Briefing 19 — October 2019

Satellites and their Applications

Galileo will operate with 27 satellites in orbit
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Summary

- *The applications of Earth-orbiting satellites impact all sectors of activity and greatly affect everyone's daily life. There have recently been many technological breakthroughs, with more still to come. Competition is global and significant economic and sovereignty issues are at stake.*
- *During the European Space Agency (ESA) Ministerial Council to be held on 27 and 28 November 2019 in Seville, Spain, the Member States will be called upon to take major decisions for the coming decade.*
- *In this perspective, we must ensure balance in French funding, which has historically prioritised launchers, in favour of support for technical innovation in satellites and the downstream end of the space ecosystem. As for launchers, we must clarify the European governance in order to coordinate our resources and maintain our scientific and industrial leadership.*

Mr. Jean-Luc Fugit, MP (National Assembly)

As described in the Office's Science and technology Briefing n°. 9, launchers attract attention by conveying an image of conquest to the public, alongside the stake of sovereignty in access to space that they represent.[1] Satellites, and especially their applications, are less well known, despite being of significant economic and social benefit. They impact all sectors of activity, production methods and value chains, and we all benefit from their services daily. Every day, each smartphone user takes advantage of the services provided by 40 satellites.[2]

Major economic trends

The space ecosystem's **added value** is essentially downstream, but it is difficult to measure and is not representative of its social importance. In particular, the estimated economic value of institutional activities is much lower than their real impact (research, observation, navigation, military telecommunications, etc.).[3]

Nevertheless, the market for applications is undeniably growing and driven by a virtuous cycle: technological breakthroughs are making increasing amounts of data available at a lower cost, offering new possibilities for services that generate new demands for data and, therefore, space infrastructure.[4] As a result, the trend is toward the vertical integration of activities where the downstream side calls the shots.[5]

Key figures for the space sector in 2018[(*)]:

- Downstream: commercial revenue
  - **€121.5 billion**: telecoms. (**+4.4%** over 5 years)
  - **€115.8 billion**: navigation (**+9%** over 5 years)
  - **€4.2 billion**: Earth observation (+**16.2%** over 5 years)
- Upstream: commercial and institutional revenue
  - **€19.5 billion**: manufacture of satellites
  - **€6.1 billion**: launcher manufacture and services

(*) Source: Euroconsult[6]

Many technological breakthroughs

The combination of "New Space"[7] (technological breakthroughs, the lower cost of access to space, the growth in the number of public and private players) and the digitisation of the economy ("Big Data",[8] artificial intelligence (AI), etc.) is leading to a series of major technological innovations.[9] The space sector is at a turning point and is evolving very quickly.

Telecommunication satellites are increasingly flexible and can now be **reconfigured**[10] using embedded processing and AI capabilities to adapt to market demands in real time, readjusting their assignments during their lifespan or even giving them a new life.[11] As a result, the model of custom-made and ondemand satellites is becoming obsolete, and many of them can now be standardised and produced more quickly (18 months instead of 3 to 5 years).

Furthermore, progress in nanotechnologies and the miniaturisation of electronic and mechanical components allow for satellites to be manufactured in smaller sizes and weights.[12] In a true paradigm shift, these **small, mass-produced satellites** can be launched in clusters and put into orbit by electric propulsion,[13] significantly reducing the cost of access to space.

Until the early 2010s, the model was based on big, high-capacity geostationary satellites used for television broadcasts or telecommunications and some few low-orbiting satellites for Earth observation. Now, miniaturisation and the mass production of low-cost satellites are leading to plans[14] for **constellations** of small satellites[15] in medium (MEO) or low earth[16] orbits (LEO) as well. Despite their smaller capacity (accuracy, power), these constellations have low latency[17] and a more frequent revisit rate.[18] But the business model for these constellations, which require a very large number of satellites to be effective,[19] still needs to be developed and optimised.

Plans for small satellite constellations

- Telecommunications
  - O3B (already operational): 20 MEO satellites
  - OneWeb: 648 LEO satellites
  - Kuiper: 3,200 LEO satellites
  - Leosat: 78 – 108 LEO satellites
  - Starlink: 2,000 – 10,000 LEO satellites
  - Telesat LEO: 117 – 300 LEO satellites
  - Kineis (internet of things): 25 LEO satellites
  - ELO (internet of things): 25 LEO satellites
- Observation
  - Blacksky: 60 LEO satellites
  - Northstar (space monitoring): 40 LEO satellites

Finally, technological breakthroughs in observation instruments are abundant.[20] Miniaturisation and technological innovation in the field of **embedded instruments** are key factors of competitiveness. In the field of telecommunications, using quantum encryption and optical telecommunications for data security[21] is being developed.

An increasing number of applications

We are always finding new applications in space: telecommunications, geolocation, Earth observation, meteorology and climate change, infrastructure monitoring, defence, and security as well as connected objects, health care and smart cities.

Satellites are a **telecommunications** breakthrough similar in scope to the arrival of mobile telephones and the Internet 30 years ago.[22] Sustained growth in data exchanges reinforces the need for satellites[23] and their coverage of land, sea and air as an integrated solution to a global infrastructure that includes terrestrial technologies. The growth of internet of things[24] further increases this need.[25] Satellite internet, while still underdeveloped, will cover sparsely populated, remote, or hard-to-access areas where installing fibre optics or 4G/5G antennas would be unprofitable.[26] Communication satellites are a serious solution to bringing high-speed internet everywhere at the same price as fibre optics, especially in rural areas and overseas territories.[27] By reducing or even eliminating a digital divide that is likely to increase with terrestrial 5G, they participate in land-use planning.[28] Space telecommunications are also helping many sectors to transform themselves, for example with the development of telemedicine.[29]

For **Earth observation**, satellites are already essential to monitoring the environment and understanding climate change,[30] thanks in particular to the European Copernicus programme:[31] 35 essential climate variables out of 53 are observed from space.[32] By using observations made from space, weather forecasts have made considerable progress,[33] providing strong economic and strategic impact. Spatial imagery data has also penetrated a wide range of domains, including agriculture,[34] finance,[35] economics,[36] and insurance.[37] Many innovative space missions are being developed to obtain new data on the atmosphere and our environment, including anthropogenic CO_2.[38]

Geolocation is being used throughout all types of transport:[39] land, sea and air. Europe's Galileo geolocation system, in conjunction with EGNOS,[40] can now be used by any recent smartphone owner. One billion devices with a Galileo chip have already been sold.[41] The Galileo signal provides much better accuracy than the American GPS system (one meter versus ten). Galileo's accuracy and complete coverage will be needed to develop self-driving cars, ships and trains.[42] In air transport, satellites already facilitate navigation and will allow air connectivity for passengers and the cabin crew. One day, they may even be used to manage air traffic.

The **ground segment**[43] of the space sector is essential to developing satellite applications. France is well positioned in the satellite command and control segment as well as in scientific data processing. On the other hand, it is almost absent in the "consumer" device market allowing customers to receive data from space telecommunications (satellite internet, for example).[44]

A new ecosystem

Thanks to cloud computing,[45] owning expensive infrastructure is no longer needed to be able to analyse spatial data. Furthermore, lower construction costs allow new players to emerge.[46] This fosters the rise of a new **start-up** ecosystem alongside the traditional industrial contractors ("primes")[47] and makes space and its applications accessible to everyone.[48]

Since 2015, the state-industry coordination committee on space (COSPACE)[49] has set up support structures led by competitiveness clusters with the aim of identifying innovative digital service projects using spatial data. Seven "boosters"[50] have been created in France in the mainland and overseas territories modelled on the *Satellite Applications Catapult* programme at the British Space Agency. They are particularly useful for bringing together the space, digital and sectoral applications.[51] Currently funded out of the competitiveness clusters' budgets, boosters would surely benefit from having dedicated funding.

Space agencies are setting up support actions for research and technology (R&T) and innovation. ESA has created 20 Business Incubation Centres (BIC) in 17 European countries.[52] It manages the ARTES programme which supports private companies' projects in telecommunications satellites and applications.[53] Since opening an innovation, applications and sciences department in 2016, the CNES has developed two project support platforms[54] and has launched the Connect-by-CNES scheme to encourage the spread of space technologies to all sectors.[55] It helps to fund them by supporting the CosmiCapital investment fund, for example, whose goal is to raise €100 million.[56]

Additionally, in the face of significant US and Chinese capabilities and funding,[57] some are calling for protective measures[58] to be implemented. A **European preference**[59] should be put in place for institutional satellite orders and the purchase of spatial data.[60] Beyond this, in a competitive and globalised market, it seems necessary to support industrial sectors and innovation by making them more competitive. This requires providing funding at the moment the risk inherent in breakthrough technologies is taken. Only a sustained level of investment in R&D will allow European industry to retain its leadership.

Issues of sovereignty and security

Mastering key technologies is the condition to maintaining a French and European ecosystem with operational autonomy and control of the data source.[61] Satellite telecommunication services are an immediate backup solution should terrestrial infrastructures be destroyed (natural disaster, war, cyberattack, etc.).[62]

The open data policy in meteorology and Earth observation has obvious advantages in terms of spreading information and allowing for multiple applications. But large American (GAFAM)[63] and Chinese (BATX)[64] technology companies have understood the stakes of spatial data and risk capturing added value. This is the case with free Copernicus data funded by European taxpayers. Indeed, American tech companies are the best performers in developing AI tools and services and cloud computing[65] more generally to efficiently handle massive amounts of spatial imagery data.[66] To avoid this data's added value being siphoned abroad and to protect its most sensitive uses, Europe needs a high-capacity **sovereign cloud** computing provider that allows the downstream ecosystem to independently process and manage spatial data.[67]

Special attention should be paid to the resilience of satellite systems, the security of spatial data, and the resulting **respect for privacy**, notably because of American tech companies' participation in satellite networks. The dependence on space systems is real but often poorly understood. Background work is needed to evaluate it and offer security and redundancy (space/ground). Here as elsewhere, **cybersecurity** must be a constant concern.

Space defence and protection

Space technologies are **dual**. They provide our armies with secure communications, intelligence, and navigation.[68] Despite the treaty ensuring the peaceful use of space,[69] no one is safe from the risks of hacking, jamming, dazzling, taking remote control, or destruction of satellites.[70] To take these new risks into account, the government is considering a draft revision of the 2008 law on space operations[71] which could be submitted to French Parliament in 2020.[72] In a speech on 13 July 2019, French President Emmanuel Macron announced the creation of an air and space force with a "great space command".[73]

In addition, the development of private mega-constellations increases the risk of **space debris** and collisions.[74] It is urgent that Member States establish and enforce a common set of rules (in an international treaty, for example)[75] and provide appropriate funding to "clean up" the thousands of pieces of debris present in various orbits.

The use of radio frequencies

Radio waves are at the heart of how all satellite services operate.[76] But the space sector is not alone in using radio waves, which are also essential for terrestrial telecommunications. These many uses require **global coordination** of emissions, which are managed by the International Telecommunication Union (ITU), to avoid interference between signals. We must ensure that the frequency bands allocated to terrestrial 5G do not encroach on those used for current and future satellite services, particularly for very high-speed broadband connectivity projects in rural areas or for meteorological observations.[77] Moreover, as frequencies can be used for harmful purposes, France would benefit from a civilian tool that monitors how frequencies are used in space.[78]

Governance

The governance of European space policy is particularly complex (administrations and companies)[79] and sometimes a source of inefficiency.[80] Of course, for satellites and their applications, ESA's rule of **geographical return** poses fewer problems than for launchers,[81] but it breaks up the European industrial production apparatus and skills and gives priority to national interests over competitiveness and global ambition.[82] A true European vision must be preferred.

Financing

In the Multiannual Financial Framework of the European Union (2021-2027), the European Commission proposes €16 billion (compared to €11 billion between 2014 and 2020) for space.[83] While it is important to ensure the continuity of the Galileo and Copernicus programmes, it is regrettable to note the limited resources devoted to the development of innovative programmes (3.1%), despite a period full of breakthroughs.[84]

The **ESA ministerial council** on 27 and 28 November 2019 will be a moment of important budgetary decisions (2020-2022).[85] In France, while preparing the draft finance act for 2020 and the three-year budget plan, the group of French aeronautical and space industries (GIFAS) and CNES together identified three scenarios for the French contribution to ESA (2020-2022), ranging from €2.2 to €3.1 billion.[86] According to manufacturers, the low-end scenario would lead to irreversible losses of skills and jobs and French leadership in the European space programme. Supporting a contribution as close as possible to the higher amount (€3.1 billion), close to what might be the German contribution, in the French budgetary debate would be appropriate. It will be important to ensure that the needs identified by COSPACE for supporting the competitiveness of the satellite telecommunications industry and satellite applications in general will be funded through the appropriate budgetary channels.[87]

Recommendations

In conclusion, the following recommendations can be made:

- Organise a **use of the spectrum of frequencies** that ensures that the growth of terrestrial 5G networks does not hamper current or future satellite communications or spatial observation capabilities, such as in meteorology;
- strengthen our space **defence** strategy to protect our vital satellites and ensure the security of space-based data;
- define a legal and technical framework for the use of European data by European players, notably to foster high-capacity **sovereign cloud computing** solutions in Europe;
- **balance public funding** between major domains in space, with the launchers that have historically enjoyed large budgets,[88] and the satellites and downstream ecosystem which create more value.
- simplify, clarify, and optimise the **governance** of space in a coordinated approach with companies, national space agencies, ESA, and the European Union to make it more effective in serving our scientific and industrial leadership.

The OPECST's websites:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst/

Experts heard

Mr. Gilles BRÉGANT, General Manager, Mr. Eric FOURNIER, Director of Spectrum Planning and International Affairs, Mr. Thomas WELTER, Head of the Regulatory and Orbit/Spectrum Resources Department, French national frequencies agency ANFR

Mr. Patrice BRUDIEU, Space Adviser to the Director General, Head of the Space Policy and Defence Department, Ms. Christele DONADINI, Space Industrial Strategy, Mr. Alban DUVERDIER, Deputy Head, Ms. Isabelle BENEZETH, Inter-Ministerial Co-ordinator, Copernicus and GEO, Research and Innovation Strategy Service, Directorate-General for Research and Innovation (DGRI), Ministry of Higher Education, Research and Innovation (MESRI), and Mr. David COMBY, Interdepartmental Coordinator for the European GNSS Programmes, Ministry of Ecological and Solidarity Transition (MTES/CGDD/DRI)

Mr. Leonard COX, Deputy Chairman of Public Affairs and Corporate Social Responsibility (CSR), Mr. Tristan NITOT, Deputy Chairman of Advocacy, Mr. Gaël MUSQUET, Ethical Hacker, Qwant

Mr. Gilles DAWIDOWICZ, Google Maps Platform Manager for France, Benelux, and Africa, Ms. Floriane FAY, Institutional Relations Manager, Google

Mr. Antoine DENOIX, Managing Director of AXA Climate, a unit of Axa Next

Mr. Olivier DUBUISSON, CEO of CapDecisif Management

Mr. Jean-Loïc GALLE, CEO of Thales Alenia Space (TAS), Mr. Riadh CAMMOUN, VP for Public & Regulatory Affairs

Mr. Jean Marc GARDIN, CEO of Telespazio France and Deputy General Manager of Telespazio Group

Mr. Pierre IZARD, Deputy Managing Director, Rail System and Technologies, Ms. Laurence NION, Parliamentary Advisor, Mr. Patrice LUCCIARDI, TECH4RAIL Project Manager (Innovation & Research Department), SNCF

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Mr. Jean-Yves Le GALL, Chairman of CNES, Mr. Gilles RABIN, Director of Innovation, Applications, and Science, Mr. Pierre TRÉFOURET, Principal Private Secretary to the Chairman

Ms. Christine LEURQUIN, Deputy Chairman, Public Relations, SES, Mr. Alexandre DE MONTESQUIOU, Associate Director, AI2P, consultant for SES

Mr. Phil MONBET, Deputy Director of Pole Mer Bretagne Atlantique, General Delegate of the Morespace booster

Mr. Alain RATIER, CEO of Eumetsat

Ms. Magali VAISSIÈRE, Director of Telecommunications and Integrated Applications, Head of the European Centre for Space Applications and Telecommunications (ECSAT), and Mr. Christophe ALLEMAND, *Institutional Programmes Officer*, Telecommunications and Integrated Applications Directorates, European Space Agency (ESA)

Experts consulted

Ms. Florence FUSALBA, manager of industrial partners for space and aeronautics, innovation laboratory for new energy technologies and nanomaterials (LITEN), CEA
Mr. Pierre LIONNET, Eurospace
Ms. Corinne MAILLE, Deputy General Manager, Telespazio France
Mr. Giao-Minh NGUYEN, Open Cosmos
Mr. Michel SCHELLER, Chairman of the Aeronautical and Astronautical Association of France (3AF)

Visit on the topic of space in Toulouse on 2 and 3 October 2019

CNES and other space actors:
Mr. Jean-Claude Dardelet, Deputy Chairman of Toulouse Métropole, Deputy Chairman of Cité de l'Espace; Mr. Jean-Baptiste Desbois, Director of Cité de l'Espace; Ms. Caroline Laurent, CNES, Director of Orbital Systems; Mr. Frédéric Pradeilles, CNES, head of the Toulouse Space Centre, Director of Digital Issues and Operations; Mr. Pierre Trefouret, CNES, Principal Personal Secretary to the Chairman; Mr. Jean-Claude Souyris, CNES, Deputy Director of the Innovation, Applications and Science Branch; Mr. François Alter, CNES, Project Manager in the Finance Department; Mr. Albert Cerro, Thales Alenia Space (TAS), Director of the Toulouse site; Mr. Philippe Dandin, Météo France, Toulouse centre; Ms. Stéphanie Limouzin, CLS (satellite location collection), Deputy Director General; Mr. David Henri, Exotrail, co-founder and CEO

Airbus Defense & Space (ADS):
Mr. Jean-Marc Nasr, Chairman of ADS, Mr. François Lombard, Chairman of Airbus Intelligence, Mr. Alain Wagner, Director of Space Institutional Sales, ADS; Ms. Annick Perrimond du Breuil, Director of Parliamentary Relations, Department of French Public Relations, Airbus group

Nova booster of the Aerospace Valley competitiveness cluster:
Mr. Marc Péré, Space Project Manager, Mr. Philippe Lattes, Deputy Director of the Space Sector

Contributions

Académie de l'air et de l'espace (AAE); Académie des technologies; Association aéronautique et astronautique de France (3AF); Eutelsat; Euroconsult; Orange group

References

[1] *Science and technology briefing on "Reusable Space Launchers" presented on behalf of OPECST by Mr. Jean-Luc Fugit in January 2019: http://www2.assemblee-nationale.fr/content/download/74092/759161/version/4/file/Lanceurs+r%C3%A9utilisablespages+V12.6.pdf*

[2] *Visit to the Airbus Defence & Space (ADS) site in Toulouse on 3 October 2019; statement by Mr. Alain Wagner.*

[3] *A thesis on downstream encryption is underway at the Bureau d'Economie Théorique et Appliquée (BETA, Office of Theoretical and Applied Economics) at the University of Strasbourg, co-funded from CNES and Telespazio.*

[4] *According to Euroconsult, the total weight of satellites launched between 2008 and 2017 amounts to 2,223 tonnes (for 1,019 satellites launched). Projections of the total weight of satellites to be launched over the 2018-2027 period amount to 3,069 tonnes (for 3,323 satellites), representing growth of 38% of the total weight launched and three times as many satellites put into orbit. Source:* Euroconsult Satellites to be built and launched, 2018 Edition.

[5] *According to an "as a service" model.*

[6] *Source:* Satnav - Euroconsult Satellite Value Chain (using the public report from the GSA called the GNSS Market Report), 2018 Edition *;* EO - Euroconsult Satellite-based Earth Observation Market Prospects, 2019 Edition *;* Satcom - Euroconsult Satellite Connectivity and Video Markets Survey, 2019 Edition (http://www.euroconsult-ec.com/)

[7] *New space or NewSpace, since the end of the 1990s.*

[8] *Bid Data or Big data, also since the end of the 1990s.*

[9] *Consultation with Ms. Corinne Mailles, Telespazio.*

[10] *For example, ADS's Eutelsat Quantum satellite and the SES17 and Konnect VHTS satellites developed by Thales Alenia Space (TAS).*

[11] *Interactions with satellites in orbit (refuelling, repairs in space, etc.) may become widespread, especially thanks to 3D printing which is particularly suited to producing small runs of complex and spare parts in space. However, we must remain cautious this model's technical feasibility and business model have yet to be proven.*

[12] *They are called minisatellites when they weigh less than 500 kg, microsatellites when less than 100 kg, and nanosatellites when less than 10 kg.*

[13] *This is how the Starlink and OneWeb constellations were launched. Other technologies that use dedicated launchers exist. Cluster launches using big launchers are low cost but offer low accuracy offset by electric propulsion that readjusts their orbital position. Small launchers, reserved for small satellites such as those from Rocket Lab, are precise but more expensive. We can see that the satellites' evolution has concrete consequences on how launchers are configured.*

[14] *Everything suggests that the future satellite infrastructure will combine constellations and geostationary satellites for both the business and institutional markets.*

[15] *Euroconsult's contribution: "Between 2009 and 2018, the average number of small satellites (less than 500 kg) launched per year was 147. The top three applications for these small satellites (as a percentage of the total number launched over the period) were technology (40%), Earth observation (35%), and information (13%). Between 2019 and 2028, the average number of small satellites launched per year (less than 500 kg) is estimated at 859. The top three applications for these small satellites (as a percentage of the total number to be launched over the period) will be telecommunications satellites (49%), Earth observation (19%), and information (14%). "Technology" applications include all the R&D projects that seek to test new technologies. "Information" applications pertain to satellites whose task is ensuring satellite-to-satellite communication (Machine to machine - M2M) and collecting data from terrestrial, airborne, and atmospheric sensors.*

[16] *- GEO (Geostationary Earth Orbit or Geosynchronous Equatorial Orbit): geostationary orbit, 35,786 km above the Earth.*
- LEO (Low Earth Orbit): low orbits generally between 500 and 1,000 km.

- MEO (Medium Earth Orbit): intermediary orbits traditionally around 20,000 km (GPS, Galileo, etc.), but other altitudes can be used (the new O3B constellation, for example, is in MEO orbit at 8,000 km altitude).

http://www.cnes-csg.fr/automne_modules_files/standard/public/p10688_2fd578009e14ecf8e083c10a877b6060CNESMAG-Poster-GEO-MEO-LEO-v2.pdf

[17] *Low latency (transmission delay) is an important characteristic for telecommunications.*

[18] *The frequent revisit rate improves the quality of the data obtained by the observation satellites.*

Hearing from Philippe Keckhut, Director of the LATMOS Laboratory (UMR8190), Deputy Chairman of Innovation at the University of Versailles Saint-Quentin in Yvelines UVSQ: "The 'Nanosatellites' and 'AI" approaches represent a historic breakthrough. The lower launch costs are a driving force in making it more competitive to implement miniaturised space systems. The development of nanosatellites weighing just a few kilos represents a tremen-

dous technological and scientific opportunity. In just a few years, these small platforms combined with miniaturised sensors have democratised access to space and made mission development easier. Sensors can be manufactured in universities and research laboratories. However, these new technologies require a very high level of expertise, which fosters partnerships between research organisations and the private sector.

Today's scientific problems require observing the Earth at several points in the world simultaneously and covering several parts of the diurnal cycle. Only a constellation of satellites is capable of this. The AI applied to the satellite data allows us to imagine a new era for Earth observation. It allows us to take into account measurement, drift, and non-linearity biases to avoid complicating and overloading the measurement devices in orbit and to obtain overall performances similar to those of larger satellites."

[19] *The number of satellites required to operate a constellation strongly depends on the altitude of its orbit. Constellations in MEO require far fewer satellites (less than 100) than most LEO constellations (several hundred or even thousands of satellites). Furthermore, these satellites have a shorter lifespan and need to be replaced more frequently.*

[20] *Observation in field of hyperspectral imaging; the development of optical sensors with a resolution up to 30 cm; very large mirrors that allow for observation from geostationary orbit, and, generally, an improvement in the observational satellites' revisit rate and accuracy.*

[21] *Spatial optical telecommunications is a category of space telecommunications based on using (infrared) lasers for data transmission. They have the advantages of reduced power required for transmission, a reduced risk of interference, and faster transmissions. On the other hand, they require extreme targeting accuracy and are sensitive to atmospheric disturbances (clouds, etc.). The high speed that these communications allow make them particularly interesting for ground-to-aircraft and intra-constellation links. The first trials date back to 2001, but the technology is still in the experimental stage. France is one of the leaders in this field.*

[22] *Hearing of Mr. François Alter, CNES.*

[23] *Hearing of Mrs. Christine Leurquin, SES.*

[24]*Science briefing on "Internet of things" presented on behalf of OPECST by Mr. Didier Baichère in March 2018: http://www2.assemblee-nationale.fr/content/download/65396/664019/version/8/file/note+1+-+4+pages+objets+connectes.pdf*

[25] *Using hybrid connected objects whose information can be received by terrestrial and satellite networks, Sigfox will expand beyond the 65 countries it already covers to reach the entire world with Eutelsat's ELO constellation (https://www.sigfox.com/en). The Kinéis project led by CLS and supported by TAS is based on a constellation of 25 nanosatellites using a unique communication technology that will be put into orbit in 2022 (https://www.kineis.com).*

[26] *Contribution of the Academy of Technologies concerning operator costs: "In France, satellites offer a network connection cost up to four times lower than fibre optics in low-density areas (€1,000 for satellite compared to €4,000 on average for fibre to connect the last 5% of the French population does not have it to the network: 1.5 million households. Note that the cost of access to fibre optics increases exponentially for the last homes to be connected)."*

[27] *After the commercial failure of Globalstar or Iridium's first-generation telecommunication satellites, new generations of telecommunications satellites should provide very high-speed internet in all regions at the same cost as fibre optics, particularly in mainland rural areas and overseas territories.*

France is already covered by the Nordnet (Orange subsidiary) satellite broadband internet offer (which relies on Astraconnect satellites operated by SES and the KA-SAT satellite operated by Eutelsat), albeit with high latency, bandwidth with data transfer rates of up to 22 Mbit/s in download (and up to 30 Mbit/s for professionals) whose prices are nevertheless the same as land-based offers (https://www.nordnet.com/connexion-internet/internet-satellite). A contribution from Orange gives details on the cost of Internet access by satellite, which is subsidised by the government and local authorities for end customers: "The amount the end customer pays for Internet access by satellite is between €330 and €530 excl. VAT, depending on whether the customer decides to purchase the access kit (at about €330 excl. VAT) and install it themselves (like 50% of subscribers) or to have it installed by a professional (at a cost of about €200 excl. VAT). These costs are borne by the end-user but may be partially or totally reimbursed by government aid (under its "digital territorial cohesion" scheme: https://www.amenagement-numerique.gouv.fr/fr/comment-beneficier-dune-offre-cohesion-numerique) and/or subsidies provided by local authorities (https://www.nordnet.com/internet-satellite/national)".

Eutelsat is developing a state-of-the-art, very high-capacity, geostationary satellite system called KONNECT VHTS for very high-speed fixed-satellite service and in-flight connectivity for commercial aircraft in Europe (https://www.eutelsat.com/fr/sites/eutelsat-internet/home/satellites/future-launches.html#konnect)); the satellite, expected to be commissioned in 2022, will be built by TAS and distributed by Orange and Thales (https://www.thalesgroup.com/fr/monde/espace/press-release/eutelsat-commande-konnect-vhts-un-satellite-de-nouvelle-generation-pour).

[28] *The "France very high seed" plan (https://www.francethd.fr/) has shown benefits for business, health professionals, education and learning, culture, and entertainment.*

[29] *In France, the MEDES (Institute of Medicine and Space Physiology), the CNES's subsidiary for healthcare, uses space telecommunications to provide fixed telemedicine or mobile medical remote imaging (lorries): http://www.medes.fr/fr/index.html.*

[30] *ADS's Starling app tracks forest changes, for example tracking and certifying palm oil crops for large food corporations (https://www.intelligence-airbusds.com/en/8273-airbus-and-partners-launch-starling-satellite-service-after-successful-pilot-phase-with-ferrero-and-nestle). CLS's ALMACEN project helps fight environmental crime and illegal trafficking (illegal fishing, trafficking, transhipment, etc.) involving the maritime sector (https://www.cls.fr/cls-pret-a-relever-defi-de-croissance-bleue/). There are also tools for surveillance and disaster relief, such as the Regional Image and Remote Sensing Service (Service régional de traitement d'image et de télédétection, SERTIT) at the ICube laboratory in Strasbourg (https://plateforme.icube.unistra.fr/sertit/index.php/Accueil).*

[31] *Copernicus: 7 satellites are already in orbit, and 12 will be in the near future. 6 operational environmental monitoring services are available to Copernicus users. For example, Mercator Ocean International operates the operational oceanography service. Atmospheric chemistry and climate change are entrusted to ECMWF.*

[32] *Hearing of Mr. Alain Ratier, Eumetsat.*

[33] *Hearing of Mr. Alain Ratier, Eumetsat: "Geostationary meteorological satellites have significantly improved the accuracy of predictions of fast-developing local phenomena, while polar-orbiting satellites and advances in computer models have reduced global forecasting by 4 days in 20 years. The reliability of forecasts a week out are equal to those of 2-3 days 20 years ago. Ocean and atmospheric composition forecasts have also become operational thanks to the Copernicus satellites."*

[34] *Satellites support the development of precision farming by controlling the quantity and surface of plant protection products applied. 18,000 farmers have subscribed to ADS's FarmStar app, which maximises yields by leveraging spatial and aerial data: https://www.myfarmstar.com/ . The "Assurance*

Prairies" application, also developed by ADS, protects fodder. These satellite tools could be used to monitor the common agricultural policy (CAP) and its environmental changes.

[35] *For example, the American company Orbital Insight (https://orbitalinsight.com/products/go-energy/) provides information on the quantities of oil stored in different countries, particularly China, which has consequences on oil prices.*

[36] *With an optical precision of 30 cm, we can count the number of cars in a supermarket's parking lot and estimate its turnover in real time.*

[37]*The Axa Climate unit at insurer Axa uses spatial observations to insure its farm customers against climate risks using a "parametric" insurance model. This model relies on continuously generated data (meteorological sensors, spatial observation data, etc.) that triggers instant compensation when an anomaly is detected (hail, storm, etc.).*

[38] *Six high-priority missions for the Copernicus programme are being developed: one to identify anthropogenic CO_2 emissions, three missions to monitor the polar regions, one mission for biodiversity, and one for agriculture. The Copernicus Sentinel 4 and 5 satellites will be used to measure air quality, stratospheric ozone, and solar radiation. (https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-4_and_-5).*

At the national level, the CNES's MicroCarb (https://microcarb.cnes.fr/fr/microcarb/en-resume/accueil) and MERLIN (Methane Remote Sensing Lidar Mission) (https://merlin.cnes.fr/fr) projects, aimed at measuring the distribution of CO_2 and methane on a global scale, will help to map sources and sinks. It is expected that these programs will be technologically ready in 2024 and operational by 2030 and integrated into future Sentinel satellites, for example to help set up a carbon tax and respect international commitments.

[39] *Geolocation can be applied in a wide range of fields, for example in managing fleets, trucks, and containers.*

[40] *EGNOS:* European Geostationary Navigation Overlay Service. *This is a complementary European geostationary satellite navigation service developed by TAS.*

[41] *Hearing of Jean-Loïc Galle, Thales Alenia Space.*

[42] *SNCF has joined forces with CNES to use satellite data for railway purposes (a collaboration that falls within the framework of SNCF's innovation programme launched in 2016 called Tech4Rail: https://tech.sncf.com/programme/tech4rail/). Accurate positioning of trains would allow for "20% more trains in circulation" (Hearing from Pierre Izard, SNCF, and Patrice Lucciardi, Tech4Rail, SNCF) and improve security and costs (the expected savings are about €100 million, according to David Comby, MTES). Satellite imagery can optimise monitoring of the rail network (vegetation, hydrological risks, fine monitoring of ballast distortions with an accuracy of less than one centimetre, etc:) and, to a lesser extent, telecommunications for passengers and crews. The savings these solutions generate could noticeably change the business equation of certain rail lines.*

[43]*Terrestrial infrastructure and services are indeed essential for commanding and controlling the satellites in orbit as well as for using the data they provide (collecting and processing observational data, receiving telecommunications, etc.).*

[44] *Hearing of Mr. Alban Duverdier, MESRI.*

[45] *Cloud computing consists in providing a set of computer services (for example, storage and data analysis capabilities) through servers made available to remote customers.*

[46] *Students design nanosatellites, and "ethical hackers" (hearing of Qwant managers) develop space solutions on a shoestring budget.*

[47] *In Europe, the two historic satellite manufacturers are Airbus Defense and Space (ADS) and Thales Alenia Space (TAS). ADS operates upstream (satellite building) and downstream (operations) of the sector. The Thales and Leonardo (Italian) corporations have jointly created two subsidiaries: TAS for construction and Telespazio for operations. Finally, there is one more European satellite manufacturer, Orbitale Hochtechnologie Bremen (OHB).*

[48] *French company Qwant contributes and encourages various open or participatory projects: OpenPilot (free autopilot software for autonomous vehicles), OpenStreetMap (a community of 5 million contributors worldwide work to provide free, open maps), and SatNOGS (community satellite observation).*

[49] *The state-industry coordination committee on space (COSPACE) was launched in 2013 by the Minister of Higher Education and Research Geneviève Fioraso. It brings together all the public and private players in the space ecosystem (representatives from relevant ministries, CNES, GIFAS, manufacturers ranging from general contractors to SMBs, operators, and service providers). Its mission is to establish joint proposals for the future of the French space industry.*

[50] *http://boosters-cospace.fr/decouvrir-le-programme-boosters/*

[51] *The booster* ***Morespace*** *in Brittany centred on maritime issues; the booster* ***Nova*** *in Toulouse, Bordeaux, and Montpellier for blue growth, energy, smart cities, agriculture, control of space and living environment and Southern economies; the booster* ***Space4Earth*** *in the South region for issues of security, environmental technologies, mobile services related to geolocation and smart cities (smart transport, energy, sustainable cities, etc.); the booster* ***Seine Space*** *in the Seine and Normandy regions to develop new services in the city and mobility sectors, logistics, smart energy management, climatology, environment, leisure, education, etc.; the booster* ***Centaura*** *in the Auvergne-Rhône-Alpes region for sharing and popularising knowledge (digital content, data visualisation) and land-use planning (mountain, tourism); the booster* ***Morpho*** *in French Guyana for natural resources (renewable energies, fighting deforestation, etc.) and remote applications in agriculture and health; the booster* ***Rhinespace*** *in Strasbourg-Mulhouse-Colmar for sustainable and smart uses in dense areas and regional sectors (innovative mobility, water, energy, urban planning, and infrastructure): http://boosters-cospace.fr/les-7-boosters/*

[52] *https://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Business_Incubation/ESA_Business_Incubation_Centres12*

In France, the incubation centres are: "Sud France" (Nouvelle Aquitaine, Occitanie, Auvergne Rhône Alpes and Provence-Alpes-Cote d'Azur) and "Nord France" (Brittany, Pays de Loire, Normandy, Île-de-France, Hauts-de-France, and Grand Est).

[53] *Advanced Research in Telecommunications Systems: https://artes.esa.int/*

[54] *CESARS platforms for telecommunications and Lab-OT for Earth observation for companies, operators of vital importance (OIV), and government ministries.*

[55] *Its engineers support many projects developed in boosters, incubators, and accelerators. For researchers and start-ups, CNES organises competitions and meetings (Hackathons, Hackers & Makers): https://entreprises.cnes.fr/fr/connect-cnes*

[56] *Hearing of Mr. Olivier Dubuisson, CEO of CapDecisif Management: https://cosmicapital.com/*

[57] *According to Eurospace, 2018 global public investment in the space sector was distributed as follows: $44 billion by the United States; $9 billion from Europe; $8 billion by China; $3 billion by Japan; $1.5 billion by Russia; $1.5 billion by India. In total, global public investment amounted to about $70 billion.*

[58] *Contribution of the French Académie des technologies.*

[59] *A long-rejected European preference for space launchers could finally emerge with a Proposal for a Regulation of the European Parliament and of the Council establishing the EU's space programme and the European Union Agency for the Space Programme (COM/2018/447 final) which is under discussion; Article 5, as drafted, reaffirms the principle of autonomous access to space (institutional support for launch activities).*

[60] *Similarly, subsidiaries of non-European companies should not be able to benefit from European public funding for developments and purchases.*

[61] *The fact that there are European "trust operators" (such as ADS and TAS) allows us to trace information, guarantee their integrity, and be able to mobilise it quickly should an urgent need arise.*

[62] *Thus, the EUMETCast system contributes to Europe's resilience and is a complement way to process alerts. For the 2024 Olympic Games, the company Qwant is participating in a call for bids from ANR to prove that a multichannel alert is possible in case of crisis.*

[63] *GAFAM: Google, Amazon, Facebook, Apple, Microsoft.*

[64] *BATX: Baidu, Alibaba, Tencent, and Xiaomi.*

[65] *With massive storage and high related computing capabilities.*

[66] *The US Ocean and Atmospheric Observing Agency (NOAA) is preparing to put its data on several American tech companies' platforms, and Amazon will soon offer all data from NASA and the US Geological Survey (Landsat satellites). Google offers its Google Earth Engine infrastructure with an algorithm to help scientists and space service companies develop processing chains on its resources and data. Despite the European Commission's efforts, the Copernicus Data and Information Access Services (DIAS) hardly competes with those of major American tech companies.*

[67] *Contribution of the Académie des technologies. "We must insist on the need to see ESA and Brussels working hand-in-hand on these issues to define and put into practice a legal (and technical) framework that can protect 'European' data and encourage its use by European players as a priority."*

[68] *The global satellite navigation system from the Galileo programme offers five services, including a "public regulated service" (PRS), for government-authorised users for sensitive applications that require effective access control and a high level of service continuity (decision no. 1104/2011/EU of the European Parliament and of the Council of 25 October 2011 on the methods for accessing the public regulated service offered by the global satellite navigation system from the Galileo programme: https://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32011D1104&from=FR).*

[69] *Law no. 70-514 of 19 June 1970 authorising the ratification of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other celestial bodies, of 27 January 1967: http://www.unoosa.org/pdf/publications/STSPACE11F.pdf*

[70] *In 2018, the Russian spy satellite Luch-Olymp approached the French-Italian satellite Athena-Fidus to hack communications; since then, it has approached eight other satellites belonging to different countries.*

[71] *Law no. 2008-518 of 3 June 2008 on space operations.*

[72] *This revision, conducted by MESRI with the support of the Ministry of the Armed Forces, would also give the latter to greater autonomy in decision-making.*

[73] *https://www.elysee.fr/emmanuel-macron/2019/07/13/discours-aux-armees-a-lhotel-de-brienne.*

Armed Forces Minister Florence Parly presented the Defence Space Strategy on 25 July 2019. For the duration of the military programme act, she announced an additional budget of €700 million in addition to the €3.6 billion already planned for renewing satellite capacity, in particular to fund programmes that modernise space surveillance systems (Graves, Tarot, Geotracker), the Thales Stratobus stratospheric balloon, patrol nanosatellites, and the defence component of the Kineis constellation:
https://www.defense.gouv.fr/salle-de-presse/discours/discours-de-florence-parly/discours-de-florence-parly_presentation-de-la-strategie-spatiale-de-defense

[74] *Hearing of Messrs. Jean-Loïc Galle and Riadh Cammoun, TAS: 500,000 objects larger than one centimetre fly around in space and, given their speed, can destroy satellites that weigh five tonnes. A visit to the ADS site in Toulouse: satellite operators (Eutelsat, SES, Inmarsat, etc.) conduct an evasion manoeuvre on average once a week.*

[75] *Responsibility, quality, supervision, end of life management, etc.*

[76] *Radio waves are used for all space telecommunications and are also essential for geolocation systems. Additionally, the radio waves naturally emitted by the natural radiation from the Earth and the Universe are analysed by observation satellites.*

[77] *The next World Radiocommunication Conference (WRC-19) will be held in Egypt in November 2019. WRCs are held every four years with the goal of amending radiocommunication's statutory instruments, the international treaty that governs the use of the radio waves. The allocation of frequencies for terrestrial 5G is on the agenda of WRC-19; it will be important to ensure that spectrum planning is done according to the recommendations that will be made during this conference.*

[78] *In 2012 and 2013, the satellites of the French company Eutelsat suffered numerous jamming and hacking attacks coming from Syrian and Iranian territories with the aim of disrupting the broadcast of international television channels.*

[79] *National space agencies, the European Space Agency (ESA), the European Commission (DG GROW), the European GNSS Agency (GSA), which is set to become the European Union Agency for the Space Programme, manufacturers (ArianeGroup, Airbus Defense & Space - ADS. Thales Alenia Space - TAS, Telespazio, Orbitale Hochtechnologie Bremen - OHB, etc.). See the Proposal for a Regulation of the European Parliament and of the Council (under discussion) establishing the EU's space programme and the European Union Agency for the Space Programme: https://eur-lex.europa.eu/legal-content/FR/ALL/?uri=CELEX%3A52018PC0447).*

[80] *Europe has two industrial general contractors (*"primes"*), ADS and TAS, for the construction of satellites. While competition is healthy for public and private buyers to remain competitive, we must avoid duplicating development capacity by seeking technological complementarities and avoiding relentlessly expanding into outside markets that risks eliminating profit margins. Moreover, since ESA and the European Commission favour competition, an ADS/TAS merger could play into the hands of OHB, their German competitor.*

[81] *In the ARTES programme, the rule of geographic return applies* a posteriori *after the competitive selection of equipment manufacturers and, therefore, does not harm the competitiveness of the business offer. About 90% of the activities are initiated by the industry that co-funds them and decides how they are organised. Each Member State decides how to allocate its funding to the activities and supervises their execution.*

[82] *Satellites offer Europe the opportunity to respond to new institutional needs by developing large pan-European infrastructures (particularly for air and maritime traffic management) and by strengthening their resilience.*

[83] *There will also be R&D funding for space within the framework programme for research and innovation (Horizon Europe)* of about €1.3 to €1.5 billion.

[84] *€16 billion between 2021 and 2027: €9.7 billion for Galileo and EGNOS; €5.8 billion for Copernicus, which could be given a new mission on climate change; €500 million would be devoted to improving performance, increasing space surveillance autonomy (SSA programme), and developing secure government telecommunications by satellite (Govsatcom program).*

[85] *ESA proposes a three-year budget of €12.5 billion, of which €2.5 billion is earmarked for "compulsory" expenditures (scientific programmes and operations for a compulsory expenditure amounting to €4.3 billion over 5 years). The programme's optional budget breaks down as follows: €2.7 billion to make the transition from Ariane 5 to Ariane 6 and prepare for future developments; €2 billion to fund the International Space Station (ISS) and exploration on Mars and the Moon; €2.3 billion to support space observation programmes; €1.5 billion for telecommunications programmes and €1.5 billion for other programmes (security, navigation, GSTP, and PRODEX).*

[86] *The €2.1 billion scenario was the only one compatible with the initial draft finance act for 2020.*

[87] *In particular, ESA estimates that France's contribution to the ARTES programme should be increased to €350 million, given the estimated €400-450 million British contribution and a growing German contribution. It points out that more than 60% of European jobs in the telecommunications satellite sector are located in France, while our country only funds 16% of the ARTES programme. It argues that the operating rules of geographic return mean that the country that contributes the most to a project is attributed the manufacturing pilot runs, giving them an undeniable advantage in commercialising mass production runs. The Agency stresses that, while the sector is in a stage of rapid innovation and profound transformation, no position should be taken for granted, and that maintaining France's leadership in Europe in 2025 depends on a high level of R&D investment in the coming period, which will be key to the sector's entire future.*

For its part, CNES highlights the delicate trade-offs to made between issues (launchers, telecommunications, Earth observation, navigation, exploration, universe science, etc.) when needs are growing in all fields in a context of total transformation and increased global competition. It considers that a contribution from France to the ARTES programme should be complementary to national instruments (CNES and PIA).

[88] *The share of France's contribution to the ESA budget devoted to the Ariane 6 launcher programme is around 55%; the total cost of the Ariane 6 programme (and the development of the P120C thruster) is estimated to be €3.7 billion over five years (2015-2019), thus this contribution is about €2 billion. In comparison, at the 2016 ministerial council, France contributed 16% of the three-year budget for the ARTES programme, which amounts to approximately €1.3 billion; this corresponds to France contributing €200 million.*