Verification of GNSS Applications at Italian Regional Airports

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Abstract

ENAV S.p.A. has planned that the first GNSS approach operations will be introduced at the major airports, as an integration of the current conventional operations.
On the other hand, the greatest benefits of GNSS, namely EGNOS, are expected at regional airports. The SIAM experimental project was launched by ENAV in mid 2006. Its primary goal is to confirm a methodology for the verification of GNSS applications, including possible safety-related issues driven by local constraints. To this end, three regional airports (< 100.000 pax/year) were chosen as representative of the operational scenarios of central/southern Italy: terminal operations based upon a single navaid, one runway end served by ILS CAT I approach procedures (in the best cases), and the opposite one served by no instrumental procedure, acceptable average weather visibility as compared to prescribed minima.
The availability of ADS-B surveillance at such airports will take further benefits, as compared to current non radar scenarios.
Starting from the design to the AIS, through the validation stage, significant safety, operational and economical benefits can derive from the support of automation, such as the AIRNAS operational environment set-up by ENAV S.p.A., in cooperation with IDS S.p.A, which includes the modelling of the electromagnetic scenarios.

BIOGRAPHY

Giovanni Del Duca is presently the Manager of the Satellite Systems Unit inside the Technical Directorate of ENAV S.p.A.¸ with more than 20 years of professional experience in the technical field of ATM and Navigation Service provision. He is involved in Satellite Navigation from 1996, participating as Italian nominated member in the GNSS Panel (now Navigation Systems Panel) in ICAO. At European level, he is working on EGNOS, GBAS and other activity related to satellite Navigation introduction in Civil Aviation and is advisor in the Italian delegation at PbNav of the European Space Agency (ESA). Other relevant activities are the program MIDAN flight demo (Cairo, Egypt), and presently the METIS project with GSA.

Renato Perago was born in Napoli (Italy) in 1968, where he became Doctor in Navigation (University “Parthenope” of Napoli). From 1998 to 2000 he has worked as navigation and cartographical expert of GNSS applications of civil aviation at Ingegneria Dei Sistemi (IDS) S.p.A., and at the University “Parthenope” of Napoli. From 2000 to 2001 he has worked as system analyst about GalileoSat project (ESA) at Alenia Spazio S.p.A. In 2001 he joined ENAV S.p.A, where he is manager of the GNSS applications, including: precision area navigation (P-RNAV), LNAV, APV and GBAS CAT I approaches.

Valerio Paciucci received the B.S. and M.S., in telecommunication engineering from the University of Roma “Tor Vergata” in October 2003. He completed the Master of Science in Advanced Communications and Navigations Satellite Systems at University of Roma “Tor Vergata”.
He has been working for IDS – Ingegneria dei Sistemi S.p.A. since September 2005; he is currently the Project Manager of the SIAM project.

Giuseppe Di Bitonto received the B.S. and M.S., in telecommunication engineering from the University of Roma “Tor Vergata”. In 2007 he collaborated with RadarLab of “Tor Vergata” University in a research project for Elettronica s.p.a. He has been working for IDS – Ingegneria dei Sistemi S.p.A. since November 2007, as system analyst in Aeronavigation Systems and Applications Laboratory.

Fabio Principe received the Master Degree in Telecommunications Engineering from the University of Pisa in May 2003.
In December 2006, he got the Ph.D. grade in Information Engineering at the University of Pisa. During such studies he collaborated with INTECS S.p.A., ESTEC, and LABEN S.p.A. Additionally, he spent 7 months at the Communication Sciences Institute – University of Southern California of Los Angeles, as visiting scholar, in collaboration with Prof. Keith M. Chugg. In February 2007, he joined the E.M. Framework Design Laboratory of IDS S.p.A as system engineer.

INTRODUCTION

ENAV S.p.A. provides Air Navigation Services to the civil aviation community in Italy.
The operational approval of GNSS applications envisages a number of steps, which shall be carried out by different stakeholders:

a) the certification of airborne equipment;
b) the obligations of aircraft operators, such as: flight and operation manuals, crew training;
c) the availability of radio navigation signals of sufficient performance along the prescribed routes or procedures (Service Providers);
d) the publication of the relevant aeronautical information (Service Providers).

Since 2004 the European Safety Regulation Requirements (ESARR) have been mandatory to European States, in the frame of the overall Single European Sky (SES) Regulation.
In particular, *ESARR 4 (Risk Assessment and Mitigation)* requires that any change to Air Traffic Management (ATM) be verified by the Service Provider proposing the change itself and accepted by the State Regulator where it is to be implemented. This verification and demonstration process requires a total system approach be adopted, including: equipment, procedures, human factors and environment issues. In other words, the application of existing standards, such as ICAO Annexes and Procedures, is no more sufficient to achieve the operational approval.

Moreover, the safety of innovative navigation operations is normally to be verified at each specific operational scenario. To this end, some contributions, in terms of hazard identification and risk mitigation are expected also from airframe/avionics and operators, such as for RNP Authorisation Required (AR) operations.

Among the local issues, the vulnerabilities of GNSS and mitigation of related outages have already been identified by ICAO. At least the following actions *(ICAO 11th Air Navigation Conference, Recommendation 6/2)* can be addressed to Service Providers:

a) to assess the likelihood and effects of GNSS vulnerabilities in their airspace;
b) where determined that terrestrial navigation aids need to be retained as part of an evolutionary transition to GNSS, give priority to retention of DME in support of INS/DME or DME/DME RNAV for en-route and terminal operations, and of ILS (or MLS) in support of precision approach operations at selected runways.

1. BENEFITS ANALYSIS

The Global Navigation Satellite System (GNSS) and Automated Dependant Surveillance (ADS) are low-cost solutions for air navigation. Some of GNSS benefits are listed below:

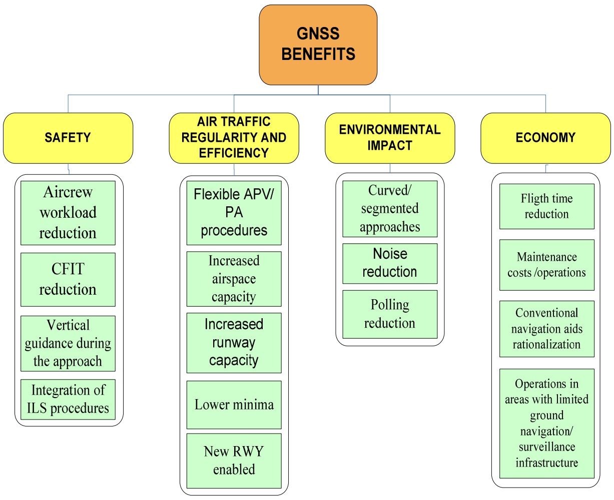


Fig. 1 – GNSS benefits for civil aviation

In the frame of SIAM project, three regional airports (< 100.000 pax/year) were chosen as representative of the operational scenarios of central/southern Italy: terminal operations based upon a single navaid, one runway end served by ILS CAT I approach procedures (in the best cases), and the opposite one served by no instrumental procedure, acceptable average weather visibility as compared to prescribed minima:

- Parma (LIMP);
- Perugia (LIRZ);
- Taranto Grottaglie (LIBG).

Palermo airport (LICJ) was included as well, taking into account of the operational interest and of the availability of a GBAS CAT I facility.

The innovative scenarios of the three airports (Parma, Perugia, Taranto Grottaglie), based upon EGNOS, provide evidence of the following benefits:

- safer operations, avoiding to fly over the town of Parma and all areas densely urbanized,
- instrumental operations on both runways (subject to ICAO Annex 14 standards of visual aids) and category D aircraft,
- independent approach/missed approach procedures,
- independent arrival and departure operations,
- flight path reduction,
- less workload both pilots and controllers,
- reduced environmental impact.

Quantified benefits have been:

- lower minima;
- more direct segments (flight time reduction);
- increased runway capacity;
- cost reductions.

The main results of the comparison between the current NDB approach procedure (Fig. 2) and the experimental GNSS non precision approach (Fig. 3) at Parma airport, are reported. Additional safety and operational benefits can be gained from the introduction of the LPV segment supported by EGNOS.

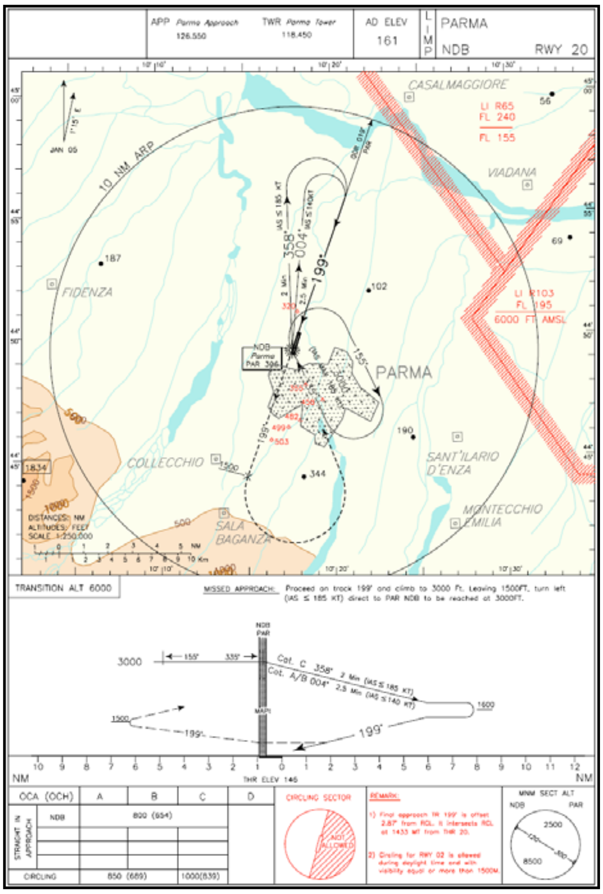


Fig. 2 – NDB Approach Chart

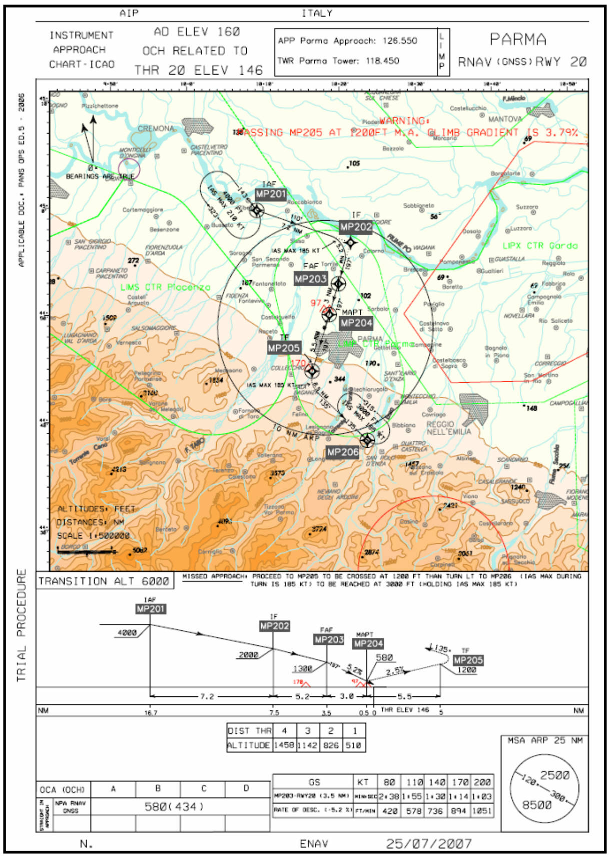


Fig. 3 –GNSS NPA Approach Chart

The Obstacle Clearance Altitude (OCA) supported by the GNSS NPA (CAT D is not included in the published NDB chart) is lower than NDB by more than 200 ft (Fig. 4).

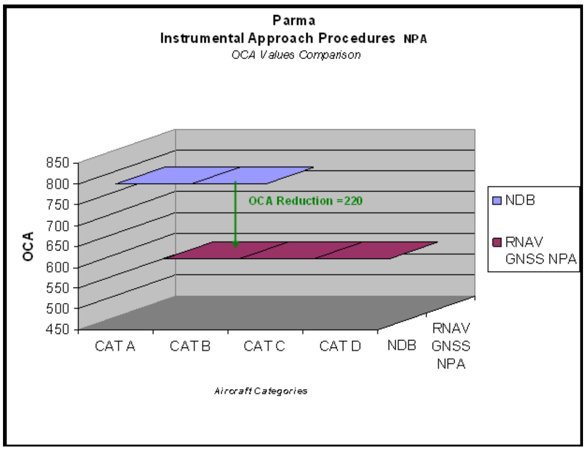
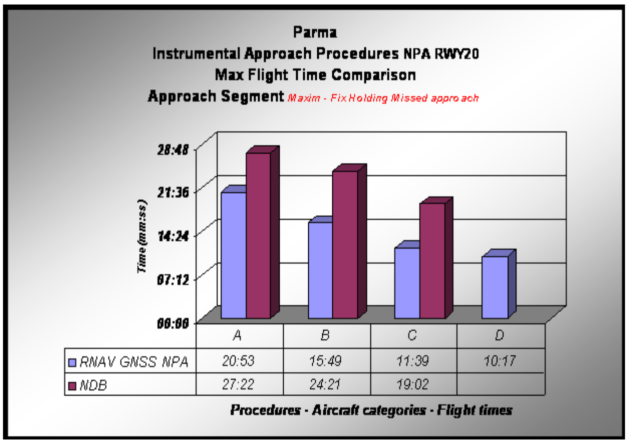


Fig. 4 – OCA comparison

The use of flexible RNAV legs, supported by the improved availability of EGNOS signal-in-space as compared to GPS augmented by RAIM, achieves more direct paths and less speed variations. Consequently, flight time can be reduced of up to 30% (Fig. 5). The analysis of the total cost/hr and cost/NM of a Learjet 24 D reveals that GNSS NPA introduces cost saving by at least 20%.



	A	B	C	D
🟦 RNAV GNSS NPA	20:53	15:49	11:39	10:17
🟥 NDB	27:22	24:21	19:02	

Fig. 5 – Flight Time comparison

Due to flight time reduction, EGNOS allows:

- reduction of separations between subsequent arrivals (RWY 20, non radar airspace),
- instrumental approach operations at both runways.

This means that the Theoretical Runway Capacity (TRC) of runway 20 is increased by about 50% (Fig. 6).

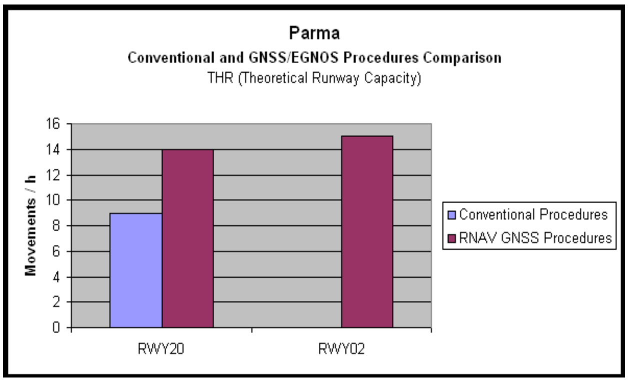


Fig. 6 – TRC comparison

Theoretical Runway Capacity (TRC): *Average number of flights per hour, handled in safety and assuming that there are always aircrafts waiting to approach the landing field.*

Further benefits, in terms of overall traffic flow and airport capacity will be achieved by the use of Automatic Dependent Surveillance Broadcast (ADS-B), as compared to the current procedural surveillance limitations (non radar airspace). In addition ADS-B will take the following benefits:

- the controller situational awareness of aircraft status;
- drastic reduction of voice position reports by digital messages with higher transmission rate;
- both pilot and controller workload reduction (maintaining their roles unchanged).

2. VERIFICATION METHODOLOGY

ENAV has developed a verification methodology of GNSS applications relying on the combination of: analyses, data collection and numerical modeling. In fact, such methodology takes into account of the limited in-flight data set, as opposed to the variable configuration of the GNSS geometry and electromagnetic signals at a given operational scenario. At least four goals have been identified:

1. relevant inputs to Local Safety Assessment (ESARR 4);
2. support to decision making and planning;
3. rationalization of flight missions;
4. siting of GNSS (and ADS-B) equipment, where required.

The characterization of the local GNSS electromagnetic scenario is properly addressed by such methodology, in terms of possible local degradation (interference and/or multipath) of GPS signal-in-space + space or ground augmentation. With specific reference to unintentional interference, two principal aspects have to be considered in the evaluation of the operational risks:

a) the likelihood of GNSS outage;
b) the impact of GNSS outage.

By considering these aspects as a function of airspace, it can be determined whether mitigation is required and, if so, to what level. Mitigation is required for outages with major impacts having a moderate to high likelihood of occurrence.

As a result, a systematic approach is required to verify RNAV GNSS applications:

1. preliminary analysis and planning (including local operational and technical constraints and possible SW simulations for signal usability);
2. on-the-ground data collection for performance monitoring and siting analyses (interference and multipath);
3. design, including flight procedure definition, charting and encoding (ARINC 424);
4. numerical modeling and analysis (including coverage of DME/DME and other navaids) for preliminary validation;
5. flight check and data processing;
6. analysis of results and validation.

The applied methodology makes extensive use of the AIRNAS operational environment, which includes an infrastructure developed by ENAV S.p.A, in cooperation with IDS S.p.A., comprising dedicated tools (Fig. 7):

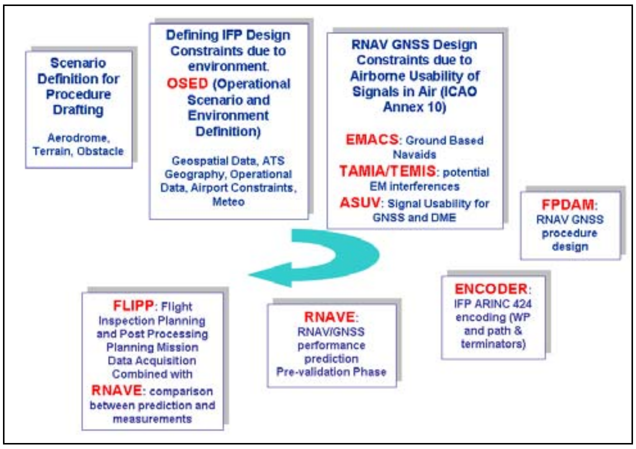


Fig. 7 – Use of dedicated AIRNAS tools

In fact, appropriate SW simulations are carried out, at different steps of the overall process. Moreover, feedbacks are normally expected by more than one step, such as the use of RNAVE tool (see Fig. 8).
Flight and static data are compared, in order to investigate the origin of possible anomalies. Moreover, tool simulation allows GNSS performance evaluation in different configurations (e.g. period of analysis, geometry, etc.).

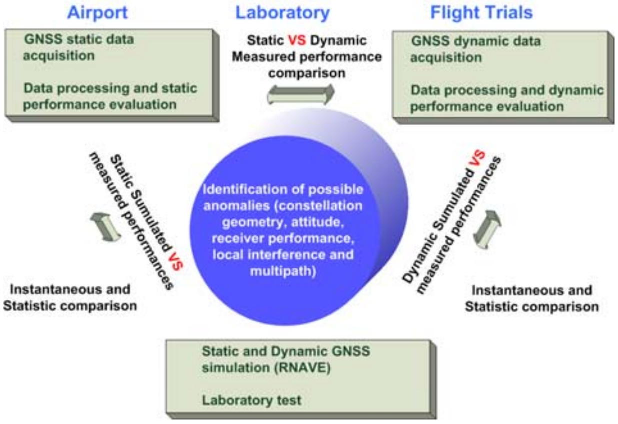


Fig. 8 – Static/Dynamic performance comparison logic

3. DATA COLLECTION

During the SIAM project on–the-ground measurement campaigns were executed at: Parma, Perugia, Taranto and Palermo during 2008, for the following evaluations:

- Optical/EM Horizon determination and satellite visibility,
- XDOP and Position Errors,
- Service Availability,
- Range Accuracy (Multipath),
- GPS Signal Analysis,
- Interferences.

At Palermo airport surveys were targeted the most suitable sites where to install GBAS CAT I facilities.

To this and, appropriate equipment has been installed in the GNSS Van (GVAN - Fig. 9).

Fig. 9 – GVAN instruments

- Dual frequency antenna (Novatel GPS-533),
- Ashtech Zxtreme receiver for True Trajectory computation,
- two (or three) Septentrio Polarx2 GNSS receivers, set in GPS and GPS/SBAS mode,
- Rubidium Clock for Rx stabilization,
- spectrum monitoring system (Fig. 10),
- Personal Computer.

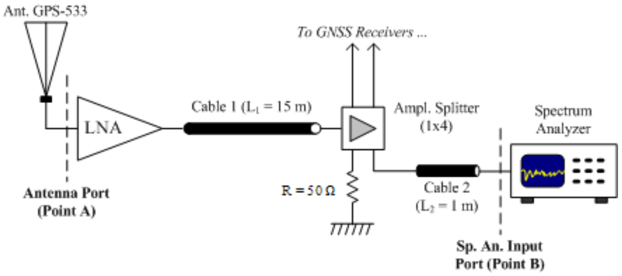


Fig. 10 – Spectrum monitoring system

In-flight data was collected by means of the experimental avionics installed on board the CESSNA Citation of ENAV (Fig. 11):

Fig. 11 – CESSNA Citation used for flight trials

- 2 GPS antennas;
- Septentrio PolaRx2 set in GPS/SBAS mode;
- Ashtech ZXtreme receiver;
- TSO-compliant SBAS receiver (Garmin GNS 430W);
- VHF antenna for GBAS VDB message acquisition;
- VDB Telerad 9009 receiver;
- Spectrum Analyzer;
- Sensor attitude Axitude AX-1;
- PC Laptop.

A total of eight SBAS approaches (at RWY 02 and 20) and eight missed approaches (6 hours of flight) were flown at Parma airport in December 2008. During flight trials simultaneous static and dynamic data acquisition was carried out, in order to allow comparison analysis between on-board and static GNSS performance (*proximity effect*).

4. NUMERICAL ANALYSES

The overall AIRNAS facilities supported each step of the verification process of SIAM, from the draft definition of the GNSS procedure to the post-flight performance evaluation.

Among them, the RNAVE tool is conceived for the ground validation of GNSS and DME/DME procedures, and has been used for:

- pre-flight and post-flight performance analysis;
- on-the ground and in-flight post processing, in order to verify possible performance discrepancies between static and dynamic data;
- extrapolation of relevant results to different scenarios.

The creation of GNSS simulation scenarios at the three regional airports took into account of:

- terrain/obstacles data;
- GPS Almanac, including possible NANUs;
- periods of analysis (each typically 24 hrs.);
- iono/tropo conditions;
- aircraft relevant dynamic parameters;
- duration of each flight (Periods of Operation - POPs), typically 20 min.;
- ARINC 424 procedure coding;
- wind condition.

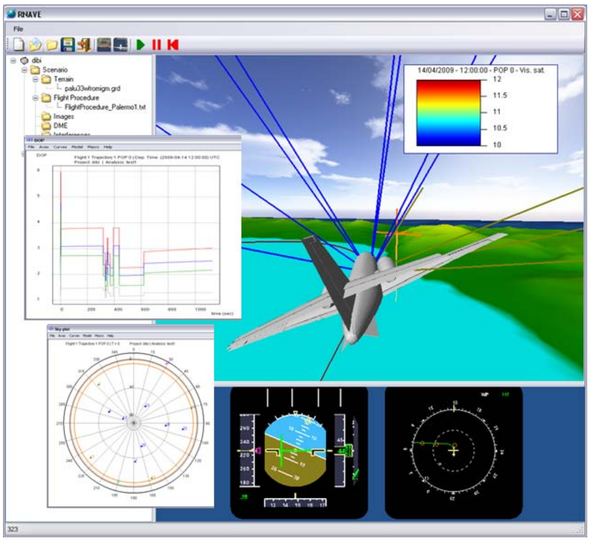


Fig. 12 – RNAV GNSS flight simulation

Fig. 13 shows the comparison between GPS static simulated PDOP (red curve) and static observed PDOP (blue curve) over a 24h time span (day 326/2008), at Parma airport.

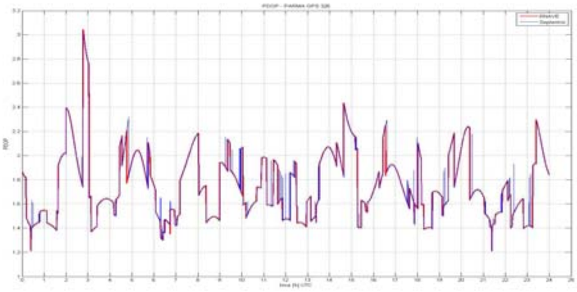


Fig. 13 – GPS PDOP (Parma): AIRNAS predicted (red) vs. observed (blue)

Fig. 14 shows the comparison between simulated EGNOS VPL (red curve) and static observed VPL (blue curve) over a 24h time span (day 326/2008), at Parma airport. It has to be noticed that the tool is offline, with respect to EGNOS system. In other words, it does not generate real-time EGNOS messages, but takes into account of conservative assumptions about such messages (e.g. iono), to propagate signal-in-space conditions along time and aircraft trajectory.

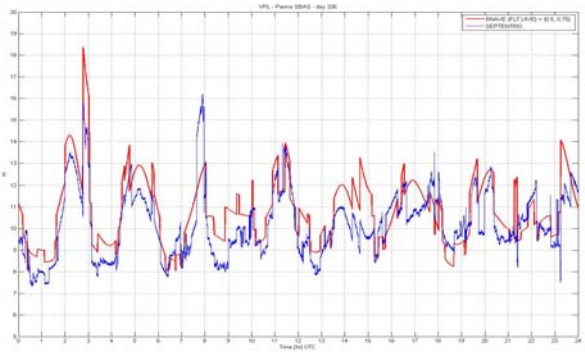


Fig. 14 – EGNOS VPL (Parma): AIRNAS predicted (red) vs. observed (blue)

5. RESULTS

On-the-ground and in-flight GPS/EGNOS data sets collected at Parma airport were processed and compared. Fig. 15 represents the processing workflow followed to verify GPS/EGNOS performance. Such chain can be set, in order to properly integrate both Pegasus tool, developed by Eurocontrol, and RNAVE tool.

The geo-referencing of the GNSS antenna was carried out in DGPS kinematic differential mode, achieving a precise 3D-accuracy (< 2 cm rms), by means of the GVAN (Fig. 16).

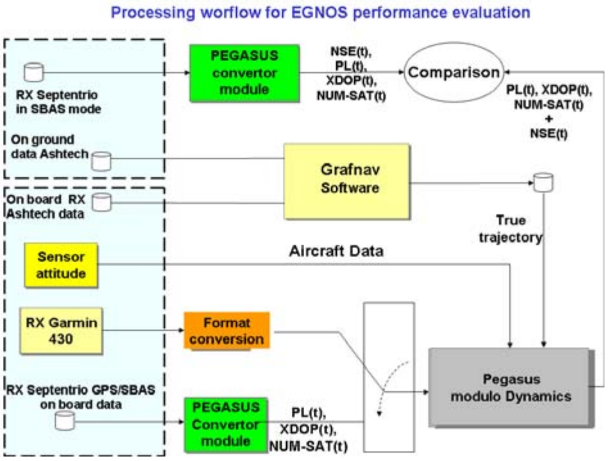


Fig. 15 - Workflow for GNSS performance evaluation

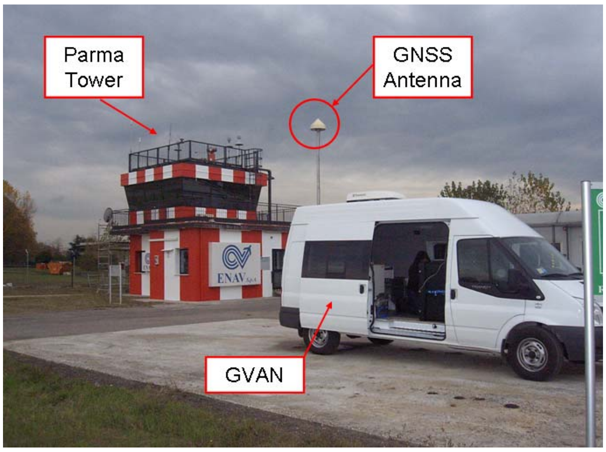


Fig. 16 – GVAN in Parma airport

Satellite visibility analysis was carried out to determine the electromagnetic horizon (Fig. 17). At Parma site the flat optical horizon, determined by a theodolite, is coincident with the e.m. horizon. In addition, an 8° mask angle was set ground and airborne Septentrio and Ashtech receivers, to reduce errors due to satellites at low elevation angles.

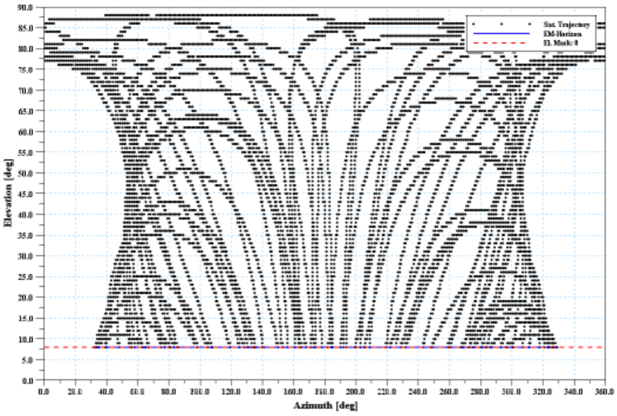


Fig. 17 – Satellite traces identify EM Horizon

GNSS flight procedures at Parma (RWY 02 and 20) were flown, and data set analyzed in terms of: true trajectory computation, NSE, XPL, attitude and geometrical considerations. A total of eight approaches was flown, as reported in the next tables, that summarize flybys time (GPS-Time) of each waypoint.

RWY 02	Approach # 2	Approach # 4	Approach # 5	Approach # 7
Start	10:36:04	11:11:00	14:50:51	15:24:47
IAWP MP021	10:38:00	11:13:16	14:54:38	n/a
IWP MP022	10:39:37	11:15:08	14:56:36	15:26:27
FAWP MP023	10:40:48	11:16:40	14:58:11	15:28:02
MAWP MP025	10:42:05	11:18:24	14:59:54	15:29:46
TWP MP026	10:43:34	11:19:48	15:01:19	15:31:20
HWP MP027	10:46:08	11:22:23	15:03:39	15:33:58
End	10:50:00	11:23:36	15:04:22	15:34:33

Tab. 1 - Waypoint flybys Time for RWY02

RWY 20	Approach # 1	Approach # 3	Approach # 6	Approach # 8
Start	10:20:00	10:52:40	15:10:47	15:38:49
IAWP MP201	10:20:41	10:52:56	15:12:25	n/a
IWP MP202	10:24:19	10:58:52	15:15:50	15:41:48
FAWP MP203	10:25:52	11:00:25	15:17:14	15:43:21
MAWP MP204	10:27:02	11:01:32	15:18:27	15:44:33
TWP MP205	10:28:55	11:03:36	15:20:23	15:46:40
HWP MP206	10:31:53	11:06:24	n/a	n/a
End	10:36:40	11:10:50	15:23:14	15:49:32

Tab. 2 – Waypoint flybys Time for RWY20

The data collected by the couple of Ashtech receivers (GVAN and on-board) was processed by the GrafNav 8.1 tool, in order to obtain the Actual Flight Path (AFP). Most of the time, an optimal accuracy Quality Factor was achieved (QF = 1, accuracy <15cm, 1 rms), see Fig. 18.

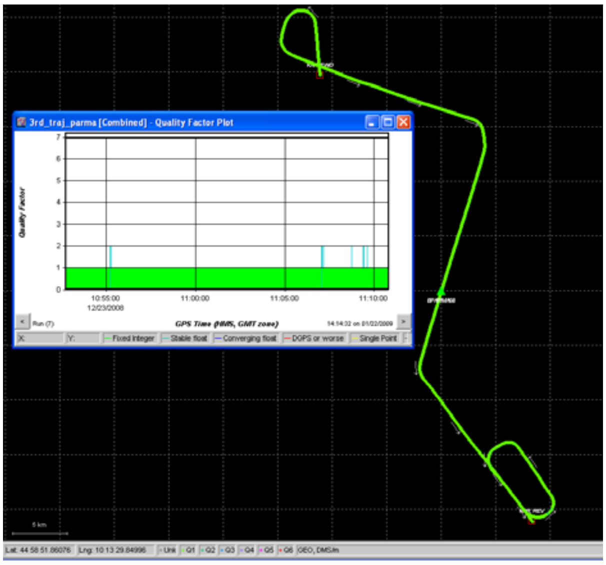


Fig. 18 – Approach #3 in GrafNav

Fig. 19 shows the execution of Approach #3. Each yellow place mark represents a waypoint of the RWY20 NPA flight procedure and the green triangle points out the GVAN position (the master station).

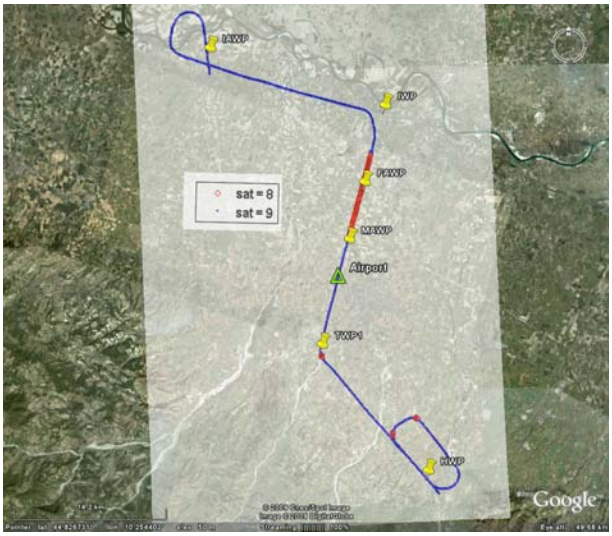


Fig. 19 – Approach #3: used satellite during trajectory

In-flight GPS/SBAS data acquisition was carried out by the Septentrio receiver. The upper plot of Fig. 20 shows: Vertical Position Error (VPE), VDOP, number of satellites used and Vertical Protection Levels made available by the Septentrio receiver. Waypoint flybys are in yellow boxes. In the lower plot of Fig. 20, aircraft attitude parameters are shown.

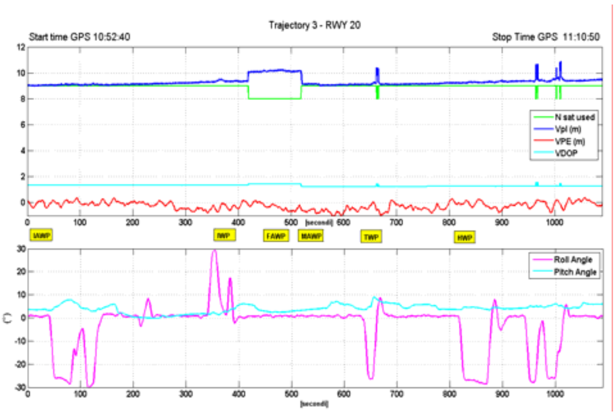


Fig. 20 – On-board Septentrio and Axitude mesurements for Approach #3

In addition, the comparison between static and on-board performances (Fig. 21) confirms that the *proximity effect*, in terms of satellite visibility, Positioning Errors and Protection Levels, is met during Approach #3. The green dashed curve indicates the satellite used by the on-board receiver, while the black one represents the number of satellites used by the GVAN. The differences occur rarely and are due to the specific aircraft attitude which causes the loss of one satellite by the on-board receiver (Fig. 19).

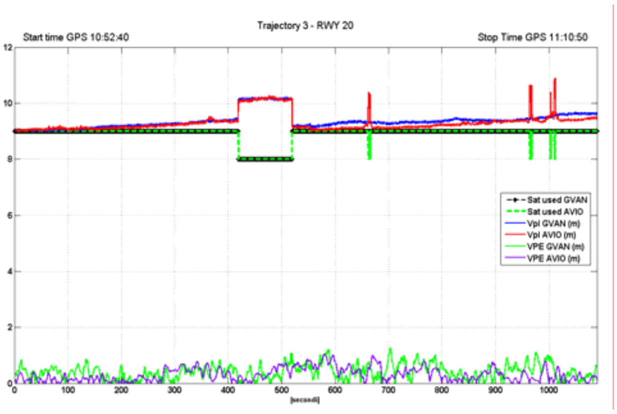


Fig. 21 – Static vs. on-board performance during Approach #3

Statistic analyses of the overall flight campaign at Parma demonstrate the compliance to ICAO GNSS SARPs APV I and APVII requirement: full availability and no (H)MI events. Vertical Navigation System Error and Vertical Protection Levels are shown in Fig. 22 and Fig. 23.

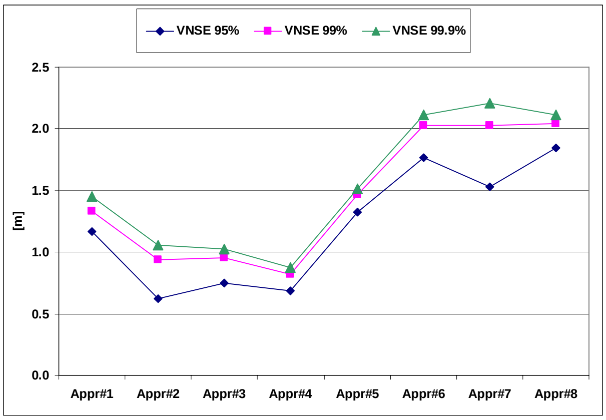


Fig. 22 – VNSE in flight approaches (Parma)

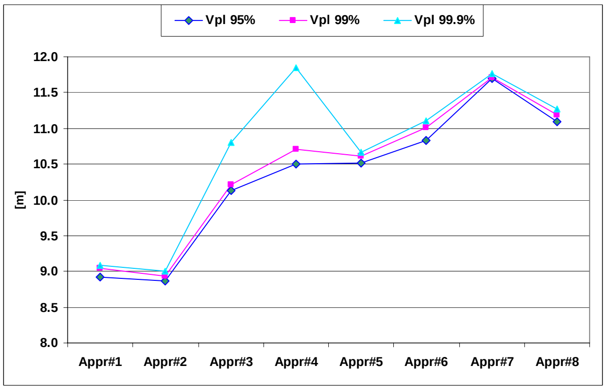


Fig. 23 – VPL in flight approaches (Parma)

A dedicated electromagnetic survey of the GPS L1 bandwidth was carried out at Parma, in order to detect possible interferences of GPS signals. Fig. 24

reports the spectrum amplitude, as a function of time and frequency, measured during the Approach #3, at Parma. Higher signal amplitude values at the central frequency (L1) are due to antenna frequency range.

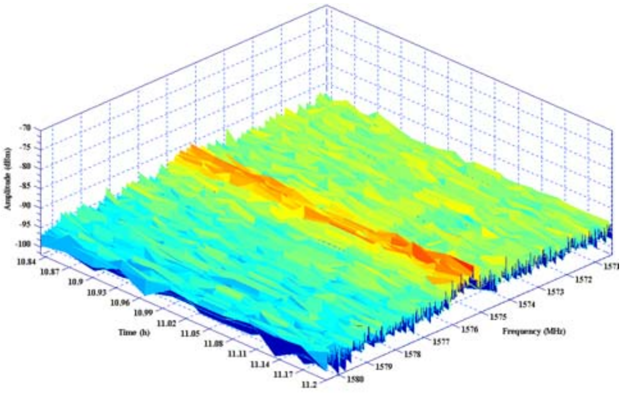


Fig. 24 – Spectrum analysis during the Approach #3

Similar surveys and analyses of the GPS spectrum have been also performed at Perugia and Taranto Grottaglie airports, showing compliance to the ICAO interference mask of Annex 10.

7. CONCLUSION

ENAV S.p.A. has developed a verification methodology of GNSS applications relying on the combination of: analyses, data collection and numerical modeling. The lessons learned in the frame of the SIAM and AIRNAS projects confirm that such methodology is suitable to properly address and mitigate possible safety, operational and economical issues which are driven by local constraints, including GNSS performance. The causes of vulnerability of GPS signals, including possible local electromagnetic interference are expected to be the greatest risk in terms of continuity of GNSS operations. During the surveys no actual interfering sources were discovered at the airports of: Parma, Perugia and Taranto Grottaglie. In principle, this could be not the case of other areas, affected by possible known and military interfering plants to be modelled suitably.

To date, no hazard caused by local unwanted emissions was discovered causing possible integrity risk of EGNOS LPV operations. This excludes the possibility of intentional signal corruption (such as spoofing or meaconing).

Eventually, the verification methodology adopted by ENAV provides a contribution to the Resolution of the 33rd Assembly of ICAO (2001), asking the Council (Appendix R): "*…to circulate to Contracting States information concerning significant developments respecting improvements to radio navigation ground equipment, including associated ground testing and monitoring facilities, to the extent that those developments will serve to minimize the need for flight testing…*".

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