EGNOS
The first European implementation of GNSS
Project status overview

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Abstract

The European Tripartite Group (ETG), (ESA – EC – EUROCONTROL) is implementing, via the EGNOS project, the European contribution to the Global Navigation Satellite System (GNSS-1) which will provide and guarantee navigation signals for aeronautical, maritime and land mobile trans-European network applications. On behalf of this Tripartite group, the European Space Agency is responsible for the system design, development and qualification of an Advanced Operational Capability (AOC) of the EGNOS system.

The EGNOS System (European Geostationary Navigation Overlay Service) will broadcast augmentation signals to the American GPS and the Russian GLONASS systems via two INMARSAT III satellite navigation transponders plus the ARTEMIS satellite developed by ESA. The project is now in its Implementation Phase, started in December 1998 and will be completed by the end of 2003. The EGNOS system, the first European implementation of GNSS, will then be integrated as a building block into the GALILEO program, the European contribution to GNSS-2.

The EGNOS AOC system is an Satellite Based Augmentation System (SBAS) which will largely meet the positioning, velocity and timing requirements of the land, maritime and aeronautical modes of transport in the European Region:

- For maritime applications, positioning accuracies in the range of 4-8 meters will be provided in the European coastal waters, and better than 30 meters in oceanic waters of the European Maritime Core Area (EMCA),
- For land applications (road and rail transport) in continental Europe will benefit from the same range of accuracies provided for aviation over landmasses, i.e. 5-10 meters.
- For civil aviation applications, EGNOS AOC will meet primary means navigation requirements for all phases of flight from en-route to non-precision approach (NPA) as well as precision approach with a decision height capability down to Category 1 Landing within the European Civil Aviation Conference (ECAC) area.

The EGNOS system will be fully interoperable with other SBAS systems under development in the USA (WAAS) and Japan (MSAS). The built-in expansion capability of EGNOS will also enable extension of the services over regions within the Geostationary Broadcast Area of GEO satellites used, such as Africa, Eastern countries, and Russia.

This paper describes the EGNOS System requirements, the overall System design, as well as the current status of the on-going development activities.

1. Introduction

The current capabilities of GPS and GLONASS, although very adequate for some user communities, present some shortfalls. The lack of civil international control presents a serious problem from the institutional point of view. In addition, there is a need for enhanced performance. In particular, civil aviation requirements for precision and non-precision approach phases of flight cannot be met by GPS or GLONASS only. Marine and land users may also require some sort of augmentation for improving GPS / GLONASS performances.

The first generation Global Navigation Satellite System, GNSS-1, as defined by the experts of the ICAO/GNSS Panel, includes the basic GPS and GLONASS constellations and any system augmentation needed to achieve the level of performance suitable for civil aviation applications. EGNOS, which is a regional satellite based augmentation equivalent to the American *Wide Area Augmentation System* (WAAS) or the Japanese *Multi-transport Satellite based Augmentation System* (MSAS), is the first European implementation to GNSS. It is part of the European Satellite Navigation Programme (ESNP) involving GNSS-1 activities (e.g. EGNOS and local area augmentation) as well as GNSS-2 activities, mainly the recently approved GALILEO definition studies.

3. Description of the EGNOS Mission

3.1 General Objectives

The purpose of EGNOS is to implement a system that fulfils a range of user service requirements by means of an overlay augmentation to GPS and GLONASS based on the broadcasting through GEO satellites of GPS-like navigation signals containing integrity and differential correction information applicable to the navigation signals of the GPS satellites, the GLONASS satellites, EGNOS own GEO Overlay satellites and the signals of other GEO Overlay systems (provided they can be received by a GNSS-1 user located inside the defined EGNOS service area).

EGNOS will address the needs of all modes of transport, including Civil Aviation, Maritime and Land users.

3.2 Aeronautical Applications

The performance objectives for aeronautical applications are usually characterised by four main parameters: accuracy, integrity, availability and continuity of service. The values for these parameters are highly dependent on the phases of flight. For typical phases of flight, typical requirements are those included in Table 1. Neither GPS nor GLONASS can meet the above integrity, availability and continuity of service objectives without a system augmentation, although their performance in terms of accuracy alone could meet the requirements of en-route, terminal area navigation and non-precision approaches.

These requirements are currently being finalised at ICAO GNSS-Panel under the form of SARPS [1] (Standards and Recommended Practices.)

Table 1: Aviation GNSS Signal-in-space performance requirements

<table>
<tr><th>Typical operation(s)</th><th>Accuracy lateral /vertical 95%</th><th>Alert limit lateral /vertical</th><th>Integrity</th><th>Time to alert</th><th>Continuity</th><th>Availability</th><th>Associated RNP type(s)</th></tr>
<tr><td>En-route</td><td>2.0 NM / N/A</td><td>4 NM / N/A</td><td rowspan="4">10^{-7}/h</td><td>5 min.</td><td rowspan="4">$1-10^{-4}$/h to $1-10^{-8}$/h</td><td>0.99 to 0.99999</td><td>20 to 10</td></tr>
<tr><td>En-route</td><td>0.4 NM / N/A</td><td>2 NM / N/A</td><td rowspan="2">15 s</td><td rowspan="2">0.999 to 0.99999</td><td>5 to 2</td></tr>
<tr><td>En-route, Terminal</td><td>0.4 NM / N/A</td><td>1 NM / N/A</td><td>1</td></tr>
<tr><td>Initial approach, NPA, Departure</td><td>220 m / N/A</td><td>0.3 NM / N/A</td><td rowspan="2">10 s</td><td rowspan="4">0.99 to 0.99999</td><td>0.5 to 0.3</td></tr>
<tr><td>NPV-I</td><td>220 m / 20 m</td><td>0.3 NM / 50 m</td><td rowspan="3">$2x10^{-7}$ per approach</td><td rowspan="3">$1-8x10^{-6}$ in any 15 s</td><td>0.3/125</td></tr>
<tr><td>NPV-II</td><td>16 m / 8 m</td><td>40 m / 20 m</td><td rowspan="2">6 s</td><td>0.03/50</td></tr>
<tr><td>Category I</td><td>16.0 m / 4-6 m</td><td>40 m / 10-15 m</td><td>0.02/40</td></tr>
</table>

3.3 Maritime Applications

The performance objectives for maritime applications are generally broken down into sea, coastal and harbour navigation. The related accuracy requirements considered today are:

Sea navigation	1 to 2 NM
Coastal navigation	0.25 NM
Harbour navigation	8 to 20 m

Even without system augmentation, GPS or GLONASS can easily meet sea and coastal navigation precision requirements. However, for harbour approach differential techniques have to be applied.

3.4 Land Mobile Applications

In general, land vehicles do not need radio navigation as such, but rather radio positioning. The two main applications under development world-wide making use of GPS receivers are route optimisation and fleet management.

Depending on the application, the accuracy required for the various systems ranges from a few meters to hundreds of meters or more. In many cases, then, they require the use of differential corrections.

3.5 Performance Objectives of the EGNOS System

Of the three user communities, civil aviation requirements are the most stringent (in terms of integrity and continuity) and hence the EGNOS performance objectives are driven by the needs of civil aviation, covering then, the needs of land and maritime user communities.

The coverage area serviced by EGNOS will be the European Civil Aviation Conference (ECAC) service area comprising the Flight Instrument Regions (FIR) under the responsibility of ECAC member states (most of European countries, Turkey, the north sea and the eastern part of the Atlantic ocean). ECAC is defined in Fig. 1.

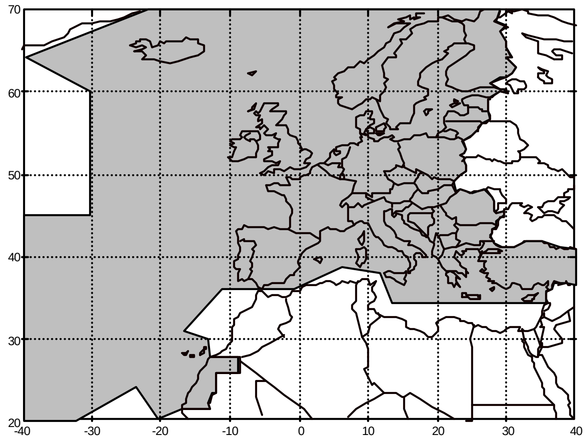

Fig- 1: The ECAC Service Area

The EGNOS AOC performance objectives is to provide a primary means service of navigation for en-route oceanic and continental, non precision approach, NPV-I, NPV-II and CAT-I precision approach within the ECAC area. In addition, EGNOS has potentially the capability to offer en-route and NPA services over the full Geostationary broadcast area, and discussions are being pursued with international partners to provide this capability in order to offer to the users a full seamless service.

4. Description of the Main EGNOS Functionalities

The EGNOS system will provide the following functions:

- **GEO Ranging (R-GEO):** Transmission of GPS-like signals from 3 GEO satellites (INMARSAT-3 AOR-E, INMARSAT-3 IOR and the ESA ARTEMIS satellite) for the AOC phase (for the FOC additional GEO satellites will be provided). This will augment the number of navigation satellites available to the users and, in turn, the availability of satellite navigation using RAIM.

- **GNSS Integrity Channel (GIC):** Broadcasting of integrity information. This will increase the availability of GPS / GLONASS / EGNOS safe navigation service up to the level required for civil aviation non precision.

- **Wide Area Differential (WAD):** Broadcasting of differential corrections. This will increase the GPS / GLONASS / EGNOS navigation service performance, mainly its accuracy, up to the level required for precision approaches down to CAT-I landing .

5. EGNOS Architecture and System description

The EGNOS Reference architecture is depicted in Fig-2. It is composed of four segments: ground segment, space segment, user segment and support facilities.

The EGNOS Ground Segment consists of GNSS (GPS, GLONASS, GEO) *Ranging and Integrity monitoring Stations* (called RIMS) which are connected to a set of redundant control and processing facilities called *Mission Control Center* (MCC). The system will deploy 34 RIMS located in mainly in Europe and 4 MCCs located in Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). The MCC determines the integrity, PseudoRange differential corrections for each monitored satellite, ionospheric delays and generates GEO satellite ephemeris. This information is sent in a message to the *Navigation Land Earth Station* (NLES), to be uplinked along with the GEO Ranging Signal to GEO satellites. These GEO satellites downlink this data on the GPS Link 1 (L1) frequency with a modulation and coding scheme similar to the GPS one. All ground Segment components are interconnected by the *EGNOS Wide Area Communications Network* (EWAN). The system will deploy 2 NLESs (one primary and one back-up) per GEO navigation transponder and an NLES for Test and Validation purposes, located in Torrejon (E), Fucino (I), Aussaguel (F), Raisting (D), Goonhilly (UK), and Sintra (P) respectively.

The EGNOS Space Segment is composed of Geostationary transponders with global Earth coverage. The EGNOS AOC system is based on INMARSAT-3 AOR-E and IOR, and the ESA ARTEMIS navigation transponders. The EGNOS FOC will require additional transponders to guarantee availability during the 15 years mission duration.

The EGNOS User Segment consists of an EGNOS Standard receiver, to verify the Signal-In-Space (SIS) performance, and a set of prototype User equipment for civil aviation, land and maritime applications. Those prototype equipment will be used to validate and eventually certify EGNOS for the different applications being considered.

Finally, the EGNOS support facilities include the *Development Verification Platform* (DVP), the *Application Specific Qualification Facility (*ASQF) located in Torrejon (Spain) and the *Performance Assessment and System Checkout Facility* (PACF) located in Toulouse (France). Those are facilities needed to support System Development, Operations and Qualification.

The EGNOS AOC Pre-Operational Implementation involves the detailed design, development, deployment and verification of three elements defined hereafter as:

- EGNOS System Test Bed (ESTB)
- EGNOS Advanced Operational Capability (AOC) System
- AOC Complementary Activities

The EGNOS System Test Bed (ESTB) will be used to support the development of the AOC system by industry, to verify and validate international standards (SARPS) prior to formal approval and to support the development of GNSS operational procedures by users. Its signal has been and will be also used to support a number of experiments and demonstrations, to promote Navsat Applications in Europe.

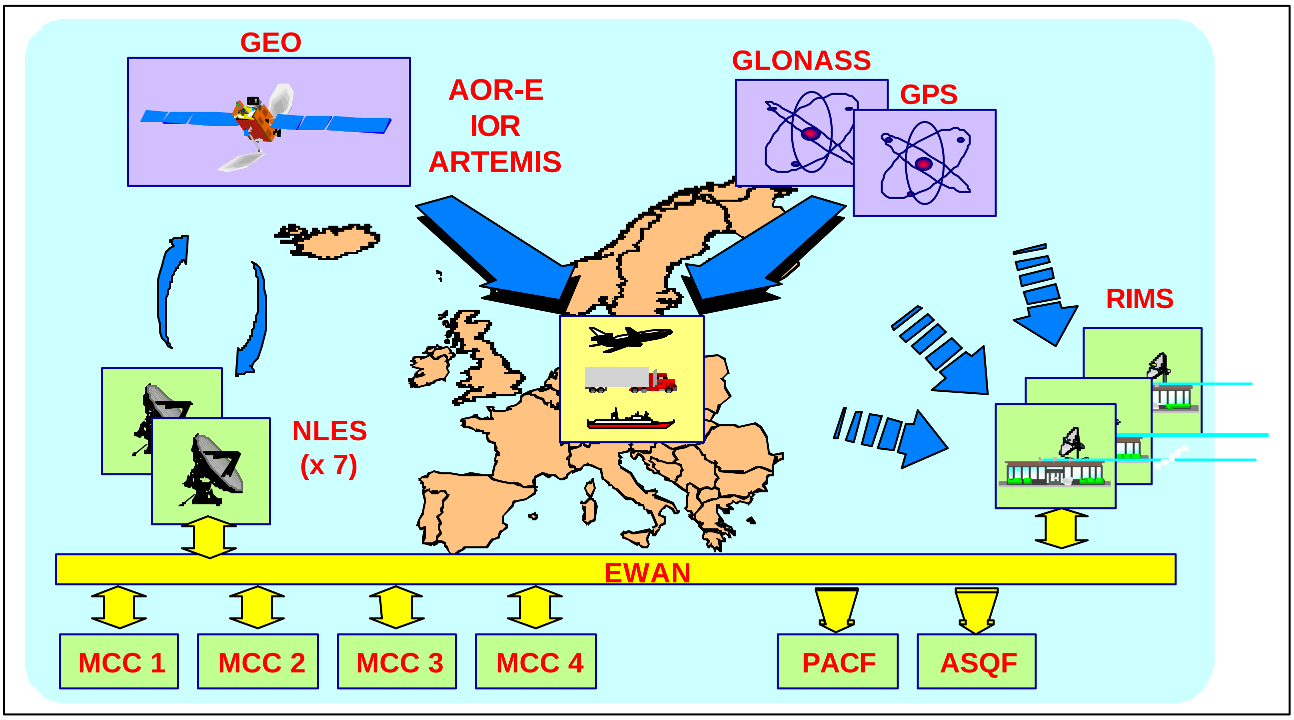

Fig- 2: EGNOS System Architecture

6. Interoperability of SBAS Systems

In addition to EGNOS, there are currently two other regional SBAS systems under development namely: the North American WAAS, and the Japanese MSAS.

To guarantee seamless and worldwide system provision, it is essential that the 3 systems do meet some common interoperability requirements and do provide adequate system. The service providers of those SBAS systems are regularly meeting through so called "*interoperability working group (IWG)*" meetings to conclude on a the precise understanding of the term interoperability, and on the identification of the necessary interfaces among SBAS that each conceivable interoperability scenarios may imply. The EGNOS system include specific requirements so that interoperability may be achieved. In parallel, several initiatives are going-on to perform testbed interoperability demonstrations and flight trials in the near future.

7. EGNOS Programme Status Overview

The EGNOS programme comprises two different phases: Initial phase and AOC Implementation phase; The EGNOS Initial Phase was successfully concluded in November 1998 with the System Preliminary Design Review (PDR).

The industrial team in charge of EGNOS AOC development is led by Alcatel Space Industries (France) with the participation of companies from all participating States, as illustrated in figure 4.

The Agency's Program Board has approved full implementation of the EGNOS AOC System in December 1998; and the prime contract was signed with Alcatel on 16 June 1999. Since then, all sub-system activities have been kicked-off in 1999, and the project is currently proceeding with the Sub-system PDR activities. In december 1999, an important change request was signed with Industry to reflect latest evolutions in EGNOS interface requirements, including latest versions of ICAO (SARPS) and RTCA (MOPS) known at that time. This change request brings the main development contract to an amount of 214 M€, and to an Opertional Readiness Review scheduled in december 2003.

The EGNOS AOC Implementation Phase schedule is illustrated in figure 3. Next key milestones are the subsystems CDRs (planned by the end of year 2000), the System Critical Design Review (CDR), planned in mid 2001, the System Factory Qualification Review (FQR) in early 2003, and the EGNOS AOC Operational Readiness Review (ORR) in december 2003.

In addition, this implementation contract include development of the EGNOS Test Bed, which already broadcasts over Europe an EGNOS-like Signal in Space since February 2000, through the INMARSAT AOR-E Satellite. The Test bed signal performance is very good (few meter accuracy), and very demonstrative trials have already been performed. By mid 2000, the test bed will be further extended to provide broadcast over IOR Satellite, and, in collaboration with the European Commission, to enable further coverage extensions to support SBAS service demonstrations outside Europe. By the end June 2000, a "Test Bed Users" Workshop will be organised to further promote the use of this Test bed signal, to enable the wide European potential user community in setting up Navsat application demonstrations and trials experiments.

The EGNOS project includes significant contributions from the French Space Agency (CNES), the Norwegian Mapping Authority (NMA), and main European Air Traffic Management service providers like AENA (E), NAV-EP (P), DFS (D), ENAV (I), DGAC (F), NATS (UK) and swisscontrol (CH). Those partners will in particular provide ESA with in-kind deliveries, including the infrastructure to host a number of the necessary EGNOS ground stations. Some other hosting sites are being finalised by ESA via specific agreements with potential hosting entities. Site survey activities will start in mid 2000, and last until mid 2001.

In parallel of those on-going development efforts, future evolutions of the EGNOS System to become the European Integrity System for GALILEOSAT constellation are being analysed. The upgraded EGNOS system (EGNOS+) should enable continuation of the initial GNSS-1 mission, and will therefore maximise re-use of European EGNOS investments into the future GALILEO System. Current results are very promising, and demonstrate that the EGNOS system can be used as a sound building brick on which the GALILEO system architecture can capitalise.

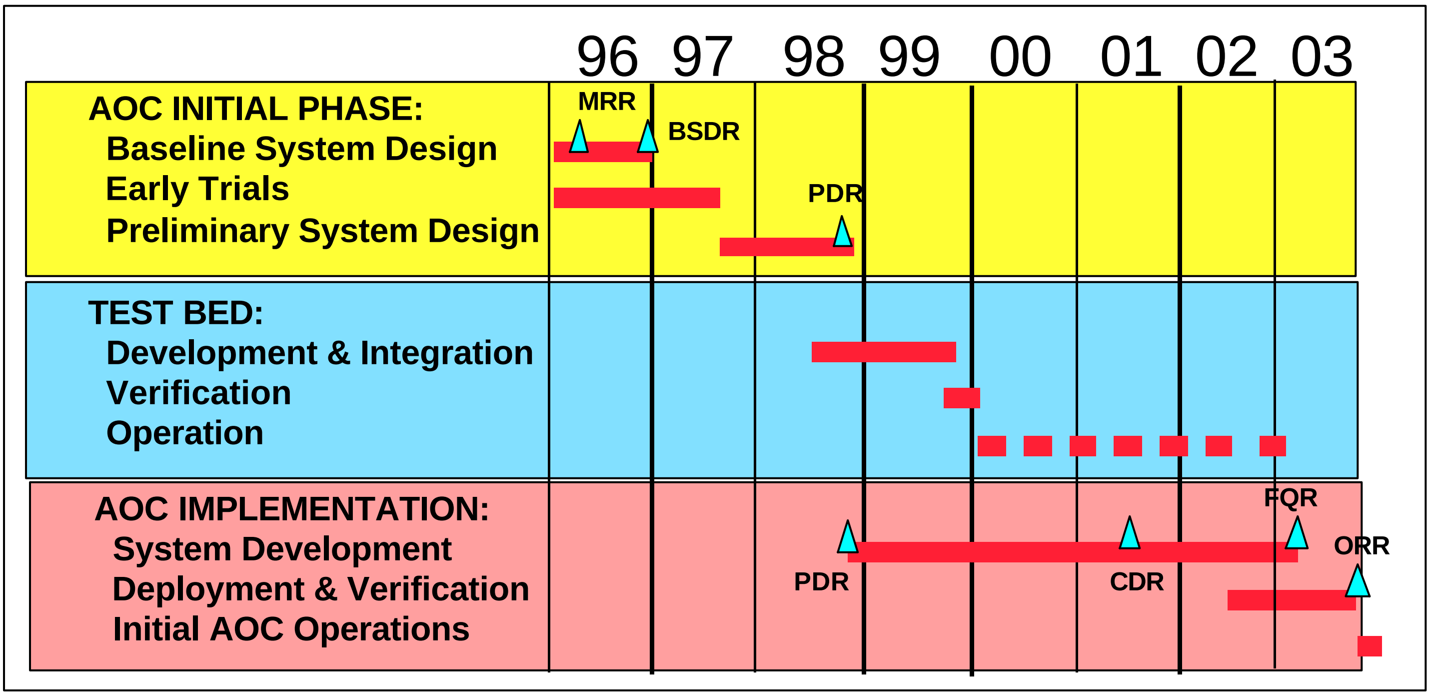

Fig- 3: EGNOS AOC Summary Schedule

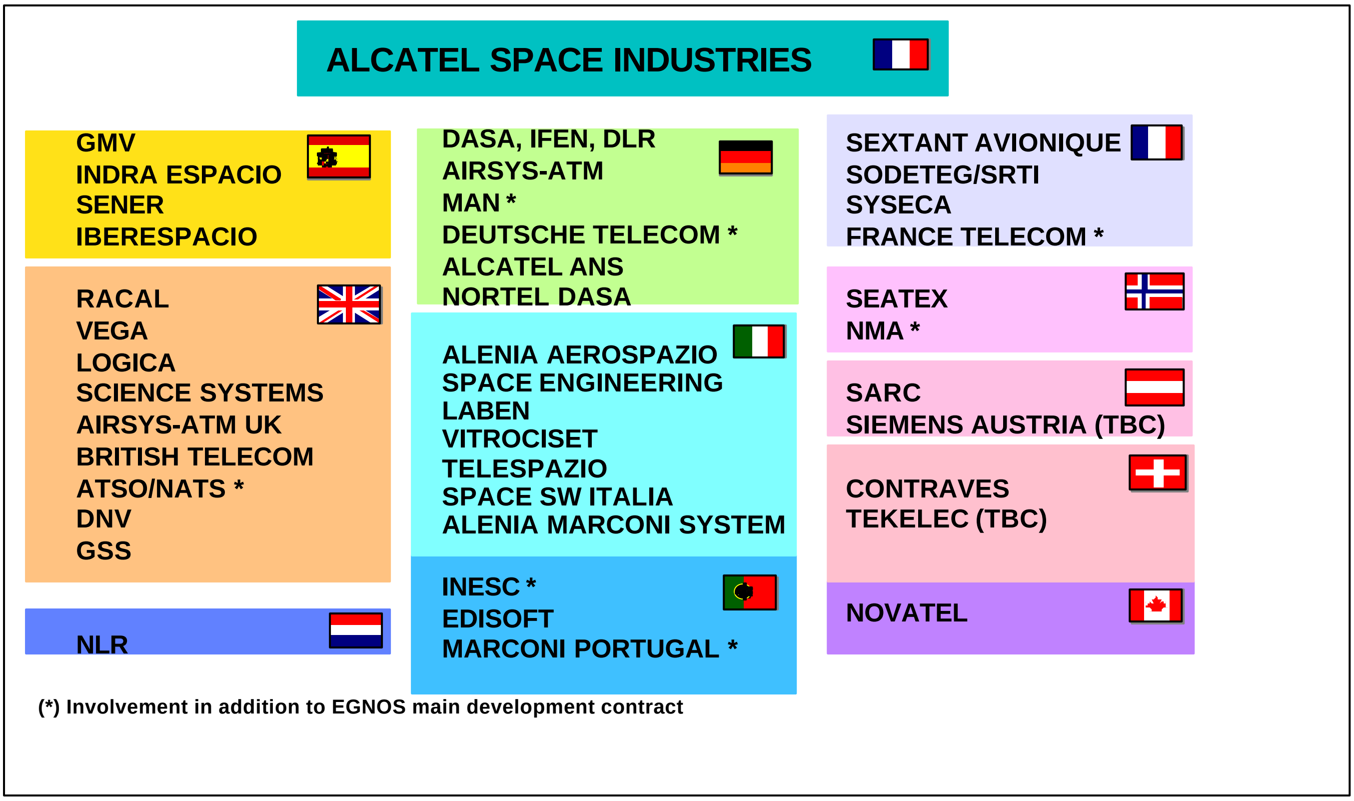

Fig- 4: EGNOS Industrial Consortium

8. Summary

EGNOS is the main European contribution to GNSS-1 to serve the needs of, maritime, land transport and aeronautical applications in the European and neighbouring regions. For aviation, EGNOS AOC can be used in the ECAC Region as a primary means of navigation for all phases of flight down to CAT-I.

EGNOS Test Bed signal-in-space is available, and is used to support demonstrations and trials in Europe, Africa, South America and interoperability trials with US (WAAS) and Japan (MSAS).

EGNOS AOC development will be completed by the end 2003, to enable start of operations in 2004.

The EGNOS System will latter on evolve to provide the future European Integrity System for GALILEOSAT constellation. This upgrade (EGNOS+) will have to continue the initial GNSS-1 mission, and will therefore maximise re-use of European EGNOS investments into the future GALILEO System.

References

[1] Satellite-Based Augmentation System (SBAS) Standards and Recommended Practices (SARPS), draft 7, International Civil Aviation Organisation (ICAO).

[2] RTCA/DO-229-A, Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System Airborne Equipment, June 1998.