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Review Article

Building the Appropriate Capacity for Enabling Space Programs in Africa: The Nigerian Experience

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Abstract: This paper x-rays the two-decade gradual yet steady strides made by Nigeria in building the capacity of its workforce in space science and technology. Information concerning the technical training modules on earth observation satellites (EOS), communication satellites, space transport and propulsion systems, and space systems application software is provided. Details are also provided of the locations for these training, the number of personnel involved and the associated cost implication for some of the capacity building programs. This review concludes that despite the funding challenges, global legal bottlenecks and the security implications associated with undertaking and executing a national space program, a continual investment in space capacity building programs is necessary, crucial and essential. This is because the immediate and long-term national benefits of these capacity building programs are immense and the spin-offs have trans-generational impacts.

Keywords: Capacity Building, Space Program, Africa, Nigeria, Know-How Technology Training, Hands-on Training

1. Introduction

Africa's resolve to develop competence in space technology has been underscored by the seemingly increasing interest by many African countries to make space science and technology part of their overall development strategy. It is evident that space technology offers a wide range of innovative and cost-effective solutions to the challenges of national development, arising from the need for critical communication and geospatial data acquisition infrastructures [1].

African nations that have begun to make gradual inroads into space science and technology include Nigeria, Algeria, Egypt, South Africa, Morocco, Ethiopia, Kenya, Gabon and Ghana. Viewed dispassionately, the steps taken thus far are the elementary stages, nevertheless, these steps represent significant indications of intent by these countries to be major players and stakeholders within the global space industry. Despite the meagre resources invested in the technology sector, Africa appears to have a budding appetite for advanced space technology, with experts now advising that a concerted effort among African countries could help the continent realize its ultimate goal of a Pan-African space technology program [2, 3].

To support capacity-building in space science and technology in Africa, the United Nations through its Office of Outer Space Affairs (UN-OOSA) established two African Regional Centres for Space Science and Technology; one in Morocco to cater to French-speaking African countries and the second one in Nigeria to cater to English-speaking African countries. The aim of the Centres is to increase indigenous capability in space science and technology applications through education and training. Presently, post-graduate diploma and MSc courses are offered in Remote Sensing and Geographic Information Systems (RS and GIS), Satellite Communications (SATCOM), Satellite Meteorology and

Global Climate (SATMET), and Space and Atmospheric Sciences. The Centres also engage in activities targeted at increasing public awareness of the benefits of space technology for sustainable national development and ways to include space education in the national curricula in junior schools in Africa [4].

According to the United Nations, the ability of a country to follow sustainable development paths is determined to a large extent by the capacity of its people [5]. One cannot underestimate the sense of sovereignty and national pride associated with having a people who possess such nation-building capacities and capabilities; in addition to these is that such self-reliance brings about a reduction in capital flight which hitherto results from an over dependence on foreign or imported goods and personnel.

To this end, the afore-listed African countries have set up some form of national mechanisms aimed at acquiring or building the needed capacity for space science and technology development. Capacity building encompasses a country's human, scientific, technological, organizational, institutional and resource capabilities.

Building indigenous space capacity in Africa will require partnership with nations that possess capacity and capabilities in advanced space technology infrastructure development and know-how technology training. It is essential for individual countries to identify priorities and design programs that fit into their national needs. Technical cooperation, including that related to technology transfer and know-how acquisition, is effective only when it is derived from and related to the country's own strategies and priorities on development [5]. These priorities must include addressing the dearth of space scientists, engineers and technicians relevant to the development of space science and technology components in Africa, with a view to maximizing their benefits.

The Nigerian experience in building capacity in the field of space science and technology provides a good case study of the efforts made by an African country to provide the needed and appropriate capacity necessary to enable some level of self-reliance in its space programs. This paper x-rays these efforts and provides hindsight evaluation of the results of such efforts. Furthermore, suggestions are proffered to current challenges and finally a 20-year forecast of NASRDA is done.

2. The Nigerian Experience

Nigeria's desire to venture into Space Technology was first made known to Organization of African Union (OAU)/UNECA meeting in Addis Ababa in 1976. In other to actualize this desire, the National Space Research and Development Agency (NASRDA) was established by the Nigerian Government in 1999 to promote and co-ordinate the space program.

The mandate of NASRDA is to:

i. To vigorously pursue an immediate attainment of indigenous space capability in Nigeria as an essential tool for its socio-economic development for the enhancement of the quality of life of its people.
ii. To foster bilateral and multilateral cooperation in all aspect of space science and technology to ensure that Nigerian Scientists and Engineers benefit from global development in the space enterprise [6].

In pursuance of this mandate, NASRDA signed development contract agreements with the UK and China which dovetailed into the launch of four satellites as well as one replacement satellite within a period of six years. The launches of Nigeria's satellites within the first ten years of NASRDA's existence presented opportunities for Nigeria to train and develop human capacity in satellite design, building, test, operation of ground station and data utilization. These human capacity developments involved hands-on training and technology-know-how training programs.

Other contract agreements/MOUs between NASRDA and several space-related industries and learning institutions in China, USA, Russia and South Africa resulted in trainings for well over 100 scientists and engineers in various fields of space technology - Satellite Network Management, Space Transport and Propulsion Systems, Launch Site Development, Software Development and Application Software, Space Systems Assembly, Integration and Test (AIT) procedures, Geographic Information Systems (GIS), etc.

Furthermore, NASRDA is also committed to the academic development of its technical staff. At its onset, NASRDA had less than ten Masters degree and five Ph.D. degree holders. However, the structured academic development programmes of the Agency has resulted in the addition of 400 Masters degree and 150 Ph.D. degree holders to the workforce. These higher academic qualifications are spread across different areas of space technology such as satellite communications, satellite navigation, satellite altitude and control system, on-board data handling and operation, space propulsion systems, space technology applications, etc., obtained from various universities all over the world. This collection of well-trained and highly skilled personnel at NASRDA remain agents of positive technological developments in Nigeria. It must be mentioned that some of these personnel are already supporting some universities in Nigeria by engaging in teaching and collaborative research with the academia. The results of these collaborative researches have led to publications addressing various space application areas [7-12].

2.1. Know-How Technical Training on Low Earth Orbit Imaging Satellite

Beginning from 2003 to date, Nigeria through NASRDA has launched four (4) Low Earth Orbit (LEO) Imaging or Earth Observation (EO) Satellites – NigeriaSat-1 (N1), NigeriaSat-2 (N2), NigeriaSat-X (NX) and Edusat-1. These assets were acquired with capacity development components for Nigerian scientists and engineers. The capacity building/training components included [13, 14]:

i. The Imaging payload: 2.5m, 5m, 22m and 32m resolution
ii. The Radio Frequency (RF) subsystem: S/X Band,
iii. The Attitude and Orbit Control Subsystem (AOCS):

Gravity Gradient Boom Technology, 3-Axis Stabilization Technology
iv. The Satellite Propulsion Subsystem
v. The On-Board Data Handling Subsystem (OBDH): Solid State Data Recorder (SSDR) Technologies, OBC 186 Technology, OBC 386 Technology and OBC 750 Technology
vi. The Mechanical Structure Subsystem
vii. Electrical Power Subsystem
viii. Mission Control Centre: Telemetry, Tracking and Control (TT&C)
ix. System and Subsystem Test Procedures
x. Antenna design, fabrications and installation

In addition, Nigerian personnel participated actively in the Satellite Launch Campaign Operations. This provided the opportunity to understand intricacies of launch procedures. It should be noted that Earth Observation Satellite Ground Station in Abuja is managed solely by Nigerian personnel.

2.2. Know-How Training on Geostationary Earth Orbit Communication Satellite

Nigeria launched its communication satellite NigComSat-1 on the 14th of May, 2007, in China using the Long March 3B rocket. The NigComSat-1 Know-How Technology Transfer (KHTT) training began in 2005 and ended long after the launch of the satellite. The capacity development program included [15]:

i. The Communication Payload Subsystem
ii. Navigation system
iii. The Attitude and Orbit Control Subsystem (AOCS): 3-Axis Stabilization Technology
iv. The Satellite Propulsion Subsystem
v. The On-Board Data Handling Subsystem (OBDH):
vi. The Mechanical Structure Subsystem
vii. The Thermal Control Subsystem
viii. Electrical Power Subsystem
ix. Ground Station Telemetry, Tracking and Control (TT&C)
x. System and Subsystem Test Procedures
xi. Satellite Assembly, Integration and Test
xii. Satellite Launch Campaign Operations
xiii. Industrial visits to satellite hardware development and management centres
1. Xi'an: Antenna Development Centre
2. Lanzhou: (i) IMUX and OMUX Development Center (ii) Multipactor Test Facility (iii) Propulsion Tank Development Centre
3. Yantai: Data Control Board Development Centre
4. Urumqi: Ground Station RF Systems
5. Xinjian Zhong: Ground Station Point to Point Communication Systems

xiv. Basic Lessons in Chinese Language

Nigerian personnel participated actively in building the ground control station. The training on ground control station operation were carried out in China and Nigeria and the Communication Satellite Ground Control Station in Abuja is managed solely by Nigerian personnel.

2.3. Know-How Technical Training on Advanced Space Transport and Propulsion Systems

Capacity development trainings on space transport and propulsion system took place in Russia, USA and China. The Russia and USA training modules were divided into:

(i) Hands-on Advanced Rocket Program
(ii) Acquisition of higher degrees (MSc and Ph.D.).

The China program, unlike the others, had funding challenges and so could not be concluded as planned.

2.4. Know-How Training on Space System Application Software

Training programs on space system application software were also organized. Some of these software modules included:

i. The Satellite Tool Kit (STK) training held at the Analytical Graphics Inc. office in Maryland, USA, and at London, UK.STK is a physics-based software package that allows engineers and scientists to perform complex simulation and analysis of ground, sea, air and space assets and share results in one integrated solution. STK is now referred to as Systems Tool Kit.
ii. Mechanical Design, Analysis and Simulation in support of NASRDA's Design Centre (DC) and Assembly, Integration and Testing (AIT) Centre. Modules included CAD Software, CAE Software and simulation software. Training was located in Beijing, China.
iii. Geographical Information Systems - Automated Imaging Systems and IN-CAR Navigation Systems. Trainings were conducted in South Africa.

Table 1 summarizes some of Nigeria's investment in space technology capacity development.

3. Challenges

The Nigerian space capacity development plans have suffered some challenges since inception. These include but not limited to:

1. Funding limitations
2. Unfavorable International Policies and Regulations

Table 1. *Capacity development programs organized by NASRDA.*

S/N	Capacity Development Training	Location	No. of Trainees	Cost of Training
1.	[1]KHTT training on [2]LEO Imaging satellite & Launch of NigeriaSat-1 Spacecraft	Surrey Satellite Technology Limited (SSTL) Surrey, Guildford, United Kingdom	15	> £ 600,000.00
2.	KHTT training on [3]GEO Communications Satellite, Ground Station design and management & launch of NIGCOMSAT-1.	China Academy of Space Technology, Beijing, Yantai, Xi'an, Langzhou, China	50	NA

S/N	Capacity Development Training	Location	No. of Trainees	Cost of Training
3.	[1]KHTT training on [2]LEO Imaging satellite & Launch of NigeriaSat-2 and NigeriaSat-X Spacecraft (included MSc and Ph.D. components)	Surrey Satellite Technology Limited (SSTL) Surrey, Guildford, United Kingdom	26	£ 3,770, 057.19
4.	Advanced Space Propulsion Systems (MSc & Ph.D.)	Alabama, USA	7	>$ 721,240.00
5.	Advanced Space Propulsion Systems (MSc & Ph.D.)	Russia	11	>$ 616,720.00
6.	Design & Development of 7 km & 70 km Nigerian Rocket	Xian, China	14	NA
7.	Communication Satellite Engineering – Mechanical Design, Analysis and Simulation in support of NASRDA's Design Centre (DC) and Assembly, Integration and Testing (AIT)	China Academy of Space Technology, Beijing, China	10	NA
8.	Software Training: STK; CAD Software, CAE simulation software; Geographic Information Systems (GIS): Automated Imaging Systems; IN-CAR Navigation Systems; Satellite Data Processing and Management	Maryland USA; London England; Beijing China; South Africa	40	NA
9.	Edusat KHTT	Japan		$1000,000.00

[1] KHTT: Know-How Technology Training; [2] LEO: Low Earth Orbit; [3] GEO: Geo-Stationary Earth Orbit; NA: Not Available

3.1. Funding Limitations

Building the needed capacities for space ventures is capital intensive. The Nigerian space capacity building programs have largely suffered over the years due to inadequate funding - which is provided for by appropriation, and the untimely release of funds meant for such training programs. Figure 1 is a chart comparing 2017 fiscal year budgets for various government space agencies. It is obvious from the chart that NASRDA suffers funding challenges which is directly linked to the paucity of funds within government coffers. Nonetheless, at this juncture, we do hope, suggest and encourage, that in the event of improvement in the government coffers, that this should also translate to improvement in funding of space-related programs. Secondly, we suggest that NASRDA continue to take advantage of funding support programs available to third-world countries for the training of its technical personnel, especially in technologies that will not draw unnecessary attention to it capacity building efforts or create friction between Nigeria and the advanced space economies who may be overly sensitive to regulations on such technologies.

We must state however, that regardless of this funding challenge, NASRDA is fully committed to implementing the Nigerian space policy. Therefore, to address the myriad of needs confronting the Nigerian space venture, the NASRDA management has made the judicious administration of available resources topmost on the list of priorities. It has been able to build research infrastructures such as the Advanced.

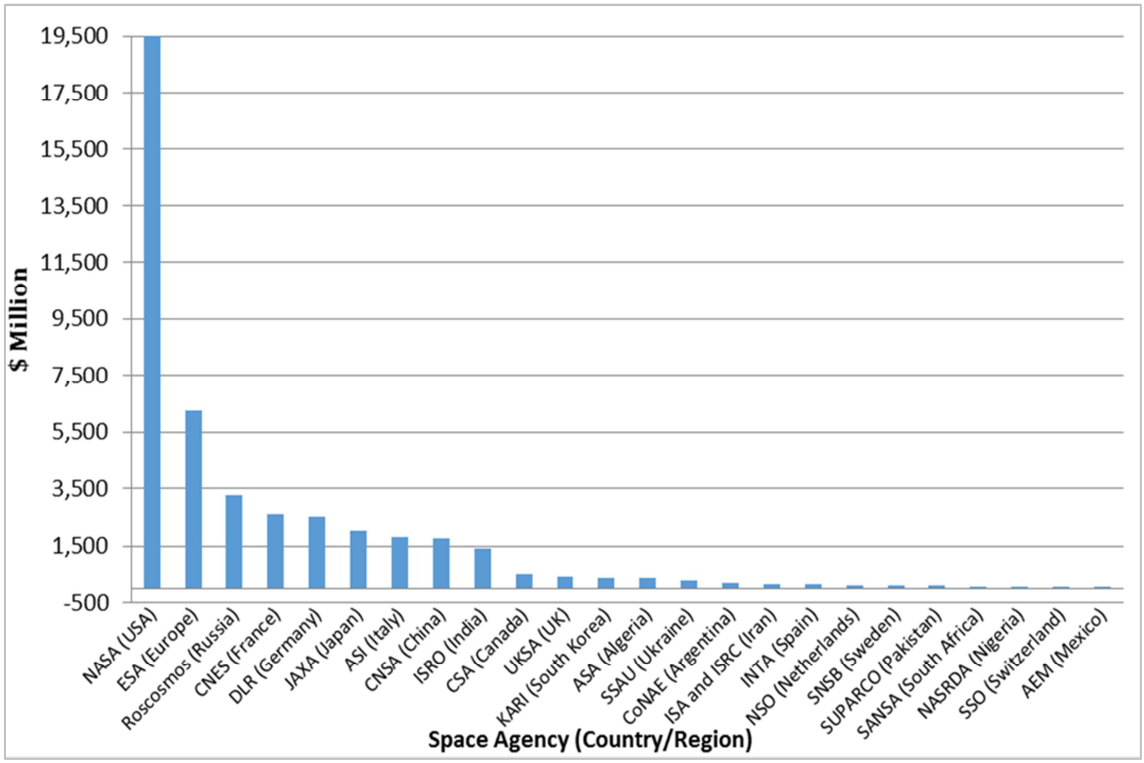

Figure 1. *Comparison of the 2017 Fiscal Year Budgets for various Government Space Agencies [16].*

Computational Laboratory and the Incubations Centre. These infrastructures are strategic in that they will support the sustainability of all developed and acquired technologies.

3.2. Unfavourable International Policies and Regulations

Actualizing hands-on and know-how capacity development programs demand more than financial investments. Space ventures have global security and legal implications. Thus, an understanding of these security and legal implications backed by a strong political will and a committed leadership is a foremost requirement for the success of any national space program. Consequently, even in the event that adequate funding is made available, there is the prerequisite of a strong and trusted diplomatic relation and cooperation between space-intending nations and nations that possess advanced space know-how. This is in order to overcome any trade restrictions that might arise from legal or security concerns.

Thus, the notion that it would be possible for Africa to obtain advanced space technologies from abroad without the development of an indigenous broad-based scientific and technological infrastructure is mistaken [17]. To buttress this point, in the recent past, training modules on space transport and launch vehicle capability (rocketry systems development) for Nigerian scientists and engineers suffered challenges because of the International Trade in Arms Regulation (ITAR). Such limitations can only be overcome through strong international cooperation and collaborations at top government levels. Thus, we do suggest and encourage the Nigerian government to continue to build strong alliances, foster bilateral and multilateral cooperation and collaborations, in order to limit over-regulation of NASRDA's capacity building efforts.

4. NASRDA: 20 Years from Now

NASRDA has taken the initiative to map out an action plan spanning a period of 25 years. These include [18]:

1. Launch a Satellite manufactured in Nigeria
2. Launch a Satellite manufactured in Nigeria from a Launch Site in Nigeria on a Launch Vehicle made in Nigeria
3. Produce a Nigerian Astronaut

To actualize this plan of cause means indigenous space capacity development will continue to receive adequate attention and priority. Forecasting the next 20 years, it is strongly believed that NASRDA would possess

1. Satellite and Launch Vehicle Assembly, Integration and Test (AIT)infrastructures- Thermo-Vacuum chambers, Vibration Test Equipment, Electrical Ground Support Equipment, Mechanical Ground Support Equipment, etc.
2. Specialized Centres for the development of Satellite Components and Subsystems – Antenna Systems, Attitude and Control Systems, Propellant Tank Systems, Thermal Control System, etc.
3. Specialized Centres for development of Rocketry and Launch Systems and Components – Propellants, Boosters, Thrusters, etc.
4. Rocket launch infrastructures such the launch site and rocketry harnesses, and
5. Astronaut Training Infrastructures

While this plan may seem daunting and ambitious, NASRDA is fully determined and focused on achieving each one.

5. Conclusion

The adoption of space technology for sustainable socio-economic development of a nation requires technical capability and human capacity development across its various fields. This is true especially for African nations, who can take full advantage of the derivable benefits of space science and technology by including it as a component of the country's overall development strategy. Developed nations ventured, saw the huge benefits, and have sustained their investments in the development of technical capability and human capacity through continuous investment in space science and technology.

Recognizing this, Nigeria through NASRDA engages in continuous space technological expansion and development of its citizens through various training and higher academic programmes. It is an unquestionable fact that a continual investment in space capacity building is a costly venture, nonetheless it is a necessary one. The immediate and long-term benefits are immense and the spin-offs have transgenerational impacts. Nigeria's venture into space science and technology and at acquiring capacity in space technology has spanned almost two decades. Despite the challenges encountered, progress has been steady though gradual. Hence, there is strong optimism that as the Nigerian government improves on the investment in space technology, acquired capacity and technical capabilities will also improve proportionately.

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