

Galileo

*The European Programme for
Global Navigation Services*



European
Commission



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BR-186

May 2002

ISBN 92-9092-730-5

ISSN 0250-1589

Coordinator: Apostolia Karamali, Galileo Interim Support Structure

Editor: Andrew Wilson, ESA Publications Division

Design & layout: Carel Haakman, ESA Publications Division

Published by: ESA Publications Division, ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands

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Price: EUR 10

Printed in The Netherlands



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Galileo

Galileo, the first satellite positioning and navigation system specifically for civil purposes, will be more advanced, more efficient and more reliable than the current US GPS monopoly. The scale of future navigation needs and the requirement for global coverage cannot be satisfied by a single system alone.



Galileo: a Technical, Economic and Political Challenge

Galileo will provide the first satellite positioning and navigation system specifically for civil purposes. Its profitable applications will spread into many areas of all our lives – starting with safe and efficient transport. Using only small receivers, we will all be able to determine our locations to within a few metres.

Galileo is vital for the future of Europe's high-technology industries. It will generate new, large markets and provide the critical advance in technology for Europe to be a global competitor.

It is crucial for Europe and the whole world to have a choice independent of the current US Global Positioning System (GPS) monopoly, which is less advanced, less efficient and less reliable. In addition, the scale of future navigation needs and the requirement for global coverage cannot be satisfied by a single system alone.



The Galileo programme has finally been launched. While the cost of deploying the system is some EUR 3.2-3.4 billion, the cost of rejecting it would have been immense: more than 100 000 new jobs and a market for equipment and services worth some EUR 10 billion per annum by 2010.

Galileo



Getting the Most from Satellite Navigation

Satellite Navigation and Timing

Satellite navigation pinpoints a location by measuring the distances to at least three known locations – the Galileo satellites. The distance to one satellite defines a sphere of possible solutions. Combining three spheres defines a single, common area containing the unknown position. The accuracy of the distance measurements determines how small the common area is and thus the accuracy of the final location. In practice, a receiver captures time signals from the satellites and converts them into the respective distances.

The position accuracy depends on the accuracy of the time measurement. Only atomic clocks provide the required accuracy, of the order of nanoseconds (10^{-9} s). Such clocks are a major technology element aboard the Galileo satellites and could contribute to the definition of international time standards. The time measurement will be improved by including the signal from a fourth satellite, so special care

will be taken in selecting the numbers of satellites and their orbits.

The Advent of Galileo

Galileo comprises a constellation of 30 satellites divided between three circular orbits at an altitude of around 24 000 km to cover the Earth's entire surface. They will be supported by a worldwide network of ground stations. At present, there are two radio navigation satellite networks: the US GPS and the Russian Glonass systems, both designed during the Cold War for military purposes. Since the Russian system has not generated any civil applications, Galileo offers a real alternative to the *de facto* monopoly of GPS and US industry.

GPS is used to a large extent for civil purposes but it does have several major shortcomings:

- a mediocre and varying position accuracy (sometimes to only several dozen metres), depending on place and time;

- the reliability leaves something to be desired. Regions at high latitudes, crossed by many aviation routes, do not have dependable coverage. Signal penetration in dense areas and town centres is unreliable. Furthermore, the predominantly military character of GPS means there is always a risk of civil users being cut off in the event of a crisis.

Whether intentional or otherwise, signal interruptions can have disastrous consequences, especially as there is no warning and no immediate information about errors. For example, a Canadian research body highlighted the case of an aircraft affected by an unannounced signal interruption of more than 80 minutes, aggravated by an initial positioning error of 200 km when contact was reestablished. The Icelandic aviation authorities reported several transatlantic flights in their control zone similarly disturbed. Civil aircraft suffered 20-minute signal interruptions in three mid-US states,



and airline captains have reported the same phenomenon over the Mediterranean.

In August 2001, the report of the Volpe National Transportation Centre commissioned by the US Government clearly stressed a number of such shortcomings. Even the advent of the improved GPS III, which the US is considering, would not resolve all of them. There is a total absence of service guarantee and accountability – as these are incompatible with the system's military objectives – with all the implications that can be envisaged in the event of an aviation accident or an oil tanker wreck.

The European Union (EU) therefore decided, in close cooperation with the European Space Agency (ESA), to develop a system of its own that meets the criteria for accuracy, reliability and security.

Galileo offers superior and constant accuracy thanks in particular to the

structure of its satellite constellation and ground relay system. Guaranteed accuracy to 1 m is necessary for certain applications, such as entering a sea port or locating a stolen vehicle even if garaged.

Galileo offers superior reliability because it includes an integrity message that immediately informs users of possible errors, and because it covers difficult areas such as northern Europe.

For some services, Galileo will provide the very high level of continuity required by today's business, particularly for satisfying contractual responsibility.

Applications Markets

Satellite transmission is now a fact of life in telephony, television, computer networks, aviation and shipping and many other areas. The range of applications open to the Galileo system is extremely varied and the number of potential spin-offs immense.

For example, the benefit to aviation and shipping operators alone is put at some EUR 15 billion between 2008 and 2020. This includes savings generated by more direct aircraft flights through better air traffic management, more efficient ground control, fewer flight delays and a single global multi-purpose navigation system. Similar benefits can be expected for shipping.

The benefits to future driving systems are also of vital importance. At present, road accidents (including 40 000 fatal ones) generate social and economic costs corresponding to 1.5-2.5% of the gross national product (GNP) of the European Union. Road congestion entails additional estimated costs of around 2% of the European GNP. A significant reduction in these figures as a result of Galileo will therefore have enormous socio-economic benefits, quite apart from the number of lives saved.

The number of inland transport applications is expanding. Motor



vehicle makers now offer their customers navigation units that combine satellite location and road data to avoid traffic jams and reduce travel time, fuel consumption and therefore pollution. Road and rail transport operators will be able to monitor the movements of their lorries, wagons and containers more efficiently, and combat theft and fraud more effectively. Taxi companies now use these systems to offer a faster and more reliable service to their customers.

The value of Galileo is not limited to the economy and companies. It will also clearly be a valuable tool for the emergency services (fire brigade, police, paramedics, sea and mountain rescue), who will respond more rapidly to those in danger. Galileo can guide the blind, monitor Alzheimer's sufferers with memory loss, and guide explorers, hikers and sailing enthusiasts.

Many other sectors will also benefit from Galileo. It will be used as a

surveying tool for urban development and large public works, for geographical information systems, for managing agricultural land more efficiently, and helping to protect the environment. It will be a means towards developing third-generation mobile phones with Internet-linked applications. It will facilitate the interconnection of telecom-munications, electricity and banking networks and systems via the extreme precision of its atomic clocks. It will also be of paramount importance to help developing countries preserve their scarce natural resources and develop their international trade.

The applications prospects are enormous. As with the microcomputer 20 years ago or the Internet 10 years ago, it is highly likely that at the moment we can only see the tip of the iceberg.

To meet all these demands, Galileo will offer several levels of service:

- a basic level free of charge, emphasising consumer applications and general-interest services. GPS is also free for these applications but Galileo offers better quality and reliability;
- restricted-access service levels for commercial and professional applications that require superior performance to generate value-added services. These levels range up to a highly restricted service for applications that must in no event be disturbed.

The paid-for services will contribute to the economics of the system.

Crucial Issues

Crucial issues are at stake for the future of Europe. Galileo will enable Europe to acquire technological independence, as it did with the Ariane and Airbus initiatives. It is vital that Europe should be included in one of the main industrial sectors of the 21st century, an area that is already widely recognised in the US. Without Galileo, the





development or even the survival of European new technology sectors would be under very serious threat. The technological advance from Galileo will give the participating European industries a considerable competitive advantage in this sector and in the many ensuing applications.

According to various studies, the equipment and services market resulting from the programme is estimated at around EUR 10 billion per annum, with the creation in Europe of more than 100 000 highly skilled jobs. Conversely, if Europe misses out on these new developments, many electronics and aerospace jobs would ultimately disappear.

In terms of international cooperation, leading-edge technologies are prime assets for Europe's standing in the world.

The EU has clearly stated that it is willing to involve interested non-member countries in Galileo's research,

development and industrial commissioning activities. This can only strengthen our links and common interests, quite apart from the choice that will be offered to the entire world.

Investment and Economic Viability

It should be said that Galileo is not expensive. Its development and deployment cost, including the launching of 30 satellites and the installation of ground equipment, is EUR 3.2-3.4 billion. This is equivalent to the cost of building 150 km of semi-urban motorway or a main tunnel for the future high-speed rail link between Lyon and Turin (assuming the tunnel has only one track!). This is less than the Øresund link between Denmark and Sweden, or the fifth terminal now being built at Heathrow airport. It is roughly two-thirds the cost of the high-speed rail link between Liège, Cologne and Frankfurt, or the 160 km Betuwe rail infrastructure project for container transport in the Netherlands.

The various studies carried out show that the project is economically viable. The latest study, by PricewaterhouseCoopers, based on updated projections over a period of 20 years, indicates a cost/benefit ratio of 4.6 – higher than for any other infrastructure project in Europe. The report specifies that it made conservative estimates, and the benefits calculated take into account only aviation, shipping and, to some extent, road applications.

An Original and Innovative Structure

Galileo is adopting an original and innovative legal structure to encourage public-private partnership. To complete the development and validation phase, and pave the way for the deployment phase, an original form of company provided for in Article 171 of the Treaty establishing the European Community has been set up: a Joint Undertaking. Its founder members are the EU and ESA. In addition, the European Investment bank and, at a later stage, firms subscribing individually or collectively



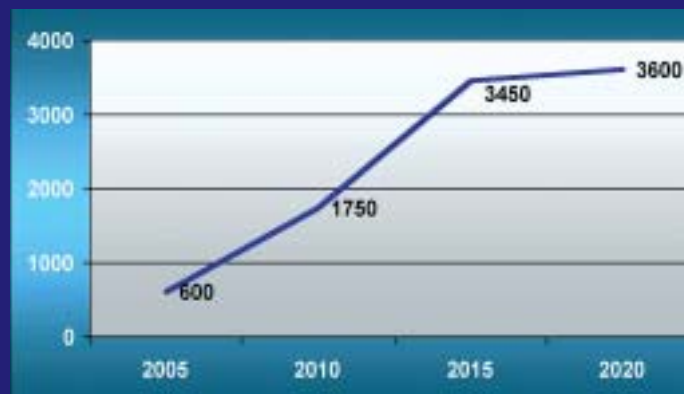
(a minimum of EUR 0.25-5 million for Small- and Medium-sized Enterprises) can also become members.

This structure is designed to encourage the private sector to become involved. On the one hand, it avoids companies having to board a moving train, but, on the other, it would be wrong for the industrial companies who will be the main beneficiaries of the enormous markets generated by Galileo to sit and wait for public contracts to fall into their laps.

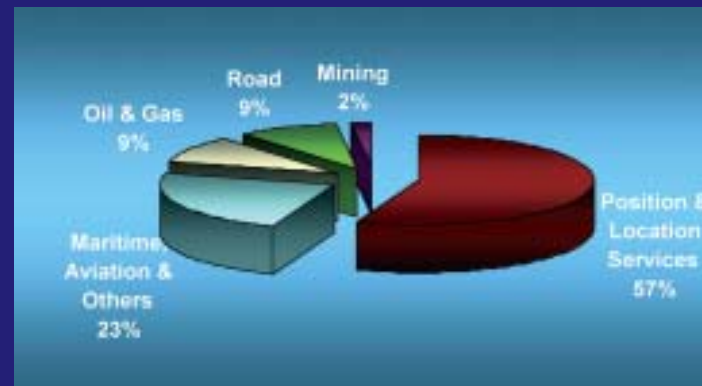
In addition to the space sector, which is accustomed to benefiting from the EU's research programmes, the foundations for public-private partnership must be laid with a wide range of firms. By contributing to the capital of the Joint Undertaking, firms will take their share of the normal risks inherent in industrial activities. Public funds cannot be expected to cover all of the costs involved.

While it is the responsibility of the public sector to carry out forward analyses, detect future emerging markets and encourage their development – as with Ariane and Airbus – it is also necessary for large firms, which in some cases have until recently been featherbedded by the public authorities, to look themselves beyond the short term if they want to survive in the face of world competition.

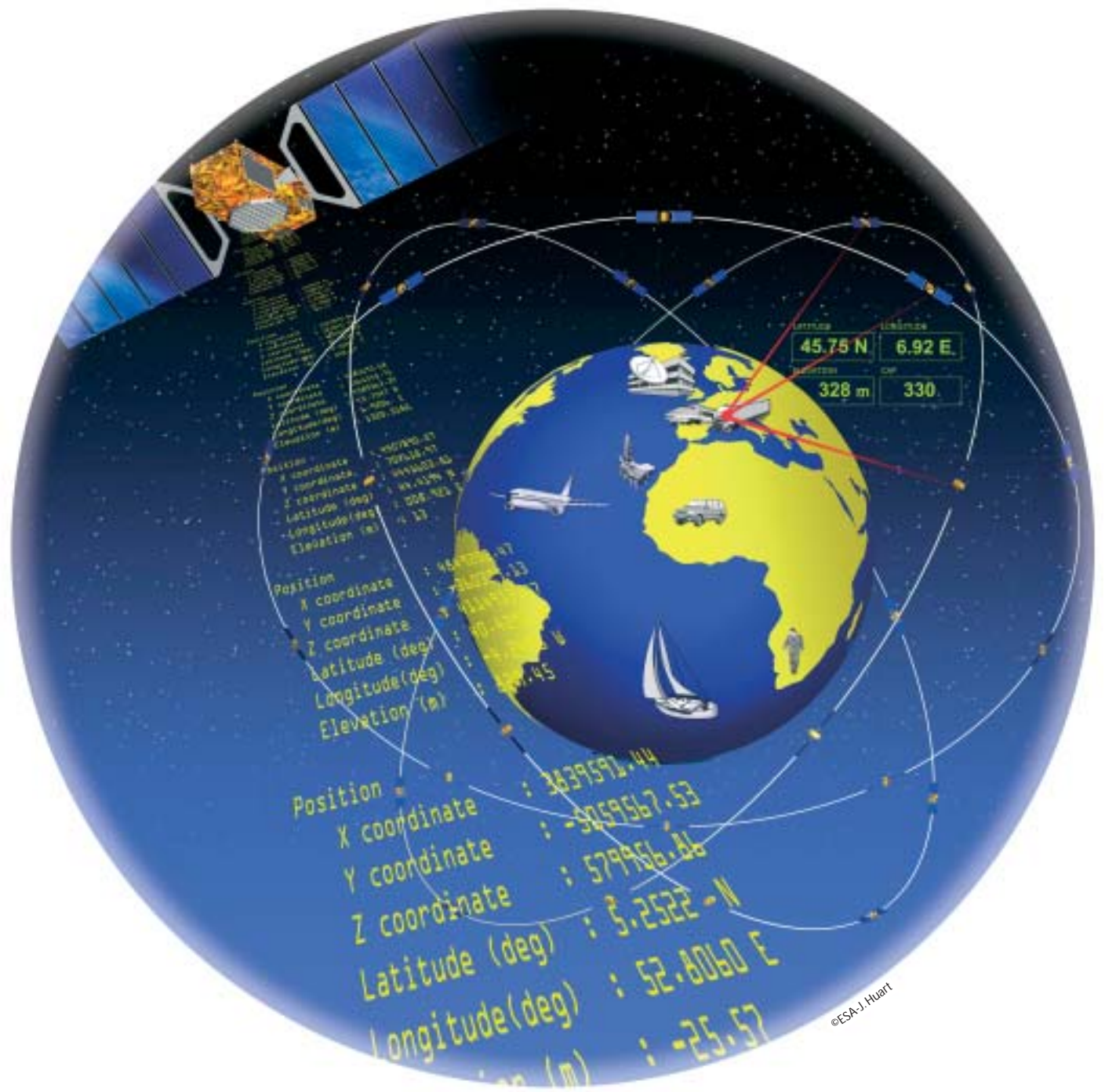
Projected Worldwide GNSS Chipset Market



Projected GNSS Market for GALILEO in 2020 by Application



Galileo



Applications: Opening New Horizons

Galileo is conceived as a core infrastructure upon which applications will be built. It will form part of society's greater technical infrastructure, including communications and broadcasting systems, that we will all rely on heavily. The applications made possible by Galileo stretch beyond the determination of a user's position and time, and in will integrate new technologies to satisfy coming user needs.

Applications underpin and foster European innovation in industry, research and small- and medium-sized enterprises. In some areas, they can produce direct benefits for citizens and their social environment by improving system efficiency and economic return, or simply by facilitating everyday activities.

Galileo applications will rely on integrated services: navigation data are combined with additional information layers. The numerous domains range from transport (air, rail, maritime, road,

pedestrian) to timing, engineering, science, environment, search and rescue, and even recreation. These in turn directly affect business areas such as oil and gas, banking, insurance, telecommunications and agriculture.

Some applications require the system to have special features. These features do not exist in the current positioning systems and will constitute added value for Galileo as a civil system. They may include service guarantee, liability of the service operator, traceability of past performance, operation transparency, certification and competitive service performance in terms of accuracy and availability. New applications are appearing every day in this huge market, which is projected to reach at least 1750 million users in 2010, and 3600 million in 2020. A few examples are described below to illustrate Galileo's potential.

Transport

The transport applications are the user category par excellence for Galileo. The

system's services will be used in every transport domain – air, maritime, road, rail and even pedestrian. Each user segment has its own characteristic needs, and Galileo is designed to satisfy them all.

In civil aviation, Galileo can be used in the various phases of flight: en route navigation, airport approach, landing and ground guidance. Galileo will be particularly beneficial where infrastructure such as ground-movement radar does not exist.

In maritime navigation, Galileo will be used for onboard navigation for all forms of transport, including ocean and coastal navigation, port approach and port manoeuvres. Galileo's characteristics, which make it suitable even for today's most demanding applications, will permit the definition and development of new applications, such as the Automated Identification System, to improve safety in navigation. Inland waterway navigation, even in critical environments, will also benefit



from Galileo and its interoperability with other systems and sensors.

Road applications include in-car navigation, fleet management of taxis, lorries and buses, and driver assistance. Information services for road users can also be based on Galileo. Traffic behaviour can be monitored via onboard navigation recorders to generate useful information for other road users. Vehicle data can be stored together with exact time stamps and precise position information for liability purposes in case of accident. In order for the recorded data to be usable in court and for insurance companies, they need to be highly reliable, guaranteed and derived from a certified system. Galileo meets these requirements.

Galileo performance levels – often supported locally by terrestrial components – and its enhanced reliability (guaranteed continuity and integrity) will improve safety and mobility in road traffic. Advanced Driver

Assistance Systems combined with Galileo receivers will include features such as collision warning, vision enhancement and low-speed manoeuvring aids.

The rail community will benefit, from train control, train supervision, fleet management, track survey and passenger information services. Railway operations are a safety-of-life application, where Galileo can help to reduce the number of accidents, which may involve hundreds of victims. To control such risks as hazardous materials travelling through densely populated areas, a high level of accuracy is required together with high levels of integrity, availability and guarantee of service. Certification of the service is a *sine qua non* for deploying a system meeting the safety needs of rail applications.

Satellite navigation will play a role in improving border controls. Physical controls could be restricted to goods or persons not monitored via this

technique. Increased efficiency will benefit customs authorities as well as the public.

Galileo will have a primary role in all of the above applications because of its core characteristics of certification, operations transparency and service guarantee derived from its civil nature. In addition, the integrity monitoring feature (real-time 'integrity flags') of the navigation performance over the whole service area makes Galileo suitable for all the safety-of-life applications.

Energy

The very precise timing obtainable via Galileo will help to optimise the transfer of electricity along power lines. Galileo could also help in the maintenance of the electricity-distribution infrastructure. Power grids are continuously monitored by a range of instruments spread around the system. Information from these instruments is used to repair the system when a power line breaks or weaknesses appear in the grid. Galileo



will improve the instruments' time synchronisation to provide a speedier return to full service.

The oil and gas sector can benefit from Galileo in a large number of areas. For instance, marine seismic exploration will use the positioning service both for the seismic acquisition vessel as well as for the seismic streamer arrays and gun arrays. This will enhance the safety of drilling activities, by enabling high-resolution surveys of the new sites and the identification of any geomorphological or geophysical risks.

The positioning of the rig and its anchor-handling vessel will be improved through Galileo. Accurate positioning information will be provided during transit and final positioning of tow tugs relative to the rig, the anchoring of semi-submersibles and any independent drilling rigs. The final position of the drilling facility will be determined as well as the final orientation of the platform to a high degree of accuracy.

The trend in the oil and gas sector is to move away from established finds towards remote sites without any local infrastructure. In these areas, satellite positioning and communications are of vital importance. Real-time data transmission combined with position determination enables oil companies to make real-time decisions on drilling operations. Integrity information, provided by Galileo, is of paramount importance when approaching the target and preparing to anchor or lower the drilling platform legs.

Finance, Banking and Insurance

As online financial transactions become an increasingly common part of daily life, the integrity, authenticity and security of transmitted data have emerged as major issues in the electronic exchange of documents. For example, one of the biggest concerns in e-commerce is the security of information provided by the customer in the purchasing process. This usually calls for a dedicated encryption system.

Similarly, e-banking suffers from risks such as falsified transactions and unauthorised access to documents, accounts and credit cards. Stock exchange activities are subject to similar risks. Data-stamping based on a legally traceable time reference will reduce these risks.

Online systems have created the need for accurate and legally accepted documentation that provides detailed information on the user and the type and size of transaction. Electronic signatures are currently used, but time-stamping will dramatically enhance the security of these systems. A Galileo-based trusted-time signal could be used for a reliable encryption system, offering the additional value of traceability and liability of the time information.

In the insurance sector, Galileo provides an effective way of controlling and monitoring valuable goods. This includes the transportation of gold bullion between national banks, works



of art, and large numbers of banknotes for distribution to banks or for destruction. Continuous tracking reduces the risks and thus benefits the insurance companies and their customers.

The certified services offered by Galileo not only provide legally-accepted information, but also enable a great number of services related to car and property insurance. This is expected to generate significant return for the insurance sector as well as for the end users, as it could bring about innovative prime and policy conditions.

Agriculture and Fisheries

With food security climbing ever higher up the decision-makers' agenda, together with food risks and consumer concerns, achieving traditional productivity targets at all costs is no longer the main driver in agriculture. On the contrary, farmers aim for better quality agricultural products, while respecting the environment and maintaining acceptable income.

Navigation can contribute to yield monitoring and the spraying of fertilisers, herbicides and insecticides to replenish low-yield areas and control of weeds and pests. Galileo receivers can be easily installed on harvesters, tractors and self-propelled sprayers.

Proper yield monitoring entails not only effective resource management and consequently significant return, but also contributes to safeguarding the agri-environment, which, in turn, is often regulated by a series of rules. There might be a legal requirement for farmers to provide map evidence showing the exact areas where chemicals were sprayed.

The fisheries sector will similarly benefit from Galileo. Apart from the day-to-day navigation and positioning of vessels, Galileo can help to monitor fish resources. This can be enhanced with data from the sea and environs.

Certified Galileo services will allow authorities to confirm that fishing

vessels operate only in designated areas. This applies all the more at the international level, where there are strict rules governing the invasion of national water boundaries.

Similarly, Galileo will provide the means to establish or improve land registries. This will help to create legal security where cadastral information today is often inaccurate or even unavailable.

Personal Navigation

Galileo opens the door to several location-based services by integrating positioning with communications, typically in handheld terminals. A handset will determine its position using either Galileo alone or in conjunction with other systems.

Location-based services depend on service providers or network operators knowing the position of the mobile caller in order to provide appropriate information. Data sent to a user's handset can be automatically customised to provide on-demand

services such as information about nearby restaurants, hotels and theatres, and weather forecasts.

This technique is particularly important in emergency situations for identifying callers with only vague ideas – or none whatsoever – of their locations. The locations can be automatically determined and reported to the nearest emergency services. This concept is part of the development, in Europe, of the E-112 emergency call programme.

People-tracking is another application, where external staff could be coordinated more efficiently: medical and welfare employees visiting patients; policemen; fire engines; commercial workers. This service can be generally used to control and coordinate the activities of a group. The same technique can improve the safety of children on their way to school.

The billing systems of mobile communications networks could be



improved. Today, mobile network operators vary their call charges depending on the time of day. Soon, by pinpointing handsets, they could also charge on the basis of location, allowing corporate tariffs in small areas. Location-based billing could extend to services such as road tolling and automated tourist guides.

Search and Rescue

The majority of today's emergency distress beacons operate within the COSPAS-SARSAT satellite system. Unfortunately, the accuracy is very poor (typically a few kilometres) and the alert is not always issued in real-time. The advent of Galileo is expected to improve Search and Rescue (SAR) operations dramatically, while maintaining compatibility with existing emergency transmitters onboard ships and aircraft.

The distress signals must be detected under severe conditions from anywhere on Earth. Galileo will significantly improve the system by

detecting distress beacons in real time and locating them with an accuracy of a few metres. Adding a return link – from the SAR operators to the beacons – will further help the rescue operations. Galileo's SAR element will be Europe's contribution to a wide international humanitarian effort.

Crisis Management

Crisis management requires fast response times and the most efficient use of resources. An effective response to forest fires, for example, calls for early alert and reliable and accurate position information about the location of the fire. Police and emergency services need reliable and accurate knowledge of the location of deployed forces in order to coordinate them efficiently.

Other crisis situations include floods, maritime emergencies, oil spills, earthquakes and humanitarian aid operations.

Environmental Management

Galileo is expected to play an important role for the scientific community. For example, the continuous collection of data will allow new experiments in various research areas. Galileo could contribute to ocean and cryosphere mapping, including the determination of the extent of polluted areas (and tracking offending tankers to their origins), studies of tides, currents and sea levels, and tracking of icebergs. It will help to monitor the atmosphere, including the analysis of water vapour for weather-forecasting and climate studies, and ionospheric measurements for radio communications, space science and even earthquake prediction. In nature, the movements of wild animals can be tracked to help preserve their habitats.

Recreation

The leisure market will see a tremendous surge in developments that we cannot even imagine today. GPS services are already established for

recreational flying and sailing, but Galileo will extend them to personal navigation via handsets with map displays and secondary communication functions. Integration with mobile communications technology will open up new scenarios and applications for personal mobility.

Attractive tourist packages can be based on Galileo coupled with interactive multimedia communications linked to local information providers.

The key advantage of Galileo is its focus on interoperability, which will easily allow its integration – at system and user levels – with existing and future systems, such as GSM and UMTS.

In the same way that no-one nowadays can ignore the time of day, everyone in the future will need to know their precise location.

Galileo



Services: Bringing Space to the User

Satellite navigation positioning and timing services are becoming an indispensable element in many activities. Managing and controlling the various modes of transport, and their related safety-of-life aspects, communications networks and many other utilities are expected to rely heavily on satellite navigation. Mass-market applications, including combined mobile communications and navigation systems, are growing rapidly, with their own needs. Galileo is designed to satisfy the requirements of such a wide range of applications.

The Galileo Services Approach

In contrast to GPS, Galileo will broadcast integrity information for some critical applications, assuring the quality of positioning accuracy. Users will receive a timely warning whenever the system fails to meet its stated accuracy. The Galileo system guarantees that this warning is sent out quickly enough even for the most demanding of applications, such as aircraft landing.

Guaranteeing signal accuracy and integrity provides a competitive edge for the swift introduction of Galileo's services in the presence of the existing GPS system. Galileo will give service providers and users alike the necessary confidence in their investments.

Guaranteed accuracy and integrity calls for a scheme defining the roles of the public and private partners. Globally recognised signal standards are essential for the worldwide acceptance of satellite navigation and will permit speedier adoption of the system by all user communities. Certification of system elements or functions that are mandatory for safety-critical applications will assure other users that the system is reliable.

This framework will be defined in consultation with international organisations such as those dealing with air and maritime navigation, and with national authorities regulating specific applications.

Galileo as a Global and Open System

It is clear that Galileo needs to serve all parts of the world, not only to provide a seamless service to maritime and civil aviation users but also to allow European equipment-makers and operators to sell their products globally. The synergies between navigation and communications are obvious and need to be fostered right from the beginning. There are immediate opportunities in conjunction with mobile terrestrial networks such as GSM and UMTS, with satellite communications networks providing the extensions where needed.

To guarantee European independence, Galileo needs to be a standalone infrastructure, yet it must be compatible and interoperable with systems such as GPS, not only to achieve the highest possible availability but also to ease the introduction of its services. Moreover, in the interest of future cooperation, Galileo should be able to accommodate the later integration of regional components.

User Needs and Services Mapping

The need for several service categories, in terms of accuracy, service guarantees, integrity and other parameters, has been identified. Most requirements will be met solely with the satellite signal, in many cases in combination with auxiliary sensors that can, for instance, be in the user's vehicle. Improved service requirements can be satisfied most effectively by local components, offered as value-added services by private operators. The various service requirements and their associated performance level and security aspects can be rationalised into five distinct service groups, as described below.

The Galileo **Open Service** (OS) is defined for mass-market applications. It will provide signals for timing and positioning, free of charge. The Open Service will be accessible to any user equipped with a receiver, with no authorisation required. Position accuracy and availability will be superior to those of GPS and its planned evolutions (GPS IIF and GPS III).

The Open Service will lead to low-cost receivers, as there will be real competition with GPS receiver manufacturers. Even cheaper single-frequency receivers will be used for applications requiring reduced accuracy. However, most applications will use a combination of Galileo and GPS signals, which will improve performance in severe environments such as urban areas.

The Open Service will not provide integrity information computed by the system, and the quality of the signals will only be estimated by algorithm at the user-terminal level (Receiver Autonomous Integrity Monitoring). There will be no service guarantee or liability from the Galileo Operating Company (GOC) on the Open Service.

The **Safety-of-Life Service** (SoL) will be used for most transport applications where lives could be endangered if the performance of the navigation system is degraded without real-time notice. The Safety-of-Life Service will provide

the same accuracy in position and timing as the Open Service. The main difference is the worldwide high-integrity level for safety-critical applications, such as maritime, aviation and rail, where guaranteed accuracy is essential.

This service will increase safety, especially where there are no traditional ground infrastructure services. This worldwide seamless service will increase the efficiency of companies operating on a global basis – airlines and transoceanic maritime companies. The EGNOS regional European enhancement of the GPS system will be optimally integrated with the Galileo Safety-of-Life Service to have independent and complementary integrity information (with no common mode of failure) on the GPS and Glonass constellations.

The Safety-of-Life Service will be certified and its performances will be obtained by using certified dual-frequency receivers. Under such

conditions, the future Galileo Operating Company will guarantee SoL. To benefit from the required level of protection, SoL will be implemented in the Aeronautical Radio-Navigation Services frequency bands (L1 and E5).

The **Commercial Service** (CS) is aimed at market applications requiring higher performance than offered by the Open Service. It will provide added value services on payment of a fee. CS is based on adding two signals to the open access signals. This pair of signals is protected through commercial encryption, which will be managed by the service providers and the future GOC. Access will be controlled at the receiver level, using access-protection keys.

The uses foreseen for CS include high data-rate broadcasting and resolving ambiguities in differential applications. These will be developed by service providers, which will buy the right to use the two commercial signals from the GOC.



Developing commercial applications either by using the commercial signals alone, or by combining them with other Galileo signals or external communications systems, opens a wide range of possibilities. The worldwide coverage brings a strong advantage for applications requiring global data broadcast.

Typical value-added services include high data-rate broadcasting; service guarantees; precise timing services; the provision of ionosphere delay models and local differential correction signals for extreme-precision position determination.

Galileo is a civil system providing a robust and access-controlled service for governmental applications. The **Public Regulated Service** (PRS) will be used by groups such as police, fire, ambulance, military and customs. Applications cover transport of nuclear waste, road tolling and customs control. Civil bodies will control access to the encrypted PRS. Access by region

or user group will follow the security policy rules applicable in Europe.

PRS is required to be operational at all times and in all circumstances, notably during periods of crisis, when other services may be jammed. PRS is separate from the other services, so they can be denied without affecting PRS operations. A major PRS driver is the robustness of its signal, which will protect it against jamming and spoofing.

The **Search and Rescue Service** (SAR) is Europe's contribution to the international cooperative effort on humanitarian search and rescue. It will allow important improvements in the existing system, including: near real-time reception of distress messages from anywhere on Earth (the average waiting time is currently an hour); precise location of alerts (a few metres, instead of the currently specified 5 km); multiple satellite detection to overcome terrain blockage in severe conditions; increased availability of the

space segment (30 Medium Earth Orbit satellites in addition to the four Low Earth Orbit and the three geostationary satellites in the current COSPAS-SARSAT system). Galileo will introduce new SAR functions such as the return link (from the SAR operator to the distress beacon), thereby facilitating the rescue operations and helping to reduce the rate of false alerts. The service is being defined in cooperation with COSPAS-SARSAT, and its characteristics and operations are regulated under the auspices of IMO and ICAO.



Galileo



Infrastructure: From Space to Ground

Space and Ground Segment

The core of the Galileo system is the global constellation of 30 satellites in medium Earth orbit, three planes inclined at 56° to the equator at 23 616 km altitude. Ten satellites will be spread evenly around each plane, with each taking about 14 hours to orbit the Earth. Each plane has one active spare, able to be cover for any failed satellite in that plane.

The satellites will use largely proven technologies. The body will rotate around its Earth-pointing (yaw) axis for its solar wings to rotate and point towards the Sun (generating peak power of 1500 W). A basic box structure will group the payload and platform elements on separate structural panels. Care will be taken to position sensitive elements like the atomic clocks away from any disturbances arising from moving elements, such as momentum wheels. The launch mass will be ~ 700 kg each.

After the initial constellation is established, further launches will

replace failed satellites and replenish the system as the original satellites reach their ends of life. The baseline for creating the constellation is to carry multiple satellites on a single rocket, with a dispenser able to deliver up to eight spacecraft simultaneously into medium Earth orbit. Smaller launchers will be used for the early in-orbit validation missions and for replenishments. The launchers satisfying these requirements include Ariane-5, Soyuz, Proton and Zenith.

Two Galileo Control Centres in Europe will control the constellation, as well as the synchronisation of the satellite atomic clocks, integrity signal processing and data handling of all internal and external elements. A dedicated global communications network will interconnect all the ground stations and facilities, making use of terrestrial and VSAT satellite links.

Data transfer to and from the satellites will be performed through a global network of Galileo Uplink Stations, each

with a Telemetry, Telecommunications and Tracking Station and a Mission Uplink Station. Galileo Sensor Stations around the globe will monitor the quality of the satellite navigation signal. Information from these stations will be relayed by the Galileo Communications Network to the two Ground Control Centres.

Regional components will independently provide the integrity of the Galileo services. Regional service providers using authorised integrity uplink channels provided by Galileo will disseminate regional integrity data. The system will guarantee that a user will always be able to receive integrity data through at least two satellites with a minimum elevation angle of 25°. Local components will enhance the above with local data distribution by means of terrestrial radio links or existing communication networks, in order to provide extra accuracy or integrity around airports, harbours, railheads and in urban areas. Local components will also be deployed to extend navigation services to indoor users.



Frequencies and Signal Design

Galileo will transmit 10 signals: six serve open and safety-of-life services (although part may also be used for the commercial service), two are for commercial services and two are for public regulated services. They will be broadcast in the following frequency bands:

- E5A-E5B, 1164-1215 MHz, allocated to RNSS at WRC-2000 in Istanbul;
- E6, 1260-1300 MHz, allocated to RNSS at WRC-2000;
- E2-L1-E1, 1559-1591 MHz, allocated to RNSS prior to WRC-2000 and already used by GPS. Sharing this band with GPS will be on a non-interference basis, in order to avoid affecting current GPS services while offering users simultaneous access to GPS and Galileo at minimal increases in terminal cost and complexity.

Galileo navigation signals will comprise ranging codes and data messages. The ranging codes will be generated by highly stable, autonomous clocks aboard each satellite. The data messages will be uplinked to the

satellites from the ground, stored onboard and transmitted continuously using a packet data structure, which will allow urgent messages to be relayed without delay.

The data messages are expected to include not only satellite clock, orbit ephemeris, identity and status flag and constellation almanac information, but also an accuracy signal giving users a prediction of the satellite clock and ephemeris accuracy over time. It will allow receivers to weigh the measurements of each satellite and improve their navigation accuracy. Provision is made for disseminating integrity messages, determined by independent global or regional integrity networks monitoring the Galileo constellation.

The Galileo satellites are being designed to transmit up to four L-band carriers. An important aspect of the Galileo concept is the provision of revenue-generating services, of which data broadcast will be an important

element. A range of data message rates, at 50-1000 symbols per sec, is being considered. Low rates cause minimum disturbance to the navigation signal, while high rates maximise the potential for value-added services such as weather alerts, accident warnings, traffic information and map updates. Accordingly, the data broadcasting capacity within the navigation signal is being maximised without compromising navigation accuracy. Pilot components (ranging codes with no data message) are provided for improving signal tracking robustness and acquisition under adverse receiving conditions.

The use of C-band remains under consideration. The Definition Phase led to the conclusion that C-band should be considered for implementation in a second generation of Galileo satellites. However, testing C-band techniques forms part of the development programme.



EGNOS

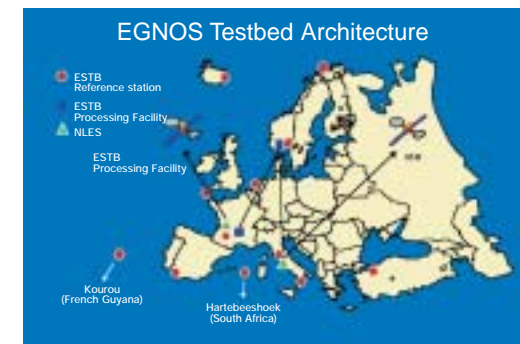
The European Geostationary Navigation Overlay Service (EGNOS) is Europe's first foray into satellite navigation. It is being developed by ESA under a tripartite agreement between the EC, the European Organisation for the Safety of Air Navigation (Eurocontrol) and ESA. Several service providers are supporting the development programme with their own investments.

EGNOS will complement the military-controlled GPS and Glonass systems. It will disseminate, on the GPS L1 frequency, integrity signals giving real-time information on the health of the GPS and Glonass constellations. Correction data will improve the accuracy of the current services from about 20 m to better than 5 m. The EGNOS coverage area includes all European states and could be readily extended to include other regions within the coverage of the two Inmarsat geostationary satellites being used. The third satellite, ESA's Artemis, was launched in 2001 and is expected to reach its operational position in late 2002.

EGNOS is one of the three inter-regional, interoperable satellite-based augmentation services (the other two are the US WAAS and the Japanese MSAS). These satellite-based augmentation services provide integrity signals that make the military GPS and Glonass systems usable for safety-critical services across a large portion of the world. EGNOS will be the first stimulus for European-led navigation services and will as such pave the way for the Galileo services. For civil aviation use, EGNOS complies with ICAO global standards. It is also expected to cover multi-modal transport and many other non-transport applications.

An EGNOS System Test Bed (ESTB) broadcasting an EGNOS test signal has been available since early 2000. ESTB provides an opportunity for validating new application developments in a realistic environment. It comprises a space segment of two transponders aboard the Inmarsat-III Atlantic Ocean East and Indian Ocean satellites, a ground segment with a number of reference stations (RIMS) throughout Europe and beyond, a processing centre and uplink facilities integrated into Inmarsat Earth stations.

From 2004, EGNOS will provide, under certain conditions, a guaranteed GPS/Glonass integrity service using the infrastructure and space segment as currently planned. From 2006/2008, the EGNOS infrastructure will be integrated into Galileo. Any evolution of the GPS integrity service will be taken into consideration.



Galileo



Excelling in Technology Development

The Galileo system depends on a number of novel technologies, ranging from signal-generation and time-keeping in the space segment to accurate control and secure operations in the ground segment. ESA began developing the most critical technologies at the inception of the Galileo programme and has since intensified the efforts. They now cover almost all areas of Galileo, including simulation tools.

This section introduces the individual technologies being developed for the different building blocks of the Galileo system.

Payload

The satellite payload consists of the Timing, Signal Generation and Transmit Sections. There will also be dedicated antennas for the search and rescue (COSPAS SARSAT) service, plus the frequency conversion and transmission and reception stages.

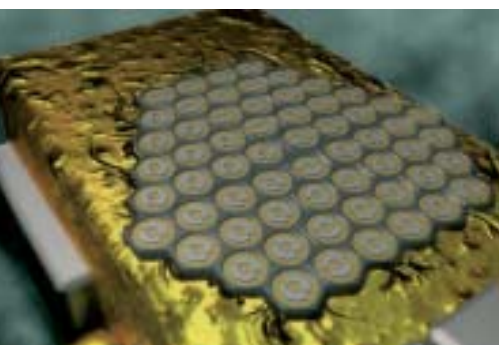
The *Timing Section* is the very heart of the payload, with the atomic clock providing the very accurate time reference. The ground position error from this clock is well below 30 cm. Two different clocks are under development. The small Rubidium Atomic Frequency Standard (3.3 kg) is derived from a commercial design used in communication networks. It is already qualified and is moving into production design. This clock oscillates at optical frequencies (laser-pumped) with a microwave beat frequency of about 6.2 GHz.

The development of the more challenging but more precise Passive Hydrogen Maser started in 2001 and has already delivered a breadboard model. The final model will weigh 15 kg. The engineering models of the physics package and electronics will soon be tested. The clock oscillates directly at 1.4 GHz. The stability of this maser is such that ground intervention is necessary only once every orbit.

The *Signal Generation Section* delivers the navigation signals. These consist of four codes that are first combined with the relevant navigation messages and then up-converted before delivery to the output transmit section. The navigation messages contain information about the satellite orbit (ephemeris) and the clock references.

Two current development activities address the Navigation Signal Generation and the Frequency Generation and Up-Conversion. An early breadboard has been built.

The *Transmit Section* amplifies the four navigation signal carriers up to about 50 W each. These signals are then combined in an output multiplexer and delivered to the transmit antenna. Two power amplifiers are being developed for the low and high bands of the Galileo frequency spectrum. The engineering models of these amplifiers will be ready by the end of 2002. The development of the engineering



model of the output multiplexer will be completed by early 2003.

The Navigation Antenna is the subject of two parallel activities that will conclude with the delivery of engineering qualified models by end-2003. The challenge with these antennas is to illuminate the Earth's surface with a quasi-isoflux power level, independent of whether a receiver is directly below the satellite or seeing the satellite at very low elevation angle.

As for the Search and Rescue payload, the development of a dedicated SAR transmit/receive antenna is under way and an engineering model is expected to be available by end-2003.

Platform

The spacecraft platform will largely use existing technologies. However, the telecommunication and telemetry functions will be supported by two different modes: the standard mode that is used for Tracking, Telemetry &

Command (TT&C) operations of most ESA missions and a new mode based on spread-spectrum signals. The new mode is envisaged mainly for nominal operations of the constellation and is intended to provide increased system robustness and security.

There are stringent safety and operational requirements for the TT&C transponders. In particular, they will operate in a more severe radiation environment than geostationary satellites. It will be possible to change the telecommand/telemetry (TC/TM) operating frequencies within a limited range to accommodate the multiple launches, reduction in interference levels, security aspects and the evolution of frequency allocation throughout the mission life cycle. In addition, the system requires the increased signal robustness provided by spread-spectrum techniques and the increased security of the TT&C link by data encryption, authentication or other techniques.

The S-band transponder will receive telecommands, ranging and other signals, and transmit telemetry and the transposed ranging. The transponder can be driven by internal and external clock references. Additionally, the ranging capability can support time-transfer and clock synchronisation functions using a highly stable ground clock reference.

Predevelopment of the TT&C transponder began in 2000 with the goal of producing an engineering model. The activity is concentrating on a flexible design with optimised mass and power consumption, and high reliability.

Galileo System Test Bed

A Galileo System Test Bed (GSTB) has been defined as an integral part of the Galileo Design, Development and Validation Phase in order to mitigate programme risks. The GSTB is divided into two main development steps.



The first version of the GSTB will collect measurements from the GPS system in order to verify the Galileo concepts for the orbit determination and time synchronisation and integrity algorithms. During its development, collaboration with the International GPS Service (IGS) community and UTC Time Community is being encouraged. Furthermore, interfaces with the EGNOS System Test Bed, Mediterranean Test Bed and other GPS-related national infrastructure are foreseen.

The second version will consist of an experimental Galileo satellite, launched by the end of 2004, and an extension of the first version of the GSTB Ground Segment including Galileo receivers and processing algorithms. GSTB will provide feedback to the definition of the critical algorithms in the Galileo Design, Development and Validation Phase. Experiments are expected to demonstrate the validity and feasibility of some of the most important assumptions and performance objectives of the final

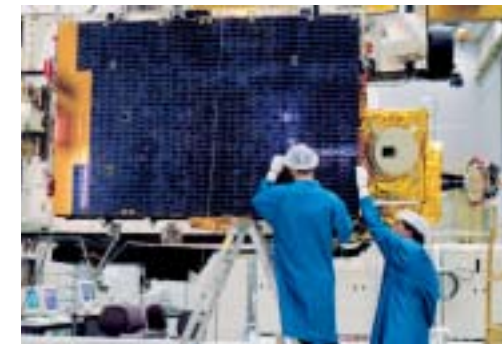
Galileo system. In particular, they will address the actual measurement and comparison of alternative algorithms in a realistic environment. They will also provide some useful input into the Galileo timing infrastructure set-up, calibration over an extended time, the early verification and tuning of simulators and build-up of adequate analysis tools, and the consolidation of the operational concept.

Simulation Tools

The Galileo System Simulation Facility (GSSF) is an end-to-end simulation tool designed to support ESA in developing the Galileo system. It provides high-level models of the Galileo space, user and ground segments, and of the environmental effects on the navigation performance. The models can be run in real-time and allow the analysis of specific figures of merit, including integrity analyses and navigation accuracy for Galileo, GPS and hybrid (Galileo/GPS) receivers.

The flexibility of the GSSF architecture allows user-defined models and algorithms to be plugged into the overall GSSF models. Future Galileo users can also use GSSF to design their navigation systems efficiently in a realistic environment.

A Microsoft Explorer-style data browser enables the user to navigate a tree of GSSF projects, scenarios, simulation runs and simulation data, and then launch the relevant GSSF components from a toolbar. As the simulation is running, the user can display the variables of interest or interact with the simulation and modify its parameters to monitor the effects on the overall system performance. The development of the initial set-up has been successful. Creation of the full-scale real-time simulator is currently under way.



Galileo



Implementation and Management

The infrastructure is being implemented in three phases:

Development and In-Orbit Validation (2001-2005)

- consolidation of mission requirements;
- development of 2-4 satellites and ground-based components;
- validation of the system in orbit.

Deployment (2006-2007)

- construction and launch of the remaining 26-28 satellites;
- installation of the complete ground segment.

Commercial Operations (from 2008)

The Development and In-Orbit Validation Phase will be co-funded mainly by ESA and the EC. The Galileo Joint Undertaking (JU) will oversee its implementation and prepare the grounds for the Deployment Phase. In that phase, a predominant contribution will come from the private sector through a concession scheme.

The development and validation of the space segment and related ground segment will be carried out by ESA in line with an Agreement concluded between the Joint Undertaking and ESA.

During the Commercial Operations Phase, private-sector revenues will range from value-added services sold to operators and collected by the concession holder, to the exploitation of intellectual property rights on chipsets. By 2015, the revenues to the concessionaire will allow the public availability payments to be reduced to zero.



The Galileo Joint Undertaking

In order to complete the development and validation phase and pave the way for the deployment phase, a novel company structure, the Galileo Joint Undertaking, has been set up. This ensures a single effective management body for the programme and enables a combination of public and private funding to be used.

The Galileo Joint Undertaking will last 4 years and is sited in Brussels. Its governing bodies are an Administrative Board, a Director and an Executive Committee. The founding members are the EC and ESA; they may be joined by the European Investment Bank and private enterprises subscribing a minimum of EUR 5 million (reduced to EUR 250 000 for Small- and Medium-sized Enterprises). However, in order to avoid conflicts of interests, private enterprises cannot become members until the tendering process is finalised for selecting the concessionaire to exploit the system.

The Galileo Joint Undertaking has the following main tasks:

1. to oversee the optimal integration of EGNOS into Galileo; implementation of the Galileo development and validation phase; help prepare for the deployment and operational phases;
2. to launch, in cooperation with ESA, the research and development activities for the development phase, and coordinate them with national activities; to launch, through ESA, a first set of satellites to validate the technology developments and to perform a large-scale demonstration of the capabilities and reliability of the system;
3. in cooperation with the EC, ESA and the private sector, help to mobilise the public- and private-sector funds needed to make proposals to the Council for the management structures of the successive phases of the programme on the basis of the following activities:
 - draw up a business plan covering all the phases of the programme on the basis of data supplied by the Commission on the services that can be offered by Galileo and the revenue they may generate;
 - negotiate, via a competitive tendering process with the private sector, an overall agreement for financing the deployment and operational phases that sets out the responsibilities, roles and risks to be shared between the public and private sectors.

Acronyms

CS:	Commercial Service
EC:	European Commission
EGNOS:	European Geostationary Navigation Overlay Service
ESA:	European Space Agency
ESTB:	EGNOS System Test Bed
Eurocontrol:	European Organisation for the Safety of Air Navigation
GNSS:	Global Navigation Satellite System
GOC:	Galileo Operating Company
GPS:	Global Positioning System
GSFF:	Galileo System Simulation Facility
GSM:	Global System for Mobile Communications
GSTB:	Galileo System Test Bed
ICAO:	International Civil Aviation Organisation
IGS:	International GPS Service
IMO:	International Maritime Organisation
ITU:	International Telecommunications Union
JU:	Joint Undertaking
MSAS:	MT Sat-based Augmentation System
OS:	Open Service
PRS:	Public Regulated Service
RIMS:	Ranging and Integrity Monitoring Station
RNSS:	radionavigation satellite service
SAR:	search and rescue
SoL:	Safety-of-Life
TAI:	Temps Automatique International
TC:	telecommand
TM:	telemetry
TT&C:	Tracking, Telemetry & Command
UMTS:	universal mobile telecommunications system
UN:	United Nations
UTC:	Universal Time Coordinated
VSAT:	very small aperture terminal
WAAS:	Wide Area Augmentation System
WRC:	World Radio Conference

Further Information

Galileo Joint Undertaking
B-1000 Brussels
Belgium
Email: JU@galileo-pgm.org

European Space Agency
Applications Directorate
Navigation Department
8-10 rue Mario Nikis
F-75738 Paris CEDEX 15
France
Tel: +33 1 5369 7247
Fax: +33 1 5369 7445
Email: contactesa@esa.int
<http://www.esa.int/navigation/>

European Commission
Directorate General for Energy and Transport
Unit E.4 Satellite Navigation System (Galileo), Intelligent Transport
DM28 1/64
B-1049 Brussels
Belgium
Phone: +32 2 29 56040
Fax: +32 2 296 5372
Email: tren-galileo@cec.eu.int
http://europa.eu.int/comm/energy_transport/en/gal_en.html

