Occasional Papers

n°44 April 2003

Gustav Lindström
with Giovanni Gasparini

The Galileo satellite system and its security implications

published by
the European Union
Institute for Security Studies
43 avenue
du Président Wilson
F-75775 Paris cedex 16
phone: + 33 (0) 1 56 89 19 30
fax: + 33 (0) 1 56 89 19 31
e-mail: institute@iss-eu.org
www.iss-eu.org

Institute for Security Studies
Institut d'études de Sécurité
European Union
Union Européenne

*In January 2002 the **Institute for Security Studies (ISS)** became a Paris-based autonomous agency of the European Union. Following an EU Council Joint Action of 20 July 2001, it is now an integral part of the new structures that will support the further development of the CFSP/ESDP. The Institute's core mission is to provide analyses and recommendations that can be of use and relevance to the formulation of EU policies. In carrying out that mission, it also acts as an interface between experts and decision-makers at all levels.*

***Occasional Papers** are essays or reports that the Institute considers should be made available as a contribution to the debate on topical issues relevant to European security. They may be based on work carried out by researchers granted awards by the ISS, on contributions prepared by external experts, and on collective research projects or other activities organised by (or with the support of) the Institute. They reflect the views of their authors, not those of the Institute.*

*Publication of **Occasional Papers** will be announced in the **ISS Newsletter** and they will be available on request in the language - either English or French - used by authors. They will also be accessible via the Institute's Website: **www.iss-eu.org***

The European Union Institute for Security Studies
Paris

Director: Nicole Gnesotto

ISSN 1608-5000
Published by the EU Institute for Security Studies and printed in France by L'Alençonnaise d'Impressions. Graphic design by Claire Mabille (Paris).

Occasional Papers

n°44

April 2003

by Gustav Lindström with Giovanni Gasparini

The Galileo satellite system and its security implications

Institute for Security Studies
Institut d'études de Sécurité
European Union
Union Européenne

Gustav Lindström is a research fellow at the EU Institute for Security Studies, and formerly served within RAND, the European Union and the World Bank. He specialises in transatlantic relations, US security policies and emerging threats.
Giovanni Gasparini is a research fellow at the Istituto Affari Internazionali (IAI), Rome, where he focuses on defence issues and the aerospace industry. He was a visiting fellow at the EUISS from 23 May to 19 July 2002.

Contents

Contents

Several EU-ISS colleagues made valuable contributions to this research; we particularly acknowledge comments by Burkard Schmitt and Antonio Missiroli of the Institute, and thank Klaus Becher, the Institute's first associate research fellow, for his suggestions on earlier drafts. The authors would also like to thank the experts contacted (listed in the references section) during the course of this study. Any errors or omissions are the responsibility of the authors.

Summary

Aiming to reach operational status in 2008, the Galileo satellite system is planned to offer positioning, navigation and timing (PNT) services worldwide. It will join the ranks of the current GPS and GLONASS systems, allowing users to pinpoint their exact locations.

While a civilian project, Galileo also has a security dimension. As a dual-use system, it will offer numerous applications in the security and defence field. PNT services give military planners and commanders means to manage assets, troops and munitions more effectively. Given its global coverage, Galileo will offer a large portion of these services to any interested party, thus opening the door for unintended users and uses. This has implications for the EU and its allies.

Even if Galileo remains a civilian project, security issues will persist. With a growing number of users dependent on precise positioning services to carry out their daily functions, economic security would be negatively impacted should there be an intentional or accidental service shutdown. Thus, besides protecting the system from unauthorised use, it will be important to safeguard the system to ensure signal continuity at all times.

Given the dual nature of the system, it is critical that European policy-makers consider the security dimensions of Galileo and take practical steps to limit its potential misuse. Among the required steps that need to be taken are: protecting the physical and electronic integrity of the system, establishing a permanent EU-US framework to handle outstanding security issues (such as the 'M-code overlay'), creating a clear chain of command for Galileo, expanding EU capacities to deal with space issues and limiting public regulated service signals (PRS) for security and defence-related purposes.

1

Introduction

The decision to launch the development phase of the Galileo Global Navigation Satellite System (GNSS) in March 2002 represents a significant step for the EU. As an independent system yet interoperable with the American Global Positioning System (GPS), Galileo will offer both civilian and potential military applications once it becomes operational – currently planned for 2008.

Unlike the majority of previous Galileo studies, this report goes beyond a description of the system's future civilian applications and considers its security dimension.[1] It does so because Galileo will have security implications *even* if it remains a civilian project. For example, once Galileo is operational, it will be important to ensure continuity of service to safeguard European economic interests relying on its signals for commercial reasons. In addition, it will have to be safeguarded against unauthorised use by third parties seeking military advantages offered by a global positioning system. Finally, the system will require adequate coordination with GPS to minimise American concern over Galileo's effects on the military portion of GPS, especially the potential for asymmetric use.[2] Besides these issues, this report considers potential Galileo applications in the security field and how these might impact future EU-US and EU-NATO relations.[3]

In order to orient the reader, chapter two outlines the principal elements that make up a Global Navigation Satellite System (GNSS) and provides an overview of the civilian benefits offered by positioning, navigation, and timing (PNT) services. Chapter three then describes the basic elements of the two current GNSS: Navstar GPS and *Globalnaya Navigatsionnaya Sputnikova Sistema* (Global Orbiting Navigation Satellite System – GLONASS). Chapter four introduces the history and current justifications for a European Galileo system. In each of these three chapters, an attempt is made to limit the amount of technical information provided. Chapter five analyses the security implications stemming from Galileo as well as its impact on transatlantic relations. Chapter six concentrates on the institutional challenges raised by Galileo given its future civilian and potential military applications. A conclusion and recommendations for institutional solutions to these challenges are provided in the final chapter.

While each chapter follows the preceding section, deliberate efforts are made to make each of the chapters 'self-contained'. A reader may thus read the chapters in order of preference.

[1] This study relies on open source and interview information gathered up to mid-March 2003.

[2] 'Asymmetric use' refers to the possibility of maintaining access to some signals while denying signal access to others (either globally or locally).

[3] However, this study does not consider the political process leading to the launch of the Galileo programme. The individual EU member states' views of the programme are also outside the scope of this research.

2

Global Navigation Satellite Systems

This chapter provides an overview of Global Navigation Satellite Systems (GNSS), including their general characteristics, military and commercial applications and system limitations. GNSS can be thought of as the larger category into which well-known systems such as the US Navstar Global Positioning System (GPS) fall. Before embarking on a discussion of specific GNSS – such as GPS or Galileo – it is important to understand the basic elements of Global Navigation Satellite Systems in general.

2.1 General characteristics

A GNSS estimates the location of fixed and moving objects on the ground, in the atmosphere and in space using precise timing and geometric triangulation. Available around the clock, GNSS satellites provide accurate three-dimensional positioning to anyone with the appropriate radio reception and processing equipment. While the coverage provided by a GNSS is 'global', its availability and precision varies according to local conditions. Generally speaking, signals tend to be weaker over the poles and in urban areas.

Positioning through GNSS

A combination of different radio signals transmitted at precise intervals by each satellite of a GNSS constellation down to earth allows a passive receiver to determine its position through geometrical triangulation. Actual positioning is possible by timing how long it takes the signals to reach the receiver from the satellites in view.[4] From the transmission time delay, the receiver can calculate the distance between it and the orbiting satellite. Using data from four satellites, the receiver can accurately determine its three-dimensional position.

In theory, a receiver could calculate its three-dimensional position by triangulating the data from three satellites. However, a fourth satellite is necessary to address a 'timing offset' that occurs between the clock in a receiver and those in satellites. Using data from the fourth measurement, the receiver's computer can calculate the timing offset and eliminate it from the navigation solution.[5] Generally speaking, a larger number of satellites results in greater accuracy.

Accurate positioning and timing are also ensured by a number of ground stations that address the user equivalent range error (UERE), and provide continuous monitoring and management of the constellation.[6] The ground stations also control the spacecraft and provide data for necessary corrections.

Architecture

A GNSS architecture typically consists of three subsystems: a satellite constellation (space segment), a ground segment to control and monitor the space segment, and end-user mobile receivers. These subsystems can in turn be enhanced through space- or ground-based

[4] Very precise atomic clocks on board the satellites are used for these calculations. Based on the decay ratio of extremely regular isotopes, such as caesium, these clocks can precisely calculate time.

[5] Pace et al. *The Global Positioning System*, Critical Technologies Institute, RAND, MR-614-OSTP, 1995.

[6] For example, in the case of GPS, contributors to a receiver's UERE are satellite vehicle (SV) and ephemeris errors, atmospheric delays, multipath, and receiver noise – including those coming from receiver kinematics; Pace et al. *The Global Positioning System*. Critical Technologies Institute, RAND, MR-614-OSTP, 1995.

augmentation.[7] Because of their military origin, certain GNSS signals tend to be very precise while jam- and spoof-resistant.[8]

Presently, there are only two space-based systems providing global coverage: the US Navstar Global Positioning System (GPS) and Russia's *Globalnaya Navigatsionnaya Sputnikova Sistema* (Global Orbiting Navigation Satellite System – GLONASS). While the American system is fully operational, the Russian programme is only partially available due to an incomplete decaying constellation of satellites.[9] Both systems originate from military requirements and continue to be funded and operated by their respective departments of defence. However, it should be noted that since 1996, GPS is governed by an Interagency GPS Executive Board (IGEB) whose membership goes beyond DoD. Galileo would become the third global GNSS provider should it reach its full operational status as planned in 2008.

2.2 Military applications[10]

Existing Global Navigation Satellite Systems have important military applications. Today, applications beyond the traditional role of providing positioning and directional information facilitating (in combination with other technologies) the guidance of munitions are appearing.

Today, most military platforms used by the US military and its allies benefit from or can be fitted with a GNSS receiver. Besides military platforms, supplies and equipment can be tracked to improve logistics. Through the use of a transmission element, positioning services can also be used to track enemy assets and positions.

The capability to synchronise the movement of different units on the battlefield – from space, air, sea and land – provides the current and future field commander with unprecedented area awareness.[11] Combined with the accurate weapons guidance provided by GNSS, there is improved strike effectiveness that may minimise the amount of collateral damage caused during an operation. The possibility to strike from a distance reduces risks to military personnel involved in operations. The use of navigation and positioning technology may also reduce the risk of accidents due to 'friendly fire'. Likewise, PNT services can lower risks to personnel operating or patrolling around unmarked borders where boundary transgressions can have dire implications.

2.3 Commercial applications

In addition to fulfilling military requirements, GNSS offer a multitude of commercial applications. The growth of the transport sector, the fast evolution of telecommunications, and the development of other services requiring positioning – such as rescue services – reinforce the notion of GNSS as a multiple-use technology.

Signal transmissions are an integral component of aviation, shipping, telephony, computer networks and many other areas. Positioning plays an important role in these fields since it enhances economic efficiency. For example, in aviation, savings may be accrued through more direct aircraft flights (attained through improved traffic management), more efficient ground

[7] An example of ground-based augmentation is Differential GPS (DGPS) that was traditionally used to circumvent the effects of Selective Availability. With respect to the space segment, it is important to recognise that any satellite with the proper payload can be used to augment a GNSS.

[8] Jamming refers to the deliberate radiation, reradiation or reflection of electromagnetic energy for the purpose of disrupting enemy use of electronic devices, equipment or systems. A receiver is 'spoofed' when it processes fake signals (for example, those produced by an enemy) as the desired signals. As a result, spoofed users can be made to believe they are in a particular location when in reality they are not. http://www.its.bldrdoc.gov.

[9] In part due to financial constraints after the collapse of the Soviet Union.

[10] This section provides an overview. Chapter 3 focuses on the military implications of GNSS.

[11] This option can be combined with the shut down of signals available to opposing forces.

control, improved use of airspace capacity and fewer flight delays. GPS is already an important tool for in-flight safety through its provision of en route navigation, airport approach, landing and ground guidance. With the launch of Galileo, economic benefits to the European aviation and shipping segments are estimated to reach 15 billion between 2008 and 2020.[12]

Positioning can also be used with current and future driving systems. According to the Commission's Directorate-General for Energy and Transport, road accidents and fatalities generate social and economic costs corresponding to 1.5-2.5 per cent of the EU's gross national product (GNP).[13] Road congestion adds an additional cost representing 2 per cent of EU GNP. The use of a very precise GNSS could lower these social costs by increasing road safety, reducing travel time and containing congestions. A more efficient use of fuels may also have positive spillover effects for the environment. Additional road applications presently gaining attention include in-car navigation, fleet management of taxis and driver assistance.[14]

In the energy sector, timing and positioning systems can be used to optimise the transfer of electricity along power grids and lines. Increased drilling safety brings benefits to the gas and oil sector.[15] For the banking sector, useful applications range from the creation of legally traceable data stamps (for the reduction of false transactions) to the synchronisation of financial operations. From an insurance perspective, GNSS may be used to monitor or trace the transport of valuable goods.

GNSS already plays an important role in emergency services such as search and rescue, disaster relief and environmental monitoring.[16] Current emergency beacons operate within the Cospas-Sarsat satellite system. However, with no real-time service guarantee and inaccurate estimates (provided in kilometres), there is room for improvement.

In addition to the professional applications described above, individuals are discovering the recreational uses offered by GNSS. Commercial GPS handsets are increasingly commonplace for trekking, sea navigation, etc.

2.4 System limitations and vulnerabilities

GNSS has its limitations in spite of its military and commercial advantages. There are three frequently referenced shortcomings. First, positioning signals tend to be less precise in urban environments or under foliage, in areas where the number of satellites in-sight are low (typically at upper and lower latitudes around the poles), and under certain weather conditions such as thick cloud. GNSS precision is also affected by the strength of the transmission – with a more powerful signal suffering less distortion as it travels down to earth. To address this, ground- or space-based augmentation – adding reference points such as additional ground stations – can be used to improve precision in localised areas.

Second, GNSS services may suffer from intermittent service coverage. Given the limited lifespan of the space component, the system needs to be replenished and/or reconfigured periodically. For example, during certain upgrading operations, receivers relying on information from ground stations or satellites being manipulated may be affected. Even if the service is degraded for a couple of seconds or minutes, the impact may be significant (e.g. air traffic). To

[12] Directorate-General for Energy and Transport, European Commission.

[13] It is unclear whether these are yearly or aggregate costs.

[14] The potential for spin-offs is large. An example cited by the European Commission vis-à-vis Galileo is the potential to issue exact time stamps and precise positioning for liability purposes in case of vehicle accidents. This information would be usable in court and for insurance purposes.

[15] The Commission also foresees a role for Galileo in assisting with rig positioning.

16 Examples include tracking floods, fires, oil spills and earthquakes.

limit this shortcoming, service providers can indicate upcoming service interruptions. For GPS, the US Coast Guard and the Federal Aviation Administration (FAA) receive periodic notices of potential GPS service interruptions that could affect service availability in a localised geographic area. This information is posted in a variety of sources.[17]

Finally, as a vital component for a growing number of commercial and military applications, global navigation and positioning systems may be vulnerable to attack by hostile entities. For example, a ground station may be physically attacked or taken over, with consequences for the service. Electronic means can be used to jam parts of the system or attempt limited system takeovers. In the distant future, these threats may also affect the space segment, with severe consequences.

System failure or shutdown may have ominous economic consequences – especially the greater the dependence on the system. In addition, any system failure may have dire consequences in sectors requiring continual and precise signals (such as aviation).

[17] See http://www.nis-mirror.com/systems/gps/interupts/.

3

The current systems

At present there are two functioning Global Navigation Satellite Systems: the US Navstar Global Positioning System (GPS) and Russia's *Globalnaya Navigatsionnaya Sputnikova Sistema* (Global Orbiting Navigation Satellite System – GLONASS). This chapter summarises the main characteristics of each of these two systems. Analysis of the usefulness of the Galileo system is limited without prior understanding of the capabilities of the current systems.

3.1 Navstar GPS

Navstar GPS is the first and at present the only fully operational PNT system. The GPS project began in 1973 and attained Full Operational Capability (FOC) in 1995. Overall GPS costs have been estimated at $14 billion.[18] Developed for and by the US military, it is physically operated by a Joint Program Office (JPO) of the Department of Defense (DoD) and US Air Force Space Command (AFSPC). The responsibility for civilian applications rests within the US Coast Guard's Navigation Center (NAVCEN).[19] An Interagency GPS Executive Board (IGEB), established through a Presidential directive of 28 March 1996, manages GPS.[20] The ultimate decision-making on GPS policies – including system openness, export regimes for receivers, usage of Selected Availability (SA) and upgrading plans – rests with the President.[21]

The space segment

The GPS space segment comprises 24 Navstar satellites (and one or more in-orbit spares) distributed in six orbital planes. The spacecraft orbit the earth in a period of 12 hours in circular 10,900 nautical mile (approx. 20,200 km) orbits – which means that each satellite passes over the same location on earth about once a day.[22] Normally, five satellites are in view to users worldwide at any given moment.[23]

During the last 28 years, four different generations of GPS satellites have been developed: Block I, Block IIA, Block IIR (replenishment) and Block IIF (follow-on). The average lifespan of each spacecraft is from 7 to 10 years for the first three generations, while the last generation is expected to last 15 years.

First launched in 1997, Block IIR satellites make up the majority of the present constellation. Block IIR satellites feature an auto-navigation capability (AUTONAV) that allows each spacecraft to maintain full positioning accuracy for at least 180 days without Control Segment

18 Pace et al., *The Global Positioning System*, Critical Technologies Institute, RAND, MR-614-OSTP, 1995.

19 In peacetime, the Coast Guard has traditionally been part of the US Department of Transportation. As of 1 March 2003, the organisation is part of the newly developed Department for Homeland Security.

20 IGEB is a senior-level policy-making body chaired jointly by the Departments of Defense and Transportation. Its membership includes the Departments of State, Commerce, Interior, Agriculture, and Justice, as well as NASA and the Joint Chiefs of Staff.

21 Selective Availability introduces errors into the clock of each satellite – a process known as 'dithering'. These errors include elements that vary both slowly and rapidly over time. SA also introduces slow changing errors into the orbital parameters that are part of the GPS message, effectively misrepresenting the position of a given satellite (Pace et al., 1995). The application of SA to GPS can generate measurement errors up to 2 kilometres (average errors usually around 100 metres), making the service useless for certain applications. The use of SA was discontinued on a global basis on 1 May 2000.

22 The satellites orbit at an inclination of 55 degrees with respect to the equator. The inclination indicates how far north and south the satellite travels during each orbit

23 Pace et al. *The Global Positioning System*. Critical Technologies Institute, RAND, MR-614-OSTP, 1995.

support.[24] The latest satellites in this series, to be launched from 2003 onwards, will carry a new military code or M-code. The M-code will be more jam-resistant than the current military GPS code (also known as P-code).[25] In addition, these satellites will offer a second civil signal on the L2 band.[26]

GPS will have 18 modernised Block IIR satellites in orbit by 2008 with full operational capability, consisting of approximately 28 satellites, achieved by 2011 (De Jong, 2002). Beyond the Block IIR, there are plans to upgrade the system through the introduction of the GPS IIF programme in 2008. The Block IIF programme will transmit a third civil signal on the L5 band. A fifth generation of GPS satellites, the Block III, is expected to dramatically enhance the performance of the system starting in 2011 (unless there are delays). These satellites will provide a more resistant, precise and reliable signal through increased transmission power.[27] The full programme will consist of 33 satellites, costing approximately $1.3 billion.[28]

The ground segment

A master control station in Colorado Springs controls the space segment. In addition to the master control station, the United States operates five unmanned monitor stations and four ground antennas to pick up GPS satellite signals.[29] The data collected by the monitor stations are used to calculate positioning corrections for the satellites. This process ensures the synchronisation of the satellites and the accuracy of the signals sent to earth.

GPS signals

GPS satellites transmit two different signals: the Precision or P-code and the Coarse Acquisition or C/A-code. The Precision code is transmitted over the L1 and L2 bands while the C/A signal exclusively uses the L1 band.[30] In the case of the P-code, the availability of two different bands to carry the same signal helps improve signal precision (by reducing errors generated during transmission through the ionosphere) and increase resistance to jamming.

The P-code is designed exclusively for authorised defence-related users and provides a so-called Precise Positioning System (PPS). To ensure that unauthorised users do not get access to the P-code, the United States can implement an encryption segment on the P-code for anti-spoofing (AS) purposes. The P-code with AS encryption (designated the Y-code) is available only to users with the correct deciphering chips.

The C/A code, on the other hand, is intended for civilian use and provides a Standard Positioning Service (SPS).[31] Given its non-military nature, the C/A code is less accurate and easier to jam than the P-code. However, being easier to acquire, military receivers frequently first track the C/A code on their receivers and then revert to the more precise P-code. The future M-code signal is being designed for autonomous acquisition so that a receiver can acquire the M-code signal without prior access to C/A or Y code signals.[32]

---

24 http://www.fas.org/spp/military/program/nssrm/initiatives/gps2r.htm.

25 The code can also be referred to as the P(Y) code when combined with anti-spoofing (see section on radio signals).

26 Within the telecommunications sector, a band – also known as frequency band – refers to a specific range of frequencies in the radio frequency (RF) spectrum. The spectrum is divided into sections ranging from very low frequencies (VLF) to extremely high frequencies (EHF). Within each band, there is a defined upper and lower frequency limit. Band usage is usually regulated, as two radio transmitters sharing the same frequency band may cause mutual interference. A summary chart of the bands used for GNSS is found at the end of chapter 3.

27 See M. Sirak, 'USA Set Sights On GPS Security Enhancements', in *Jane's Defense Weekly*, 16 January 2002, p. 30.

28 www.fas.org.

29 The unmanned monitor stations are located at Hawaii, Ascension Island, Diego Garcia, Kwajalein and Colorado Springs. The ground antennas are located in Cape Canaveral, Ascension Island, Diego Garcia, and Kwajalein.

30 There is an additional frequency band, L3 or NUDET, which is used for the detection of nuclear detonations.

31 The accuracy of the C/A signal—when Selected Availability is not active—is around ten metres. The P-code guarantees a precision of 6 metres or less.

32 Barker, B., Betz, J., Clark, J., et al. *Overview of the GPS M Code Signal*, U.S. Air Force, The Aerospace Corporation and Mitre Corporation, 2000.

GPS receivers

Overall, there are three different types of GPS terminals, categorised according to the code they can acquire:

- C/A (SPS) receivers – which are available to the wider public for civilian applications;
- C/A (PPS) receivers – used exclusively by military personnel;
- Direct P(Y) military receivers – these last-generation military receivers do not have to go through the C/A signal to track the P(Y) signal. Once all military personnel have access to direct P(Y) receivers, military commanders can switch off the C/A signal on the battlefield without fear of a negative repercussion for friendly military forces.

While C/A (SPS) receivers can be bought for a few hundred dollars in most countries (actual service is free) without prior authorisation, C/A (PPS) receivers are expensive – integrating a GPS-based system into a fighter aircraft entails costs starting at $100,000 – and under tight export control.[33] The Department of Defense is responsible for evaluating requests for C/A (PPS) receivers from abroad. In principle, exports of PPS-capable receivers are only available to authorised personnel.

3.2 GLONASS

The Russian counterpart to GPS is the GLONASS satellite system. The first satellites were launched in 1982, and full operational capability was reached in 1996.[34] While the system is currently only partially operational, the Russian government has indicated that it will attempt to revitalise the programme by 2006.[35] GLONASS is managed by the Russian Space Forces under the Ministry of Defence.

The space segment

A complete GLONASS constellation consists of 24 satellites, including three spares, travelling in three orbital planes at a height of 19,100 kilometres. The satellites orbit the earth with a period of 11 hours and fifteen minutes at an inclination of 64.8 degrees with respect to the equator.[36] Through this relatively high orbit inclination, a fully operational GLONASS would provide a better coverage of the poles than GPS. However, with less than half of the planned satellites operational, the system provides low overall performance.

The lifespan of each satellite is relatively short at about three years, requiring a large number of replacement satellites. The next-generation satellites, including the GLONASS-M and GLONASS-K, are expected to increase both lifespan and transmission power, should they materialise.

The ground segment

GLONASS is operated by a Ground-based Control Complex (GCS) made up of a System Control Centre (Golitsnyo-2) and several Command Tracking Stations (CTS). The CTS – geographically dispersed across Russia – track the GLONASS satellites in view to accumulate ranging and telemetry data. Signal information gathered by the CTS is then processed at the System Control Centre to calculate satellite clock and orbit states. The CTS also update navigation messages for each satellite.[37]

GLONASS signals

Unlike GPS, all codes broadcast by GLONASS satellites are identical. Signal differentiation is therefore achieved by each satellite having slightly different frequencies on the G1 and G2 bands. On the other hand, like GPS, GLONASS uses a C/A code and a P-code. The C/A code is

33 Pace et al. *The Global Positioning System.* Critical Technologies Institute, RAND, MR-614-OSTP, 1995.

34 Operational capability was initially forecast for 1991.

35 See P.B. de Selding, “Russia Commits To Founding New Navigation Fleet”, in *Defense News*, 7-13 January 2002, p.19.

36 http://www.rssi.ru/SFCSIC/english.html.

37 http://www.rssi.ru/SFCSIC/english.html.

transmitted on G1 while the P-code is transmitted on both G1 and G2. Since each satellite transmits on a different frequency, GLONASS is less vulnerable to jamming and spoofing than GPS.

GLONASS receivers

While GLONASS receivers were traditionally only available to military users, commercial receivers are available on the market today. Recent developments include a combined GLONASS/GPS multi-code and multi-channel receiver that can track both GPS and GLONASS signals. However, given an incomplete constellation, separate GLONASS receivers are not widely used due to low levels of accuracy, integrity and system availability.[38] Instead, these receivers tend to serve as a back-up and control mechanism for GPS data.

[38] Integrity refers to the ability of a system to provide timely warnings to users when it fails to meet certain margins of accuracy.

4

The future Galileo system

This chapter describes the history and hopes for a European Global Navigation Satellite System called Galileo. After a brief overview of the events leading to European support for Galileo, the justifications for a European GNSS and the expected architecture of the system are outlined.

4.1 Background

The European Union has been in the satellite navigation business for close to a decade. In 1995, it oversaw the deployment of a first-generation European GNSS known as the European Geostationary Navigation Overlay Service (EGNOS). A combined project between the Commission, the European Space Agency (ESA), and the European Organisation for the Safety of Air Navigation (EUROCONTROL), EGNOS will provide (under certain conditions) a guaranteed GPS/GLONASS integrity service starting in 2004. Sometime between 2006 and 2008, the EGNOS infrastructure will be integrated into Galileo. Using three International Maritime Satellite Organisation (Inmarsat) geostationary satellites and a network of ground stations, EGNOS will transmit a signal informing on the reliability and accuracy of the positioning signals sent out by GPS and GLONASS.[39]

In 1998, ESA and the European Union jointly decided to study the feasibility of a truly independent European GNSS.[40] Named Galileo, the programme was first approved in 1999. Besides being independent, Galileo is planned to offer greater accuracy, integrity, availability and continuity of services compared with present systems.[41] In spite of the dual-use nature of any GNSS system, Galileo is intended to be for civilian application only.[42] It is labelled as a 'civil programme under civil control'.[43]

On 26 March 2002, the European Council of Transport Ministers approved a package of €450 million in Community funding to initiate the development phase of Galileo.[44] The European Space Agency, which is matching this contribution, is expected to release its €550 million share in the coming months.[45] Galileo is expected to be fully operational by 2008

39 http://europa.eu.int/comm/dgs/energy_transport/galileo/doc/galileo_brochure_may2002.pdf; http://www.esa.int/export/esaSA/GGG63950NDC_navigation_0.html.

40 ESA's 15 member states are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Canada has a special status provided through a cooperation agreement that allows it to participate in certain projects.

41 Directorate-General of Transportation and Energy, European Commission.

42 The European Commission does not have external military or defence competencies. Moreover, the civilian dimension is consistent with ESA's charter, which limits its activities to 'peaceful purposes'. It should be noted that ESA includes members such as Switzerland that follow strict neutrality. Only recently has ESA taken steps to allow it to handle classified material and other aspects required for the development of security-related space activities. See John Logsdon, 'A security space capability for Europe? Implications for US policy', *Space Policy* (available online at www.sciencedirect.com).

43 Galileo Council Conclusions, 5-6 December 2002.

44 This sum does not include the €100 million authorised previously in 2001.

45 As of 15 January 2003, the €550 million had not been released. For details see 'Galileo goes ahead: the Commission proceeds despite financing difficulties within the ESA', IP/03/50 Brussels, 15 January 2003.

(Figure 1). It is important that this timeline be kept, since substantial delays could jeopardise the frequency plans allocated to the system at the 2000 World Radio Conference.

- Definition Phase (2001)
- Development Phase (2002-2005)
  - o Consolidation of mission requirements
  - o Development of 2-4 satellites and ground-based components
  - o Validation of the system in orbit
- Deployment Phase (2006-2007)
  - o Construction and launch of the remaining 26-28 satellites
  - o Completion of the ground segment
- Operational and Commercial Phase (from 2008 onwards)

Figure 1: Galileo development phases

The civilian character of Galileo means that, so far, none of its funding comes directly from defence budgets. With deployment costs estimated between €3.2-3.6 billion, financing solutions are planned to come through public-private partnerships (PPP) and fee-for service charges to be collected by the Galileo Operating Company (GOC).[46] Total costs, including operation costs for twelve years, are likely to reach €6 billion.[47] With respect to the partnerships, the European Investment Bank or private enterprises willing to pledge a minimum of €5 million may join the recently established Joint Undertaking (JU) that is presently responsible for the development and validation phase. To avoid conflicts of interest, private enterprises may not become members until the tendering process is finished.[48]

4.2 Why Galileo?

A comparison of Galileo and current GPS is helpful to better understand the needs for a European GNSS. According to the Directorate-General for Energy and Transport within the European Commission (EC), '[it] is crucial for Europe to have a choice independent of the current US Global Positioning System (GPS) monopoly, which is less advanced, less efficient and less reliable.'[49] According to the Commission, the specific drawbacks of GPS are identified as:

- *Mediocre and varying position accuracy* — depending on the time and place, GPS accuracy is sometimes given within 'several dozen metre' accuracy. From a European perspective, this is not sufficient to provide significant societal benefits – particularly within the transportation sector. With better precision, Galileo would fill this gap.
- *Questionable geographic reliability* — in northern regions that are frequently used as aviation routes, GPS provides limited coverage.[50] This also affects use of the system in northern Europe that counts with several EU members. In addition, Galileo would boost overall urban district coverage from the current 50 per cent figure (provided by GPS alone) to 95 per cent.[51]
- *Questionable signal reliability* — With GNSS services playing a significant role in society, there is concern over the possibility of service shutdown. Should the GPS system become dysfunctional or be turned off (accidentally or not), it has been conservatively estimated that the cost to

[46] According to the Directorate-General for Energy and Transport, the deployment cost is equivalent to the cost of building 150 kilometres of semi-urban motorway or a main tunnel for the future high-speed rail link between Lyon and Turin. Galileo is funded as a Trans-European Network (TEN-T) project. http://europa.eu.int/comm/dgs/energy_transport/galileo/doc/galileo_brochure_may2002.pdf.

[47] http://www.jobsbeiastrium.de/galileo/Daten_e.htm.

[48] The joining fee is €250,000 for Small- and Medium-sized Enterprises. http://europa.eu.int/comm/dgs/energy_transport/galileo/doc/galileo_brochure_may2002.pdf.

[49] http://europa.eu.int/comm/dgs/energy_transport/galileo/doc/galileo_brochure_may2002.pdf.

[50] The Icelandic aviation authorities have reported several transatlantic flights with interrupted signals in their control zones. Directorate-General for Energy and Transport, European Commission.

[51] Communication from the Commission to the European Parliament and the Council – State of progress of the Galileo programme. Official Journal C248, 15 October 2002.

European economies would be between €130 and €500 million per day.[52] As a low probability yet high impact event, this gives added impetus for a European system.

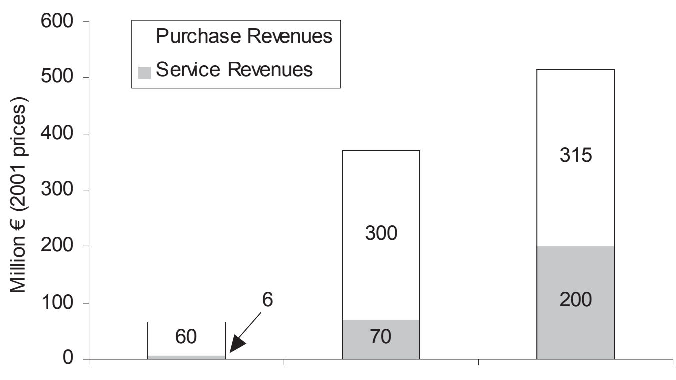
While these are notable drawbacks, they are less compelling arguments for an independent European GNSS when the future improvements planned for GPS and GLONASS are considered. For example, the second and third civil signals of GPS will increase signal redundancy and improve continuity if reception on the L1 band is lost. Starting in 2003, launched Block IIF satellites will provide the second (interference-resistant) signal for civil users. By 2005, GPS is likely to offer the third civil signal with better accuracy and reliability using a stronger signal (using more energy). Concerning planned service shutdowns, the United States is unlikely to do so given the economic impact it would have on its economy – clearly, it is not just Europe that would suffer from such an event.

A revival of GLONASS (starting in 2006) could offer greater coverage over northern Europe.[53] A similar effect could be achieved through additional ground- and space-based augmentations in certain regions requiring greater precision coverage. Thus, GPS + GLONASS receivers should technically be sufficient to meet EU civilian requirements – even if these are not going to offer integrity messages. To fully understand the arguments behind Galileo, it is necessary to consider the economic, industrial and political arguments behind it.

4.3 Economic, industrial and political justification for Galileo

Economic

An independent study by PricewaterhouseCoopers (PwC) from November 2001 on the economic viability of Galileo gives promising forecasts in spite of doubts concerning levels of private participation in the deployment phase. According to PwC, the system should generate operator revenues ranging from 66 million in 2010 to over 500 million in 2020. Examples of revenue streams include royalties on chipset sales and income from service providers who want to use the specialised encrypted signals. Based on the net present value of savings that are thought to be accrued through improvements to air traffic and maritime navigation, the PwC study calculates a benefit/cost ratio of 4.6 (i.e. benefits outweighing costs by a factor of 4.6).[54]



Source: PricewaterhouseCoopers

Figure 2: PwC Galileo market forecasts

[52] J. Vielhaber and D. Sattler, 'Why Europe wants Galileo', *Internationale Politik*, vol. 3, Winter 2002.

[53] The accuracy will improve from the present 10-20 metres to 3-5 metres. Those who need even greater accuracy (for example airports ands seaports) can take advantage of Local Area Augmentation Systems (LAAS) and the soon-to-be-operational (initial operational capability expected July 2003) Wide Area Augmentation System (WAAS). www.state.gov/r/pa/prs/2002/8673pf.htm, www.gpsworld.com.

[54] http://www.pwcglobal.com/uk/eng/about/svcs/pfp/pwc_Galileo_Information.pdf.

It should be noted that these economic projections are based on assumptions that may or may not materialise. Table 1 provides an overview of three different revenue projections, including those of the PwC. The disparities in these economic projections reinforce the fact that there is substantial variability on assumptions used (e.g. chipset royalties, state of the economy, etc.), decisions of what represents a social benefit, the euro amounts attached to such benefits and actual developments.

Industrial

The European space sector today employs about 30,000 highly qualified people in over 2,000 companies covering the full range of skills associated with systems, subsystems and components.[55] With the advent of Galileo, the EC estimates that approximately 100,000 high-skill jobs will be created, establishing a market worth around €10 billion per year.[56] While this figure is subject to interpretation, it is clear that Galileo will offer substantial industrial opportunities. The development of Galileo should stimulate research and expertise development in areas such as spacecraft design, satellite launch, transmission devices, atomic clocks and encryption systems.

Recent disagreements between Italy and Germany over industrial leadership of the Galileo project reinforce the importance attached to the industrial side of Galileo.[57] Both countries and industries are vying to receive orders and jobs to the point that ESA's funding has not been cleared. It is only recently that these disagreements have begun to be bridged. It now seems that some agreement has been found whereby Germany will finance and obtain work worth about one-fifth of the entire project. Italy is likely to get around 16 per cent. With respect to actual location of industries, Germany seems the likely candidate to host Galileo industries (responsible for the space segment) while Italy gets responsibility for industries in charge of systems engineering.[58]

From the space industrial side, the 83-member Organisation of European GNSS Industry (OREGIN), activated in February 1999, has positioned itself to support the development of the Galileo users' segment equipment and

Table 1: Revenue comparisons (€ million)

Report	PwC			GEMINUS Study			GALA Study		
Year	2010	2015	2020	2010	2015	2020	2010	2015	2020
Service Revenues*	6	70	200	65	125	165	25	80	305
Purchase Revenues*	60	300	315	10	60	215	30	75	109
Total	66	370	515	75	185	380	55	155	414

* Millions of €uros (in 2001 prices)

Source: *Inception Study to Support the Development of a Business Plan for the Galileo Programme*, PricewaterhouseCoopers, November 2001.

55 Green Paper, European Space Policy, p. 11, 21 January 2003.

56 Directorate-General of Transportation and Energy, European Commission.

57 Italy has signalled that it would like a lead role because it was involved in Galileo early on and has not received a leading role in other ESA projects such as the French-led *Ariane* programme. Germany had put itself forward as the project leader on the basis of its financial contributions to ESA, which amount to some €562 million yearly. To reinforce this stature, Germany increased its funding of ESA's scientific research programmes by an additional 30 million in 2002. http://www.dw-world.de/english/0,3367,1433_A_644077,00.html.

58 Haig Simonian, 'Galileo deal sets EU up to rival US on space', *Financial Times*, 29-30 March 2003.

services.[59] Besides stimulating information sharing, OREGIN aims to foster partnerships between industrialists - in particular between large corporations and small and medium-sized enterprises (SME).

Political

On the political side, an autonomous NPT system provides greater flexibility in the foreign policy arena, particularly in the fields of security and defence. This advantage is usually 'forgotten' or downplayed in the case of Galileo, since it is supposed to be a purely civilian project.[60] However, ignoring these advantages is dangerous given the dual nature of NPT systems. Galileo's implications for the security field are discussed in greater detail in the next chapter.

As noted previously, Galileo also serves to strengthen EU economic security. An independent system and the resulting redundancy works as a safeguard against service shutdown - intentional or not - in existing NPT systems. The notion of assured access is a strong motivator for procuring the system.

Timing

Besides these factors pushing for an independent EU PNT system is the question of timing. It is important that Galileo become operational around 2008, since the user market could be in a rapid growth phase around that time. As noted earlier, GPS aims to introduce new and more precise signals in the next few years, culminating with the probable launch of GPS III in 2011. GLONASS may similarly see a revival commencing in 2006. If Galileo is not operational around 2008 and other GNSS providers move ahead, the system will have a more challenging time entering and getting accepted in the market - especially if there are other operators providing the services free of charge. Users may become path-dependent on GPS, GLONASS or a combination of the two, making it more difficult for Galileo to make inroads in the areas of equipment and service provision.

4.4 Architecture

The space segment

Galileo's space segment will consist of 30 satellites - 27 active and 3 spare - in Medium Earth Orbit (MEO) at an altitude of 23,600 km. The satellites will travel along three circular orbits at an inclination of 56 degrees, ensuring global coverage. With a satellite orbit time of 14 hours, the configuration of the constellation will guarantee at least six in-sight satellites at any given time for any location - including the poles.

The Galileo spacecraft will have an expected lifespan of 10 years. Individual satellites will be replaced on a regular basis to account for eventual malfunctioning, residual life, and accommodation of future payload technology.

The ground segment

The space segment will be managed by two Control Centres located in Europe, supported by twenty Galileo sensor stations (GSS). Data exchanges between the Control Centres and the satellites will be done through specific up-link stations. A total of 15 uplink stations will be installed around the world to facilitate this type of data transfer.[61] As the principal component of the ground segment, the Control Centres will be responsible for the management of the satellites, the integrity of the signals, and the synchronisation of the atomic clocks onboard the satellites.

59 Examples of members include: Thales Navigation (France), Adveto AB (Sweden), Technomar (Germany), Alenia (Italy), Astrium (United Kingdom), Edisoft (Portugal), Hellenic Aerospace Industry (Greece), Indra Espacio (Spain), Tele Atlas (Belgium), Nokia (Finland), and OmniSTAR BV (Holland); http://www.galilean-network.org/documents/OREGIN_GALILEAN_Navsat.pdf.

60 In an Information Note dated 26 march 2002, the Commission acknowledged the following: 'Although designed primarily for civilian applications, Galileo will also give the EU a military capability.' http://europa.eu.int/comm/dgs/energy_transport/galileo/doc/galileo_info_note_2002_03_26_en.pdf.

61 The ten up-link stations will be made up of 5 S-band up-link stations and 10 C-band up-link stations, www.esa.int.

Galileo signals and services

Galileo satellites will transmit 10 different signals. Of these, 6 will be devoted to civilian (Open Service) and safety-of-life (SoL) services, 2 for commercial users and the remaining 2 (public regulated services or PRS) for official/regulated personnel.[62] Apart from these timing and navigation transmissions, Galileo will provide information concerning the accuracy and status of its signals. Known as 'integrity messages', these signals are specifically geared for SoL applications although they are likely to be offered to service industries requiring legal guarantees (for example during the transportation of valuable goods).[63]

The Open Service (OS) will be available to civilian users free of charge. According to Commission plans, the quality of the OS will be better than that of present and future GPS civil services.[64] The Commercial Service (CS) will operate under a fee-for-service regime. As such, access to the CS will require a payment to the GOC or the service provider in return for the encryption keys required to receive the signals. Compared to the OS, CS signals will be of higher quality and guarantee a certain level of reliability and accuracy.

The SoL Service will offer the same accuracy as the OS but with a high level of integrity. A greater level of integrity is required for effective and precise service in industries related to air and maritime navigation.[65] At some stage, SoL may be encrypted and therefore require a fee-for-access. The Search and Rescue (SAR) Service will be a certified service developed in accordance with international regulations. It will provide real-time transmissions of emergency requests to facilitate the location of distress messages.

The Public Regulated Services (PRS) signal will be for governmental use only. An encrypted signal, it is designed to guarantee continuous signal access in the event of threats or crisis. It will require non-commercial receivers that can store the needed decryption keys. Among its intended authorised users are:

EU-wide:

- The European Police Office (Europol)
- The European Anti-Fraud Office (OLAF)
- Civil protection services such as the Maritime Safety Agency (MSA)
- Emergency response services (peacekeeping forces, humanitarian response teams)

Within EU member states:

- Law enforcement and security services
- Intelligence services responsible for national security
- Services responsible for border control and supervision[66]

As a regulated service, PRS will be more jam- and spoof-resistant than the other signals. Unlike other Galileo signals, PRS will be accessible even when the other services are not available, making it possible to use Galileo asymmetrically. Not surprisingly, PRS seems ideally suited for security- and military-related operations.

Galileo receivers

No final decision has been taken regarding the final specifications and capabilities of future Galileo receivers. Just like its GPS counterpart, the quality and performance of the receiver is likely to be a function of the service requested. For example, those requiring commercial or PRS services will have superior performance and offer encryption capabilities. Concerning receiver interoperability, it is expected that a portion of the receiver market will offer both Galileo and Galileo/GPS dual receivers.

62 These signals are to be broadcast over the following frequency bands: E5A-E5B (1164-1215 MHz); E6 (1260-1300 MHz); E2-L1-E1 (1559-1591 MHz); Directorate-General Energy and Transport, EC.

63 This raises liability questions. For example, will the future operator be monetarily liable should the service fail at a given moment?

64 See EC and ESA, 'Galileo', May 2002, p. 20.

65 The International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO) will certify SoL. The GOC will require and guarantee the adoption of dual-frequency receivers for added reliability.

66 A complete listing is not publicly available; Communication from the Commission to the European Parliament and the Council - State of progress of the Galileo programme. Official Journal C248, 15 October, 2002, p. 7. None the less, it is very likely to include certain military personnel.

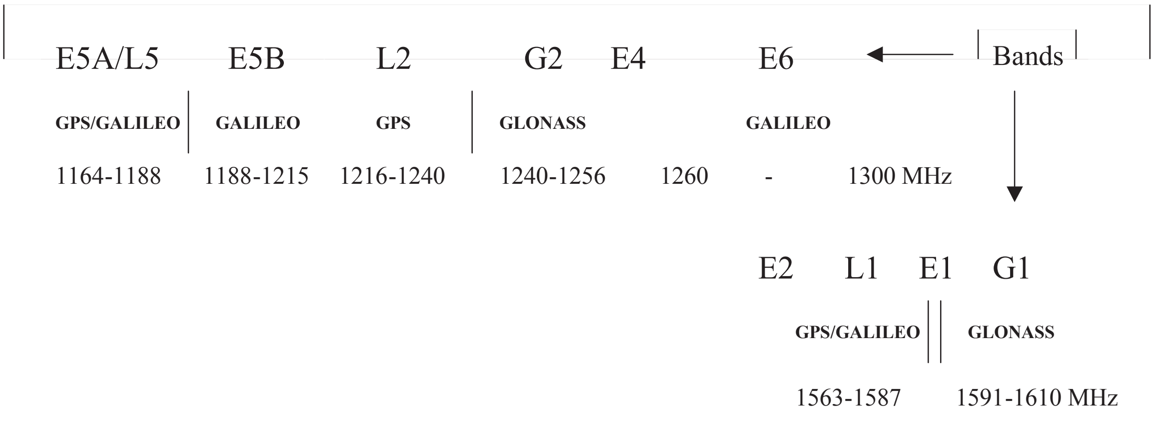


Figure 3: Summary of frequency bands and distribution

5

Galileo security applications and their implications

While Galileo is branded and will be launched as a civilian project, the dual nature of the system gives it a range of potential defence-related applications. These raise a host of security- and defence-related implications that require careful consideration. As mentioned earlier, security implications will arise even if the system remains a civilian project. From a broad perspective, Galileo will affect the nature of CSFP/ESDP, EU relations with the United States and the EU-NATO interactions. This chapter maps out these issues in greater detail and considers some of the 'unintended consequences' that may emerge as Galileo becomes operational.

5.1 Galileo and CFSP/ESDP

Once Galileo is operational, European policy-makers will have the option of using its NPT signals to boost the scope of both the Common Foreign and Security Policy (CFSP) and the European Security and Defence Policy (ESDP).[67] For the developing Rapid Reaction Force (RRF), access to Galileo would serve to enhance its operational performance. For example, during low-intensity Petersberg-type operations, Galileo could be used to monitor troop movements (given adequate tracking devices), facilitate the transport of supplies, establish perimeters, etc.[68] For high-end Petersberg operations requiring the use of force, the positioning system could be used for traditional GNSS tasks such as logistics planning, targeting and munitions guidance. Under both types of operations, reliance on the PRS signal would be advantageous given the possibility to use it asymmetrically.

Even if decision-makers decided against the military use of Galileo, the use of the RRF in any high-end Petersberg mission – which is more likely around the time Galileo becomes operational – will require contingency plans should opposing forces decide to exploit its positioning signals against European forces or interests. Precautions could include shutting down Galileo's open signals (although this would have substantial economic side-effects for the EU), introducing an artificial error or jamming all positioning signals in the area of operations.

However, should CFSP/ESDP embrace Galileo, European policy-makers would have greater possibilities to launch operations. While independent operations are unlikely to become the norm, there is the possibility that the United States may choose not to be part of some operations. Moreover, should Galileo be applied for ESDP purposes, the risks associated with signal loss from GPS at critical stages of an operation would be diminished, especially if the United States was involved in a concurrent mission elsewhere requiring GPS signal shutdown.

At the political level, an independent navigation and positioning system increases the leverage of EU CFSP. Specifically, independence from GPS monopoly gives Europeans greater weight during negotiations with the United

[67] ESDP has already been 'operationalised' through the EU Police Mission in Bosnia-Herzegovina. The EU took over the NATO mission (*Allied Harmony*) in Macedonia on 31 March 2003.

[68] The Petersberg Tasks include humanitarian and rescue tasks; peacekeeping tasks; and tasks of combat forces in crisis management, including peacemaking (referred to as 'peace enforcement' in other contexts). Art. 17.2 TEU.

States – especially if the systems are interoperable – since it affects the possibility to use signals asymmetrically.[69]

From a different perspective, ownership of a GNSS brings with it added responsibilities. While the European Commission considers Galileo a civilian system, other countries may not. They may see Galileo primarily as a military tool that could serve to advance their military objectives in some form or another. Since a large portion of Galileo's precise positioning signals will be openly available, any user – including terrorist cells and hostile countries – equipped with the proper receivers will have the option of using positioning data for military purposes such as targeting, ordnance guidance, etc.[70] At the operational level, this means that European policymakers need to be prepared to deal with the eventual unauthorised use of the system by third parties.

5.2 Galileo from the US perspective

From the US perspective, Galileo was initially perceived as a duplication of GPS offering questionable added value. In a letter of 1 December 2001 to NATO member governments, Deputy Secretary of Defense Paul Wolfowitz asked European military leaders to become more engaged in the Galileo process and not to let all the planning fall into the hands of the research and transport ministers. Wolfowitz also recommended that the system should not be deployed. If it were deployed, he recommended it be done in a manner allowing the United States to safely jam the Galileo signals without affecting GPS.

Once it became evident that the European Commission and ESA would forge ahead with Galileo in spite of US objections, the United States changed its tone. Presently, it accepts the system as long as no signal interference arises. Unfortunately, this position has led to disagreements between the two sides concerning the European decision to overlay one of its future PRS signals with the future M-code (military GPS). If not resolved satisfactorily, this dispute will have wide-ranging implications for the transatlantic link.

The M-code overlay dilemma

The United States has for some time voiced particular concern over European plans to overlay one of the two future Galileo PRS signals with one of the two future US military (M-code) signals at a specific modulation (BOC 10,5) in the high frequency band.[71] From the US perspective, an overlay with the M-code results in unacceptable risks to US and NATO personnel and assets since it no longer becomes possible to selectively jam one of two signals overlaid on a single frequency band using the same modulation without seriously degrading the other. The United States argues it would no longer have the capability to use GPS asymmetrically.[72] This inability to jam PRS receivers should need be is seen as a compromise of the GPS system, since it could lead to significant US casualties during wartime should opposing forces obtain access to the PRS signals or all signals are shut down.[73] From the EU perspective, the United States faces a similar control issue regarding third-party access to its future M-code receivers. Since October 1993, a dozen non-NATO countries and civilian agencies (examples ranging from US federal

[69] Under current plans, Galileo will be interoperable with GPS so that each system can work as a back-up for the other in the event of partial or complete failure by one of the two systems.

[70] For more, see Alexander Kolovos, 'Why Europe needs space as part of its security and defence policy', *Space Policy* (available online at www.sciencedirect.com).

[71] In technical terms, the modulation of the M-code signal is a binary offset carrier (BOC) signal with subcarrier frequency 10.23 MHz and spreading code rate of 5.115 M spreading bits per second – abbreviated as BOC(10,5) modulation.

[72] Underlining its determination to have an asymmetric possibility to use GPS, the United States (and soon NATO) plans to develop an electronic warfare system (NAVWAR) that will allow it to locally jam civilian signals while safeguarding access to the future GPS M-code.

[73] The United States is already considering alternative methods that can provide positioning services if GPS is unavailable (e.g. in urban areas) or if the system cannot be used. The Defense Advanced Research Projects Agency (DARPA) is currently trying to develop an Inertial Navigation System (INS) based on Micro-Electromechanical Systems. See www.darpa.mil/spo/SPO_handouts/MEMS_INS.pdf.

agencies to the Norwegian Police) have had some access to the military P(Y) code.[74]

From the European Commission's perspective, an overlay with the M-code is perfectly justifiable. There is limited space in the frequency spectrum, and the frequency used by the M-code provides the 'best performance in peacetime, particularly in terms of resistance and robustness, the best cost/benefit ratio, and the best guarantee of continuity and integrity.'[75] Moreover, to attain the PRS required sub-metre precision coupled with minimal interference, the signal needs two frequency bands that are spaced far apart, making the choice of the L1 (denominated G1) band even more imperative. At the 2000 World Radiocommunication Conference (WRC) held in Istanbul, it was decided that there was not enough bandwidth in the L1 band for all potential signals, effectively opening the way for overlaps.[76] It should be noted that while GLONASS also uses the L1 band, overlaying with its signal is not considered a viable option for Galileo, since it is based on a design that is significantly different from Galileo and GPS.

The European Commission currently sees no viable alternatives to BOC (10,5). The other frequently suggested option, BOC (14,2) modulation, would simply be less efficient and competitive. It is not currently known whether a BOC (14,2) signal can provide certain technical functions needed for smooth operation of the PRS signal. Of greater concern to European interests, however, is that a choice of BOC (14,2) would allow the United States to unilaterally jam PRS users, something it wants to avoid to ensure continuous signal access and the influence that comes with it.

The Commission also argues that it has followed the standard protocols to gain access to the frequencies in question. According to international regulations laid down by the International Telecommunications Union (ITU), frequencies available for satellite navigation do not belong to a particular country or system. As such, a country that wishes to use a frequency simply has to file an application for its use. If approved, the country or system gets a priority claim on its use. However, any other country can use the same frequency provided that it does not result in excessive electromagnetic interference with the other system. After two years of studies by European experts in electromagnetic interference, the Commission has concluded that the EU is capable of designing a PRS system that will not interfere with the GPS M-code.[77]

At the next WRC, to be held in June/July 2003, European decision-makers expect that the frequency plan already allocated to Galileo will be confirmed. With respect to system control, Europeans are confident that they can maintain a watchful eye on PRS receivers so that the system does not fall in the hands of unauthorised users. To minimise possibilities of wrongful use of PRS signals, access to the signals is to be controlled by 'an appropriate European body'. This organisation, which is yet to be defined, will exert control through its authority over the encryption system and the appropriate key distribution. At the individual level, PRS receivers will be strictly controlled – to the point that users will be identifiable by name. They will be traceable so that stolen receivers can be reported and disabled according to a predetermined procedure. However, it should be noted that military receivers are susceptible to smuggling, reverse engineering or decryption of the transmission keys. While this risk applies to GPS too, the addition of PRS receivers means that a greater aggregate number of receivers are susceptible to these threats.

[74] Communication from the Commission to the European Parliament and the Council – State of progress of the Galileo programme. Official Journal C248, 15 October, 2002.

[75] Ibid., pp. 7-8.

[76] The second PRS signal has enough bandwidth in the medium frequency band known as E6.

[77] Ibid., p. 24.

Implications for US homeland defence

Beyond the new challenges presented on the battlefield, Galileo will have implications for US homeland defence, including the development of a US national missile defence system. With missile delivery ranges steadily improving, it is only a question of time before US (and allied) territory can be reached from significant distances. As recently as February 2003, the CIA warned that the *Taepo Dong 2* (TD-2) missile 'could target parts of the U.S. with a nuclear weapon-sized payload in the two-stage configuration' and will have the 'range to target all of North America if a third stage were used'.[78]

Through the use of precise positioning, these threats could become more damaging. As an example, it has been calculated that commercially available GPS guidance can improve the accuracy of short- and medium-range missiles by approximately 20-25 per cent; for intercontinental ballistic missiles (ICBMs), GPS aiding can 'significantly enhance' accuracy by minimising the effects of boost phase inertial instrument errors.[79] Once Galileo is operational, outsiders will have access to a variety of additional positioning signals (besides GPS signals) that could be used to guide these types of munitions.

Even its freely available Open Service would be more than sufficient to do lasting damage if these groups can use Galileo NPT services to guide their munitions. For example, should hostile groups acquire a technology similar to the Joint Direct Attack Munition (JDAM) and adapt it to their missile technologies, any guidance signal could be used for their purposes – open signals would be more than sufficient.[80] It should be noted that these technologies are not too costly and therefore reachable by nations willing to invest in military technology. In the case of JDAMS, while development costs run in the millions, the average unit cost is currently $18,000.[81] Clearly, continued negotiations and collaboration between US and EU decision-makers will be necessary to address these types of threats.

5.3 Galileo and NATO

From the NATO perspective, Galileo presents several possibilities. On the one hand, the combination of GPS and Galileo signals will provide greater reliability and precision in military receivers. Thus, access to several positioning signals is likely to benefit NATO assets in future missions – especially those that may take place in urban areas or under heavy foliage. For the European members of NATO, the advent of Galileo may also give forces from EU countries under NATO command a more effective role or a greater say in the conduct of operations.

On the other hand, the availability of Galileo signals also raises concerns similar to those perceived by the United States. With no control over the PRS signal, NATO forces may not be able to guarantee situational awareness advantages in areas of operations. As such, they may have to operate under the assumption that opposing forces or terrorists may exploit PRS signals, signals that are unlikely to be jammed. While this scenario is unlikely given the large overlap between EU and NATO members, awkward situations may arise between members regarding which situations require jamming, degrading, or the shutting down of signals to ensure an asymmetric advantage. Unless these misgivings are dispelled, a wedge of concern may eventually materialise between non-EU NATO members and EU members regarding signal applications.

78 Statement for the record to the Senate Select Committee on Intelligence by Defense Intelligence Agency Director Vice Admiral Lowell E. Jacoby on 11 February 2003. http://www.dia.mil/Public/Testimonies/statement10.html.

79 G. Frost and I. Lachow, 'GPS-Aided Guidance for Ballistic Missile Applications: An Assessment', reprinted from *Proceedings of the 51st Annual Meeting of the Institute of Navigation*, RAND/RP-474, 1995.

80 The Joint Direct Attack Munition (JDAM) GBU-31 is a tailkit that can be attached to unguided 'dumb' bombs, effectively making them precision weapons through the use of the GPS guidance system.

81 http://www.fas.org/man/dod-101/sys/smart/jdam.htm.

5.4 Galileo system protection

A different type of security concern relates to the physical security of the Galileo system. As NPT services play an increasingly important role in the proper functioning of society, it is important to protect them from attacks. In the case of Galileo, this means ensuring adequate protection from external threats that may arise once it is operational. Galileo is likely to become a target for terrorists and others because of the economic ramifications its temporary shutdown or disruption would have. The most likely form of attack would be the jamming of the open signals or a physical attack on the ground stations. While unlikely, Galileo also faces threats from traditional military sources. Means of attack range from ground-based to space-based weapons.[82]

[82] Alternative options may materialise, including the use of electromagnetic radiation (in the form of an electromagnetic pulse) or using other satellites as a weapons platform.

6

Institutional challenges raised by Galileo

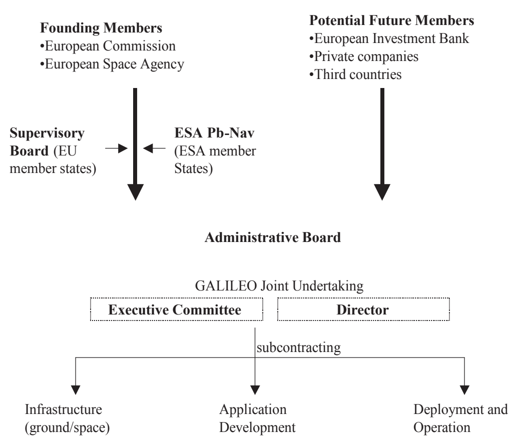
Galileo's military potential raises important questions concerning who can access the system. This chapter provides an overview of the current governance system, focusing on the defence side. It also highlights likely institutional challenges that may arise as Galileo becomes operational.

6.1 Current system governance

As previously mentioned, Galileo is a joint initiative of the European Commission and ESA.[83] On the Commission side, responsibility for the Galileo programme rests with the Directorate General for Energy and Transport. Within ESA, development responsibility lies with the Director for Applications Programmes.

The Joint Undertaking (JU), agreed in March 2002 by the Council of European Transport Ministers, is responsible for the management of Galileo's development phase. Planned to last until the end of 2005, it will also contribute to the deployment and operational phases of Galileo.[84] As Figure 4 shows, the JU consists of an Administrative Board, a Director, and an Executive Committee.

The Administrative Board is made up of representatives from the members of the JU. It is responsible for all strategic programming decisions including financial and budgeting areas. The Executive Committee consists of three members: an EC representative, an ESA representative and a representative assigned by the Administrative Board who has to come from the private sector. The Executive Committee is tasked to assist the Director and carry out the tasks it receives from the Administrative Board. The Director is the legal representative of the JU and ensures day-to-day management.



Note: ESA Pb-Nav stands for ESA's Programme Board for Navigation
Source: European Commission, Directorate-General Energy and Transport

Figure 4: Organogram of the Joint Undertaking

[83] The EC's initiative stemmed from a mandate provided by the EU Council of Ministers.

[84] The JU's operational lifespan may be extended by amendment of the statutes.

With a clear focus on the economic and partnership questions surrounding Galileo, the JU has limited guidance vis-à-vis security-related issues. While this is understandable given Galileo's civilian nature, it also raises concerns arising from the dual nature of the system. Although the JU is not directly responsible for security matters, it has entrusted an ad hoc Security Board to begin examining some of these issues.[85]

Until the end of 2002, the Security Board had not been formally established. In its absence, the Commission took the lead concerning security issues by independently convening security experts of the member states. During 2002, expert committee meetings chaired by the Commission were held in May, June, and September. After some EU member states raised concern over this arrangement, arguing that these meetings should be chaired by a member state representative or co-chaired with the Commission (fulfilling the role of Secretary), the Transport Council of 6 December 2002 formalised the Security Board. It is currently co-chaired by a representative of the EU Council Presidency and the Commission and has three main tasks. These are to:

- Provide expertise on technical matters regarding security (encryption).
- Assist the Commission in its negotiations with third countries by providing expertise (e.g. frequency sharing with the United States).
- Assist with the set-up of a future operational framework for security. This includes responsibility 'for the relationship in the event of a crisis to interrupt or restrict signal emissions', definition of authorised users and supervision vis-à-vis international commitments on non-proliferation and export control. [86]

To fulfil these tasks, the Board has set up four separate groups (headed by German, French, Italian and Spanish chairpersons) that are assisted by a team of experts.[87] It is planned that the Security Board will continue its activities until a Galileo Security Authority (GSA) is established. As part of the GSA, the Commission is now preparing a proposal to form a Galileo permanent and operation crisis centre that will be capable of taking the measures required (such as signal scrambling and interruption) in the event of a crisis.[88] The make-up of this body, in terms of membership and competencies, will have important implications for how Galileo might be used in security and defence matters. For example, should PRS signals be used during an operation, this body should be able to quickly shut off signals to unauthorised receivers (lost units, units unaccounted for, etc.). A short time horizon in the decision-making process would be required to limit potential negative outcomes stemming from unauthorised system use.

A vital issue that still needs to be clarified is the relationship between the Commission, EU member states, ESA and the Secretariat General of the Council, particularly the office of High Representative Javier Solana. The current arrangement provides limited input possibilities for the EU Council and member states that are ultimately responsible for CFSP and ESDP. This difficulty results from the peculiar institutional relationship between the Commission and CFSP/ESDP as well as diverging individual EU member state attitudes towards European involvement in security and defence affairs.[89]

---

85 Article 7 of Regulation 876/2000 (JU) stipulates that a Security Board will be set-up to deal with security matter concerning the Galileo system.

86 Communication from the Commission to the European Parliament and the Council – State of progress of the Galileo programme. Official Journal C248, 15 October, 2002.

87 http://www.eiwa.it/eiwaprojects10.html.

88 Information accurate as of 11 February 2003. Source: European Commission, Directorate-General for Energy and Transport. The Commission is planning to present a proposal to the Council on creating the future security body sometime in the summer of 2003.

89 Under Article 18(J8)(4) of the Amsterdam Treaty, the Commission is associated with the work carried out in the field of CFSP. Like any EU member state, the Commission may refer to the Council any question relating to CFSP as well as submitting proposals to the Council. However, the Commission does not have decision-making competencies with respect to CFSP and ESDP.

Under the current regime, it is clear that Galileo is not due to take part in defence-related activities starting in 2008. This is a political decision that cannot be taken by the Commission. While a final decision does not have to be made until the system is operational in 2008, it is important to begin thinking about these issues. There exist numerous security-related questions that cannot be solved quickly, e.g.:

- Who will decide if the service can be shut down/jammed during a crisis?
- What role would the potential crisis centre (that has the technical capability to shut down the system) have vis-à-vis disruption of the signal?
- If the shut-down/jamming decision is up to the Council, should the decision necessarily be taken by unanimity?
- Who would 'license' PRS signal users and monitor unauthorised use?
- If it is up to each member state to control access, who would ensure harmonised policies across EU member states?
- Who should negotiate with the United States and NATO in the event that the RRF or some other entity participates in a multinational operation?
- Should individual EU member states have access to PRS for their own military operations abroad?
- What would the PRS access policy be for individual EU member state(s) should an operation not be sanctioned by other member states (alternatively by the UN Security Council)?

Questions such as these require answers – especially if the system eventually gets defence-related applications.

6.2 Relations with the United States and NATO

An important institutional dimension that needs special attention concerns the appropriate forum for EU-US exchanges. A strong forum for negotiation and consultation is necessary to settle questions relating to the asymmetric use of signals, forms of utilisation during coalition operations, GPS/Galileo receiver specifications, and so forth.

On 5 December 2002, the Transport Council reinforced the Commission's position by inviting it to:

> [F]inalise the negotiations held with the United States of America on the basis of the negotiating directives agreed on in October 1999 and in close consultation with the Special Committee, with a view to achieving interoperability at user level and compatibility at system level, of both GPS and Galileo.[90]

While a Commission and ESA-led forum of negotiations has worked so far, some European governments (particularly non-EU allied) and US officials have expressed their preference for NATO serving as the forum for discussion. The United States has simultaneously requested that discussions move to a higher political level – possibly on a bilateral country-to-country level, involving the diplomatic and military authorities of member states and NATO.

A deadlock may materialise as the EC is intent on maintaining bilateral US-EU talks, bypassing other bodies such as NATO. From the Commission perspective, NATO is not the proper framework in which to discuss a programme whose ownership is in EU hands. However, the question remains what entities should represent the EU during EU-US bilateral talks – especially while the EC does not make decisions in the field of external security. Americans have voiced concern that they are not willing to discuss classified GPS issues, particularly those that have military dimensions, with EC counterparts.

With these considerations in mind, it will be important to consider the appropriate format for continued negotiations as security issues increasingly become part of the agenda. Only with a proper framework that ensures the participation of all European and US stakeholders can a fruitful discussion develop.

[90] Council conclusions on Galileo, 5-6 December 2002.

6.3 Relations with China, Russia and other nations outside NATO

Ever since the Council's decision to launch Galileo, several countries have expressed their interest in the programme. Most notably, both China and Russia see participation in the programme as a strategic objective.[91] In the Chinese case, Prime Minister Zhu Rongji has expressed China's interest in being fully involved in the Galileo project at the financial, technical, and political level.[92] The Chinese Ministry for Research has already come up with a list of areas of cooperation. In response, the Commission is set to provide a proposal for a directive on specific negotiations with China.

From Russia's side, there is a desire to develop the GLONASS/Galileo relationship concerning systems and standards. Ever since the Russia-EC bilateral summit held on 29 May 2002, both parties have decided to re-examine the scope of cooperation, given their mutual interest in 'expanding cooperation in terms of both developing technology and financial investment'.[93] In addition to promoting industrial and scientific links, both sides have agreed to negotiations aiming to conclude a cooperation agreement at the earliest possible opportunity.

Besides these countries, the EC has established contact with a host of other states. These include the EU candidate countries, the Mediterranean nations forming part of the Barcelona process, several Latin American nations, Canada, Australia, Japan, the Ukraine, and India.

Through Article 5 of the Regulation setting up the Galileo Joint Undertaking, third countries can form part of the Galileo project by becoming members of the JU. This has important implications, given the JU's extensive role in the development phase, including the early phases of the operational stage. While cooperation will help to facilitate financial and technical solutions for Galileo, there should be caution with respect to sharing applications that may be used for defence purposes. Again, the focus on Galileo as a civilian tool by the EC and ESA does not mean that other countries share that position. Particular areas of concern relate to the PRS technology, PRS receivers and the encryption methodology used. While the actual receivers are planned to be tightly controlled, there is a possibility that third parties might be able to tap into PRS independently once they have a good understanding of the system's architecture. The transfer of this technology to unauthorised hands – whether intentional or not – needs be avoided at all costs.

91 Communication from the Commission to the European Parliament and the Council – State of progress of the Galileo programme. Official Journal C248, 15 October 2002, p. 11.

92 China is clearly interested in a positioning system. It is independently developing a regional system adapted to its own needs and has applied to the ITU for access to dedicated GNSS frequencies.

93 Ibid., p.12

7

Conclusion and recommendations

This chapter summarises the study's main findings and offers a number of recommendations to address the emerging security challenges arising from Galileo.

Conclusion

Like its predecessors Ariane and Airbus, Galileo represents a unique example of European cooperation in pursuit of common strategic goals. Should it become operational in 2008, Galileo is likely to offer a range of services that will gradually transform European society and bring benefit to users worldwide. Galileo is planned to facilitate processes in industries ranging from the banking sector to oil exploration, enabling firms and civil society at large to benefit from increased safety, greater efficiency, a healthier environment and lowered costs.

As a dual-use system, Galileo will offer several applications in the security field. PNT services offer military planners and commanders a wide range of applications to manage assets, troops and munitions more effectively. Given its global coverage, Galileo will facilitate a large portion of these services for interested parties around the world, opening the door to uses that were not originally intended. This has ramifications for the EU and its allies – particularly the United States and other NATO countries. Even if decision-makers decide that Galileo should remain a civilian project there will be security issues that need to be addressed. Besides maintaining the physical integrity of the system to ensure continued economic security, policy-makers need to take measures to avoid its unauthorised use for military purposes.

Given the dual nature of the system, it is critical that European policy-makers consider the security dimensions of Galileo and take practical steps to limit its potential abuse and misuse. Finally, there is a need to resolve outstanding issues with the United States concerning interoperability levels between the two systems. The following recommendations are offered to address some of the emerging security implications of Galileo:

1. **Seriously assess the military- and defence-related aspects of Galileo**

Galileo continues to be heralded as a civilian project. In the long run, this posture is not only irresponsible but also dangerous. Decision-makers should take steps to consider the dual nature of Galileo to safeguard European economic security and limit unauthorised use. Even if Europeans want to see Galileo as a civilian project, others may not, potentially leading to catastrophic events in the future. An acknowledgement of the dual nature of Galileo is necessary before active steps can be taken to limit the potential for inadequate system use.

2. **Limit PRS signals for defence-related purposes**

PRS signals will offer the possibility to use Galileo asymmetrically. It is clear that PRS signals fulfil military requirements. Since it is already being reserved for government use, policy-makers should consider further limiting its availability to just military forces. Organisations currently identified to use PRS in the future, such as OLAF and EUROPOL, do not need the level of integrity and precision offered by PRS. Their needs should be more than amply covered through Galileo CS (Commercial Services).

3. **Provide the EU Council with a greater role for the application of PRS**

If Galileo is to play a role under the auspices of CFSP/ESDP, it is necessary that the EU Council, in particular the office of High Representative Solana or its successor, be involved to a greater degree. A new relationship needs to be forged between the Commission, ESA and the Council staff responsible for CFSP/ESDP. This relationship could be initiated through secondments, staff exchange or liaison officers.

4. **Expand the General Secretariat's capacity to deal with space issues**

To successfully involve the General Secretariat of the Council or its future equivalent, it will be necessary to expand the unit's policy or military staff organisation.

5. **Create a clear chain of command for Galileo**

This is a key ingredient for the successful operation of Galileo. While it is still early to visualise the required institutional framework given the ongoing work of the Convention as well as the Commission's proposals for the GSA, a clear governance system is needed between the EC, ESA, the Council and EU member states.[94] One option would be that:

a) The Commission handles the civilian side of Galileo.
b) The EU Council, in collaboration with ESA and the GSA/future operational crisis centre, handle the security dimension.
c) The External Relations Directorate-General takes the lead on bilateral or multilateral negotiations with third countries outside the ESA/NATO framework.
d) The JU coordinates day-to-day management, stressing an active role for the Supervisory Board.

6. **Establish a permanent EU-US framework to cover Galileo-GPS negotiations and applications**

A permanent forum or working group needs to be established between the EU and the United States to handle ongoing and future outstanding issues. It is important that this body be composed of decision-makers of comparable levels with the appropriate clearance. Discussions should range from frequency overlay negotiations to the practical steps required for the development of dual receivers so that end-users can benefit from greater precision and accuracy. A second working group, composed of military representatives from both sides, should be considered to coordinate transatlantic policies in time of crisis (e.g. asymmetric signals use and jamming).

7. **Take practical measures to protect the physical and electronic integrity of the system**

Given Galileo's military potential, the system needs adequate protection. Potential countermeasures should initially concentrate on the physical security of ground stations and satellite launch pads. Examples of such measures include increasing the number of security personnel at certain facilities and practising the damage-limitation steps to be executed in the event of an attack. In the longer term, an option to increase redundancy might be achieved by building an extra Control Centre to serve as back-up should one be shut down.[95] Spending more at the present time is unlikely to be cost-effective. However, in the distant future, countermeasures may be required against attacks on the space segment.

[94] Including institutional bodies/actors involved in the elaboration and implementation of CFSP such as the Military Committee, Military Staff, Situation Centre and Political and Security Committee.

[95] Several of these tasks would fall under the responsibility of ESA's Technical Centre (ESTEC). Located in Noordwijk (Holland), the centre works on technologies for the space segment and related ground elements.

8. **Establish a proper mechanism to guarantee that sensitive system information and technology does not leak to third countries**

Ideally, collaboration agreements with third parties should follow a conservative approach relying on control mechanisms to limit the transfer of information that may be used for military purposes. Until Galileo's military potential has been widely acknowledged, this will be an uphill battle. The control mechanism, most likely in the form of an independent 'auditing' group, would require personnel with both technical and security-related expertise.

9. **Formulate a European Space Policy (ESP)**

In the end, Galileo provides European policymakers with an opportunity to develop a long-term space policy.[96] In current circumstances, what are our objectives in space? What should our future aspirations be? What is the appropriate balance between civilian and military applications in space? As Galileo becomes operational, steps should be taken to create a vision to guide both Galileo and future European space ventures.

[96] Work on a European Space Policy is slowly taking form. A Green Paper was adopted by the European Commission on 21 January 2003 to 'initiate a debate on the medium- and long-term future use of space for the benefit of Europe and on policy options available.' The text will eventually serve as the backbone for a future action plan (White Paper). http://europa.eu.int/comm/space/doc_pdf/greenpaper_en.pdf.

Annexes

Abbreviations

AUTONAV	Auto-navigation
C/A	Course Acquisition
CFSP	Common Foreign and Security Policy
CS	Commercial Service
CTS	Command Tracking Stations
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
ESTEC	ESA's Technical Centre
EHF	Extremely High Frequency
ESDP	European Security and Defence Policy
EUROCONTROL	European Organisation for the Safety of Air Navigation
EUROPOL	European Police Office
FAA	Federal Aviation Administration
FOC	Full Operational Capability
GCS	Ground-based Control Complex
GLONASS	Globalnaya Navigatsionnaya Sputnikova Sistema (Global Orbiting Navigation Satellite System)
GNP	Gross National Product
GNSS	Global Navigation Satellite System
GOC	Galileo Operating Company
GPS	Global Positioning System
GSA	Galileo Security Authority
GSS	Galileo Sensor Station
ICAO	International Civil Aviation Organisation
ICBM	Intercontinental Ballistic Missile
IGEB	Interagency GPS Executive Board
INS	Inertial Navigation System
ITU	International Telecommunications Union
JDAM	Joint Direct Attack Munition
JPO	Joint Programme Office
JU	Joint Undertaking

Km	Kilometre
LAAS	Local Area Augmentation System
MEO	Medium Earth Orbit
MHz	Megahertz
MSA	Maritime Safety Agency
NASA	National Aeronautics and Space Administration
OLAF	European Anti-Fraud Office
OREGIN	Organisation of European GNSS Industry
OS	Open Service
PNT	Positioning, Navigation, and Timing
PPP	Public-Private Partnership
PPS	Precise Positioning System
PRS	Public Regulated Service
PwC	PricewaterhouseCoopers
QMV	Qualified Majority Voting
RF	Radio Frequency
RRF	Rapid Reaction Force
SA	Selected Availability
SAR	Search and Rescue
SME	Small and Medium-sized Enterprise
SoL	Safety-of-Life
SPS	Standard Positioning Service
SV	Satellite Vehicle
UERE	User Equivalent Range Error
VLF	Very Low Frequency
WAAS	Wide Area Augmentation System
WRC	World Radiocommunication Conference

Bibliography

Articles, books and working papers

- ‘U.S. May Stall GPS System’, *Defense News*, 10-16 June 2002, p. 3
- ‘Eppur si muove - or maybe not’, *The Economist*, 1 June 2002, p. 33
- ‘US steps up offensive against European rival to GPS’, *Space Daily*, 7 March 2002, www.spacedaily.com
- Barker, B., J. Betz, J. Clark et al. *Overview of the GPS M Code Signal*. US Air Force, The Aerospace Corporation and Mitre Corporation, 2000
- Bildt, Carl. ‘A Europe fragmented in space’. *Financial Times*, 31 December 2001, p. 9
- Campagne, Pascal. ‘Galileo and Security’, *Galileo’s World*, 1 June 2002, www.galileosworld.com
- De Jong, Kees. ‘Future GPS and Galileo Signals’, *GeoInformatics*, September 2002
- De Selding, Peter B. ‘Strong Run Seen for Galileo Race’, *Defense News*, 17-23 June 2002, p. 58
- De Selding, Peter B. ‘Russia Commits To Funding New Navigation Fleet’, *Defense News*, 7-13 January 2002, p. 19
- Dombay, Daniel. ‘NATO warns military could be at risk’, *Financial Times*, 21 June 2002, p. 2
- European Space Agency. Galileo: *Satellite System Design and Technology Developments*, November 2000
- European Commission and ESA. *Galileo: The European Programme for Global Navigation Services*, ESA Publication Division, The Netherlands, May 2002
- European Commission and ESA. *Galileo: Services and Applications*, presentation at EC/ESA Seminar on Space, Warsaw, 20 June 2002
- European Commission and ESA. ‘*Galileo: The European Programme for Global Navigation Services*’, http://europa.eu.int/comm/dgs/energy_transport/galileo/doc /galileo_brochure_may2002.pdf
- European Commission. *Towards a European Space Policy*, Communication from the Commission to the Council and the European Parliament, Brussels, 7 December 2001
- European Commission. *Communication from the Commission to the European Parliament and the Council*, Official Journal C 248, 15 October 2002
- European Commission. *Galileo: an imperative for Europe*, Information note, DG for Energy and Transport
- European Commission. *Galileo: the European project on radio navigation by satellite*, Information note, DG for Energy and Transport, 26 March 2002
- European Commission. *Green Paper: European Space Policy*. COM(2003) 17 final, 21 January 2003, http://europa.eu.int/comm/space/doc_pdf/greenpaper _en.pdf
- European Commission. *Space Industry Developments in 2000*, Brussels, 15 June 2001
- European Council. *Council Regulation (EC) No 876/2002 of 21 May 2002 setting up the GalileoJoint Undertaking*, Official Journal of the European Communities, 28 May 2002, L 138
- European Union. *Conclusion of the Transport Council of 26 March 2002 on the GalileoSatellite Radio-Navigation Programme*, 26 March 2002, Spanish Presidency, www.ue2002.es
- Frost, Gerald and Irwing Lachow. ‘GPS-Aided Guidance for Ballistic Missile Applications: An Assessment’. Reprinted from *Proceedings of the 51st Annual Meeting of the Institute of Navigation*. RAND/RP-474, 1995
- Galileo Council Conclusions, 5-6 December 2002
- Grant, Charles and Daniel Keohane. *Europe needs more space*, London, Centre for European Reform, 20 May 2002, www.cer.org.uk/pdf/newstatesman_space.pdf
- Hein, G.W. et al. *The Galileo Frequency Structure and Signal Design*, European Commission Signal Task Force, 2002
- Hein, Gunter W. *From GPS and GLONASS via EGNOS to Galileo Positioning and Navigation in the 3rd Millennium*, Survey Ireland, Winter 1999
- IISS. ‘Russia’s military satellites’, *Strategic Comments*, vol. 7, Issue 6, July 2001
- James, Barry. ‘U.S. Out of Line on Global Positioning, EU Says’, *The International Herald Tribune*, 19 December 2001, p. 1
- Kavvada, Catherine. *Galileo*, presentation at EC/ESA Seminar on Space, Warsaw, 20 June 2002
- Kolovos, Alexander. ‘Why Europe needs space as part of its security and defence policy’, *Space Policy*, www.sciencedirect.com
- Lake, Darren. ‘All go for Galileo?’, *Jane’s Defense Weekly*, 10 April 2002, p. 21
- Lembke, Johan. *The Politics of Galileo*, University of Pittsburgh, Center for International Studies, EU Center, Center for West European Studies, European Policy Paper no.7, April 2001
- Logsdon, John. ‘A security space capability for Europe? Implications for US policy’, *Space Policy*, www.sciencedirect.com

- Nardon, Laurence. *Galileo and GPS: Cooperation or Competition?*, The Brookings Institution, Center on The United States and France, June 2002, www.brookings.edu
- Nones, M., J-P. Darnis, G. Gasparini and S. Silvestri, *The Space Dimension of the European Security and Defense Policy*, Istituto Affari Internazionali, Rome, March 2002
- Nottingham Scientific Ltd. *Galileo: Friend or Foe? - Briefing*, Washington DC, 28 February 2002
- Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques, *Rapport sur la Politique Spatiale Française: Bilan et Perspectives*, Assemblée Nationale n. 3033, Sénat n. 293, 2-3 Mai 2001
- Pace, S. et al. *The Global Positioning System : Assessing National Policies*, Critical Technologies Institute, RAND MR-614-OSTP, 1995
- Pasco, Xavier. *Galileo: a corner stone of the European space effort*, The Eisenhower Institute, Occasional Paper n.1, June 2002, www.eisenhowerinstitute.org
- PricewaterhouseCoopers. *Inception Study to Support the Development of a Business Plan for the Galileo Programme - Executive Summary*, TREN/B5/23-2001, 20 November 2001
- Singer, Jeremy. 'U.S. Air Force Could Delay GPS 3 Launch', *Defense News*, 17-23 June 2002, p. 60
- Sirak, Michael. 'USA sets sights on GPS security enhancements', *Jane's Defense Weekly*, 16 January 2002, p. 30
- Technomar GmbH. *Structural Analysis of the European Satellite Navigation Application Segment, Final Report Executive Summary*, October 2000
- US Army Space and Missile Defense Command, *Army Space Reference Text 2000*, May 2000
- US Department of Defense. *Navstar GPS User Equipment Introduction*, September 1996
- US Department of Defense. *Space Technology Guide FY 2000-01*, Washington DC, 2000
- US Department of Defense. *GPS Standard Positioning Service Performance*, October 2001
- US Department of State *U.S. Global Positioning Service and European Galileo System*, 7 March 2002
- Vielhaber, J. and D. Sattler. 'Why Europe wants Galileo', *Internationale Politik*, vol. 3, Winter Issue, 2002
- Volpe National Transportation System Center. *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*, Final Report to the US Department of Transportation, August 2001
- Zyfer Company. 'SAASM and Direct P(Y) signal acquisition, a better way of life for the military GPS user', April 2002, www.zyfer.com

Websites

- www.esa.int
- europa.eu.int/comm/space/intro_en.html
- www.galileosworld.com/galileosworld/
- www.gpsworld.com
- mx.iki.rssi.ru/SFCSIC/english.html
- www.fas.org/spp/index.html
- www.redsword.com/gps/apps/general/misuse.htm
- www.trimble.com/gps/index.html
- europa.eu.int/comm/energy_transport/en/gal_en.html
- http://europa.eu.int/comm/space/doc_pdf/greenpaper_en.pdf
- www.igeb.gov
- gps.losangeles.af.mil
- www.navcen.uscg.gov
- www.spaceandtech.com
- www.spacedaily.com

Experts consulted

Jan Alhadeff	Council of the European Union
Carl Bildt	Former Swedish Prime Minister
Heinz Hilbert	European Commission, DG TREN E4 (Galileo)
Jean-Christophe Martin	European Commission, DG TREN E4 (Galileo)
Maurizio Melani	Italian Ambassador to EU Political and Security Committee
Xavier Pasco	Senior Research Fellow, Foundation for Strategic Research (FRS), Paris
Laurence Rist	European Commission, DG TRADE F1
Veniero Santoro	European Union Military Staff
Lars Wedin	European Union Military Staff

Occasional Papers

All *Occasional Papers*
can be accessed via the Institute's website:
www.iss-eu.org