

A GIS-BASED INFRASTRUCTURE FOR THE PRODUCTION OF THE OFFICIAL AERONAUTICAL CHART

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Abstract

The Portuguese Official Aeronautical Visual Flight Rules (VFR) Chart contains information for air navigation and air operations under VFR conditions of Portugal mainland at 1:500 000 scale. This Chart is published and promulgated by NAV Portugal.

This paper presents a complete workflow to convert the information, previously created in CAD, to an ESRI geodatabase considering all geographic and aeronautical information. In addition, functionalities to incorporate new information, with the inherent editing processes, to create different symbologies, to generalize some themes, to validate and to print final maps are also part of the workflow. Basically, a new cartographic process is established, taking advantage of the tools available in a GIS environment, to generate the final mapping products.

As future work, the GIS database generated will be complemented with other aeronautical information that can help air navigation, control and decision-making process not only in a daily basis but also in a crisis response environment.

Keywords: *Cartography, Geographical Information Systems, Air Navigation, Workflow, Aeronautical Information*

INTRODUCTION

Since the first flights that many instruments were developed to guide the pilots in the air. Some of those instruments were invented in Portugal. Gago Coutinho was a Portuguese aviation pioneer who, together with Sacadura Cabral, was

the first to cross the South Atlantic Ocean by air, from March to June 1922, from Lisbon to Rio de Janeiro. Gago Coutinho invented a type of sextant incorporating two spirit levels to provide an artificial horizon. This adaptation of the traditional marine sextant allowed navigation without visual reference to the real horizon. He also invented an optical flight instrument, to be mounted on the plane's cockpit floor, which measures leeway in flight whenever ground remains visible. At that time all flights were performed by visual guidance, nowadays called visual flight rules (VFR). Visual flight rules are a set of regulations under which a pilot operates an aircraft in weather conditions, generally clear, enough to allow him to see where the aircraft is flying. The pilot must be able to operate the aircraft with visual reference to the ground, and by visually avoiding obstructions and other aircraft.

The International Civil Aviation Organization (ICAO) is a United Nations (UN) specialized agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention). ICAO works with the Convention's 191 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. These guidance also exists in the establishment of VFR rules and in the production of aeronautical charts.

In Portugal, the first known aeronautical chart for VFR conditions is from 1947, and it is mainly a representation of the terrain with the main towns surrounding the chart as it can be seen in Figure 1..

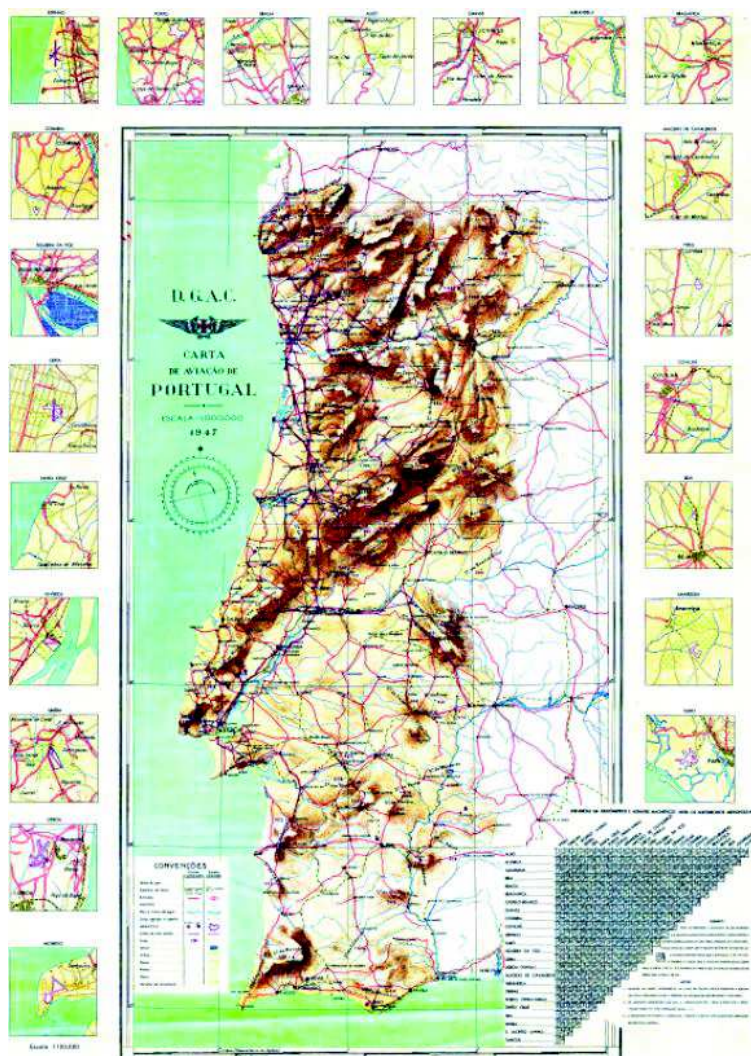


Figure 1. Aeronautical Chart from 1947

Meanwhile, other editions were published. Since this chart is produced by the Army Geospatial Information Center (CIGeoE) this is the 3rd edition produced to the Air Navigation Authority, NAV Portugal since this Authority do not has the skills and the cartographic knowledge to produce these maps. On the other hand, CIGeoE has the experience, the

background, the human and technical resources to develop new methodologies to produce this cartographic product in order to fulfill the highly demanding requirements.

The previous editions were produced in a Computer Aided Design (CAD) environment. Although this is a friendly way to produce this kind of maps, continue with this methodology was never an option. The migration to a Geographic Information System (GIS) was obvious and presents new challenges which are discussed in the study here presented.

GOALS

The main objective of this study is to develop a methodology to establish a spatial data infrastructure to enable the integration of information from different sources and formats for the production of the aeronautical chart, taking into account the international standards. Moreover, this methodology should ensure the interoperability of this information with different systems that are used in aeronautical world and be effective in upgrading the data infrastructure, allowing faster and easier updates cycles and the development of future projects based on GIS. The generated products of the proposed methodology should consist on a paper map, a GeoTIFF and a GeoPDF.

METHODOLOGY

Workflow

To establish the proposed methodology, it was necessary to implement a sequential set of cartographic procedures to convert all the information existing in CAD format to an ESRI geodatabase (ESRI, May 2015). The data in question consists of both topographic base information and aeronautical information. The conversion to a geodatabase comprises also the integration of new information, with the inherent editing processes, different symbologies, generalization of some themes and respective validation before printing the final maps.

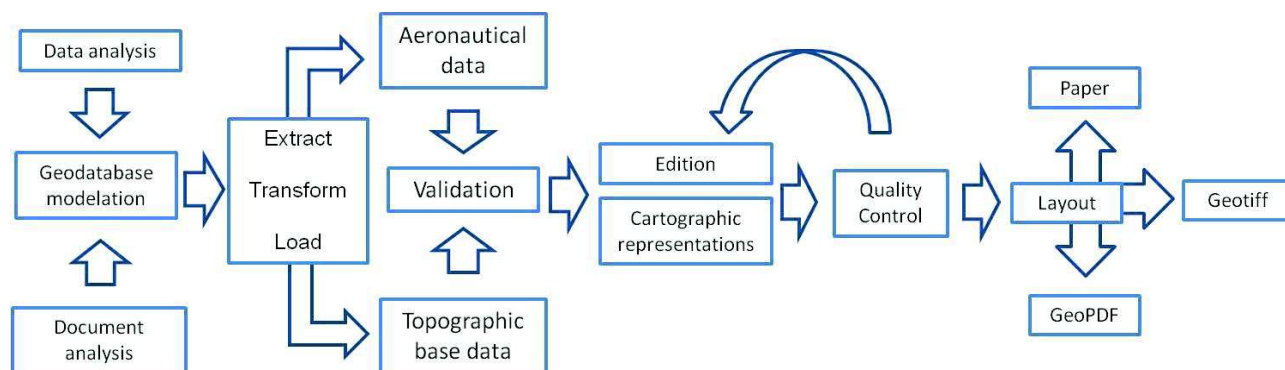


Figure 2. Workflow representing the proposed production process

Figure 2. shows the proposed and established workflow where it can be seen that the database modeling is a result from the analysis that was done, both from the documents and from the existing data in order to satisfy data requirements and the client needs. After modeling the database the system was ready to proceed to the migration of geospatial information. To complete this task it was used an ETL (Extract, Transform, Load) process, both for aeronautical and topographic base information, although the process was different for these two kinds of information.

Once the ETL process was concluded some validation tasks were executed, in order to validate geometry and topology of the information. Because geographic information for air navigation depends highly on symbology, the next step was the production of symbology in concordance with the internal standards implemented in CIGeoE but also with the technical specifications and representation rules defined by ICAO.

Then, the quality control phase was performed, internally and externally to CIGeoE, to ensure that all the standards were met.

Finally the layouts design took into account the different products generated, as referred before. The design that was achieved was a commitment to facilitate not only the production but also the interpretation of the cartographic products.

Software

For this project several software packages were used due to the extent of the conversion processes that had to be done. These procedures included, among others, format and platform changes and also the production of new geospatial information from tabular data. ArcMap 10.3.1 (ESRI, May 2015) was used as base software which contains functionalities applied to complete several operations, like for instance, the generation of isogonic lines from the World Magnetic Model to the period 2015-2020, using ESRI Production mapping extension with Magnetic Isolines Tools. Additionally it were also used, as support for certain processing steps, the following softwares packages: QGIS 2.6.1, MicroStation, PostgreSQL with PostGIS extension and Adobe Photoshop 7.0 for the production of the final layout of the legend, in the paper product.

In order to better interact with those software packages different types of programming language (e. g. SQL, Visual Basic, Python, HTML, and the MicroStation Development Language (MDL)) were also used.

For some other processings were used the OGR (OpenGIS Simple Features Reference Implementation) and GDAL (Geospatial Data Abstraction Library) libraries, enabling processing of large amount of information in a short time as was the case of the altimetric information and the calculation of the Maximum Elevation Figure (MEF) value.

Data Format

The data formats used in this project included dgn, shape file, geodatabase and GeoPDF. Raster data in TIFF and GeoTIFF format and external data in xls, txt and other common formats.

In order for GIS work properly, a strong and robust integration of geospatial data is essential. To achieve this goal, global initiatives have been taken in an attempt to establish standards, such as the creation of the Open Geospatial Consortium (OGC) and initiatives which objective is the implementation of Spatial Data Infrastructures (SDI), such as the NSDI (National Spatial Data Infrastructure) of the United States and the INSPIRE (Infrastructure for Spatial Information in the European Community) in Europe. In addition to these initiatives, the internet is also a powerful tool to disseminate geospatial data. The standards defined by the World Wide Web Consortium (W3C) also have their importance. Thus it is decisive that the format of the resulting products could be accepted by the community that uses it. The GeoPDF and GeoTIFF formats were obvious choices, in addition to the paper map, because of its international recognition and degree of acceptance.

DESIGN AND MODELING OF GEOSPATIAL DATABASE

Beyond the production of the 3rd edition of the Aeronautical Chart of Portugal at 1:500 000, this project also aims the migration of the cartographic production process, previously based on CAD system (Microstation), to a GIS (ArcGIS) environment, being mandatory the implementation of a spatial data infrastructure, developed on ESRI technology, to host and interact with information. To achieve this objective, the modeling of a relational spatial database was carried out to ensure the migration of the information between those two environments and subsequently create cartographic representations, housing topologies, classes relationship, representation rules and symbologies.

Consultation and Analysis of technical documentation

Due to the extremely technical aspects of the work, it was also necessary to perform some research inside the existing and extensive technical documentation. Besides the CIGeoE internal rules for the working scale, the most important documents that were analyzed were the following:

- Aeronautical Charts, Internacional Standards and Recommended Practices, Annex 4 to the Convention on Internacional Civil Aviation;
- Manuel des cartes aeronautiques, DEUXIEME EDITION – 1987, ICAO;
- Guidance Material for Aeronautical Chart – ICAO 1 : 500 000, Version 1.6 , 2011;
- FAA Aeronautical Chart User's Guide 12th EDITION OCTOBER 2013.

Database Modeling

As refered before, there were mainly two different types of information, each one with its own characteristics and with different layers inside. Figure 3. shows all the information that was used to construct the base infrastructure from which were produced all the cartographic pieces.

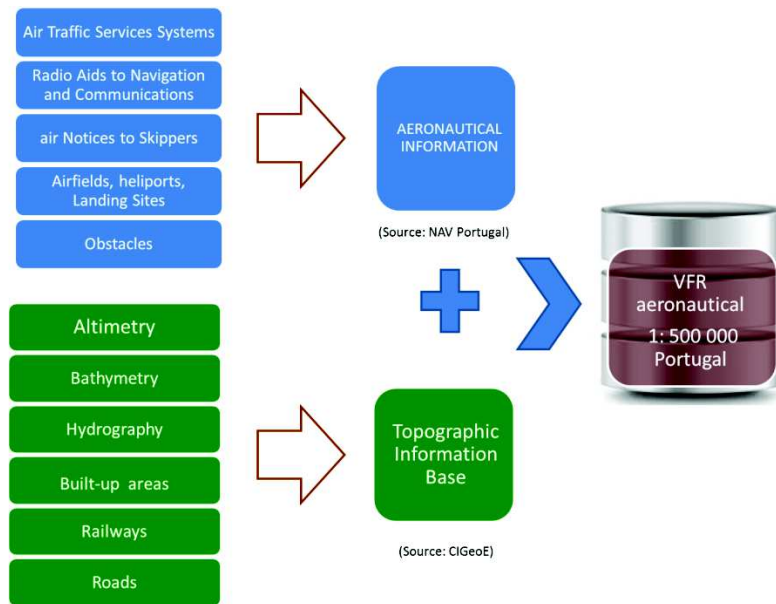


Figure 3. Information to upload the geodatabase

To load all the information in the geodatabase, it was decided to group that information in two feature datasets, one for each type of information. This classification is due to some reasons: because the differentiation between base topographic information and aeronautical information was always an assumption in this project and also because the ETL process was also different.

DESIGN AND DEVELOPMENT OF ETL PROCESS

Conceptually, the ETL process allows the extraction of data from external sources, the transformation of that data in order to the realization of products that satisfy our clientes needs and the upload of a data base. Figure 4. shows the way that ETL process runs on a production environment.

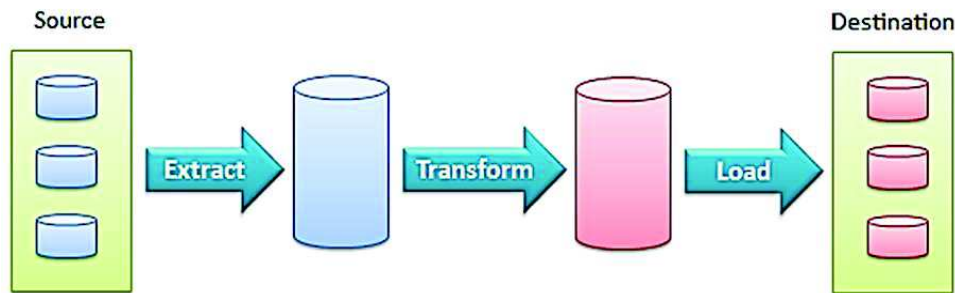


Figure 4. ETL Process on a production environment

Due to the nature of CIGeoE, the ETL process is well developed and consolidated and was implemented in the production of other cartographic products.

ETL process on Topographic Base Information

Being a geospatial information producer, CIGeoE has topographic base information but the way that is structured is not suitable, without any processing, to be used in this product. The object catalog is different, the object density is adjusted to the production of 1:25 000 scale maps and so some production processes were necessary so this information could be used in a suitable manner. Some of these processes were already made because CIGeoE also produces 1:250 000 scale maps both ground and aeronautical not only for military use. Because the scale change from 1:25 000 to 1:500 000 is huge, it was decide to use, as base information, the one that is used for the production of the 1:250 000 road maps. The change in scale is not so significant and all process is much more friendly and easy to implement.

Thus the themes that were available, because of their affinity with VFR rules, are the following: Altimetry, bathymetry, hydrography, urban areas, main railways, main roads, territorial sea and high voltage powerlines.

CIGeoE also produces a map of Portugal mainland at scale 1:500 000 with last edition in from 2014. This is a road map in which the available themes had already been exported from dgn format to shapefile. Thus the topographic base information of certain classes of information was obtained from that product, as was the case of bathymetry, hydrography, highways and railways. The missing themes were the altimetry, urban areas, the territorial sea and the high voltage powerlines. The procedures taken with this information will be described below.

The ETL process applied to topographic base information is based mainly on the importation of diverse geographic information from some CAD files from MicroStation. The data model of the information in these files is based on the differentiation of data through the different graphics features available in this format, in particular the type of geometric entity (point, line and polygon), as well as their characteristics (level, color, weight and style). Based on the differentiation of the data referred above, it was possible to extract the desired information by applying ArcCatalog. From this software it was guaranteed the access to the geodatabase and import the required information for each feature class of the feature dataset of topographic base information. Since the source and the destination cartographic reference systems were different, it was necessary re-project all geographic information to the projection normally used in aeronautical mapping which is the Lambert Conical projection. To do so was used the ArcGIS toolbox.

Territorial sea

The territorial sea information was supplied by the Hydrographic Institute of the Portuguese Navy, in shapefile format. It was the first time that this theme was considered in aeronautical maps. These files were re-projected and integrated in the geodatabase, to which a geometric and topological validation process was applied in order to ensure that this information was coherent.

Altimetry

In previous editions, the altimetric information used for the production consists only on contour lines with an interval of 1000 feet and the most important geodetic tri-dimensional control points.

However, due to the enormous importance of the terrain information to air navigation under visual rules, it was also decided to include a significative sample of terrain elevation points and reduce the contour lines interval so that the final maps have a higher density of altimetry information. Thus, the main contour lines have an equidistance of 660 feet, completed with intermediate contour lines of 330 feet and 990 feet.

From the base information, it was used a selection by attribute using SQL language to select the elements which will be represented in the final product. Later in the process, the generalization of the selected information was done using the Bezier Algorithm (Li, 2007), the Remiss Selection (Li, 2007) and the Elimination Algorithm (Li, 2007). To the particular case of hilltops it was used the scale algorithm so they can be visible at 1:500 000 scale. The same procedures were done with terrain elevation points.

Concerning the bathymetric information it was used the information that is produced in the line of production of the geographic information, taking in account for example that the coastal line is the contour line with 0 meters height, which acquisition is done with photogrammetric methods. This information was then subject to generalization processes identical to the altimetry information.

It was also necessary to generate two raster products, in GeoTIFF format, one with the different hipsometric classes and other to create a shadow model. Both of this files has the Aster GDEM V2 terrain model as base information. The objective was to have another terrain representation. To process the base information were used several batch files, via DOS command line, that were programmed internally, according to our needs, associated with the GDAL library, mainly the gdaldem color-relief and hillshade. To generate the shadow model was used, as light source, the azimuth 315°, a vertical angle of 45° and an exaggeration of the vertical scale of 3x. Instead of using Adobe Photoshop to blend and merge those files, it was used Globalmapper.

All this products and the way they were processed, highlight the importance of the terrain representation in the final product.

Urban areas

In respect to this theme, the client intention was to represent more elements than in the previous editions, because they are good references to air navigation. In the previous editions only the most important cities were represented. In this edition the client intention is to represent all the cities. It were used information from Portuguese Statistics Institute, that allows us to extract from other map series produced in CIGeoE only the information with interest, using SQL queries, operating over the attribute selection. After validation of these geographic entities, some generalization processes were applied such as aggregation, simplification and smooth.

High Voltage Power Lines

The information to this theme comes from two different sources: the CIGeoE database for the production of 1:25 000 scale maps and the official information supplied by the National Electric System Company in dwg format. Both were processed, integrated in the geodatabase and then subjected to a generalization process using the available tools in ArcMap like smooth that uses the Bezier interpolation method, Collapse Dual Lines To Centerline, Merge Divided Roads and Collapse Road Detail. All these operations were applied in order to became the information more readable and more understandable according to the scale.

ETL process of Aeronautical Information

There are plenty of coordination measures and rules in aeronautical operations. The ICAO try to establish consensus on international civil aviation Standards and Recommended Practices. In Portugal, Portuguese Civil Aviation Authority (ANAC) is the authority for civil aviation but is NAV Portugal that provide air navigation services. Together, they try to combine national laws with ICAO rules to ensure a safe and efficient air navigation.

So the aeronautical information was a responsibility from NAV Portugal which provided all available information in tables in excel and PDF format. NAV Portugal contacted all entities that could have interest and experience to help building this project, like the Portuguese Air Force. Simbology was made according ICAO Rules or according NAV designations.

The themes represented in aeronautic information were:

6. Air Traffic Services Systems:
 - a. FIR (Flight Information Region) - greater division of airspace where flight information services are guaranteed;
 - b. CTR (Control Zone) - controlled airspace extending from the earth's surface to a defined upper limit;
 - c. TMA (terminal Control Area) - terminal control area usually at the confluence of ATS routes along one or more aerodromes;
 - d. ATZ (Aerodrome traffic zone).
7. Radio Aids to Navigation and Communications:
 - a. Distance measuring equipment (DME);
 - b. Non-directional radio beacon (NDB);
 - c. UHF tactical air navigation aid (TACAN);
 - d. VHF omnidirectional radio range (VOR).
8. Air Notices to Skippers:
 - a. Danger Areas;
 - b. Prohibited Areas;
 - c. Restricted Areas;
 - d. Temporary Reserved Airspace.
9. Aerodromes, heliports and Landing Sites.
10. Obstacles - natural or artificial elements that juts a surface that exceeds the vertical separation of 100 meters from ground level.

Contrary at topographic base information, that was almost a generalization from other maps and scales or information that already exists, the aeronautic layer was generated from the beginning. Since the last edition produced in 2012, there were many changes in aeronautic layer and some symbols were not according ICAO rules, so it was decided to generate a new layer with symbols according ICAO rules instead of import any existing information.

The main difference in the preparation of the aeronautical layer was the ETL process that was carried out. The information was spread by several documents and so the way the information was extracted, transformed and loaded on the geodatabase was quite different from the other information. This need was identified as soon as the analysis of existing documentation started because of particularities of this kind of information.

Geometric entities Processing

All point information that was available was placed in a xls file and then imported to the geodatabase using Display XY Data tool. The information was organized in the geodatabase by subtypes and domains in order to facilitate the symbolization of this information. The same procedure was taken for line entities being that, after the importation, the points were connected by lines. The areas were built in the same manner but in the validation phase some errors were detected. Those errors were due to some inconsistency of the supplied coordinates.

TOPOLOGICAL AND GEOMETRIC VALIDATION OF GEOSPATIAL INFORMATION

A major concern was the validation of the information that became available after all the processes described above. Only this way was possible to ensure that the information meets the highly demanding requirements and was suitable to the needs of the client. Three different kinds of validation was made: structure, geometric and space integrity, both realized in a 2D and 3D environment. It was used some ArcMap 10.3.1 validation tools, including the Data Reviewer and Topology extensions available in the geodatabase ESRI format.

The validation process, in a ArcGIS software environment, is a sequential application of tools available in that platform, fully parameterized according to the permissible tolerances values that are established. Conceptually this process includes the validation of structure and geometric errors and spatial integrity. Methodologically the validation takes place sequentially, as shown in Figure 5..

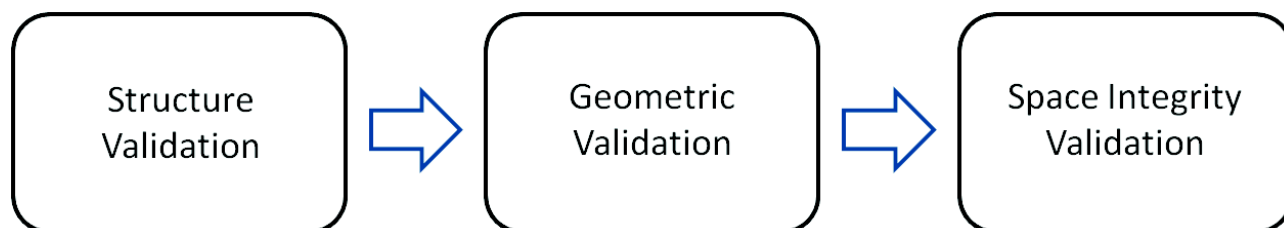


Figure 5. Validation Process

In the data structure validation phase, adaptation procedures were performed in order to prepare the data so they can be validated in geometric terms. Existing data to validate were copied, moved and organized in order to be able to follow the validation process. The structure was checked through the Feature Classe (FC) attribute table which is modified according to the needs of the tools that are used for the geometric validation.

In the geometric validation it was intended to detect and correct geometric errors. There were implemented different processes to altimetry and to the other themes that belong to planimetry. Specific models were developed (toolboxes) for each type to simplify its application.

With the implementation of the models that compose the toolboxes, along with the procedures, the geometric corrections of the data were performed. Among them are highlighted:

- Repair of the geometry of each feature class of the geodatabase;
- Elimination of duplicated geographical entities;
- Elimination of entities which dimensions are below the threshold set for each entity;
- Union of the geographical entities that share the same final vertex of the same FC (Unsplit tool);
- Correction of overshoots and undershoots;

- Detection of topological errors.

During the validation of geometry, topological errors were also detected and corrected. This operation was also obtained in the form of a model where appropriate topological rules for each geographical entity were created. Some common rules for this process for line type entities were as follows:

- Must Not Overlap - a linestring must not overlap another linestring;
- Must Not Intersect - a linestring must not intersect another linestring;
- Must Not Have Dangles - a linestring must not have loose ends;
- Must Not Self-Overlap - a linestring must not overlap itself;
- Must Not Self-Intersect - a linestring must not intersect itself.

The topological errors detected by the operator were individually analyzed and then corrected. Were used also the Error Inspector and the Data Reviewer tools. Data Reviewer allows the detection of anomalies with the FC, attributes and relations in geodatabase. This tool was also used to perform the spatial integrity validation because of the capacity of detecting anomalies in spatial relationships between geographic entities.

The implementation of spatial integrity validation was materialized through verifications to the data using the Data Reviewer ArcGIS tool. Were created rules that, integrated into batch jobs files, allow to detect anomalies in spatial relationships between geographic entities. The verifications that were carried out in this space integrity validation phase were intersections and overlaps between different geographical entities whose spatial layout should be logical and coherent with the real world. Spatial integrity was analyzed between the altimetry, hydrography and planimetry as well as between geographical entities belonging to the same theme.

EDITION OF VECTOR INFORMATION AND ATTRIBUTES LOADING

At this stage, due not only to the paper map scale, but also because of the symbology that had to be used, some generalization algorithm were used in order to make the represented information more readable. Those algorithms were applied to some themes including point type entities (obstacles), line type entity (powerlines), polygon type entity (urban areas). It was also performed the upload of some attributes in order to facilitate the production of certain notes, using for this the Conversion of Labels to Annotation tool, as will be specified later.

Mentioning (Jones, 2003), cited by (Lopes, 2005), the two main types of generalization are:

- Semantic Generalization - based on the initial choice of the relevant information to be displayed on the map;
- Geometric Generalization - based on manipulation of the characteristics of the various geographical entities represented on the map.

It should also be highlighted contextual generalization, more difficult, that usually is performed manually.

In this project, various types of generalization processes, some referred above, were applied. In addition to the generalization operations on some altimetry themes and base topographic information mentioned earlier, it were also applied generalization algorithms to the aeronautical information. Among other entities to generalize, the obstacles that are essential to be represented in a VFR aeronautical map, not only because some are good reference points, but mainly for security reasons. According to the rules established in Portugal, all obstacles with more than 100 m height should be represented. However, this is not possible in a map with this scale, mainly because the number of entities to be represented, including distance and size of the used symbols. So it was necessary to generalize this theme. The aim was to maintain the relative density of obstacles, considering also the highest altitude obstacles. Thus, the algorithm used was manually applied, taking into account the risk and importance associated with the obstacles. Initially it was applied the Aggregation operator to aggregate points less than 100 m from each other. In each area resulting from aggregation were selected those with the highest obstacle height. The objective was to reduce the number of points to represent maintaining its dispersion and ensuring safety. Other operations that were carried out in edition phase were the result of amendments arising from the quality control process that was carried out both internally and externally.