SENEGAL LAUNCHING ITS FIRST SATELLITE INTO ORBIT: STORY OF A TWO-YEAR JOURNEY TO SPACE

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ABSTRACT

The launch of the very first Senegalese satellite is imminent. A 2- to 3-year long technical adventure, which germinated at the Ministry of Higher Education, Research and Innovation of Senegal around 2020. Although the present paper provides information about the technical characteristics of the satellite (a CubeSat) and its mission, the focus is put on the implementation strategy of the relevant project. The authors review the intentions of the project and the context in which it was deployed. It is intended to highlight that the plan to build and launch a CubeSat should not be simply a technical initiative. It is preferable that such an initiative is part of a medium/long term strategic vision in the space business with everything this may entail in terms of financing, skills training, employment, etc. In addition, the alignment of the project with other national strategies, outside the space domain itself, will facilitate its political, academic and social acceptance. It will make it easier to obtain the support necessary for the implementation of a CubeSat project, which some may find expensive. Building and launching a CubeSat actually involves much more than only technology.

1 GAINDESAT-1A

1.1 GaindeSAT-1A

The first Senegalese satellite called GaindeSAT-1A is a "modest" 1U CubeSat of 1 kg. The satellite is based on the 1U v3.5 platform developed by the University of Montpellier Space Center, which has already been used successfully in several missions such as CELESTA [1], Djibouti-1A [2] and ENSO [3].

1.1.1 Development planning

The GaindeSAT-1A project was developed in accordance with the standard, that is in six phases as shown in Figure 1, with review committee meetings as often as necessary. Classic phase F (Disposal) is not yet concerned [4].

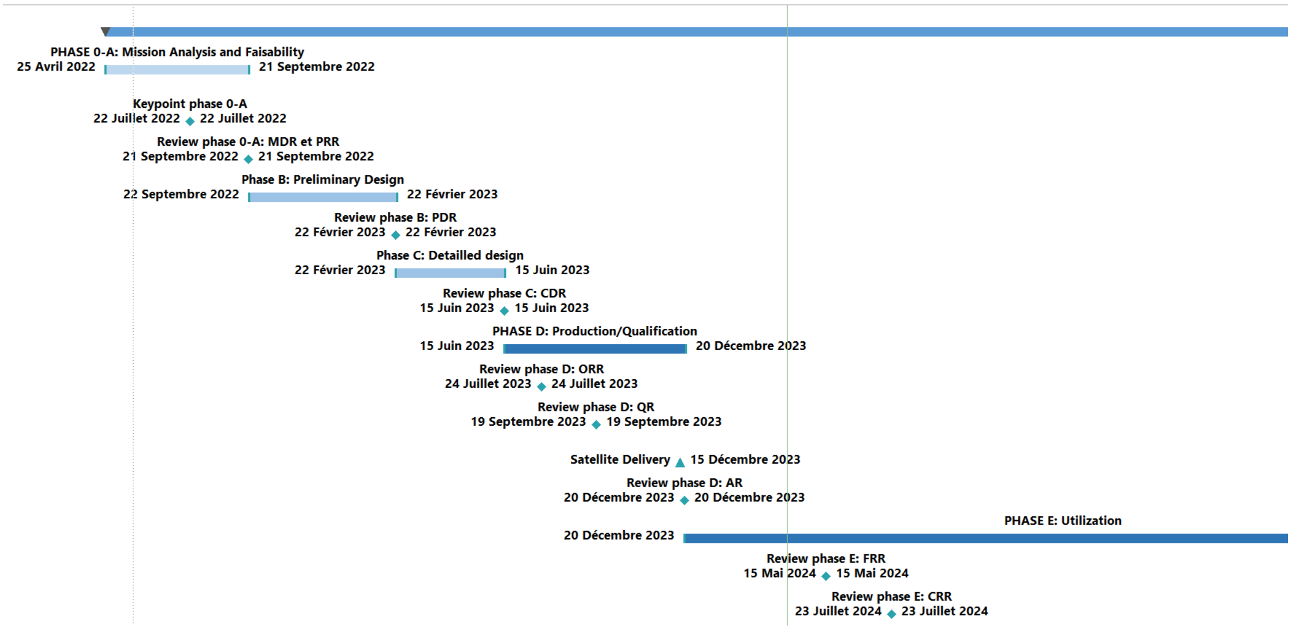

Figure 1. GaindeSAT-1A development planning

1.1.2 Intermediary satellite models

The 4 satellite models shown in figures 2 to 5 were built before the final version. The philosophy of such a multi-model approach was adopted to ensure satellite compliance with operational and compatibility requirements step by step, more efficiently and safely. This step-by-step method additionally reduces technical risks [5]. The experience of CSUM made it possible to optimize the number and type of intermediate models for a good compromise between cost, deadline, performance and quality issues.

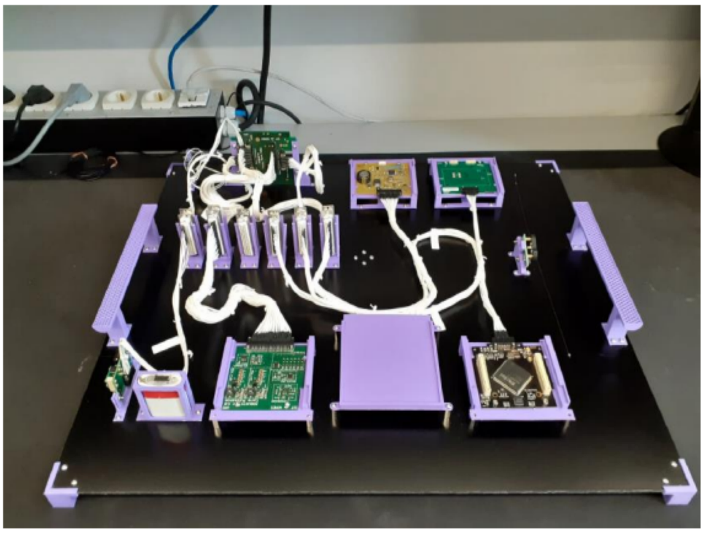

Figure 2 : FlatSat model (payload functionality test)

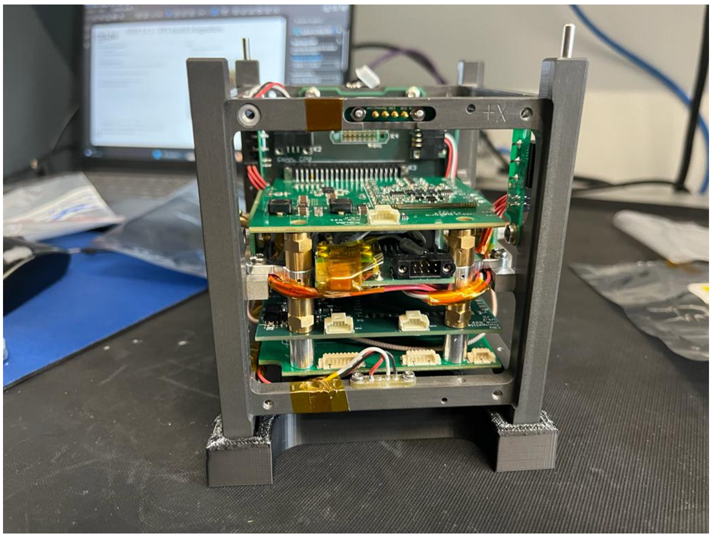

Figure 3: Engineering Model (functional and radio frequency tests with beacons and ground station)

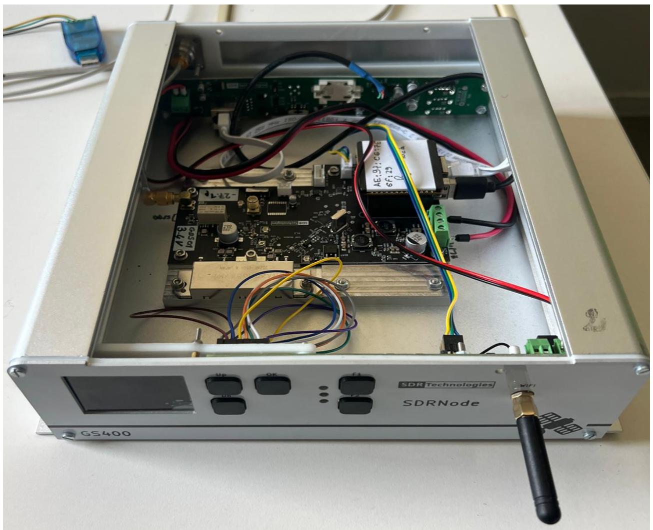

Figure 4: Data collection station model

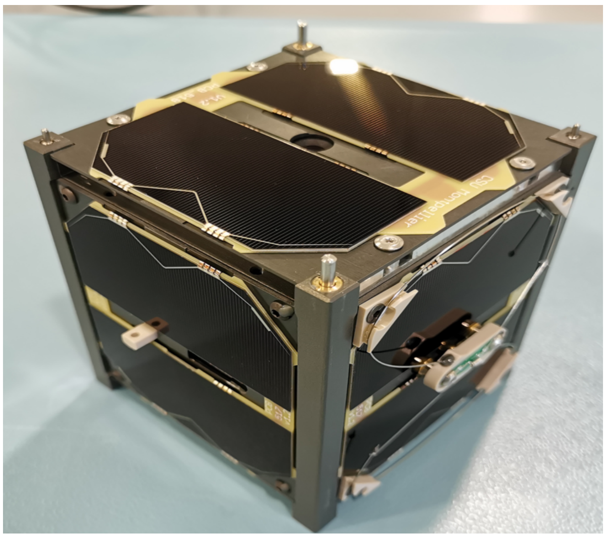

Figure 5: Flight Model (Ambient and environmental tests [6])

1.1.3 Tests Facilities

The CSUM has a 200 m² clean room, ISO class 8 in which all AIT activities requiring a controlled environment were carried out. The clean room allows to meet cleanliness (cleanliness and contamination) and environmental (temperature, relative humidity, differential pressure, saftey and access control of protected areas) requirements. The characteristics of the CSUM's ISO 8 room are summarized in Table1.

Table 1: CSUM's clean room features

ISO 8 room	Particle contamination (mm/m²/24 hours)	Molecular contamination (ng/cm²/week)
	275	500

All other GaindeSAT-1A activities not requiring a controlled environment were carried out in a regular workshop or on dedicated test benches.

Mechanical tests were carried out on the CSUM's 58 kN vibrating pot allowing to perform 3-axis vibration tests for elements to be tested up to 50 kg (Figure 6). During tests, the satellite was inserted into a deployment device (adaptor) similar to the flight one in terms of configuration, and fixed on the vibrating pot [7].

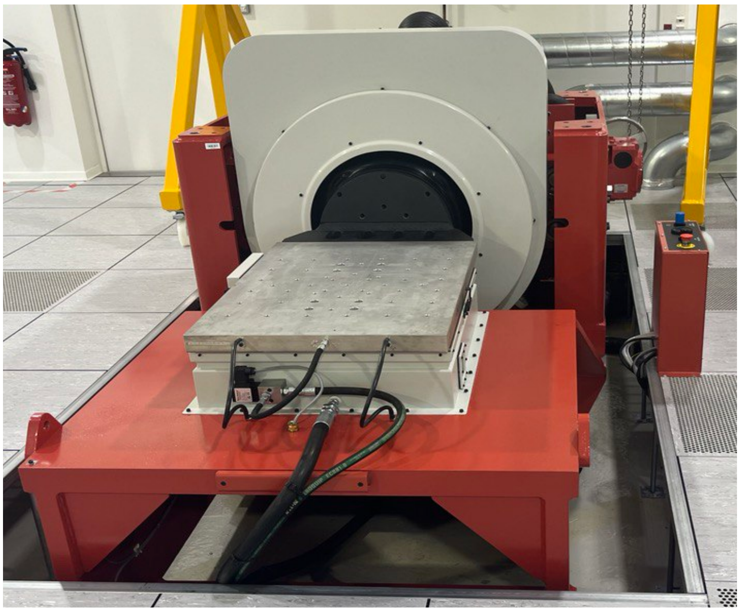

Figure 6: CSUM's vibrating pot

Temperature tests were carried out in the CSUM's thermal vacuum chamber of figure 7 for a temperature range of -140°C to +140°C under a pressure down to 10^{-7} mbar [8].

Figure 7: CSUM's thermal vacuum chamber

1.1.4 GaindeSAT-1A delivery

On December 15, 2023, the satellite GaindeSAT-1A was handed over the Senegalese government in the person of M. Moussa Baldé, Minister of Higher Education, Research and Innovation during an official ceremony (Figures 8 and 9).

Figure 8: Official handover of the satellite Senegalese in the presence of the Senegalese Minister of higher Education, Research and Innovation and Consul General of Senegal in the clean room

Figure 9: GaindeSAT-1A team and the Senegalese Minister of higher Education, Research and Innovation

1.2 Payload and mission

The payload on GaindeSAT-1A is twofold: a Ucam-3 type on-board camera capable of shooting pictures with a resolution of 10 km, and a data transmitting-receiving system (400 MHz - 450 MHz capable of collecting and sending data each time the satellite passes over Senegal (2 to 3 times a day).

The satellite, placed in a sun-synchronous orbit at around 520 km, will collect the data sent by around 10 ground sensors (humidity, temperature, water level etc.) and send them back to a ground station installed in the satellite's mission control facility. Current satellite's end-users (DGPRE, OLAC, ANACIM, etc…) will thus move from manual data collection every 4 months to automatic data collection several times a day.

The images will be used for different purposes including educational ones for high school students to Masters students. The data will be used to help flood forecasting and to optimize millet or peanut sowing strategies.

The device is scalable in that sense that it will later be possible to deploy additional ground sensors wherever in Senegal to benefit from the satellite's resources.

1.3 Ground station

The ground segment is composed of a series of interconnected hardware and software components that together implement data paths from RF signals to data bytes and vice versa. The ground segment allows:

- Satellite tracking;
- Receiving and sending of RF signals through relevant RF interfaces;
- Decoding and encoding of multiple radio packets;
- Decoding and assembling of mission data from received radio packets;
- Storing decoded data in a database for GAINDESAT-1A mission;
- Display of decoded data in a concise way to satellite operators;
- Dispatch telecommands to registered satellite mission through intuitive graphical;

User interface :

- Sending data to SENSAT external partners through Data Division Platform [9].

Figure 9 shows the mission control center from where the satellite is operated. Figure 10 shows the antenna used to send instructions to the satellite, and receive signals from it. It is located in Diamniadio, Senegal.

Figure 10: Mission control center

Figure 11: Antenna of the ground segment

2 STRATEGY

For its first satellite, Senegal chose a "simple" 1U CubeSat which it decided to design and assemble itself, with the help of a partner, in the framework of a training program. This section addresses the elements that led Senegal to adopt such a strategy.

2.1 Starting modestly with a CubeSat 1U

A CubeSat like the one Senegal is about to launch into orbit, has an operating life of about 2 to 3 years, and necessarily limited capability. However, building a CubeSat has several significant advantages, particularly for emerging countries that want to access space to benefit from the opportunities offered by space technologies.

The design and manufacturing times of a CubeSat are quite short (around 2 years for the first satellite) which makes it possible to achieve and showcase tangible results fairly quickly after the decision is made to build and launch a satellite. It is sort of a reassuring argument for decision makers.

The design and functioning of a CubeSat are to some extent rather standard and simple, ground control stations do not need to be too sophisticated. CubeSats disintegrate in the atmosphere after their mission, there is no end-of-life to manage.

The costs of designing, manufacturing, testing and launching a CubeSat are relatively low compared to traditional satellites. CubeSats are generally made of standard, simple components that are usually easily found commercially. Plans and even "off-the-shelf" construction kits are available online. The size of a CubeSat necessarily limits its sophistication. For a country with limited resources, the project of building and putting a satellite into orbit is therefore affordable with a CubeSat. However, as with a large satellite, we cannot rule out an incident during launch or ensure that the satellite will work once in orbit. With a CubeSat, the financial risk is low.

Despite its small size and simplicity, a CubeSat can be equipped with various scientific instruments that will collect data on the space environment, earth or other celestial objects. This data may be used for research activities, particularly on climate or the environment. The deployment of a simple CubeSat can thus be useful to global research projects bringing additional opportunities for countries to join international cooperation.

A CubeSat can also be used for very practical applications such as border surveillance, natural disaster management, remote communication and education, etc. These applications can have a direct impact on the daily life of a country's citizens by improving security, communication and access to information... A CubeSat can therefore be used in an inclusive approach to both serve people and promote and popularize space technologies and science in general.

Senegal is counting on the construction, launch and operation of its CubeSat to strengthen its international image as an innovative and technologically advanced/capable nation. Senegal hopes the initiative will pave the way for new international partnerships and regional cooperation in space, providing additional opportunities for long-term development and growth. Space companies from developed countries have already contacted the government of Senegal.

Finally, CubeSats, for which plans and ready-to-assemble kits can be found online, allow students to acquire exceptional practical experience in the development of spacecrafts and space missions, from design to launch and operation. CubeSats are great educational objects for training in the fields of engineering, space science and technology, IT, communications or project management, thus providing an additional way to contribute to the overall development of the country.

2.2 Installing and operating a useful payload

From the start of the project, it appeared essential that the payload of the Senegalese CubeSat provided a concrete service, and was not just a technical and/or educational exercise for the satellite designers.

It seemed important to the team that Senegal's first satellite, as modest and limited as a 1U CubeSat might be, had to be intended to effectively fulfill a mission to make profitable, if not justify, the financial, human and technological resources invested in the project.

The satellite could have been used for scientific data collection, Earth observation, communication, surveillance, or any other function. In the present case, the data collected will be used primarily to improve the quality of information services to farmers for the cultivation of groundnut or millet. The data will also be used for educational purposes to promote space and, more broadly, STEM among young people in high schools. It was important that the satellite mission reached as many people as possible and had a significant social, if not economic, impact.

Developing, launching and operating a CubeSat come with a cost. A payload capable of providing sufficient value, over the entire lifespan of the satellite, will make it easier to justify the expense. If the service provided by the payload can be monetized, this may even help make the initial investment profitable. In the case of Senegal, this was not sought.

So, a CubeSat, in itself, is a technological tool. To get the maximum benefit, it is necessary to integrate it into applications and projects that meet the real needs of the country. This may include environmental monitoring, natural resource management, communication, education, or other areas that have a direct impact on society

Our point is that it is essential that a CubeSat project is not considered only as a technological challenge. Right from the outset of the project, it should be meant as an opportunity to meet a specific need, whether it is monitoring natural phenomena for agricultural or environmental purposes, improving communications to open up isolated areas, supporting military or disaster relief operations, etc. The payload must be adapted to meet these specific needs with, preferably, a direct and positive impact on society. At worst, the mission of a CubeSat will always have educational virtues.

2.3 Planning for the long term with a strategic vision

The construction and launch of a satellite are synonymous with financial and human investment. The question of return on investment arises. In this regard, we saw in the previous section that it was essential that the satellite payload provided a concrete service.

For Senegal, it was also essential that the project was part of a broad enough strategic vision to maximize the return on investment and to enable the country to become a recognized and respected player in the space economy which is developing very quickly, particularly in Africa. The burgeoning space industry is expected to offer huge potential for investment, job creation and economic growth.

In Senegal, the SenSAT program, a component of which the GaindeSAT-1A project is, is a full part of the Senegal's National Research and Innovation Strategy document drafted in 2022 by the Ministry oh Higher Education, Research and Innovation (MESRI) and adopted by the Senegalese government in 2023. The roadmap of the SenSAT program drawn up by the MESRI led in 2023 to the creation of the Senegalese Agency for Space Studies (ASES) placed under the dual technical supervision of the Minister, Secretary General of the Presidency of the Republic of Senegal, and the Minister of Higher Education, Research and Innovation, and under the financial supervision of the Minister in charge of Finance. Therefore, the GaindeSAT-1A project has the full support of public authorities and academic institutions, which is important for its implementation.

GaindeSAT-A1 is actually the first stage of an ambitious program which will continue with the construction of a second 1U CubeSat to consolidate the learning outcomes from the first CubeSat project, a third CubeSat (3U) and a fourth Cubesat (12U) capable of providing images of the entire national territory with a resolution of a few meters. This gradual increase in skills of the current team will, however, take some time. The development of a university space center with the necessary equipment to ensure good training, research and space engineering is also envisaged in the space focus of Senegal's national research and innovation strategy. The approach requires operational and budgetary planning over several years.

Thus, the construction and launch of Senegal's first CubeSat must be considered as the mark of the beginning of the country's long-term commitment in the space sector. It is expected that the positive momentum reached throughout the overall strategy adopted by Senegal will additionally open up opportunities for the country to play a greater role in global scientific research, international collaborations, and technological and economic development initiatives.

2.4 Training of human resources

For its satellite project (SenSAT), Senegal chose not to buy an off-the-shelf satellite but to train young Senegalese women and men in "space systems design". This is why the project was carried out in close partnership with the CSUM, the French leader in the development and launch of university nanosatellites. The approach has many virtues. Sovereignty: the acquisition of technological knowledge and know-how will allow Senegal to dialogue on an equal basis with other space faring countries involved in space programs and/or providing space-based solutions, and to develop its future projects and own space economy. Sustainability: in the future, Senegal young generation will be able to design such satellites. Risk minimization: in case of destruction during launch or misfunctioning of the satellite once in orbit, the technicians and engineers trained at CSUM will be able to design, build and launch a new satellite on their own.

More specifically, around 15 carefully selected young technicians and engineers were sent to CSUM for training. Sending a cohort of students of this size makes it possible to build a team of different specialists with all the skills necessary for the design, manufacturing, operation, launch and mission monitoring of a satellite. The young Senegalese sent to Montpellier, France, for 2 years benefited from almost individualized coaching. They could acquire both generic (management, quality, outreach of space projects …) and specific skills (space systems, functional and environmental testing …). The pedagogy implemented by the CSUM is such that all project and internship type exercises were used for the management, engineering and quality activities of the Senegalese satellite.

Investing in training and skills development was thought essential to ensure the sustainability of the SenSAT program (see section 2.3) and the development of a long-term space program by Senegal.

More broadly, by investing in education and training in the fields of engineering, computer science and space sciences, the country aims to train a highly skilled workforce, ready to support emerging industries in the space sector. These skills would not only benefit the space industryy, but could also be applied in other sectors of the economy, thereby strengthening the country's overall competitiveness.

2.5 Partnering

Training Senegalese engineers and technicians in space systems development required joining forces with a partner. The choice of the partner was dictated by also considering the following elements, among others:

- The manufacturing and testing of a satellite require dedicated and expensive facilities such as specific electronic test benches, a clean room, thermal and mechanical test facilities, etc.;
- Remote control and operation of the satellite, once in orbit, requires having adequate ground facilities;

- Launching a satellite requires know-how that goes well beyond the technical skills necessary for the design and assembly of the satellite. Indeed, putting a satellite into orbit requires purchasing a place on a launcher, often located in a third country to which the satellite must be transported after having settled a certain number of formalities. The repatriation of the satellite must be planned in the event of a problem during transfer to the launch site;
- The country that owns a satellite in orbit must be insured in the event of damage caused to a third party. To do this, it must have ratified a certain number of international treaties and passed national space laws. The country must also be prepared to protect itself against not responsible enough or unscrupulous investors or space operators. The lack of experience of a country with any form of space law would do little to raise hopes for effective oversight of activities originating from its soil and carried out by private (foreign) companies.

Senegal first turned to national agencies and entities such as CNES and Ariane Group, France, with which agreements were signed. But for different reasons, the MESRI finally turned to the Centre Spatial Universitaire de Montpellier (CSUM), a flexible, specialized, experienced, well equipped university structure capable of training technicians and engineers and, above all, mastering the entire chain of operations to be carried out from design to the placing into orbit and control of a satellite, including the contractual and legal aspects of such an operation.

CSUM was able to offer a complete service including degree-awarding training dedicated to satellite design and assembly, the provision of its own equipment for the obligatory qualification tests of the Senegalese satellite, complete assistance with the launch of the satellite, support for the preparation of Senegal's space law, etc. All along the project, CSUM has always been present to help resolve the various difficulties encountered throughout the project.

Training began in 2021 with the sending of 3 young Senegalese. In 2022, 10 additional Senegalese were sent to CSUM and 02 in 2023. The ground station (monitoring and control of the satellite's mission) was installed at the "Cité du Savoir" (Knowledge city) in Diamniadio, Senegal, at the end of summer 2023. In parallel, Senegal has also already started writing its space law. The satellite was officially handed over to the government of Senegal on December 15, 2023

2.6 Retaining human resources

Although we had to face unexpected problems, including difficulties due to a faulty third party, by far, the major risk of the project SenSAT was neither technological nor financial. It essentially lies in the ability to retain the young talents trained though the program.

The truth is that one of the young trained at CSUM left the project prior to its end for a private company. We would certainly have lost other key team members if sufficient short- and long-term incentives had not been offered by the MESRI to ensure that they agree to take the project to its end.

In this regard, it is important to again emphasize that the design, manufacturing and launch of a satellite cannot be considered as an end in itself. This is why GaindeSAT-1A is only one element of the much broader national program SenSAT, which incidentally recently led to the creation of a Senegalese space agency, and includes the strengthening of the country's innovation ecosystem for the development of satellite-data based services. The project is therefore part of a national medium/long term development policy and strategy, which is moreover consistent with other governmental initiatives including the commissioning of a supercomputer, the revision of the national Geomatics plan, a data and an AI strategies and roadmaps (see section 3). It is hoped that this general momentum will be able to provide sufficient job opportunities, including research positions, for the young women and men sent for training to CSUM.

3 ALIGNMENT with OTHER NATIONAL INITIATIVES

Given the investment the construction and launch of a CubeSat represents for a country like Senegal, such a project would make little sense if it were just a simple and/or individual technological initiative outside any general innovation-oriented background. If so, the project longevity and its impact on society would be limited.

In the case of Senegal, the GaindeSAT-1A initiative embodies a bold strategic vision which aims to position the country on the world stage as an important player in the space and technological field. The project reflects the long-term vision for the country's development, and demonstrates Senegal's commitment to innovation, research and technological progress, which includes the deployment of other key initiatives or strategies establishing a favorable context for the growth of a space economy. Among these key initiatives: a revision of Senegal's National Geomatics Plan, a digital strategy and an IA strategy all useful if not essential for the development of the space sector in the country.

This section briefly provides information about the context in which the GaindeSAT-1A project takes place. It is intended to show the consistency between the national strategies currently being implemented and the GaindeSAT-1A project. The importance of this consistency is implicitly outlined.

3.1 Space sector

Aware of the leverage represented by the space sector and, more particularly, the potential of satellite data, in the socio-economic development of a country, Senegal has in recent years taken various initiatives in order to support in all these forms the development of this sector.

Senegal, for example, has initiated a revision of its National Geomatics Plan initiated in 1996. The initiative is supported by the "Groupe Interinstitutionnel de Coordination et de Coordination" in Geomatics (GICC, created in 2016). In this context, in partnership with the Korean Green Growth Fund (KGGTF), the GICC began working on the renovation of Senegal's Geospatial Data Infrastructure (in the sense of all human resources and physical and organizational structures addressing geospatial data).

Senegal is also involved in the GMES & Africa program, the 2nd phase of which aims in particular to provide Earth observation data relating to terrestrial, aquatic, marine and coastal areas, using space technologies deployed in particular within the framework of the Copernicus program. The "Centre de Suivi Ecologique" coordinates the activities carried out in this framework in Senegal (CSE).

However, despite the efforts made by the Senegalese government to create a stabilized institutional framework favorable to the structuring of a genuine innovation and entrepreneurial ecosystem around the use of satellite data, and despite the need for well identified digital space-data-based services, so far this ecosystem with a significant potential for job creation and high added value is struggling to develop.

This is why the SEN Spatial project was set up. This project, carried out jointly by the GICC and the French Embassy in Senegal, aims to support the growth of the Senegalese innovation ecosystem centered on the use of satellite data, and support the Senegalese government's wish to become a major hub of innovation and digital economy of French-speaking Africa.

Space data can be used to monitor climate change, assess water and agricultural resources, and predict the risk of natural disasters such as floods and droughts. By investing not only in space infrastructures but also in the development of its innovation ecosystem for the production of geospatial services, Senegal is sustainably arming itself, in a sovereign way, to improve its capacity to anticipate and mitigate the challenges it faces every day, thereby contributing to the security and resilience of the nation.

3.2 Other sectors related to the space sector

The management and analysis of Earth observation data requires storage and processing capacities within a sufficiently regulated data use framework. The development of a complete space ecosystem therefore appears strongly correlated to, if not dependent of the development of digital technology.

In this regard, Senegal launched its national digital strategy (Sénégal Numérique 2025-2035) linked to the Plan Sénégal Emergent (PSE). This digital strategy is structured around 2 priority axes (i) the promotion of an innovative and value-creating digital industry, and (ii) the diffusion of digital technology in priority economic sectors. It has recently been updated, with one of the priority activities being support for the development of emerging technologies among which space technologies.

As part of the implementation of this strategy, Senegal has numerous assets to develop digital services based on satellite data: a regulatory framework (National Geomatics Plan – being updated), universities and research laboratories, network infrastructures, start-up incubators, data center, a supercomputer, digital technologies center, etc. The SenSAT and SEN Spatial projects will be opportunities to mobilize and promote some of these national digital infrastructures.

It is also in this very proactive context that the Ministry in charge of digital technology in Senegal (MCTEN) recently completed the drafting of the country's national artificial intelligence (AI) strategy and its corresponding roadmap. The strategy is the result of a 6-month collective reflection process involving the entire scientific, entrepreneurial and institutional AI community, the animation of which was entrusted to Expertise France with the support of the French Embassy in Senegal and the European Union.

The Senegalese data science and AI ecosystem, although embryonic and still unstructured, demonstrates remarkable dynamism with resources that have so far been reduced. The needs for digital services that can use AI are particularly numerous and some are well identified to meet the challenges of sustainable economic development in Senegal. Following the model of the Sen Spatial project, the Sen Hub IA project, "Supporting the development of the Artificial Intelligence ecosystem of Senegal through the establishment of a national Hub on artificial intelligence" aims to support the structuring of the Senegalese AI ecosystem, consistent with Senegal's AI roadmap and with Senegal's "spatial" ambition. The use and support of AI in the processing of spatial data will be considered in this project.

4 CONLUDING REMARKS

Senegal, a dynamic and booming country on the African continent, is at a crucial moment in its economic development. In this modern era where land borders no longer limit growth possibilities, embarking on the space economy presents, if not considerable advantages, at least unprecedented opportunities for the country. This is why Senegal has launched into this sector, in particular through the construction of a first satellite, a 1U CubeSat type satellite.

Starting with a 1U CubeSat, designing and manufacturing it on one's own has many advantages, and this is what pushed Senegal to adopt this strategy, the many advantages of which have been presented in this paper. It was shown how essential it is to invest in training and capacity building of technicians and engineers to ensure a successful and sustainable project.

Considering the financial, human and technological resources necessary for a project of this scale, even if they remain modest and affordable for many emerging countries, such a project will be more likely to succeed if it is in line with a broader strategic vision. Support for the project and its impact will only be strengthened.

Note that a CubeSat project may also have a significant social and educational impact. Such a project can play a role in raising a sense of national pride by demonstrating to the public the country's capacity to meet complex technological challenges. It often inspires younger generations to engage in scientific and technological fields, thus encouraging education and training in technological disciplines that may be key to the future of the country.

Developing a detailed mission plan and strategies for continued operation of a CubeSat once it is in orbit is also important. Reasons why implementing a useful payload is essential in many respects, have been presented.

In practice, strong project management is crucial to ensure the effective coordination of the various stages of CubeSat development, construction, launch and operation. This includes strategic planning, risk management, budgeting, progress monitoring, as well as an ability to proactively resolve issues that arise permanently. In Senegal, a national project coordinator was appointed by order of the Minister of ESRI.

Finally, in the present case, the project could not have been successful without a strong partnership with an internationally renowned institution capable of providing specialized expertise, equipment, and additional resources.

Despite all of the above, the authors would like to demystify the complexity of such an adventure. They strongly encourage countries concerned about their competitiveness or role in the fast-growing New Space economy, particularly African countries, to dare to embark on a similar project.

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