NAVIGATION SYSTEMS PANEL (NSP)

Working Group 1& 2 meeting
(Brussels, 8 - 19 May 2006)

Agenda Item 7 g): Report to ANC on APV/Baro (OCP/13 Recommendation 5/21)

Analysis of BaroVNAV safety issues

Presented by Michel Calvet, France

Prepared by Benoît Roturier

SUMMARY

BaroVNAV is seen by the aviation industry as a major feature of the navigation infrastructure to support RNAV, RNP approaches and possibly precision approaches in the future. During discussions which occurred during the Navigation Systems Panel meeting, Montreal October 2005, the perspective of navigation systems experts on the limited integrity of BaroVNAV with respect to other vertical navigation systems didn't seemed to be fully understood and accepted by representatives of the operational/airline community.

One of the targets of this paper is therefore to bring further technical information highlighting this topic, so that to reach a common understanding of the issues between the navigation systems and airborne/operational communities.

1 INTRODUCTION

1.1 THE INTEREST FOR BAROVNAV & RELATED CHALLENGES

Vertical navigation (VNAV) supported by a barometric altimeter vertical position information was initially implemented for determining a top of descent, in order to gain the most economical benefits of operating an aircraft in the descent and approach for landing [GRE 00]. Then, VNAV systems were further approved to be used as an advisory system to establish a stabilized descent profile while conducting a non-precision approach. This attracted a lot of interest in the aviation community, since this brought to the equipped operators an airborne technique (independent of ground aids) to avoid descending in steps to level down to the Minimum Descent Altitude during the conduct of a non-precision approach.

Building on the VNAV interest in the aviation community, the scope of use of VNAV was further developed in the context of final approaches with the introduction of the APV BaroVNAV and the RNP in final approach procedures (the RNP AR (Authorization Required) concept also relies on BaroVNAV - based on a Vertical error Budget (VEB) assessment of the vertical navigation sensor). These new approaches were first introduced in North America, with the use of specific TERPS obstacle clearance criteria and specific airworthiness material and further-on by ICAO, mainly through PANS OPS obstacle clearance criteria.

These more recent BaroVNAV operations rely on different obstacle clearance surfaces than when BaroVNAV is used as an advisory system to fly a constant descent up to a Minimum Descent Altitude (MDA) and aim toward the use of a Descent Altitude (DA) rather than a Minimum Descent Altitude (MDA). They generally also provide lower operational minima (identified on the approach chart as LNAV/VNAV or RNP x minima) than those obtained for NPA with BaroVNAV (LNAV minima).

While barometric VNAV has many advantages, it also has related issues. From a navigation system point of view, the BaroVNAV system may be represented, like any other vertical navigation system used for approaches (ILS, MLS, GBAS/GRAS, SBAS etc...), as a black box generating deviations used by the crew or airborne systems to steer the aircraft along the ideal approach path in the vertical plane. To support safe and harmonized approach operations based upon any vertical navigation system, safety studies have in particular to demonstrate that the navigation information output by the black-box meet the safety requirements. This is not necessarily straightforward for BaroVNAV, if it has to match the safety requirements of vertical navigation systems such as GRAS, SBAS or Galileo (in the future) supporting similar operations (e.g. APV operations). This is due to specific reasons discussed in details in section 2. If, for BaroVNAV based operations, relaxed safety requirements are the goal, then this should be clearly discussed and introduced in the safety cases supporting these operations. The possibility of use of mitigation means may also be considered as a complement to fulfil the requirement, but designing appropriate mitigation means may be a challenge for BaroVNAV[1], depending on the safety context.

Due to the current lack of harmonized ICAO guidance on these issues, they are currently managed differently by different regions. In Europe, most of the discussions are conducted within the regulatory material development to support airworthiness approval of BaroVNAV airborne certification process under progress, (draft documents AMC-20xx, AMC-20 xz, NPA-OPS 41) and they also have to be addressed in the safety studies to support BaroVNAV, currently managed by Eurocontrol[2].

---

[1] in particular when airborne and ATC safety nets are not allowed to be considered as a mitigation in the safety case – as is the case today in Europe when designing a safety case under the ESARR 4 regulation.

[2] At this stage in Europe, when a new procedure is introduced into airspace, resulting in a potential change to the ATM system, safety studies have to be conducted along the lines defined within the ESARR 4 methodology. This requires in particular an in-depth analysis of all the potential hazards, typically formalized under a Functional Hazard Analysis (FHA) and a Preliminary System Safety Analysis (PSSA).

1.2 AIMS OF THIS PAPER

Clearly thus, BaroVNAV is seen by the aviation industry as a major feature of the navigation infrastructure to support RNAV, RNP approaches and possibly precision approaches in the future [IAT 05]. During discussions which occurred during the Navigation Systems Panel meeting, Montreal October 2005, the perspective of navigation systems experts on the limited integrity of BaroVNAV [NSP 05] with respect to other vertical navigation systems didn't seemed to be fully understood and accepted by representatives of the operational/airline community.

One of the targets of this paper is therefore to bring further technical information highlighting this topic, so that to reach a common understanding of the issues between the navigation systems and airborne/operational communities.

A related aim of this paper is to support the safety activities undergoing in Europe related to BaroVNAV, in particular the elaboration of a generic safety case for RNAV operations in final approach by Eurocontrol.

The data presented in this document are mainly based on public information (accident and incidents reports, statistical studies, aircraft manufacturers notes, etc…) and most of the sources are documented and easily accessible throughout the world wide web.

2 VNAV INTEGRITY ISSUES

2.1 BAROVNAV AND OTHER NAVIGATION SYSTEMS INTEGRITY

The functional model of any vertical navigation systems is a box which generates vertical deviations to guide the aircraft along the approach path. An appropriate estimation of the quality of the navigation information from the point of view of safety is usually related to the integrity of the navigation system (e.g; the capacity of the crew to determine within a given time (usually 6 to 10s) that the navigation system is generating guidance information exceeding the tolerances)[3].

For conventional (e.g. ILS, MLS) and GNSS (e.g. GBAS, GRAS, SBAS) navigation systems supporting vertical guidance, these integrity requirements are defined within ICAO Annex 10 and are quite stringent since typically, for approaches supported by vertical guidance, undetected failures are not permitted to occur more than of the order of 10-7 per approach. This figure results from the All Weather Operations Panel recommendations, so that to support an appropriate Target Level of Safety (TLS) during Approach and Landing operations. Therefore a considerable amount of effort is usually devoted to prove that the integrity requirement is met when the above mentioned systems are set in operations. This may in particular require to implement within the systems automatic monitoring and automatic safety barriers to avoid propagating errors to the airborne systems and crew.

From this point of view, there is a major difference between the use of BaroVNAV for final approach operation and all other ICAO compliant systems supporting vertical navigation in final approach (ILS, MLS, GBAS, GRAS, SBAS, Galileo (in the future),…). Indeed, for BaroVNAV the human is involved in the navigation information generation in real time, since the introduction of the local altimeter pressure and - depending on the airborne architecture - of the local temperature into the VNAV system is required. Thus obviously, human errors occurring anywhere in the transmission chain from local meteorological parameters measurement to their manual introduction by the crew in the VNAV system may create a safety concern. As has been demonstrated by many studies on human factors, the integrity of data manipulated by human is limited (and far away from the 10-7 requirement; 10-3 is often cited in studies as the maximum integrity of data when processed by human beings). Checking procedures within the crew and confirmation/readback procedures with the ATC may help to increase this integrity level but meeting an integrity objective similar to other vertical navigation systems is quite a challenge, as confirmed from the identification of a wide range of events leading to the incident/accident reports introduced in section 2.5. These points are discussed in section 2.3 and 2.4.

Also, it should be noted that the existing ground meteorological measurement and transmission links to the ATC have not been specifically designed to be consistent with integrity requirement for essential systems for approaches (e.g. the 10-7/approach requirement) and crew checking procedures are not efficient against these errors. This point is discussed in section 2.2.

Finally, another major difference with respect to other ICAO compliant systems supporting vertical navigation in final approach is that, as quoted in section 1.1, the airborne BaroVNAV systems have not been in general specifically designed and implemented to support final approach operations with vertical guidance as an essential (or primary) airborne system (this may not be true for very recent high end aircraft). For example, most BaroVNAV systems flying today have been certified versus the US advisory circular AC 20-129 which only supports the use of BaroVNAV as an advisory system, without any specific requirement for the airborne system integrity. More recent industry standards for RNP and RNAV (Ref DO 236 B) also clearly do not require any integrity containment for the vertical path. Obviously, this topic should also be documented in the airworthiness documentation and in the BaroVNAV safety study. This question is not further discussed in this paper.

[3] Another parameter, is continuity of service. This is not discussed in this paper.

2.2 MEASUREMENT ERRORS BY THE GROUND

Organizations who have implemented a quality assurance auditing system for the altimeter and temperature measurement by the ground meteorological services have reported potentially significant altimeter setting errors detected occasionally by the surveying process. For example, the following is an excerpt from a January, 1998 Aviation Notice published by NavCanada [Nav 02]:

"…NavCanada has become aware of a number of incorrect altimeter settings being reported from human surface weather observation sites. The problem is systemic, with apparent errors being detected on the average of once per day. Approximately 70% of these errors would have placed an aircraft lower than its indicated altitude, some by as much as 1000 ft."

The quality control procedures include cross-checking between altimeter setting and sea level pressure, examining pressure trends and searching for gross errors. Further details and collection of reported errors may be found on the NavCanada web site. Recommended techniques to improve the integrity of the altimeter reference measurement may be found in other publications [Env 00].

These observations raise questions about the appropriate integrity of existing meteorological measurement systems at airports where BaroVNAV procedures have to be implemented, and about the appropriate auditing/mitigation means which should be put in place to ensure an integrity of these measurements consistent with the safety requirements.

2.3 TRANSMISSION ERROR FROM ATC TO CREW

Pilots and air traffic controllers routinely exchange information about aircraft position, destination, heading, altitude, speed, altimeter settings and radio frequencies. Since errors are inevitable during these data exchanges, studies have tried to assess their occurrence and provide recommendations to improve their integrity [FSF 00].

Detailed observations have indeed shown that the percentage of errors is quite high. For example, [Koe 97] showed that roughly half of all communications by pilots and controllers included at least one communication error. Other studies have analysed the percentage of errors occurring during laboratory tests, including altimetry transmission errors [FSF 98].

Concerning the specific case of altimeter setting transmission error, a number of incident reports highlight the different typical cases leading to a transmission error of the altimeter setting, details may be found for example in [ASR 91], [ASR 97], [AIR 05].

These reports also provide recommendations to improve the transmission of this safety critical data in the context of BaroVNAV approaches. Whether or not these recommendations are systematically implemented in areas where procedures supported by BaroVNAV are published should further be clarified.

2.4 CREW BLUNDER ERRORS

Getting on board an altimeter reference (and local surface temperature for those VNAV aircraft systems requiring this data) correctly measured by the ground and free of ATC to pilot transmission errors does not guarantee that this value is correctly fed within the VNAV system. Further typical human errors may still lead to a BaroVNAV integrity issue.

Several reports give examples of these occurrences, in particular when typical human factors aggravating conditions such as low-high QNH, high workload, fatigue, etc… occurs [ASR 97]. They explain that in many of these cases, the crew subconsciously ignored the correct setting in favour of a setting that seemed more appropriate. Some examples:

"The altimeter setting I wrote down was 28.85 inHg, but we had both set 29.85 inHg. I did not recognized the unusual nature of the setting, and reverted to more familiar settings during the checklist"

"I read back the clearance, understanding the altimeter to be 30.37 inHg. Factors in this incident include my hearing .37 and assuming it was the more normal 30.37 rather than the [actual] low reading of 29.37"

2.5 INCIDENT/ACCIDENT RECORDS RELATED TO BAROMETRIC ALTIMETER ERRORS

2.5.1 Introduction

A quick search through the internet using a research engine (like Google) allows to identify significant incident/accident reports which highlight the potential safety impacts of the altimeter setting error occurrences discussed in the above paragraphs.

It must be noted that although the altimeter setting errors reported here did not necessarily occurred during BaroVNAV approaches, their analysis is fully significant here since in most of the cases their impact would have been similar if an approach supported by BaroVNAV had been flown.

Of course, this section does not claim to be an exhaustive research, but rather aim to provide data suggesting that these errors do occur practically and significantly frequently in the real life – surprisingly, this has been subject to controversial discussions with some aviation actors in the past. Most of the reports originate from aviation organizations which have set up a safety reporting system; this may suggest that these altimeter mis-setting events are under-reported at this stage. In particular no report were collected in this quick search from important regions of the world like Eastern-Europe, Africa, South-America or Asia.

2.5.2 General studies

[FSF 96] This flight safety foundation digest is entitled "An analysis of CFIT Accidents of commercial operators 1988 through 1994". One of the section is devoted to the occurrences of altimeter mis-setting/reading. It reports:

"4.3.7.4 Barometric altimeter setting/reading. The incorrect setting or reading of the barometric altimeter has been associated with some CFIT accidents. The necessary data were available in only 16% of the accident reports or summaries. In five accidents (3.2% of the total sample), the barometric altimeter was set incorrectly. In only one accident (0,6%), was the barometric altimeter read incorrectly"

[CAA 00] This reports present the analysis of an 18 month data collection period (July 1998 to December 1999) of level busts over UK – a level bust occurs when an aircraft fails to fly at the required level. Five significant causes were identified in the report, altimeter setting being one of them. This collection of events was based on voluntary confidential reporting from pilots and controllers, which, as quoted in the report: *"was not expected to be easy, especially when this information might imply that pilots or controllers may have made mistakes, omitted to do things, adopted the wrong procedure or were simply distracted."* This may suggest that the events have been under-reported, which is a general issue when human factors are involved. Still, during the 18 month data collection period, 626 'level bust' reports were investigated (568 involved a 'level bust' greater than 300 ft). The altimeter mis-setting cause was ranged the 4th source of busts, involving 68 events (10,9%). The report identified that low or high QNH was a factor in nearly two-thirds of the reports.

[KHA 04] This presentation reports that altimetry error is suspected to be a 20% contributor to large jet CFIT occurrences, based on a 1988-1997 study of large jet CFIT occurrences. The most common altimeter error scenarios are reported to be:

" mis-reading altimeter, mis-set altimeter, mistakes in reading, hearing, copying setting, ignoring unexpected low setting in favour of setting that seem more appropriate, mis-setting when passing through transition level, confusion of units (inches vs mb), outdated ("Stale") QNH given to pilots, Non-Standard atmosphere (ISA)".

2.5.3 Specific incidents/accidents

[ASR 91] This Aviation Safety Reporting System (program established by the FAA and administered by NASA) discusses the issues related to the confusion of inches of mercury (inHg) units with Hecto pascal or millibars (mb) and cites six reports of altimeter mis-setting incidents. One typical report is as follows:

“The copilot who had copied the ATIS gave me 29.97 inhg when I asked for QNH. Gusty winds and [the controller] thick…accent weren’t helping things. [Obstructions] seemed unusually close to our altitude. [The] copilot had assumed 9-9-7 [mb] to be 29.97 [inHg] (500 ft low)”

[ASR 97] This Aviation Safety Reporting System cites and discusses twenty altimeter mis-setting incident reports sent to the ASRS. ASRS Analysts note that these reports often come in bunches, as numerous flight crews experience the same problem on the same day in a particular area that is encountering unusual barometric pressures. A typical incident report is quoted below:

“This was the last leg of a long 3 day-trip… Inbound…we ran the ‘preliminary checklist’, cross-checking altimeters at 30,22. This seemed a little bit odd to me at the time, as the area had a low front moving through, but we were busy and I did not press the issue. Once on approach, everything was normal until just before the final approach fix when we broke out of the clouds and a ridge was looking very close. Also, the GPWS went off as we passed over the ridge. I checked our altitude and we were right on profile. I had the Captain check the altimeter with Tower. Altimeter was 29.22, not 30,22 putting us approximately 1000 ft too low on approach”

[FSF 97a] This flight safety foundation accident prevention reports a twin turbo fan Learjet 35 accident on night medical evacuation to a Canadian airport. Two flight members and a three-member medical team were killed in the Jan. 11, 1995 accident. The transportation Safety Board of Canada (TSB), in its final report, said that the cause of the accident was that the:

“crew most likely conducted the instrument approach with reference to an unintentionally mis-set altimeter… . and unknowingly flew the aircraft into the water. The circumstances leading to the incorrect altimeter setting could not be determined, nor was it determined why the crew did not detect the mis-set altimeter”

[FSF 97b] This flight safety foundation accident prevention reports an accident involving a MD-83 approaching at Bradley International Airport (BDL), USA. An outdated altimeter setting is identified as a contributing factor to the accident.

“The barometric pressure was falling rapidly, and he crew was advised of wind-shears alerts at BDL. As the crew was descending the airplane to the MDA, the first officer looked outside the aircraft to locate the runway. He then glanced at the altimeter and noted that the aircraft was below the MDA. Moments later, the MD-83 struck trees on a ridgeline 2.5 Nm from the approach end. The final report of the U.S. National Transportation Safety Board (NTSB) said that the probable causes of this accident was: “ the flight crew’s failure to maintain the required MDA until the visual references identifiable with the runway were in sight. Contributing factors were the failure of the BDL approach controller to furnish the flight crew with a current altimeter setting, and the flight crew’s failure to ask for a more current setting.”

[FSA 99] This Flight Safety Australia report on CFITs, reports Altimeter setting as one of the important CFIT sources. The case of a Jetstream 31 involved in an incident related to incorrect altimeter setting is mentioned:

“The first officer got the ATIS. Passing FL 180 on descent, the first officer called the transition, altimeters 29,82inHg (1011 mb). I questioned that setting, and he confirmed the setting of 29,82inHg. We executed the VOR RWY 25 via the arc. Turning onto the inbound course, the minimum altitude is 800 ft, to which I started to descend. We had been in and out of clouds with a ragged ceiling and low light conditions. My focus was inside the cockpit. At about 1400 ft, I noticed that the waves on the water looked awfully close. I told the first officer to verify altimeter setting, and tower came back with 28,84inHg (978 mb). We were actually at 400 ft, not 1400 ft!”

[AFR 06] This monthly report from the Air France RNAV study group quotes an incident reported by an Airbus A 320 captain during a RNAV(GNSS) approach simulator crew training exercise :

“During our simulator session, we experimented a GNSS approach with a QNH error of 10 mb in the wrong direction. The flying method that we followed that day seemed to me strictly in accordance to the simulation, but apart from a TO STEEP PATH message from the FMS, we woke up at the minima 300 ft to low.”

2.6 HAS SOMETHING TO BE DONE ?

Blunder errors of the type discussed in section 2.2, 2.3 and 2.4 which may result in incidents/accidents presented in section 2.5 are actually quoted by the PANS-OPS as one of the area where it seems to be suggested that something has to be done:

"Chap 9 RNAV/Baro-VNAV Approach: *"§9.4.1.5 Blunder errors. Application of an incorrect or out of date altimeter setting, either by Air traffic control or by the pilot, is possible and must be prevented by appropriate operational techniques*".

It should be noted that here also the situation is dissymmetric with respect to all other ICAO Annex 10 approaches supported by vertical guidance (ILS, MLS, GBAS, SBAS). For these approaches, there is the simple possibility to crosscheck the approach slope transmitted by the Navigation system with the barometric height at one or several points along the approach path. Since this check combines two different and independent systems, this operational procedure allows to effectively mitigate errors on the altimeter setting (which may in particular impact the operational minima on these approaches) as well as potential errors due to the Navigation System. This simple and efficient crosscheck procedure is implemented today by major airlines [GOD 05].

However, since for BaroVNAV the barometer is a common mode of failure for the navigation system vertical path as well as the for altimeter setting, the classical crosscheck procedure is not working in this case. Thus one of the issue here is that there is no clear indications in ICAO documentation given to States on the appropriate mitigation means that have to be put in place to try to recapture part of the missing integrity of BaroVNAV. Are the crew self-checking procedures sufficient? Probably not, because in this case the incorrect or out of date altimeter setting transmitted by ATC could not be detected and this would not be sufficient to meet the 9.4.1.5. quoted above.

This question has been brought to the attention to the ICAO OPSP and OCP [OCP 04] in the past. In the discussion relating to implementation of APV Baro-VNAV procedures during OPSP meeting May 2004, Berlin, the meeting considered that PANS-OPS, Volume I, Part III, Chapter 9, RNAV/Baro-VNAV Approach Procedures, paragraph 9.4.1.5, concerning operational techniques to prevent blunder errors, may require amendment. However since then, no real significant progress seem to have been done at ICAO level on this topic.

3 CONCLUSIONS & RECOMMENDATION

3.1 CONCLUSIONS

The interest of the aviation community toward RNAV and RNP procedures supported by BaroVNAV vertical guidance is well and fully understood. Introduction of these procedures into published operations requires the availability of PANS OPS procedures, airworthiness and operational material, and achievement of a positive safety case.

At this stage, mainly the first of these elements is available in Europe. Airworthiness material elaboration and safety studies are currently struggling with typical BaroVNAV issues which have been discussed in this paper. In particular this paper has tried to clarify the main differences in the integrity of the BaroVNAV and other ICAO standardized vertical navigation systems. A major point is that automatic monitoring & barriers against error propagations are implemented in Annex 10 standardized systems, whereas human factors maybe involved at different level (ground, ground/air transmission, aircrew) and corrupt the integrity of the VNAV system.

Because of these human factor potential errors, and as confirmed through a quick scan of incident/accident reports available on the web, the integrity of BaroVNAV systems appears to orders of magnitude lower than the requirement applicable to Annex 10 vertical navigation systems. Whether this is acceptable or not, is not discussed in this paper but should be discussed in the appropriate safety studies.

Another factor which has not been discussed in this paper, is the lower requirements on the BaroVNAV system than on airborne systems supporting Annex 10 systems signals processing – this is due to the evolutionary process of BaroVNAV as discussed in section 1.1, whereas Annex 10 systems have been specifically designed to support final segment approach operations supported by vertical guidance. This point should probably be addressed by airworthiness authorities.

It is believed that a common understanding and identification of the issues discussed in this paper is required to progress toward a safe and harmonized BaroVNAV implementation in the European context, in particular because the safety case in Europe should be designed within the relatively stringent ESARR 4 methodology. Solutions proving that operations supported by BaroVNAV are acceptably safe may probably be found through implementation of dedicated mitigation techniques, but these require as a starting point a common understanding of the basic issues between all the involved parties, in particular the ANSPs, the pilot community, and the aircraft operators.

It should also be noted that he incident/accidents reported in this document are all related to an incorrect altimeter setting introduced into the VNAV system. However errors on the local ground temperature may induce similar effects for VNAV airborne systems requiring this data. Therefore this point should also be documented in the relevant safety studies.

3.2 RECOMMENDATION

The meeting is invited to discuss and note the information presented in this paper and in particular to use this information in the context of the NSP report to the ANC on BaroVNAV.

4 REFERENCES

[AIR 05] Airbus Flight Operations Briefing Note, “Altimeter Setting, radio Altimeter”

[AFR 06] Air France RNAV group report, January 2006.

[ASR 91] Aviation Safety Reporting System Directline, Perry Thomas, “International Altimetry”, Fall 1991

[ASR 97] Aviation Safety Reporting System, Marcia Patten and Ed Arri, “The Low-Down on Altimeter Settings”, Issue 9, March 1997.

[AUS 06] Navigation Systems Panel, presented by Australia, “Review of GNSS APV Approach standards and implementation” WP 4, Montreal, Canada, 11-21 October 2005.

[CAA 00] UK, Civil Aviation Authority, “Level Bust Working Group Final Report”, December 2000.

[ENV 00] Environment Canada, Aviation Weather Services, Operations Report – August 2000.

[FSA 99] Flight Safety Australia, “Controlled Flight Into Terrain”, April 1999.

[FSF 96] Flight Safety Foundation Digest “An analysis of CFIT Accidents of commercial operators 1988 through 1994” April-May 1996.

[FSF 97a] Flight Safety Foundation Accident Prevention “Learjet MEDEVAC Flight ends in CFIT Accident” January 1997.

[FSF 97b] Flight Safety Foundation Accident Prevention, “During Non Precision Approach at Night, MD-83 descends below MDA and contact trees, resulting in engine flame-out and touch-down short of runway”, April 1997.

[FSF 98] Flight Safety Foundation, Airport Operations, “Studies investigate the Role of Memory in the interaction between pilots and air traffic controllers, January- February 1998.

[FSF 00] Flight Safety Foundation Digest, FSF ALAR Briefing Note “ 2.3 Pilot-Controller communication”, August-November 2000.

[GOD 05] Email correspondence with captain C. Godel, Head of Air France RNAV group, 24 November 2005.

[GRE 96] Obstacle Clearance Panel, J.W. Gregory, “CFIT-Procedure Design considerations. Use of VNAV on conventional Non Precision Approach procedures”, OCP-WG- WP 4.18, St Petersburg, Russia, 10-20 September 1996.

[GRE 00] Obstacle Clearance Panel, J.W. Gregory, “Annex 4, Aeronautical chart manual and PANS-OPS amendments to support Baro-VNAV procedures”, Madrid, Spain, June 2000.

[IAT 05] Navigation Systems Panel, presented by IATA, “Navigation Aids Transition Roadmap”, IP 32, Montreal, Canada, 11-21 October 2005.

[KHA 04] R. Khatwa, “Human factors evaluation of vertical situation awareness”, 16th FSF European Aviation seminar, 17th march 2004, Barcelona.

[KOE 97] R.L. Koenig “Excess Words, Partial readbacks score high in analysis of pilot-ATC errors” Airport Operations, Volume 23, January-February 1997.

[NAV 02] Nav Canada, J.D. Andrew Graham, “The use of raw GPS for Vertical navigation”

[NSP 05] Navigation Systems Panel, “APV BaroVNAV implementation issues” Flimsy 14, Montreal, Canada, 11-21 October 2005.

[OCP 04] Operations panel (OPSP) and Obstacle Clearance Panel (OCP) Working Group of the Whole, G. Lacaze-Labadie and G. Miro, “A tentative synthesis on APV/BaroVNAV issues within ICAO”, Montreal 15 Sept. 2004.