From the Flight Procedure Design to the Flight Inspection: An Applied Test Case in a Mountainous Scenario

Alessandro Nobiletti,
Roberto Carmone
IDS S.p.A.
AeroNavigation Division

ABSTRACT

The test case presented here has been chosen because it is particularly meaningful and complex: the Aosta airport instrumentation feasibility study and executive project. This case demonstrates how in a real complex scenario the usage of computer aided design tools is mandatory to evaluate all possible solutions in an iterative design process. The data quality can be ensured via direct link between the SID, STAR and Approach procedures design environment to the flight inspection console.

BACKGROUND

The development of the **AIRNAS®** system started between the late '80s and early '90s when IDS S.p.A. proposed to ENAV S.p.A. the use of its numerical prediction tools for the solution of the e.m. problems related to the installation, maintenance and the testing of Ground/Air TLC systems, radio navigation aids and radars.

AIRNAS® is conceived to be capable of assisting both the AIS designer and the Navaid-ATM/ATC designer. **AIRNAS®** is composed of the following major blocks:

- **FPDAM®:** the Flight Procedure Design and Airspace Management is a 3-D CAD tool that provides an interactive environment for Aeronautical Flight Procedures design, Air Space management and Air Navigation using the new satellite concepts. **FPDAM®** takes into account all factors affecting flight procedure performance (aerodrome terrain model, artificial obstacles, type of aircraft, ICAO Rules, GNSS satellite constellation etc.), within an interactive environment in order to ensure the flight safety issues; **FPDAM®** is currently in use by more than 13 CAAs all over the world.

- **EMACS:** is a set of 3D validated electromagnetic modelling and simulation tools, capable of coping with EMC (ElectroMagnetic Compatibility) issues and EMI (ElectroMagnetic Interference) problems in the airport and air navigation site scenarios. The modelling functionality (including terrain models, obstacles, interfering system, ground and airborne navaid equipment characteristics etc.) allows an expert user to model the actual propagation phenomena taking place within a complex e.m. airport scenario where signals (VOR, DME, ILS, ATC Radar, GPS and Air-Ground TLC systems) interfere with artificial or natural obstructions;

THE AOSTA EXPERIENCE

The Aosta (LIMW) aerodrome is located in a narrow valley in the Alps area in NW Italy. Presently this airfield isn't instrumented and the operations are restricted to VFR conditions. The airfield (whose elevation is 1,500 ft) is located in a mountainous area whose altitude exceeds 14,000 ft. The runway is oriented East-West, very close to the valley orientation. The approach to the aerodrome is possible only from East to West due to the presence of the Mount Bianco located roughly 10 NM west of the runway. This obstacle forces the design of the missed approach segment such as to return eastbound to the initial fix. The missed approach turn is the most penalized segment of the whole procedure.

The development of an instrument flight procedure, in order to open this airport to IFR operations, was carried on by means of various feasibility studies:

- In 1995 the design of the instrument approach and departure flight procedures based on PANS-OPS rules was executed on the basis of the installation of new conventional ground based navaids. In this very first working phase, it was verified also the possibility to design a GNSS approach based on US FAA TERPS criteria: due to the potential masking from mountains a satellite visibility analysis was executed in order to verify the availability of the GNSS signals along all the segments of the flight path.

  This feasibility activity demonstrated the possibility to design instrument flight procedures in this aerodrome notwithstanding the severe limitations imposed by the terrain around the Aosta airport.

- In the year 2000 it was decided to explore the possibility to design RNAV-DME/DME instrument flight procedures. As described more in detail in a later section, it solution was abandoned due to difficulties for the selection of sites for the DME installation. The development of a procedure based on a VOR/DME was selected as final solution.

The following sections will describe more in detail the features of the various types of instrument flight procedures developed during this activity.

GNSS AND "CONVENTIONAL" BACKUP INSTRUMENT FLIGHT PROCEDURE DESIGN

In spite of the severe terrain conditions of the valley, a series of numerical analysis demonstrated that an aircraft flying a GNSS/GPS instrument flight procedure would experience a sufficient number of GNSS satellites in visibility, as fig. 1 shows.

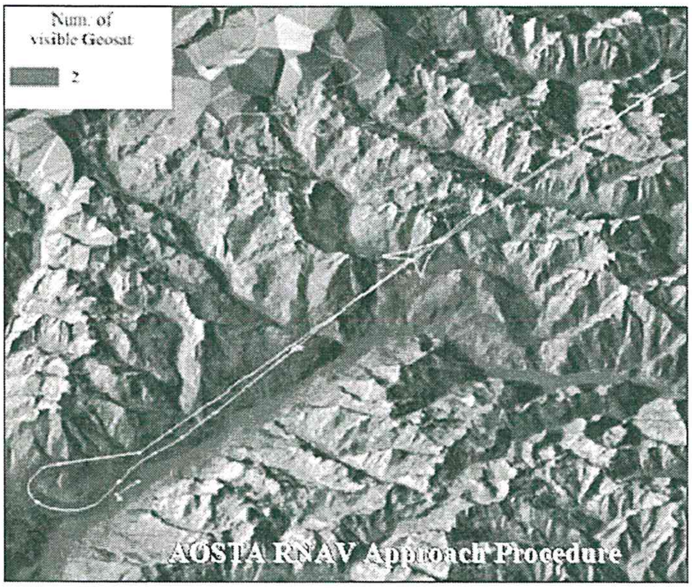

Figure 1: Example of GeoSatellite visibility analysis

This analysis was based on the hypothesis of a straight-in approach segment with a steep descent gradient. This segment is slightly misaligned with the runway centre-line: the IAWP was placed at 22 NM from the aerodrome at an altitude of 14'000 ft. The IWP is located at 20 NM DME and at an altitude of 12'000 ft (AMSL). A step-down WP has been fixed at 18 NM DME. The gradient from the SDWP to the FAWP is 5.15 %. From the FAWP, located at 9 NM at an altitude of 7600 ft (AMSL), to the MAWP located at 4 NM DME and an altitude of 4500 ft (AMSL) the gradient is 6.6 %. The obstacles/terrain environment is not so severe in the approach phase as in the missed approach one, which was based on a turn as soon as possible to the IAWP. The bank angle has been fixed at 20°; the speed has been limited to 130 Kts.

Satellite visibility check phase

As previously described, a numerical simulation was executed in order to evaluate the visibility of the:

1) GPS satellites;
2) GEO satellites

These two analyses were executed taking into account of the following factors:

- the aircraft bank angle along the turn segments,
- the GPS antenna masking angle (a 5° masking angle was taken into account)
- the terrain masking
- the satellites ephemeris
- the aircraft nominal path and its spreading within the containment areas.

Even if the maximum bank angle for the procedure is 20° it was possible to demonstrate the absence of visibility problems for both GPS and GEO satellites.

Conventional backup flight procedure

The Aosta valley is outside the radio coverage of all the existing radionavigation aids, so specific activity aimed to the design of back-up conventional instrument procedures (as later required by ICAO SARPS) was executed. This work produced two possible back-up procedures: one was based on NDB+NDB+LLZ+DME and the other one on VOR+VOR+DME.

THE DESIGN OF THE DVOR/DME INSTRUMENT FLIGHT PROCEDURE

After this first feasibility study IDS was granted with a second contract for the development of an instrument flight procedure for the Aosta aerodrome. Between the goals of this contract there were the analyses of the proposed procedure from many point of view: from obstacle clearance to the availability of the signals in space, passing from noise analysis. In a first time a solution based on an RNAV-DME/DME (shown in fig. 2) was selected.

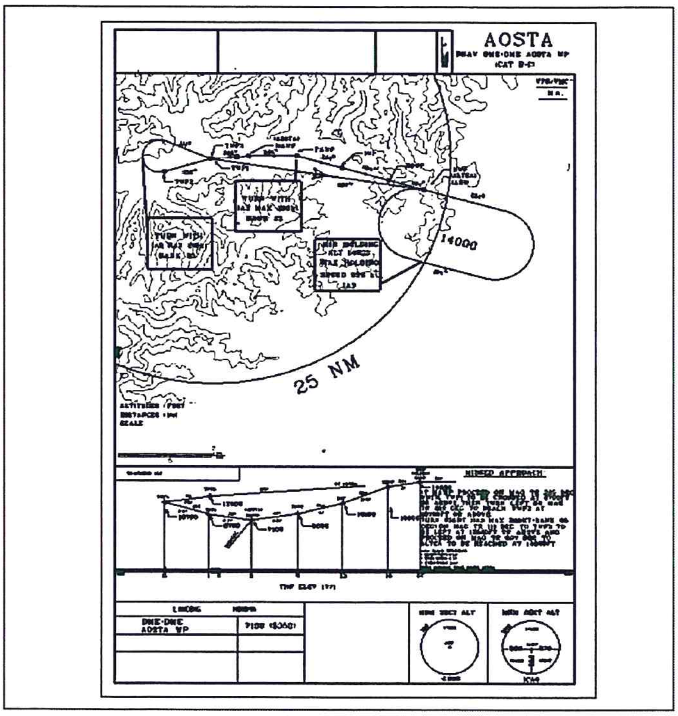

Figure 2: RNAV DME/DME instrument flight procedure for category A/B aircrafts

This solution was selected it was characterized by low radionavigation aids acquisition and installation costs. This design was executed according to the following workflow:

- A set of tentative procedure fixes were selected;
- All procedure segments and it's associated protection surfaces were drawn;
- The obstacle clearance was assessed in order to verify if it was in accordance with the ICAO Doc. 8168 requirements.

The main lessons learned were the following:

- In order to keep the protection areas as narrow as possible, the difference of altitude between the lowest procedure WP (the MAWP) and the DME stations has to be minimized;
- The requirement to avoid too steep climb gradients on the missed approach segments caused procedure minimum altitude to be fixed at 7100 ft.

After the procedure design it was necessary to select at least three sites for the DME installation. The EMC analysis tools of AIRNAS/EMACS were used in order to look for the areas:

- located around 7100 ft of altitude,
- from which the whole procedure area is within the radio coverage of both the three DME

Fig. 3 shows one of the outputs of the visibility analysis execute for the sites selection.
The site selection showed unexpected difficulties related to the unavailability of areas accessible with roads and with the availability electric power. Those difficulties led to the decision to abandon the DME/DME solution in order to

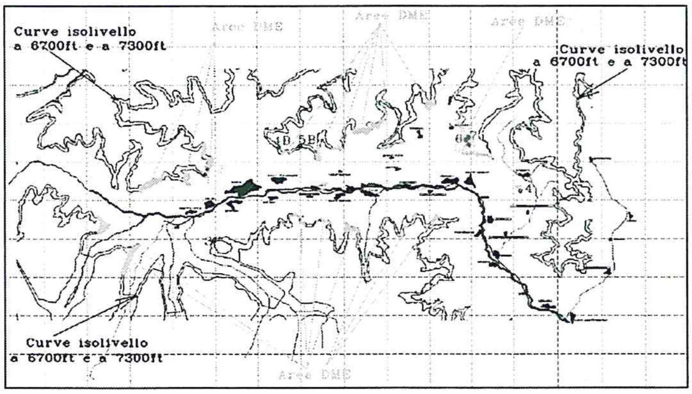

Figure 3: Candidate areas for the DME siting

explore a different one based on a conventional navaid installed within the airport area. It was selected a solution based on a single DVOR/DME, which was preferred among others because this radionavigation aids has the lowest impact on the land usage constraints. As in the case of the

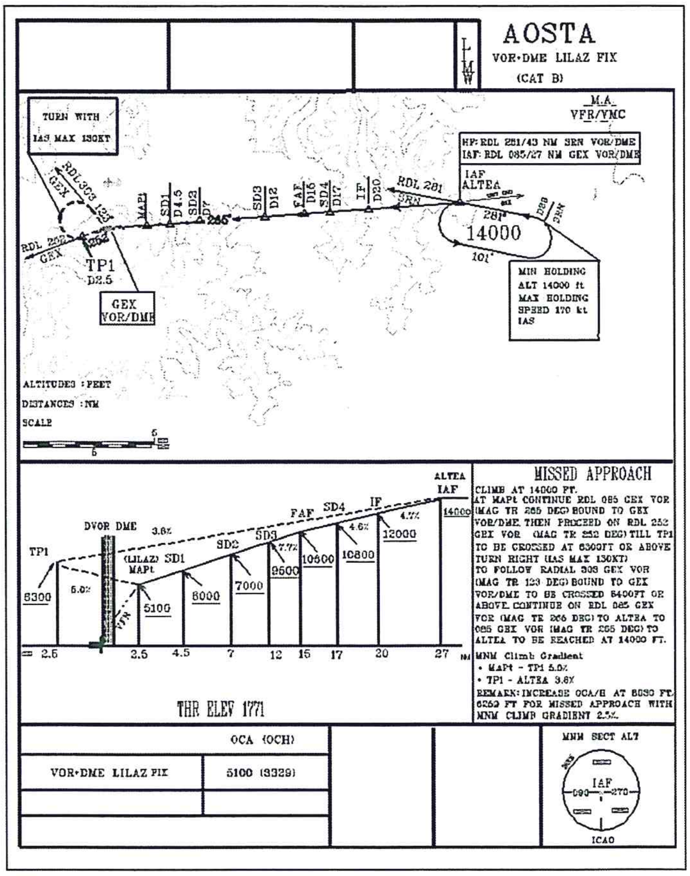

Figure 4: Cat B VOR/DME instrument flight approach procedure

RNAV-DME/DME instrument flight procedure, the approach segment is slightly misaligned with the runway centre-line. The optimization of the design of this instrument flight procedure brought to a procedure minimum a 5100 ft, with the MAPt. at 2.5 NM from the threshold, as shown fig.4. The presence of terrain obstacles in the missed approach area were the main reason to the selection of such distance MAPt point. The following limitations are related with this instrument flight procedure:

1) The distance from MAPt to THR is 2.5 NM, this segment is flyable only on VFR conditions;
2) The missed approach segment require climb rates steeper than the PANS-OPS default one: it was selected climb gradient of 6.6 % in a first segment, and 3.6 % westward of the Aosta DVOR/DME;
3) As explained more in detail in the next section, the terrain around Aosta will mask the new DVOR/DME equipment, so this signal will not be usable for the holding pattern in the IAF area.

The problem related to the radioelectric coverage limitations of the Aosta navaid on the holding circuit area were overcame using the existing Saronno (SRN) VOR/DME navaid, which is placed outside the Aosta valley. The IAF altitude was selected is order to decouple this new instrument approach procedure from the other airspace vincula due to airways and ATC areas of the nearby airdromes.

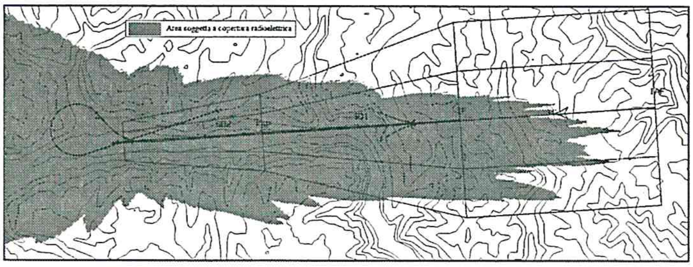

Figure 5: DVOR/DME Radio coverage at 9500 ft (AMSL)

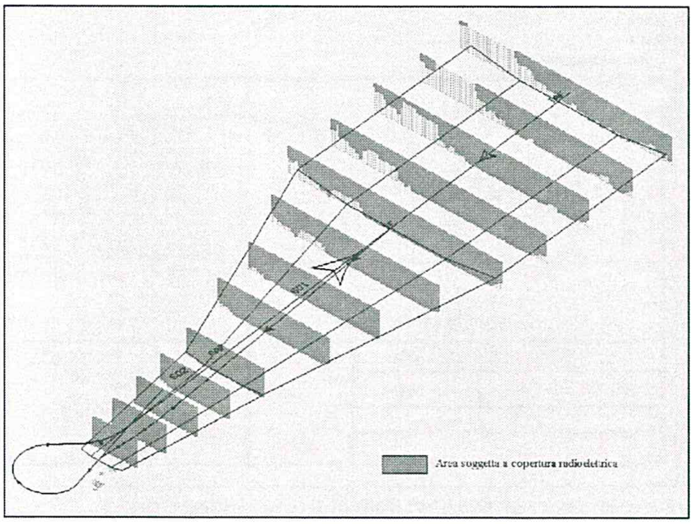

Figure 6: Example of radio coverage analysis output: this figures shows the areas in which the DVOR/DME signal is stronger than min. value requested by ICAO Annex 10 along vertical planes cutting the instrument approach procedure volume

The instrument flight procedure design was completed with the arrivals and departure procedures. In order to increase the safety of this instrument flight procedure, it was executed a study in order to select the obstacles to enlighten (see fig. 9) in order to increase the pilot situation awareness during night operations.

Electromagnetic coverage analysis

The electromagnetic analysis of the VOR/DME installation produced two important findings:

- The first one was related to the fact that the Aosta navaid cannot be used as a means of navigation in the holding circuit area (see fig. 5 and fig. 6), due to the masking effect of the mountains eastward of the aerodrome;
- The second one was related to the selection of the area for the DVOR/DME installation: the selection of the best position of this radionavigation aid was very difficult, because the few areas free from the Annex 14 OLS surfaces are characterized by the presence of AN industrial area. In order to keep to the minimum:

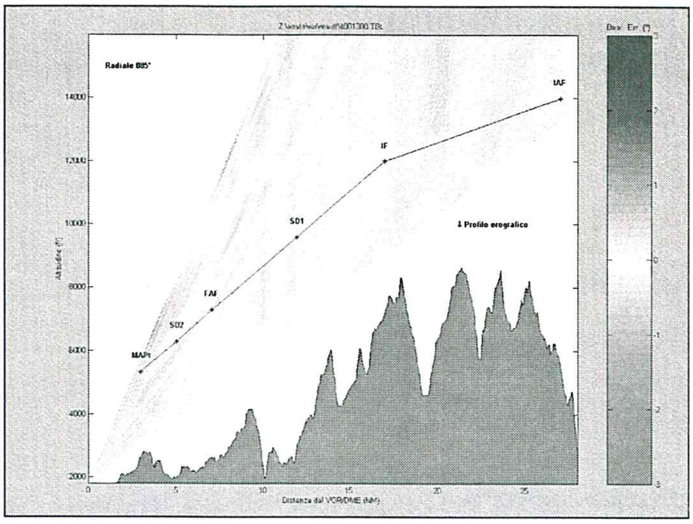

Figure 7: Example of bearing error computation along a VOR radial

- any problems from multipath from the buildings of the industrial area,
- the limitation on the land usage around the airport

it was suggested to install a Doppler VOR equipment with a counterpoise at height above the ground of nearly 10 m.

As shown in fig. 7, the multipath level on both the VOR signal and the DME one is expected to be within the limitations foreseen by the ICAO Annex 10.

Noise level analysis

Once the procedure has been designed and evaluated for all the matters related to the safety of flight, IDS designers started the analysis of the noise impact of the IFR operation on the airport area. This task was very important because Aosta airport is very close to a city. This activity was executed by means of the support of the FAA Integrated Noise Model (INM) which is able to model those aircrafts which are expected to operate on that aerodrome. The same

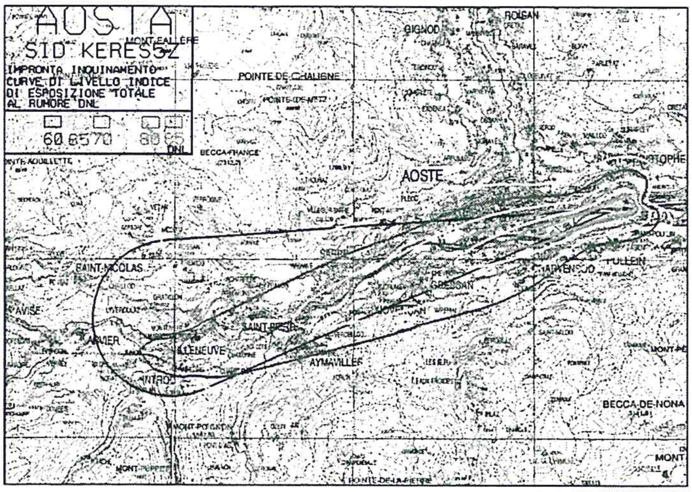

Figure 8: Example of iso-noise curves computation output for a SID flight procedure

terrain numerical models used for obstacle clearance and signal in space analysis was used by means of interface functions developed in order to create INM scenarios starting from the AIRNAS ones. The fig. 8 shows one of the output with the color coded graphic related to the ICAO standards.

SID, STAR and approach procedure data transfer to the flight inspection systems

Modern flight inspection systems rely on the knowledge of the instrument flight procedure path by means of waypoint geographical positions and path terminators (which describe how to fly the path between two waypoints). This task is potentially critical for the data integrity due to the human factors related to the data handling and elaboration. In order to reduce the number of the working stages between the instrument flight procedure design and it usage in aircraft consoles and FMS, the design tools of FPDAM were improved in order to export all the procedure data, including the FIX/WP coordinates, the Path terminator codes. The output format can be ARINC, XML based, or other customized formats.

CONCLUSIONS

The development of an instrument flight procedure in a challenging scenario like the one of an airport placed in the Italian Alps region showed the necessity to use integrated analysis and design tools in order to keep under control of the procedure designer all parameter that ensure a safe flight. In order to meet these requirement IDS developed the **AIRNAS®** tool in order to:

- Design of instrument flight procedures and to manage the airspace data (**AIRNAS/FPDAM®**)
- Analyze (by means of computational electromagnetic techniques) the radioelectric performance of TLC equipments, radionavigation aids and radar systems (**AIRNAS/EMACS**)
- Analyze the satellite constellation visibility in order to check the flyability of the designed procedure (**AIRNAS/SAPET**).

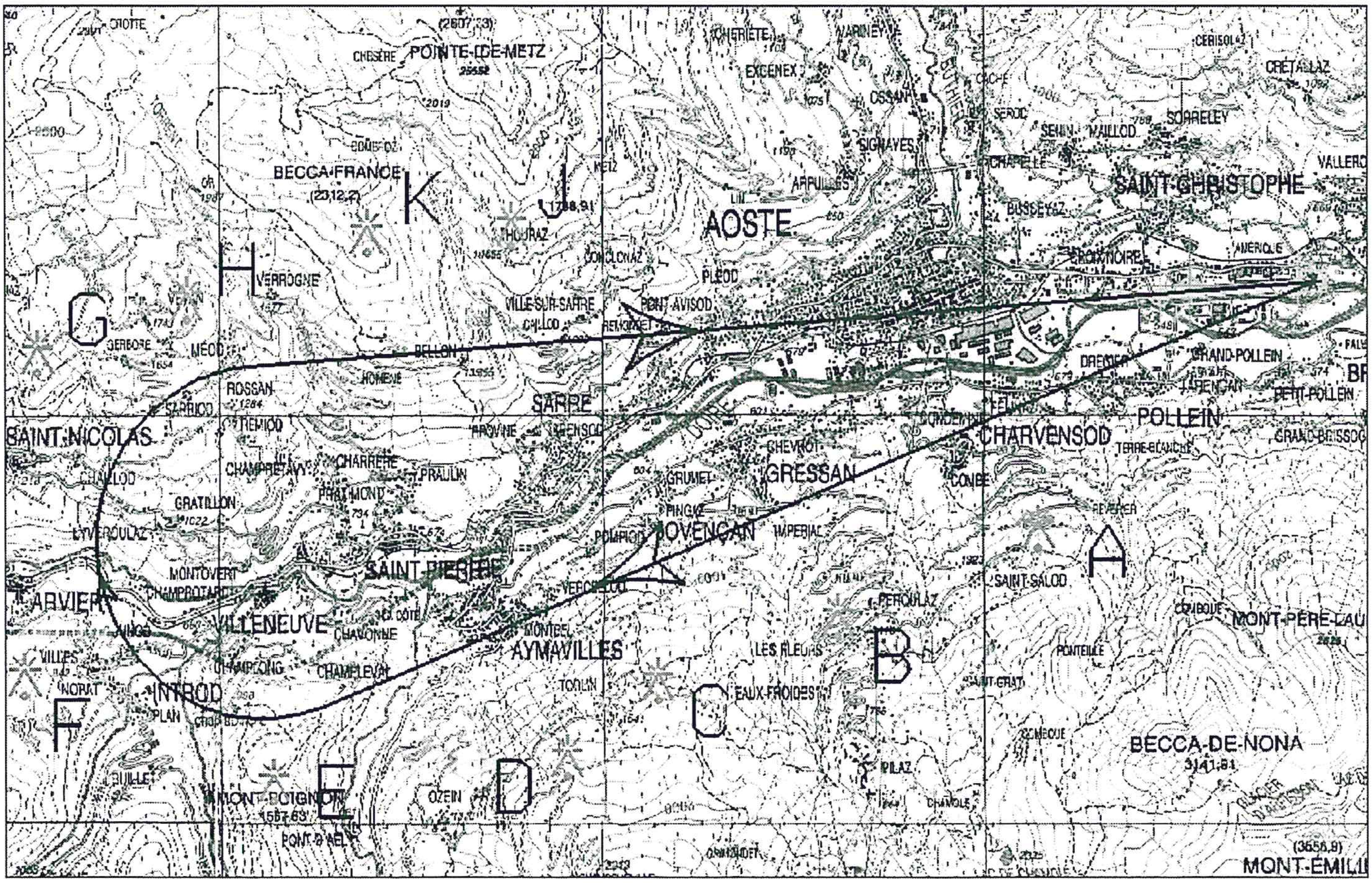

Figure 9: Example of the study relevant to the lighting of obstacles close to the initial climb segment of the SID procedures

This system has a close interaction with the instrument flight measurement data because:

- **AIRNAS®** uses those data in order to validate the numerical models of the environment around the antenna under analysis;
- To demonstrate the computational correctness of the IDS simulation procedure;
- To evaluate the degree pf the precision of the IDS tools for the DME analysis
- It increase the effectiveness of the commissioning flight inspection of new equipment because the numerical analysis is able to identify the areas of the out-of-tolerance of the signal of that equipment;
- It reduces the need (or nearly eliminates) for the use of portable equipment in the case of radionavigation aids installation in critical sites;
- It increases the safety of the flight during the equipment inspection due to the ability to compute the obstacle clearance within the volume of operation of the equipment under test.

The Aosta experience demonstrates how the numerical analysis can be useful design tools for critical tasks such as the design of the instrument flight procedure, the selection of the navaid position, the analysis of the noise level due to airport operations. Numerical tools similar to AIRNAS will help the flight inspection process to reduce the time and costs of checks.

In case of new navaids installations, the coverage/visibility can be evaluated in order to ensure the flight procedure to be covered. The flight inspection is mandatory, but a statistic on several simulation analyses can be reduce the costs and the necessary time for the installation. If an old navaid has to be moved or modified, the impact on already constructed procedure can be easily evaluated. IDS has such an experience on the navaid analysis. IDS provided both analysis cases to some CAA and at the end all the results have been compared with the real flight inspection records. The structure of the **AIRNAS®** system allows the optimisation of the data usage because these are contained in the same database. The terrain data as well as the aeronautical data are stored in the same structure.

REFERENCES

[1] ICAO Annex 10 to the Convention on International Civil Aviation

[2] ICAO Doc. 8071 "Manual on Testing of Radio Navigation Aids"

[3] FAA Doc. 8200.1A "United States Standard Flight Inspection Manual"

[4] ICAO Doc. 8168: "Procedures for Air Navigation Services – Aircraft Operations (PANS-OPS)"