential information to air traffic controllers to separate aircraft vertically.

1.3. Based on barometric altimetry, Barometric Vertical Navigation (Baro-VNAV) has been developed as an instrument approach procedure whereby the aircraft's vertical profile is determined by the aircraft's altimeter. Having the correct altimetry setting is crucial to ensure aircraft to descend via the designed vertical profile and land safely.

[1] Technical and Operational Committee (TOC). (2015). Concept of GNSS-Based Altitude. In IFATCA, Wikifatca (54th Conference, WP 87, 1-45). Retrieved from https://ifatca.wiki/kb/wp-2015-87/

1.4. Although Baro-VNAV is widely used, it has a single point of failure when the altimeter setting is incorrect, leading to possible descent below desired approach path, controlled flight into terrain and missed approach performed at low and unsafe altitude etc. This paper aims to explore solutions to reduce risk of barometric pressure setting errors.

2. DISCUSSION

2.1. Background

2.1.1. Approach procedures with vertical guidance (APV) is "*a performance-based navigation (PBN) instrument approach procedure designed for 3D instrument approach operations Type A*"[2]. As the definition suggested, these procedures are designed for Type A 3D approaches operations. There are two types of APV approach procedures:

2.1.1.1. based on vertical guidance from Baro-VNAV system, and

2.1.1.2. based on Satellite-based augmentation system (SBAS) vertical guidance.

2.1.2. Baro-VNAV is a navigation system that "*presents to the pilot computed vertical guidance referenced to a specified vertical path angle (VPA), nominally 3°. APV/ Baro-VNAV approach procedures are classified as instrument approach procedures in support of 3D approach operations.*" [3]

2.1.3. Baro-VNAV uses barometric altitude information from the aircraft's pitot-static system and air data computer to compute vertical guidance for the pilot. APV/ Baro-VNAV approach procedures are preferred over traditional step-down approach which is a Non-Precision Approach (NPA) procedure since the "*APV/ Baro-VNAV procedures provide a greater margin of safety than non-precision approach procedures by providing for a guided, stabilized descent to landing. They are particularly relevant to large commercial jet transport aircraft, for which they are considered safer than the alternative technique of an early descent to minimum altitudes*." [3]

2.1.4. Baro-VNAV is one of the essential elements in Required Navigation Performance (RNP) approaches (RNP APCH) and RNP Authorization Required Approaches (RNP AR APCH). The specified vertical path is typically computed between two waypoints or an angle from a single way point. "*During RNP APCH and RNP AR APCH operations, the aircraft's RNP system can provide both lateral and vertical guidance.*

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[2] International Civil Aviation Organization [ICAO]. (2023). Doc 9613 – Performance-based Navigation (PBN) Manual (5th Edition, Glossary, xxi)

[3] ICAO. (2018). Doc 8168 – Procedure for Air Navigation Services (Aircraft Operations) Vol. 1 (6th Edition, Amendment 11, Part II, Section 5, Chapter 5)

The RNP system relies on the definition of the barometric altitudes in the RNP APCH and RNP AR APCH procedure design and the output of the aircraft's barometric altimeter to provide vertical guidance during the instrument approach. In an instrument approach procedure's final approach segment, aircraft providing vertical guidance base the vertical guidance on the procedure's defined vertical path angle (VPA). To protect the instrument approach operation for non-standard temperatures, the RNP APCH and RNP AR APCH procedure designs publish a temperature range (or just a cold temperature limit) within which the primary barometric altimeter's biases will not compromise the procedure's provided vertical obstacle and terrain protection in the final approach segment".[4] So when using approach procedures with Baro-VNAV guidance, the flight crew should check for any published temperature limitations on the approach chart which may result in approach restrictions.[5]

2.1.5. Baro-VNAV relies on correct manual input of barometric altimetry setting, e.g. the correct input of QNH/ QFE. Incorrect barometric altimetry setting will lead to inaccurate representation of aircraft's vertical position, which will distort the flight crew's perception of where the glideslope is located versus the aircraft's actual position. For altimetry setting with higher than correct pressure setting, the aircraft will be descending below the desired glidepath; while with altimetry setting lower than actual pressure setting, the aircraft will be descending above the desired glidepath.

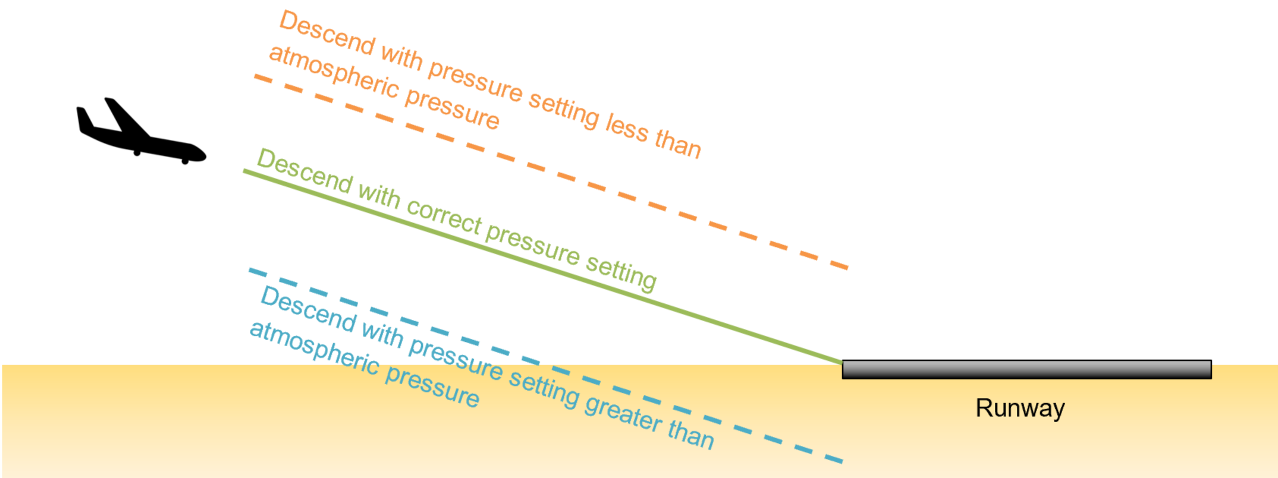

Fig.1 Illustration of aircraft approach path with different barometric pressure setting

2.2. Limitations of Baro-VNAV

2.2.1. Although Baro-VNAV has brought safety benefits over legacy non-precision approaches, e.g. LOC, NDB and VOR approaches on

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4 ICAO. (2023). Doc 9613 – Performance-based Navigation (PBN) Manual (5th Edition, Attachment B)

5 Federal Aviation Administration [FAA]. (2023). Aeronautical Information Manual (Basic Manual, 5-1-20)

unequipped runway[6], human error has become the biggest risk in carrying out Baro-VNAV approaches as the procedure involves multiple human interventions to correctly input the actual QNH setting to display the correct barometric altitude. Equipment error in obtaining correct barometric pressure is also one of the risks associated with Baro-VNAV.

2.2.2. On the other hand, *"the use of barometric altimetry is to some extent a limiting factor on safety, predictability and efficiency of aircraft operations, and reduces the potential of the trajectory-based operations capabilities."* [7]

2.3. Incidents related to Baro-VNAV

2.3.1. *"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."* [6]

2.3.2. Flight **AFR33CW** [8]

2.3.2.1. On 20 October 2021, flight AFR33CW, a Bombardier CRJ-1000 F-HMLD flew from Lyon-Saint-Exupéry (Rhône) to Nantes-Atlantique (Loire-Atlantique). "*When the crew of F-HMLD were cleared to descend to the first altitude below the transition level and to conduct the approach to runway 21, the PM (Pilot Monitoring) incorrectly read back the QNH, indicating an altimeter setting of 1021 instead of 1002. This error was not detected by the controller or the FP (Pilot Flying). When resetting the altimeter, the crew did not apply the procedure fully, omitting to check the consistency of the QNH provided by the controller against another source of information because of the turbulence experienced during this phase of flight, which was making it difficult for the crew to read the information written on the flight plan."*

2.3.2.2. *"Due to this QNH error, the aircraft's path during the approach was approximately 530 ft lower than the published path.*

[6] France. (2022). Baro-VNAV Approaches. In ICAO NCAA Meetings Document (EASPC/04 WP22). Retrieved from https://www.icao.int/NACC/Documents/Meetings/2023/GREPECAS21/GRP21WP09.pdf

[7] García-Heras, J., Sáez Nieto, F.J. (2012, May). Analysis of the geometric altimetry to support aircraft optimal vertical profiles within future 4D trajectory management. The 2nd International Conference on Application and Theory of Automation in Command and Control Systems. Retrieved from https://www.researchgate.net/publication/258845243_Analysis_of_the_Geometric_Altimetry_to_Support_Aircraft_Optimal_Vertical_Profiles_within_Future_4D_Trajectory_Management

[8] Bureau d'Enquêtes et d'Analyses [BEA]. (2023). Final Report on the Safety Investigation: Serious incident to the BOMBARDIER CL-600-2E25 (CRJ-1000) registered F-HMLD on 20 October 2021 on approach to Nantes-Atlantique (Loire-Atlantique)

However, the procedures and information on the aircraft instruments did not allow the crew to directly identify the path error in a simple way."

2.3.2.3. The crew of AFR33CW also did not detect the QNH error with abnormally low radio altimeter value. BEA has concluded the *"inherent limitations of the Baro-VNAV function in the event of an altimeter setting error … may have contributed to the non-detection of the erroneous final path…"*

2.3.3. Flight **ETD9878** [9]

2.3.3.1. The Boeing 787-10 was being operated as non-scheduled cargo flight on 6 June 2020 from Beijing to Abu Dhabi. "*During an RNP AR approach (RNAV (RNP) Y) to runway 31L at Abu Dhabi International Airport, when the Aircraft was on final approach at a distance of approximately 1.3 nautical miles from the threshold of runway 31L and approximately 210 feet radio altitude, the flight crew initiated a go-around. The go-around initiation was decided by the Commander after sighting four reds of the precision approach path indicator (PAPI) and subsequently carried out by the Copilot as pilot flying*."

2.3.3.2. "*The Air Accident Investigation Sector of the United Arab Emirates (AAIS) determines that the cause of the Aircraft flying below the vertical profile during approach was the incorrect local pressure (QNH) altimeter setting*."

2.3.4. Flight **NSZ4311** [10]

2.3.4.1. This incident relates to transmission of incorrect altimeter setting (QNH) by Air Traffic Controller, near-collision with ground during a RNP approach with barometric vertical guidance.

2.3.4.2. "*The crew of the Airbus A320 registered 9H-EMU were carrying out scheduled flight NSZ4311 between Stockholm Arlanda airport (Sweden) and Paris-Charles de Gaulle airport (France). Work was being carried out on the ILS for runway 27R at CDG, so the crew carried out a satellite approach * with barometric vertical guidance (RNP APCH down to LNAV/VNAV minima)… During the approach, in a rain shower which severely impaired visibility, the crew were given an incorrect altimeter setting (QNH) by the air traffic service with a difference of 10 hPa (1011 hPa instead of 1001)*."

* The flight was carrying out RNP approach when the incident happened. The term "satellite approach" was used in the official investigation report.

[9] Air Accident Investigation Sector of the United Arab Emirates. (2021). Serious Incident: Descent below Vertical Profile during Approach – Final Report (AAIS Case No: AIFN/0007/2020)

[10] BEA. (2024). Final Report on the Safety Investigation: Serious incident to the AIRBUS A320 registered 9H-EMU and operated by Airhub Airlines on Monday 23 May 2022 on approach to Paris - Charles de Gaulle airport

2.3.4.3. During the first attempt of approach, the aircraft was at a minimum height of 6 ft resulting in a near Controlled Flight Into Terrain (CFIT). The crew eventually performed a go-around due to visual reference not acquired.

2.3.4.4. During the approach, the flight crews stated that they did not hear any Auto-Callouts from Radio-Altimeter other than the callouts at 2500ft and 1000ft. Although the investigation report stated that "*Specific system analysis will be performed to confirm the presence or absence of auto-callouts*", it also stated that "*… design of the IFR procedures is based on normal operations and thus does not take into account an incorrect altimeter setting. The crews' operating procedures and those of the air traffic controllers did not prevent the use of an incorrect altimeter setting. Furthermore, neither the aeroplane's instruments nor the air traffic controller's tools were designed to detect this type of error*."

2.3.4.5. The investigation report further concluded that the "*… investigation found that crews frequently perform approaches with an incorrect altimeter setting without being aware of it, and that this serious incident is not an isolated case. A large proportion of these similar occurrences took place during ILS approaches where the vertical profile is not affected by an incorrect altimeter setting and did not give rise to significant incidents. Conversely, several significant incidents, even serious incidents or accidents occurred during barometric approaches.*" It proves that approaches with an incorrect altimeter setting without being aware of it is not uncommon nor isolated cases.

2.3.4.6. Following the case of Flight NSZ4311, Bureau d'Enquêtes et d'Analyses (BEA) has recommended "*whereas the BPS (Barometric Pressure Setting) information is included in the aircraft downlink data, a function made compulsory for the near-majority of aircraft operated in commercial air transport*".

2.4. Mitigation of human error in Baro-VNAV

2.4.1. Emphasizing the importance of Threat and Error Management (TEM) in detecting any error through read-back/ hear-back process would be one of the solutions in mitigating risk of incorrect barometric pressure setting. Nonetheless, ways to monitor aircraft barometric pressure setting for error detection, while without putting extra workload to controllers, should be explored.

2.4.2. Following the recommendation as stipulated in the Final Safety Investigation Report for Flight NSZ4311 by BEA in Para 2.3.4.6, Downlink Aircraft Parameters (DAPs) with BPS information is available with Mode S Enhanced Surveillance (EHS) under BDS (Comm-B Data Selector) code 4.0 – Selected Vertical Intention, as well as ADS-B DAPs with BDS code 6.2 Subtype 1 – Target State and Status Message, which provides information about the aircraft's current vertical intention, aircraft state and status information. Such DAPs *"…allow the implementation of new safety nets in ATM automation system for cross-*

checking selected aircraft vertical intention (i.e., Selected Altitude) with ATC controllers' instruction as well as verifying the barometric pressure setting applied in the aircraft with QNH setting in ATM automation system." [11]

2.4.3. "*Constantly checking if the barometric pressure setting in DAPs is consistent with the airport's QNH can alert the controller to avoid similar situations…*"[12] of aircraft having incorrect barometric pressure setting.

2.4.4. While it is technically viable for the ATMS to cross-check barometric pressure setting applied in the aircraft versus QNH setting in ATMS, such arrangement will require proper adaptation in ATMS and training provided to controllers with common phraseology and procedures to handle the process.[13] Given the extra safety net provided to mitigate human error in current approach procedures with reference to barometric altimetry, such development of technologies and/ or procedures should be supported.

2.5. Barometric Pressure Setting (BPS) Advisory Tool from NATS UK

2.5.1. Barometric Pressure Setting Advisory Tool (BAT) is *"a tool developed by air navigation service provider (ANSP) UK NATS to identify significant QNH setting errors based on downlinked Mode S Barometric Pressure Setting (BPS) data."*[14]

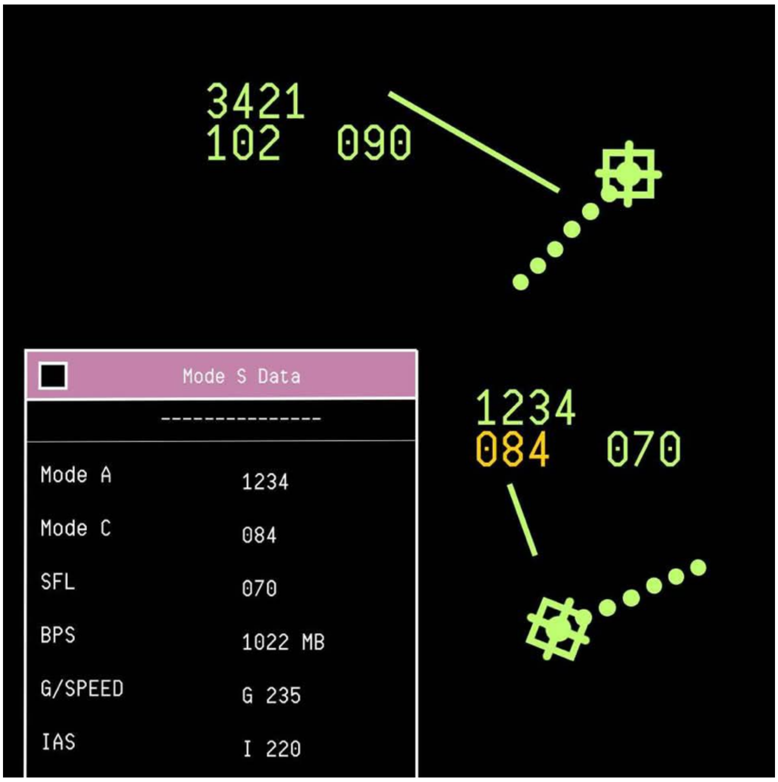
2.5.2. The BPS Advisory Tool (BAT) was developed to reduce errors in setting barometric pressure. The ATMS tool monitors the aircraft barometric pressure setting (BPS) available from Mode S DAPs to provide an advisory to the controller when the discrepancy has passed the adjustable threshold when it compares to local barometric pressure settings. It was structured for a ***single*** challenge of the aircrew to ensure a correct barometric pressure setting is used when passing through transition level in London Terminal Control, for both arrivals and departures.

2.5.3. All the pressure setting monitoring tasks are done by the ATMS without controller input.

2.5.4. Once the system detects a discrepancy of BPS of 5hPa (variable parameter in system) or larger between aircraft Mode S data and the local BPS, a BAT advisory will be generated. The monitoring is applicable for both Arrivals and Departures in London Terminal Control. The following diagram shows the example of BAT advisory for flight having Mode A code 1234, where its level field is displayed in pulse

[11] ICAO Asia and Pacific Office. (2023). Mode S Downlink Aircraft Parameters Implementation and Operations Guidance Document (Edition 5.0, 19)
[12] ICAO Asia and Pacific Office. (2023). Mode S Downlink Aircraft Parameters Implementation and Operations Guidance Document (Edition 5.0, 60)
[13] International Federation of Air Traffic Controllers' Associations [IFATCA]. (2024). ATS 3.16 The Use of Safety Nets in ATM. Technical and Professional Manual (Version 67.0)
[14] SKYbrary. (2025). Barometric Pressure Setting Advisory Tool (BAT). Retrieved from https://skybrary.aero/articles/barometric-pressure-setting-advisory-tool-bat

yellow.[15] Below shows the illustration on how the label looks like on Situation Display.



2.5.5. Regarding responsibilities of controllers, response to a BAT advisory is not a mandatory task, however, "*any response which may enable the early identification of possible level busts is encouraged. The use of BAT is not a substitute for RT read-back, which remains a mandatory controller task. Where a BAT advisory indicates a variation from the QNH provided by ATC, controllers must not state the incorrect QNH value which can be observed in the Mode S Data Window on the radar display. Controllers are required to complete a formal safety report for any BAT advisory / resolution where safety may have been compromised but place details of other BAT use in a "comments folder".*"[14]

2.5.6. Although there is no standard phraseology stipulated in ICAO Doc 4444 PAN-OPS regarding responses to BAT advisory, when controllers choose to query the discrepancy of BPS, the following phraseologies are utilised when local QNH is used:[14]

2.5.6.1. "(Callsign), Check Altimeter Setting, QNH XXXX"

2.5.6.2. "(Callsign) Report QNH"

2.5.7. The procedure design allows aircrew as much time as possible to resolve the issue when passing through the transition level. The BAT

[15] NATS. (2010). The viability and Safety Benefits of using the Mode-S Barometric Pressure Setting (Edition 1.0, 6)

advisory also provides controllers with sufficient warning to initiate necessary actions to prompt aircrew to correct the barometric pressure setting.

2.5.8. A response is not mandated from the aircrew. Once an acceptable response is received from aircrew, controllers are not required to persist. Controllers are not expected to repeat the challenge.

2.5.9. The experience from NATS UK has demonstrated that such a concept is both technically viable and practicable. It also sets an excellent example of how technology is best used to improve operational safety while keeping controllers' workload to minimum.

2.6. Alternatives to Baro-VNAV

2.6.1. Baro-VNAV is utilized as approach procedure with vertical guidance, where precision approach procedure is not available due to equipment or flight crew issues.

2.6.2. Over the years, different approach procedures based on geometric altitude with reference to Global Navigation Satellite System (GNSS) have been developed. Such procedures are independent of barometric pressure setting and have achieved CAT 1 Approach minima, e.g. Satellite Based Augmentation System (SBAS) with utilization of additional satellites, Ground Based Augmentation System (GBAS) etc.

2.6.3. In December 2020, IFALPA has published a position paper to support "*research into a possible future transition from Barometric Altitude to using Geometric Altitude for sub transition level en-route, and approach operations*"[16] with the following safety and operational benefits:

2.6.3.1. Altimeter setting error, together with the requirement to calculate cold temperature error correction for all approaches would be eradicated.

2.6.3.2. Common datum for all aircraft, including Unmanned Aircraft Systems, with multiple airfields each on different local QNH. This will be important especially during the safe integration of UAS into existing airspace.

2.6.3.3. Less stringent and comprehensive maintenance on GNSS when compared to barometric pressure sensing systems.

2.6.4. Transition into using geometric altitude for ATC purposes instead of using the barometric altitude may require long process with at least the following considerations:

2.6.4.1. Capabilities of ATMS and aircraft systems

2.6.4.2. Availability of related flight and ATC procedures

2.6.4.3. Training required for ATC and pilots

[16] The International Federation of Air Line Pilots' Associations [IFALPA]. (2020). Position Paper: Geometric Altitude

2.6.4.4. GNSS Spoofing/ Jamming issues

2.6.5. Nonetheless, given the safety benefit of mitigating risk involved in human error with barometric pressure setting brought by the concept of utilizing geometric altitude, research of development of related equipment, technologies and procedures should be encouraged.

2.7. Current related IFATCA Policy

2.7.1. In view of mitigating human error in Baro-VNAV by enabling DAPs with BPS information with Mode S EHS, the following IFATCA policies could be referred to:

2.7.1.1. ATS 3.16 The Use of Safety Nets in ATM

IFATCA Policy is: "**When implementing ground-based safety nets, common phraseology and procedures shall be used in their operation**"

2.7.1.2. AAS 1.5 Air-Ground Datalink

IFATCA Policy is: "**IFATCA supports Datalink concepts that improve frequency management provided that they demonstrate an identical or better level of safety and efficiency compared to voice communication**"

2.7.1.3. AAS 1.3 Mode S Development

IFATCA Policy is: "**ATC surveillance systems shall be able to process all data, regardless of the volume or type, necessary to provide ATC Services safely**"

2.7.2. AAS 1.19 Operational Use of Down-Link Aircraft Parameters (DAPs)

IFATCA Policy is: "**When using downlinked Altitude (PSA**):
It shall not be used to provide separation;
The display of a PSA should not be used as a substitute for a readback;
An alert should be presented to the controller for aircraft with a mismatch between PSA and the Cleared Flight Level (CFL);
Nuisance alerts should be kept to a minimum;
An alert timeout period should be applied to allow for a new level to be selected in the cockpit."

2.7.3. Regarding geometric altitude based approach procedures, the following IFATCA policy could be referred to:

2.7.3.1. AAS 1.15 Concept of GNSS-Based Altitude

2.7.3.1.1. The use of pressure-based altimeters to determine aircraft altitude has been universal across the globe for most of aviation history. This policy examines alternatives provided by Global Navigation Satellite System (GNSS) technologies.

IFATCA Policy is: "**IFATCA encourages development of technologies that improve the accuracy of vertical navigation**"

3. CONCLUSION

3.1. Human error/ intervention are the major contributing factors to incidents related to Baro-VNAV, where barometric altimeter setting is incorrectly set or incorrect QNH/ QFE is obtained. Investigation found that approaches with incorrect altimeter settings occur frequently and are not isolated cases.

3.2. Current IFATCA policies may not be specific enough to encourage the enabling of DAPs with BPS to be processed by ATMS and provide warning to controllers when incorrect barometric altimeter setting is detected.

3.3. The current policy stated in AAS 1.15 "IFATCA encourages development of technologies that improve the accuracy of vertical navigation" may not be sufficient in promoting the use of 3D approaches based on geometric altitude over non-precision approach or approach with vertical guidance. However, given the global wide GNSS jamming/ spoofing issues, it is recommended to leave the policy untouched until positive solutions have been developed regarding GNSS jamming/ spoofing.

3.4. The following measures are suggested to mitigate the human error in barometric pressure setting in different phases of flight:

3.4.1. Emphasize the importance of Threat and Error Management (TEM) to avoid any read-back/ hear-back error when passing barometric pressure setting information to aircrew.

3.4.2. Use of Altimeter Setting Monitoring Tool (ASMT), which is a tool to provide a warning to the controller if there is a discrepancy between aircraft altimeter setting and appropriate altimeter setting. This could be provided through enabling DAPs from Mode S EHS/ ADS-B on aircraft barometric pressure setting information for ATMS to cross check aircraft barometric altimeter setting, detect error and provide warning to controllers in case an incorrect barometric altimetry is set. A good example of using such a tool is the BAT from NATS.

4. DRAFT RECOMMENDATIONS

4.1. It is recommended the current IFATCA Policy:

AAS 1.19 Operational Use of Down-Link Aircraft Parameters (DAPs)

When using downlinked Altitude (PSA):

- **It shall not be used to provide separation;**
- **The display of a PSA should not be used as a substitute for a readback;**

- **An alert should be presented to the controller for aircraft with a mismatch between PSA and the Cleared Flight Level (CFL);**
- **Nuisance alerts should be kept to a minimum;**
- **An alert timeout period should be applied to allow for a new level to be selected in the cockpit**."

is amended to

Altimeter Setting Monitoring Tool (ASMT)

- **ATM systems shall have a tool which provides a warning to controllers, if there is a discrepancy between aircraft altimeter setting and appropriate altimeter setting.**

- **Implementation shall include appropriate operational requirements, procedures and training to respond to such a warning.**

When using downlinked Altitude (PSA):

- **It shall not be used to provide separation;**
- **The display of a PSA should not be used as a substitute for a readback;**
- **An alert should be presented to the controller for aircraft with a mismatch between PSA and the Cleared Flight Level (CFL);**
- **Nuisance alerts should be kept to a minimum;**
- **An alert timeout period should be applied to allow for a new level to be selected in the cockpit**.

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5.12. ICAO Asia and Pacific Office. (2023). Mode S Downlink Aircraft Parameters Implementation and Operations Guidance Document (Edition 5.0, 60)
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