

NATS Report: The viability and Safety Benefits of using the Mode-S Barometric Pressure Setting

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NATS Head Office:

Corporate and Technical Centre
4000 Parkway
Whiteley
Fareham
Hants PO15 7FL

Tel: 01489 616001

Web: <http://www.nats.co.uk/>

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Contact Person(s)	Tel	Unit
Adrian Price	+44 1489 444827	NATS ATM Research

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RESPONSIBILITY	NAME	SIGNATURE	DATE
Senior Research Analyst (Author)	Adrian Price	AJP	4/11/2010
ATC Planner (Author)	Simon Taylor	STaylor	4/11/10.
Senior Safety Engineer	Nigel King	N. King	4/11/2010
Head of ATSI	Bill Leipnik	Bill Leipnik	3/11/2010

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Contents

	PAGE
Document Characteristics	2
Document Approval	2
Document Change Record	2
Contents	3
Abbreviations	3
Executive summary	4
1 Introduction and Background	5
2 The practicalities of using Mode-S BPS	5
3 Development of the BPS Advisory Tool	6
4 Conclusion	7
Referenced documents	7
APPENDIX A Study of the viability of using Mode-S BPS	8
A.1.1 Methodology	8
A.1.2 Validation of BPS data	9
A.1.3 Altimeter setting errors on final approach	10
A.1.4 Altimeter setting errors on the arrival phase prior to final approach	11
A.1.5 Altimeter setting errors on the departure phase	12
A.1.6 Analysis of level deviations by operator type.	13

Abbreviations

ATC	Air Traffic Control
BPS	Barometric Pressure Setting
CAA	Civil Aviation Authority
DAPs	Down-linked Aircraft Parameters
EASA	The European Aviation Safety Agency
EFD	Electronic Flight Data
EHS	Enhanced Mode-S
FL	Flight Level.
FOI	Flight Operations Inspectors
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
PANS-OPS	Procedures for Air Navigation Services - Operations
QFE	The Q-code for the local atmospheric pressure at the surface.
QNH	The Q-code for the local atmospheric pressure, adjusted as though it was measured at mean sea level.
SPS	Standard Pressure Setting (1013.2mb)
SSE	Safety Significant Event
TC	Terminal Control (London)
TMA	Terminal Manoeuvring Area

Executive summary

1. The Mode-S technology provides the capability to down-link the altimeter sub-scale setting being used on the flight deck of an aircraft. Further information on altimeters and the sub-scale setting is contained in References 1 & 2.
2. ICAO Procedures for Air Navigation Services - Aircraft Operations (PANS-OPS) provides guidance for altimeter subscale setting and it has established that a clear majority of flight crews follow this guidance in a timely manner. However, despite appropriate behaviour from the majority of crews, there are a few lapses that warrant further action.
3. There is evidence that the proportion of flight crews that make an altimeter setting error on arrival into the London TMA has increased during the period December 2008 – March 2009. The chart A.1 in Appendix A depicts this trend.
4. B767 series aircraft operated by five U.S. based carriers account for 0.94% of the overall London TMA arrivals and 47.1% of the altimeter setting errors on final approach during the period 6th September 2008 to 27th April 2009.
5. The risk of level deviations caused by altimeter setting error is highest when the atmospheric pressure is low and the risk is significant when the London TMA pressure is forecast to be less than 996mb. It is NATS' policy to issue a NOTAM warning flight crews of these situations². Despite this policy, altimeter setting error is the second largest cause of reported level deviations in the London TMA.
6. Reference 3 states that the Mode-S BPS shall contain "the current barometric pressure setting". However, a large majority of Airbus aircraft transmit stale data when the aircraft's pressure altimeters are calibrated to 1013.2mb. This implementation compromises the benefit of an ATC tool that would check for altimeter setting errors on flights departing the London TMA. It is advised that Airbus Industrie is encouraged to adopt the ICAO standard for populating the Mode-S BDS 4,0 register.
7. Mode-S BPS data is provided by approximately 80% of flights in London TC airspace and, excluding the non standard data from Airbus aircraft above the transition altitude, is of high integrity. Although the provision of Mode-S BPS is not a mandated item, there is a viable opportunity to use the information below the transition altitude.
8. PANS-OPS allow flight crews to have disparate altimeter settings for transition between altitudes and flight levels. A tool that detects altimeter setting errors has been developed, which reflects the PANS OPS guidance and only monitors Mode-S BPS data once the transition is complete. It is acknowledged that flight crews may use either QFE or QNH at their discretion.
9. The provision of Mode-S BPS has not been mandated by all members of the European Civil Aviation Conference, however, BPS is included in UK legislation as documented by CAP393 Air Navigation: the Orders and the Regulations. See reference 6.

Note 1: Figure A.1 in Appendix A shows a typical relationship between the vertical profile and the Mode-S BPS setting.

Note 2: 996mb equates to a pressure differential of 500' altitude. There were 40 days in the 12 months following 01/07/2008 (i.e. 11% of the time) when the Heathrow QNH fell to less than 996mb.

1 Introduction and Background

1.1.1 NATS participates with airline operators in an ongoing campaign to reduce the frequency of cases and to mitigate the risk of level busts. As part of that campaign, NATS analyses each reported level bust to determine the likely cause of the incident. Causal factor analysis shows that Altimeter Setting Error is a major cause of aircraft deviating from their cleared level (Level Bust). The latest causal factor metrics for level busts can be viewed on the Levelbest website:

<http://www.levelbust.com/causal.htm>

Altimeter Setting Error has also caused aircraft to descend through the base of Controlled Airspace and to descend below the glide-path on final approach. One example can be found on the Skybrary website:

[www.skybrary.aero/index.php/A310,_vicinity_of_Birmingham_UK,_2006_\(LB_CFIT\)](http://www.skybrary.aero/index.php/A310,_vicinity_of_Birmingham_UK,_2006_(LB_CFIT))

NATS takes no responsibility for the security or accuracy of information on external websites

1.1.2 The aviation community has always been aware of the risk of a level bust caused by an altimeter setting error and there have been publicity drives to remind flight crews of the need to adopt stringent procedures for setting and cross checking of altimeters. NATS is also making the best use of available technology to improve its Safety Performance record, especially in the busy and complex airspace surrounding the London Terminal Manoeuvring area.

2 The practicalities of using Mode-S BPS

2.1.1 The Mode-S technology provides the capability to down-link one altimeter sub-scale setting being used on the flight deck of an aircraft. This information can be made available in the form of the Mode-S Barometric Pressure Setting (BPS) parameter.

2.1.2 The Mode-S BPS parameter has not been officially mandated in Europe, however, a study was performed by NATS ATM Research over the period 2008-2009 to determine the availability, viability and safety benefits of using Mode-S BPS data. The study showed that:

- The availability of the Mode-S BPS data was slight less than the Mode-S Selected Altitude e.g. approximately 80% for London Heathrow movements. It was noted that the Boeing B777 series does not provide Mode-S BPS data.
- Where provided, the Mode-S BPS data represented the altimeter sub-scale setting for some phases of flight¹.
- In most cases, an altimeter setting error was evident for several seconds, or even minutes prior to a level bust. This phenomenon would enable the use of an automated tool that will enable ATC to prevent level busts.

Further information of the study can be found in appendix A

Note 1: During the study, it was found that a majority Airbus aircraft and some Fokker types transmit stale Mode-S BPS data when the aircraft is above the transition altitude. Examination of recorded radar data for departure aircraft shows that the last used QNH continues to be downlinked even though it is evident that the altimeters have been set to standard pressure. This trait does not affect the safety benefit of using Mode-S BPS data for aircraft that are below the transition altitude.

3 Development of the BPS Advisory Tool

3.1.1 NATS has developed a simple tool that detects altimeter setting errors in the London TMA. Broadly speaking the tool examines the current level and the intended level (via Mode-S selected altitude) to confirm that the flight profile will remain below the transition altitude. The tool is designed to give flight crews as much time as possible to change altimeter settings and will only highlight those aircraft that are likely to breach their cleared level within the next 40 seconds (approximately).

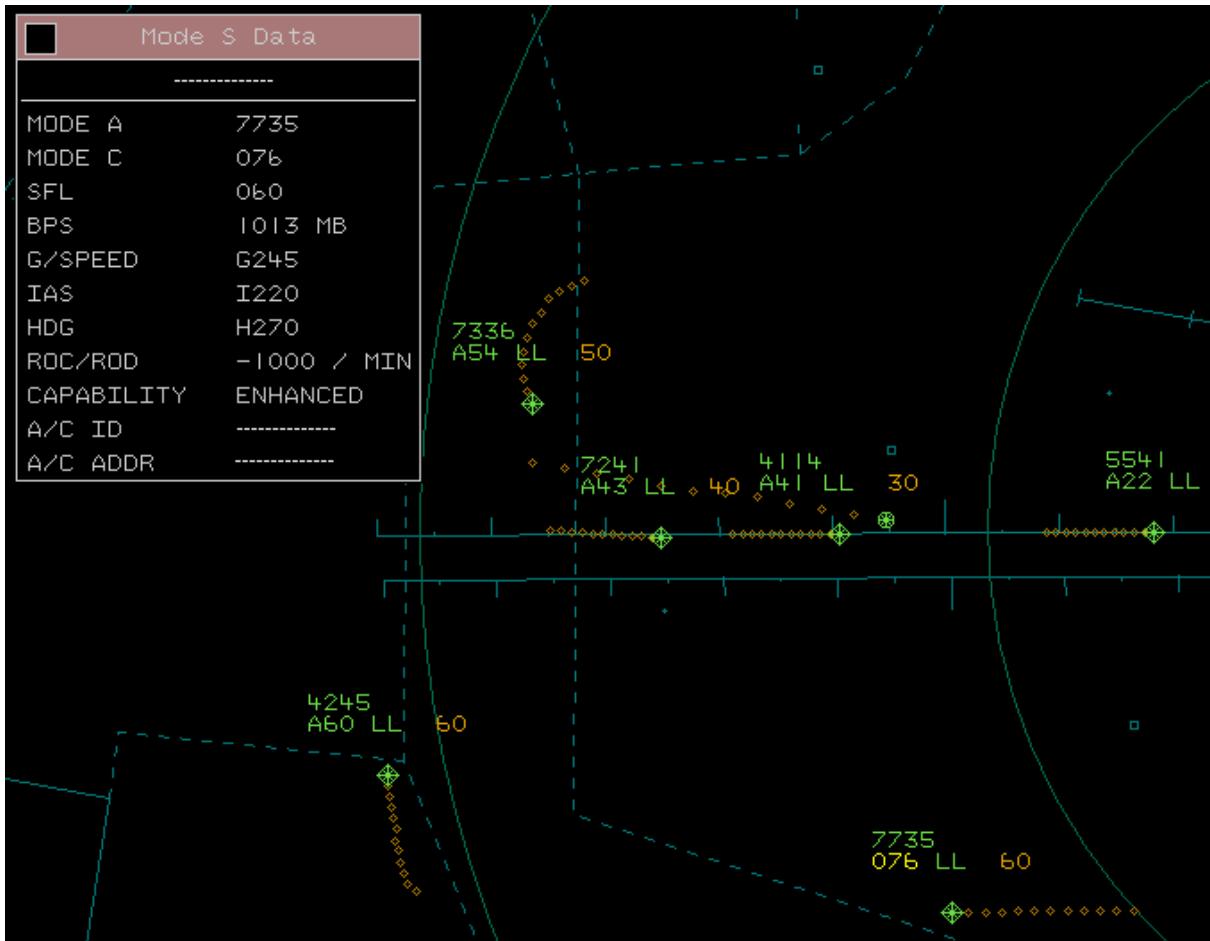


Figure 1 – Example of an altimeter setting error on 7735²

Note 2: The BPS Advisory Tool will cause the level field on 2nd line of target label to pulse yellow. Note also that the level field has not been converted for QNH. 7735's altitude was 6600' at that moment.

3.1.2 All Non Precision Approaches, such as Surveillance Radar Approach (SRA), Localiser only with DME and RNP approaches, are reliant on barometric altitude to establish an accurate vertical profile. SRAs are by far the most prevalent of these types of approaches and are guided by ATC who will reiterate the QNH at the start of the procedure and will monitor the vertical profile throughout the approach.

3.1.3 The commercial and environmental benefits of Continuous Descent Approaches (CDAs) are widely recognised and are expected to become more commonplace as ATC and airline operators strive to improve efficiency. An RNP Approach (RNP APCH) with Barometric, vertical navigation (BaroVNAV) can be a part of a CDA procedure. It is accepted that setting the local QNH is also vital to a safe and efficient RNP APCH with BaroVNAV. CDAs usually require far less ATC instruction than SRAs and if a CDA is commenced from a flight level, the flight crew must be even more vigilant to prevent an altimeter setting error.

4 Conclusion

- 4.1.1 Reference 4 is the legislation for Air Navigation in the United Kingdom states that the following as one of the mandated parameters: "reporting of the Selected Vertical Intent Downlinked Aircraft Parameter (including Barometric Pressure Setting)." The provision of Mode-S BPS has not been mandated by all members of the European Civil Aviation Conference, however, reference 5 (ED Decision 2006/12/R 22/12/2006) states "Barometric Pressure Setting should be provided where readily available".
- 4.1.2 The Mode-S BPS data is provided by approximately 80% of flights in London TC airspace and the data is of very high integrity except for the stale data provided by Airbus and some Fokker aircraft above the transition altitude.
- 4.1.3 NATS has taken the opportunity to reduce the risk of a mid air collision and Controlled Flight Into Terrain by using Mode-S BPS data in the BPS Advisory tool. The tool will not require any change in practice by operators, however, flight crews may receive an additional prompt to check their altimeter settings during the initial stage of an approach.
- 4.1.4 The benefit of this tool is currently limited to detecting altimeter setting errors below the transition altitude. The tool has the potential to deliver much greater benefit if Airbus and Fokker updated their implementation of Mode-S BPS such that downlinked data reflected when flight crews are using the standard pressure setting above the transition altitude.

Referenced documents

- [1] ICAO Doc 8168 (PANS-OPS), Volume I, Flight Procedures – Altimeter Setting Procedures
- [2] ICAO Standards and Recommended Practices, Annex 10, Volumes III and IV
- [3] ICAO Doc 9871, Technical Provisions for Mode S Services and Extended Squitter, Table A-2-64 BDS 4,0
- [4] CAP393 Air Navigation: The Order & the Regulations, section 3, part 6, article 19 paragraph 4.i (2006)
- [5] Decision n° 2006/12/R of the Executive Director of EASA
- [6] The Use Of Mode-S Selected Altitude In ATC Operational Considerations – Thesis for MSc in Air Transport Management by Rob Eagles (IATA)

APPENDIX A Study of the viability of using Mode-S BPS

A.1.1 Methodology

- A.1.1.1 The NATS ATM Research investigation into flight deck procedures used the work of Mr Rob Eagles who investigated flight crew behaviour as part of his thesis for an MSc degree in Air Traffic Management. See section 6 of reference [6] for further information.
- A.1.1.2 The recommended procedures for setting altimeter sub-scales can be found in the ICAO Procedures for Air Navigation Services - Aircraft Operations (PANS-OPS) guidance publications^{A.1}. ICAO Standards and Recommended Practices (SARPs) were also studied. See references [1] and [2] for further information.
- A.1.1.3 It was noted that while the vertical profile remained wholly above or below the transition layer, it is recommended that Pilot Flying and Pilot Monitoring should use the same subscale setting. A model was developed for off-line analysis that extracted Mode-S level data, BPS and selected altitude from recorded radar. The model embodied an algorithm that used the current level and intended altitude to define a vertical profile. The model was used to extract data from recorded radar and to compare Mode-S BPS against the current QNH.
- A.1.1.4 The study has established that a clear majority of flight crews change altimeter settings in a timely manner in accordance with PANSOPS. However, despite appropriate behaviour from the majority of crews, there are a few lapses that justified further investigation.
- A.1.1.5 The risk of level deviations caused by altimeter setting error is highest when the atmospheric pressure is low. The risk is significant when the pressure in the London TMA is forecast to be less than 996mb and it is NATS' policy to issue a NOTAM warning flight crews of these situations. Despite this policy, altimeter setting error is one of the largest causes of level deviations in the London TMA. Note also that there were only 40 days in the 12 months following 01/07/2008 (i.e. 11% of the time) when the Heathrow QNH fell to 995mb or less.
- A.1.1.6 During the study, it was found that a majority Airbus aircraft and some Fokkers transmit stale Mode-S BPS data under certain circumstances. The tool was given access to flight plan information in order to filter out the BPS values for affected Airbus and Fokker types that were above the transition altitude. The tool also examined the Mode-C behaviour against the selected altitude with the expectation that the Mode-C should not normally deviate away from the selected altitude except when the aircraft is established on final approach.

Note A.1: It is acknowledged that reference [1] allows flight crews to use either QNH or QFE when operating below the transition altitude. Examination of Mode-S radar data recorded for eight three days in a fifteen month period demonstrates that flight crews invariably used QNH when operating in the London Terminal Manoeuvring Area

A.1.1.7 The combination of analysing the Mode-S BPS value together with the Mode C altitude profile and the Selected Altitude, reveals many cases of apparent level busts. The chart below shows the correlation between a typical vertical profile and the Mode-S BPS when the aircraft is believed to have experienced an altimeter setting error. The local QNH was 999mb, which equates to a pressure altitude difference of approximately 400' compared to SPS. The selected altitude shows that the aircraft was cleared to FL100 at 20:14:25 approximately. At this time the aircraft was climbing and had already passed the transition altitude of 6000'. According to ICAO PANSOPS, the flight crew should have changed the altimeter setting to 1013mb but failed to do so. The aircraft eventually levelled off 400' above the cleared altitude at 20:15:39. The oversight is not rectified until 20:19:03 when the aircraft is passing FL196.

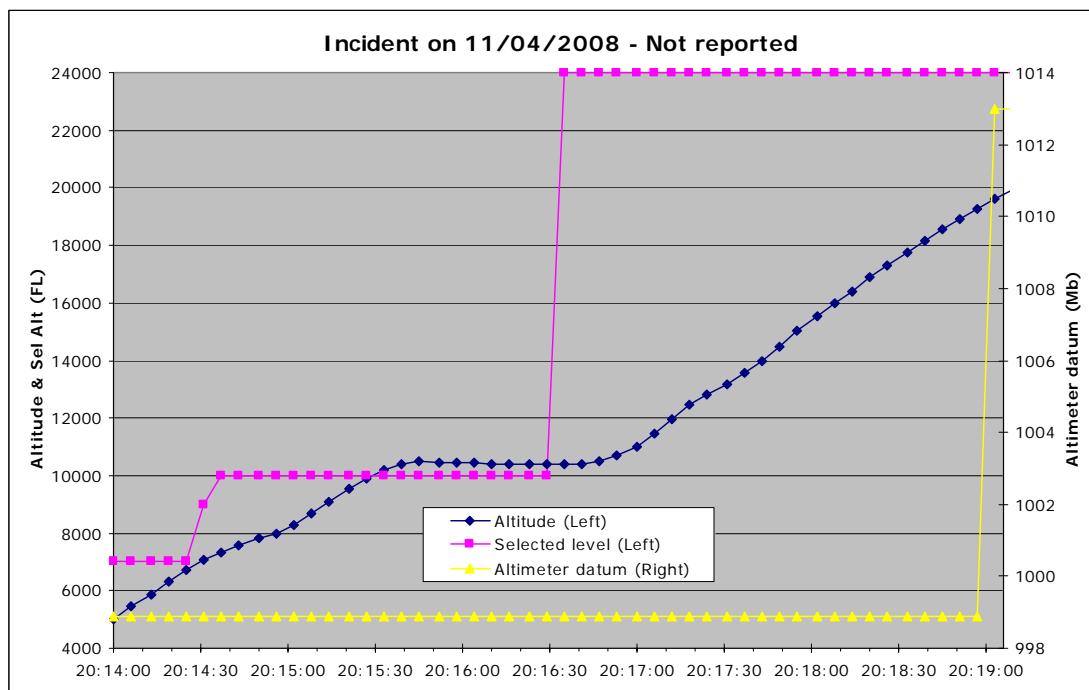


Figure A.1 – Example of an altimeter setting error lasting nearly 5 minutes

A.1.2 Validation of BPS data

A.1.2.1 Prior to the study, it was expected that faulty BPS data would be the main cause of mismatches between expected and actual results. To establish the integrity of Mode-S BPS data, 42 days of radar data were examined in detail. Faulty BPS data was encountered only twice and each time persisted for only one update. For the technically minded, bit 27 of BDS 4,0 is used to determine whether BPS data was being provided by the aircraft. For the purposes of this study, if bit 27 was set false then the aircraft is deemed as not BPS capable and bits 28 – 47 inclusive are ignored.

A.1.2.2 The integrity of BPS data was further strengthened by cross referencing radar tracks with the flight plan database and examining only those tracks that could be matched to a flight plan. This step effectively excludes general aviation from the results. Note that the tracks outside an area bounded approximately 45NM south of Heathrow to 75NM north and 60NM west of Heathrow to 52NM east were excluded from the study for expediency and to avoid problems associated with two aircraft using the same SSR code.

- A.1.2.3 The inspection of bit 27 of BDS 4.0 coupled with the cross-referencing of radar tracks to GAT flight plans ensured the integrity of the BPS data was very high. Two minor errors in BPS data were detected in the radar recordings collected for the 42 days of detailed analysis. Each day, over 650,000 responses containing BPS data were examined meaning approximately 27,000,000 responses were tested in total. This equates to an error rate of approximately 7.4×10^{-8} .
- A.1.2.4 Accuracy of BPS data is not the sole criteria for determining whether its use is viable, the proportion of aircraft supplying a non mandated item is important. For those aircraft departing or arriving at an airport within the London TMA, it was found that 80% - 85% of aircraft provided BPS.
- A.1.2.5 The continuous provision of BPS from each and every aircraft was not positively determined. However, there was no deliberate attempt to make the model resilient to the effects of stale data and none of the observed discrepancies were attributed to stale data. The implication is that even when using a single radar, the BPS data is down-linked with enough consistency to provide an indication of what is being performed on the flight deck.

A.1.3 Altimeter setting errors on final approach

- A.1.3.1 The risk of a level bust caused by an altimeter setting error is usually associated with departure aircraft that fail to set standard pressure once above the transition altitude. However, the study highlighted that altimeter setting errors were also apparent on arrival aircraft and in some cases the error was still present when the aircraft commenced final approach.
- A.1.3.2 It appeared that the rate of altimeter setting errors on final approach appeared to increase over the Winter 2008 to Spring 2009 compared to the same period in the previous year. Originally this study had examined 42 days' worth of radar data and only twelve days from 2009 were included at that time. It was decided to conduct extra analysis in order to be sure that the occurrences in table 1 were not a statistical anomaly. An extra 31 days where the pressure fell below 996mb were selected for further analysis.
- A.1.3.3 Chart A.1 shows the frequency of altimeter setting errors that were made during final approach during the periods 1st to 18th January 2008, 1st to 12th March 2008 and 7th July 2008 to 27th April 2009. A list of the individual cases can be obtained from NATS
- A.1.3.4 Traffic figures declined markedly over the period of analysis. In order to represent the number of altimeter setting error incidents as a proportion, the error rate per 1000 arrivals was calculated. In the following chart, the blue columns represent an absolute value while the red shows the relative proportion to the overall number of movements. For example:

On 07/07/2008 there were 974 aircraft that were classified as a TMA arrival and equipped with Mode-S BPS, i.e. a value of 1 equates to $1000/974=1.027$

On 02/02/2009 there were 454 aircraft that were classified as a TMA arrival and equipped with Mode-S BPS, i.e. a value 1 equates to $1000/454=2.023$

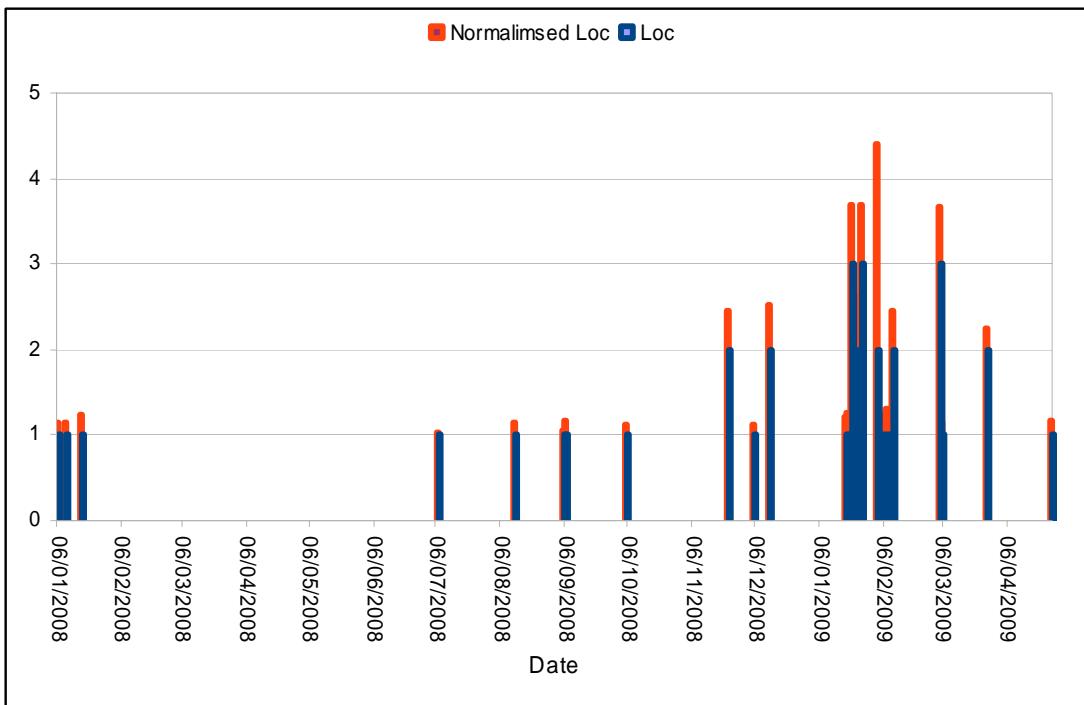


Chart A1 - Rate of Altimeter Setting Errors on Localiser

Period 01/01/08 – 27/04/09

A.1.3.5 The individual cases associated to this chart are available from NATS. Note the apparent increase in the error rate, which began around the end of November 2008 and peaked in February 2009. The cause of this increase is under investigation. On-going analysis of Mode-S data will reveal the actual trend, if any, of altimeter setting errors made by aircraft on final approach.

A.1.4 Altimeter setting errors on the arrival phase prior to final approach

A.1.4.1 In general; a level deviation during a descent is unlikely to cause a loss of separation, the exception is for the Heathrow arrivals on to runway 27R or 27L. Heathrow arrivals are usually restricted in descent to 4000' altitude on base leg to ensure separation from London City movements. If the altimeter datum of the descending aircraft has not been set to the Heathrow QNH, then there is an increased risk loss of separation with a London City departure where the standard procedure is to climb to 3000' altitude.

A.1.4.2 The following chart shows the frequency of all altimeter setting errors made below the transition altitude, which includes descent in the traffic pattern prior to commencing final approach. The increase is still evident but not as pronounced, which indicates that a slight increase in errors were being made during descent but they were significantly less likely to be rectified prior to commencing final approach during the period December 08 to March 2009.

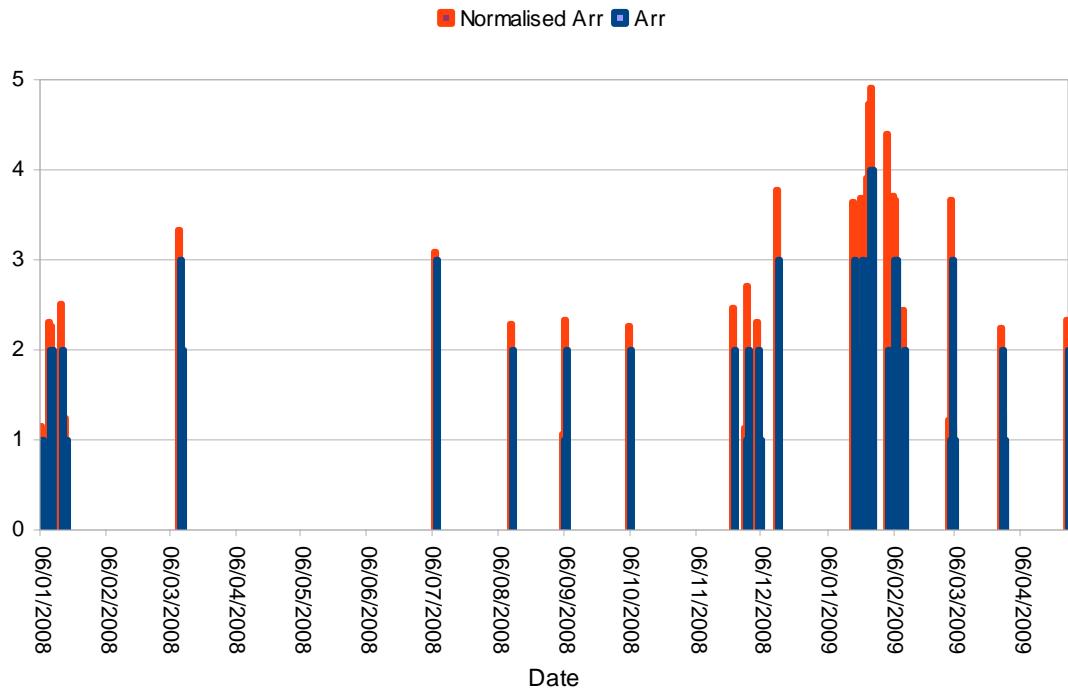


Chart A.2 - Rate of all Altimeter Setting Errors on Arrivals below transition altitude, period 01/01/08 – 27/04/09

A.1.5 Altimeter setting errors on the departure phase

- A.1.5.1 In the London TMA the first altitude clearance given by ATC at the end of the Standard Instrument Departure (SID), is to a flight level that is between the transition level and FL100. Consequently the greatest risk of a level deviation due to an altimeter setting error is between FL70 and FL100 in the London TMA. That said; there are cases where the altitude deviation has occurred well above FL100. The highest level deviation found occurred at FL230, which is in en-route airspace.
- A.1.5.2 The following chart shows the rate of altimeter setting errors made during the departure phase during the same period. There are two peaks; one on the 22nd January 2009 and another on 4th March 2009 but apart from these two peaks there is little to differentiate between the periods January to March 2008 and January to March 2009.

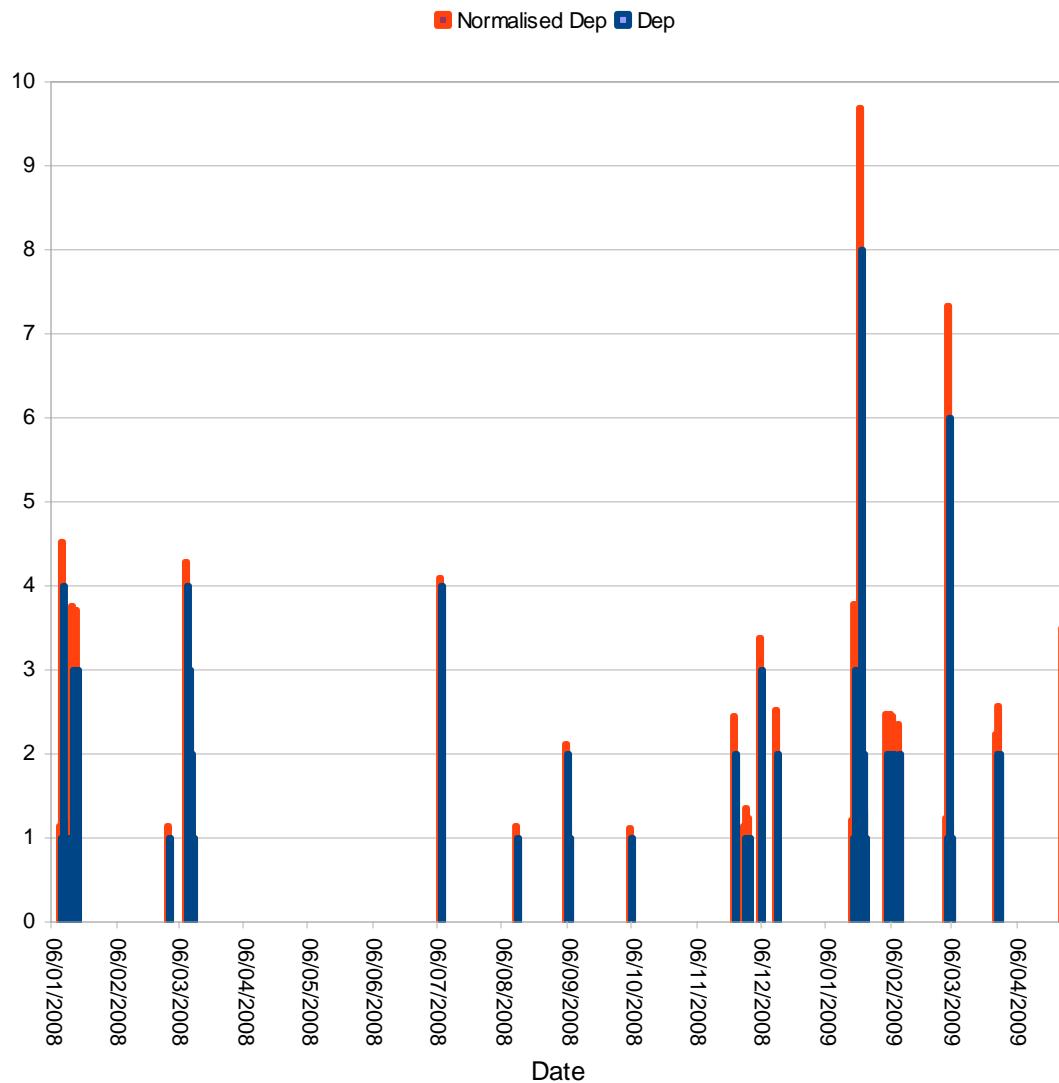


Chart A.3 - Rate of Altimeter Setting Errors on Departure

Period 01/01/08 – 27/04/09

A.1.6 Analysis of level deviations by operator type.

- A.1.6.1 Cases where the tool had detected a level deviation detected and had highlighted an altimeter setting error were examined in detail. Tables C.1 & C.2 were created to help determine whether there is a particular category of airline operators, either by nation or type, which is more prone to making an altimeter setting error that leads to a level deviation.
- A.1.6.2 Care must be taken when viewing these tables. The proportion of altimeter setting errors made by business jets operators would appear larger in 2008 compared to 2009, but consideration must be made for the decrease in business jet movements during the latter period.
- A.1.6.3 It is difficult to draw any authoritative conclusions from the tables when looking at all instances of altimeter setting errors. However, close examination of instances where there an altimeter setting error is evident on final approach has identified one particular group of operators.

- A.1.6.4 During the period 6th September 2008 to 27th April 2009, 21 out of the 34 (i.e. 61.8%) incidents of altimeter setting error on final approach were committed in a B767 series airframe. However, the Boeing 767 series only accounts for approximately 3.4% of movements in the London TMA.
- A.1.6.5 Further study shows that for the LTMA movements made by the B767 series in January 2009, approximately 27.6% are based in the USA, 9.5% in Canada and 43.8% in the UK. Of the 34 altimeter setting errors on final approach, 16 (47.1%) were committed by a B767 series operated by one of five U.S. based carriers.
- A.1.6.6 Put simply; B767 series aircraft operated by five U.S. based carriers account for 0.94% of the overall London TMA arrivals and 47.1% of the altimeter setting errors on final approach during the period 6th September 2008 to 27th April 2009.
- A.1.6.7 As stated previously, it could be possible to prevent some level deviations by communicating a potential adverse trend with the pilot representatives such as the CAA FOI and IATA. In particular, it may be possible to mitigate the altimeter setting errors made by the U.S. operators of the B767 series aircraft on final approach in the London TMA.
- A.1.6.8 The diversity of the operators who perpetrate altimeter setting errors would mean that it is unlikely that the risk of a level deviation caused by this type of error can be eliminated for all phases of flight. An automated tool to help controllers identify aircraft that have made an altimeter setting error could provide further mitigation against the risk of a consequent level deviation

For more information, please contact:

Mr Adrian Price

Senior Research Analyst, ATM Research

NATS

D: +44 (0)1489 444827

E: ade.price@nats.co.uk

CTC, Box 9
4000 Parkway,
Whiteley, PO15 7FL
www.nats.co.uk