Transition of Space Technologies and the Spin-Off Technologies Realised: An Incentive for Continued Investment in Space Exploration

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Abstract
Technology development and advancement is being embraced by the world for its potential long term benefits. The role of technology in development is vast, with technology playing an integral part in everyday human activities and practices. Technology development and application is pivotal in ensuring full system functionality and operation of key economic sectors of respective countries. The trend in advancing technology over the years has helped many businesses stay competitive and remain in the global market. Space and other aviation industries'; following the advent of space exploration has helped in realising spin-off technologies. These technologies have contributed to the efficacy of current industrial methods and practices. Space exploration investment remains a gateway for advancing space technology development, and subsequently realising spin-off technologies.
Keywords: Space Technology, Space Application, Spin-Off Technology, Transition, Investment, Future

1. Introduction

Space technology has recorded remarkable success over the years following initial space exploration in the 20th century. The advent of these technologies has made it easier for human activities and processes to be implemented through their applications [1].

NASA through space exploration has successfully embarked on numerous voyages and ground breaking expeditions enlightening the world on the advantages of continued explorations and the accruing long term benefits.

Other nations are also actively involved in space exploration and activities through their various national structures and agencies i.e. ROSCOSMOS, ESA, JAXA and CSA. This is all aimed at implementing their country's space explorations and collectively advancing further development of space technologies and applications [2].

The following will shed more light on milestone achievements realised and those predicted through space exploration activities in three (3) distinct headers i.e. Past, Present and the Future.

2. Past

The breakthrough recorded in the past century, pertinent to space exploration has been pivotal in setting a bench mark for future research and development. These are outlined as follows [1]:

1915 Robert Goddard proves validity of rocket propulsion principles in a vacuum. 1926 Goddard launches first liquid-fuel rocket engine.
1932 Wernher von Braun begins experimenting with rocket engines for his doctoral dissertation.
1933 Russia's first liquid-fuelled rocket is launched.
1934 Von Braun built his first successful rocket, the A-2.
1942 Von Braun achieves the first successful launching of a V-2 rocket.
1950 A two-stage bumper rocket is launched from Cape Canaveral.
1957 Sputnik I is launched by liquid-fuelled rocket built by Sergei Korolev.
1958 The U.S. launches Explorer 1, signalling the beginning of the space program. 1959 Russian lands a Luna probe on the moon and takes the first pictures of its far side.
1961 Russian Yuri Gagarin orbits Earth one time.
1961 Alan Shepard is launched 115 miles into space, lands 15 minutes later in Atlantic Ocean.
1962 John Glenn orbits Earth three times in a Mercury capsule, Friendship 7.
1962 Mariner 2 flies past Venus, the first probe to fly beyond another planet.
1963 RL-10 rocket engine, the world's first high-energy liquid hydrogen engine.

1963 Valentina Tereshkova, Soviet cosmonaut, becomes the first woman in space. 1963 The first communications satellite to reach synchronous orbit, Syncom II, is launched.
1964 First spacewalk, U.S. Gemini program.
1965 Early Bird is launched for use by communications services.
1965 Gemini spacecraft makes first rendezvous in space between two spacecraft. 1969 Apollo 11 moon landing, Neil Armstrong is first person to walk on moon.
1971 Earth-orbiting space station, USSR.
1973 Skylab is placed in orbit.
1976 Mars space probes, NASA's Viking I and Viking II, launched.
1977 U.S. Space Shuttle program begins.
1981 Columbia Space Shuttle, the first reusable winged spaceship, is launched.
1997 The robotic explorer, Sojourner, lands on Mars.
1997 Pioneer 10 spacecraft exits the solar system for interstellar space, and is still functioning.
1997 Discovery Shuttle mission with John Glenn aboard at age 77.

3. Present

Presently, on-going activities by government and private bodies through space technologies have been able to create industries centred on providing the following services [3]:

- Provide satellite communications (VSAT business communication systems, mobile telephones, data direct to home TV, satellite radio and wide band data services).
- Remote Sensing (mapping, resource management and land use).
- Global Positioning System (GPS) for positioning, navigation and timing services.

These services have been pivotal in mitigating problems associated with executing human activities and processes more adequately [8]. Their practical applications encompass all sectors i.e. transportation, communications, agriculture, health, banking & finance and power amongst others. Furthermore, target specific examples of on-going work primed at improving livelihood and human activities are [3]:

ADS-B (Automatic Dependent Surveillance Broadcast): Employs satellite based navigation to increase the number of aircrafts that can be managed in a nation's airspace.

NPOESS (National Polar Orbital Environmental Satellite System): To obtain precise atmospheric and environmental measurements from space in massive quantities.

3.1 Network of European Regions using Space Technologies (NEREUS)

More so, the *"Network of European Regions Using Space Technologies"* (NEREUS) publication, documents spin off technologies realised from space explorations that have real life applications. Respective developed and developing technologies and their application areas pertinent to this are as follows [4]:

3.1.1 Life Marker Chip (LMC)

An instrument used in extracting organic matter from disintegrated particles in Mars and also exploring the existence of extant life. Its application is evident in "green" chemistry for the extraction of petrochemicals from low grade oil production sources i.e. Oil Shale. The instrument is also applicable in medical and environmental sample processing in the 3rd world.

3.1.2 Mini Gamma Ray Camera (MGRC)

The MGRC is a device in the development and testing stage intended for commercialisation subsequent to medical evaluation and approval. The technology employed in its design and implementation builds on space exploration projects and X-ray astronomy satellite missions. Underlying technologies are *"Charged Coupled Devices (CCDs)"* for scintillator materials, high performance x-ray imaging and miniaturization for space missions.

Its wide application will be in the medical environment for efficient and effective diagnosis of terminal illnesses particularly cancer.

3.1.3 RiskNat

RiskNat is realised through simulations, depicting real life occurrences, resulting from space exploration technology. RiskNat is built upon a virtual simulation framework capable of simulating 4D environments. RiskNAT's three geological risk event focus areas are:

- Debris Flows.
- Snow Avalanches.
- Land Slides.

RiskNat provides the necessary information required by designated authorities to effectively manage geological risks and dangers through requisite analysis and understanding of the simulation environment.

3.1.4 HIT09

The spin off technology is adopted from technologies employed in the simulation, design and implementation of helicon plasma and hybrid rocket propulsion systems.

HIT09 technology is applicable in the design of advanced wind turbines and plasma solar panels as means of energy generation. Other application areas are in disaster management and advancing nano-technologies. The former seeks to employ an advanced, quick-response, rocket-launched device, specifically designed to operate in hazardous conditions by providing quick view of the affected area.

3.2 Spin-Off Cases of Space Technology in Japan

The tables below cover the various problem specific areas and economic sectors that space technologies are finding solutions to. The "Key" alimentary to the table is shown below, with the tables following after [7]:

*KEY: **A** - Spin-Off Cases that are transferred from JAXA's technology and based on license agreement.*

***B** - Spin-Off Cases that are transferred from JAXA's technology but not based on license agreement i.e. paper publications.*

***C** - Spin-Off Cases that are transferred from shared technology between JAXA and enterprise and implemented by the counter enterprise.*

***D** - Spin-Off Cases that are transferred from space technology owned by Japanese enterprises.*

Table 1 – Contribution to Living

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A	Water Renewal Technology for Space -Water Purification System	New Median Tech Corporation.
B	Structural Design Technology for Space Engineering – Diamond Cut can	Kirin Brewery Co. Ltd, Toyo Seikan Kaisha Ltd.
B	Material technology for Space Plane – Functionally Graded Material	Mizuno Corporation, Citizen Holdings Co Ltd.
B	Deployment Technology of Solar Array Paddle in Space – Miura Fold (Map)	Orupa Co Ltd.
D	Image Analysis Technology Associated with Optical Sensor for Earth Observation Satellites – Sugar Content Sensor for Fruits	Mitsui Smelting and Mining Co Ltd.
D	Rose onboard Space Shuttle Discovery - Perfume of Smell of Rose Blossomed in Space	Shisheido Co Ltd.

Table 2 – Contribution to Safety and Security

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A	Sensor for X-ray Astronomical Satellite - Realisation of Next Generation radiation imager used for security checks in Airports	Acrorad Co Ltd.
D	Basic Material of Rocket Nozzle and Heat Resistance – Fire proof Screen and Fire extinguishing Cloth	Nippon Muki Co Ltd.
D	Pyrotechnic Technology to Ignite Solid Motors – Initiator Technology for Gas Generator of Air Bag	IHI Aerospace Co Ltd, Nissan Motor Co Ltd.
C	Spectro-Polariradiometer for Earth Environment Observation – Road Surface Freezing Monitoring System	Yokogawa Bridge Corp.
B	Blast Simulation Programme at Rocket Launch – Design of Lead Vehicle of 500-Serise Nozomi, Linear Motor Car	Railway Technical Research Institute, Central Japan Railway Company.
D	Technology on Flexible Joint of Rocket - Laminated Rubber Bearing for Seismic Isolation for Construction	BridgeStone Corp.
D	OmniDirectional Camera for Monitoring of Solar Array onboard ADEOS-II - Monitoring Camera on Ground	Mitsubishi Electric Co, Nagasaki Ryoden Technica Co Ltd.
A	Network Security of Super Computers – Internal Security Protection Management System	Seer Insight Security Inc.
A	Recovery Technology on Sea of Stratosphere Platform Airship – GPS-Based Wave Measuring System	Zeni Lite Buoy Co Ltd.

Table 3 – Contribution to Environmental Issues

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A	Combustor Technology for Aircraft Engine – Dioxin Reduction Device/ Burned Ash Detoxifying Device	Materials and Energy Research Institute Tokyo (MERIT), Ltd.
A	Combustor Technology for Aircraft Engine – High-Performance Detoxifying Burner for manufacturing of Liquid Crystal Panel	Koganei Tex Co, Ltd.
A	Thermal Insulation Material of Rocket Fairing – Coating-Type Thermal Insulation Material for Buildings	Nissin-Sangyo Co.
A	Processing technology for Organic Waste in Space – Waste processing Facility (Animal Manure)	Tokyo Koatsu Co.
C	Power Generation system for Space (Stiring Engine) – Low-Pollution, High Efficiency Power Generation System	Matsushita Electric Industrial Co, Ltd.
A,C	Jet Engine for Aircraft - Low-Pollution Gas Turbine for Power Generation	Niigata Power Systems Co, Ltd.

Table 4 – Contribution to Medical Service and Welfare

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A	Protein Crystal Creation Equipment in the International Space Station – Crystal Creation Experimental Equipment and Service for Dual-Use in Ground and Space	Confocal Science Inc.
A	Sensors for X-ray Astronomical Satellite – Realization of precise Gamma-Ray Sensor for Medical Service and Security	Howa Sangyo Co, Ltd.
D	Special Optical Filter Technology for Satellites – Surgery Microscope Capable in Identifying Cancer Cells	Mitaka Kohki Co, Ltd.
D	Optical Instrument Technology for Satellites– High-Resolution Stereoscopic microscope for Surgery	Mitaka Kohki Co, Ltd.
D	Balancing Technology of Camera Driving System for X-ray Doppler Telescope onboard Satellite – Medical Microscope/Stand	Mitaka Kohki Co, Ltd.
A	Numerical Simulation Technology/ Visualisation Technology – Medical Image Processing System	SGI Japan, Ltd.
A	Cell Culture System to be onboard International Space Station – Cell Culture System for Medical Research	Chiyoda Advanced Solutions Corp.

Table 5 – Contribution to Industry

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A,C	Design and Analysis Supporting System for Electronics Equipment onboard Satellites – Solution for Embedded Software Development in the Ubiquitous Society	InterDesign Technology Co, Ltd.
A	Next Generation Network Standard for Space Vehicle – Micro Network	Shimafuji Electric Ltd.
B	Space Semiconductor Chip (SOI) – Applications to Electronic Equipment in Commercial Sector	Mitsubishi Heavy Industries, Ltd. Oki Electric Industry Co, Ltd.
A	SSPS (Space Solar Power System) – Solar Light and Heat Combined Power Generation System	Ryokushu Co, Ltd.
D	Precise Coordinate Measurement Technology for Stars by Telescope – Precise Measurement of Camera Lens Mounted on Mobile Phone	Mitaka Kohki Co, Ltd.
B	Large Capacity Condenser onboard MUSES-C – Toy, Digital Camera and Liquid Crystal Projector	ELNA Co, Ltd.

Table 6 – Contribution to Education, Hobby and Entertainment

Category	Space Technologies – Spin-Off Cases	Enterprise Implementing Spin-Off
A	Space Power Generation System (Stirling Engine) – Stirling Engine Kit for Educational Material	Concept Plus Corporation.
A,C	Minute Space Debris Detection Technology – Star Detection Kit for Amateur Astronomer	AstroArts Inc.
A	Bio-Filter for Experiment in Space – Bio-Filter for Tropical Fish Aquarium Purification Material	AES Co, Ltd.
D	Planetary Orbital Data – Fishing Result Prediction Program	NOI Co, Ltd.

3.3 10 - Potential Space Technology Development for the Current Year

Space technology advancements intended for the current year (2013) are: Space suits, Space crafts and MCC's amongst others. These are covered as follows [6]:

3.3.1 NASA's Z1 Spacesuit

NASA's scientist and engineers at Johnson Space Center completed a prototype of the new Z1 spacesuit. The new suit is equipped with superior mobility, large entrance port for easy donning, and increased radiation protection for longer spacewalks.

3.3.2 Space X's Grasshopper

SpaceX is the first private company to dock spacecrafts at the International Space Station i.e. Falcon 9 rocket and Dragon spacecraft. The Grasshopper reusable rocket is the first ever completely reusable spaceflight system. The rocket has the potential to lower the cost of future launches if successfully sent into low-earth orbit.

3.3.3 Commercial Orbital Transportation Services (COTS) Demo Flight

Orbital Sciences- A Dulles, Va. based Space Company, scheduled to launch its Cygnus spacecraft in 2013, as part of its NASA Commercial Resupply Services (CRS) agreement. The spacecraft was developed under a Commercial Orbital Transportation Services (COTS) contract with NASA. Its successful implementation will open the US commercial space race, increasing privatisation and improved technology creation.

3.3.4 Asteroid Mining

The potential exhaustion of earth's natural resources has led scientists into suggesting or exploring the possibility of elements such as platinum and cobalt being mined from asteroids to meet current demands. Planetary Resources, a US based company is dedicated to achieving this goal. So far, the firm has developed three satellites (Akyrd 100, 200 and 300) employed in assessing asteroids for viability.

Possible activities this year involve:

- Developing spacecraft asteroidal samples
- Performing extraction experiments.

3.3.5 Kicksat's Launch

CubeSat was developed in 1999 by Stanford University and California Polytechnic State University. This miniaturized satellite has a volume of 1 litre and has a mass below 1.33 kg. Academics have welcomed the idea because of its low launch cost.

Zachary Manchester adapted this concept as a mode of mass deployment for miniature spacecraft, whilst following his doctorate at Cornell University. The project which draws its name from *kickstarter funding platform* is slated to launch in 2013, and if successful, could revolutionize future access to space research.

3.3.6 Space Tourism and Virgin Galactic's Spaceship Two

Space Adventures, Ltd took the first civilians, Mark Shuttleworth and Anousheh Ansari on an expedition to the international space station (ISS) after paying the sum of $20 million each. Virgin Group subsidiary, Virgin Galactic, in a bid to eradicate the exclusivity of this venture, completed the first privately-funded human spaceflight with its Spaceship One vehicle in 2004. Mike Melvill was the only pilot and passenger aboard, as well as the first non-governmental astronaut. Virgin Galactic will look to expand on this success in 2013 with the new Spaceship Two vehicle, with pre-bookings selling at $200,000 per seat, a significant discount over Space Adventures' prices.

3.3.7 Spaceport Colorado

Increased interest in the commercial space industry has seen the United States investing $660000 into the development of Colorado's Front Range airport. The next pressing agenda, will be establishing "Spaceport Colorado," after satisfactory completion of FAA feasibility studies, slated for the first six months of 2013. Following this, launch activity could commence in early 2014.

3.3.8 NASA's Maven Probe

Mars Atmosphere and Volatile Evolution (MAVEN) probe, an unmanned spacecraft that will be used to sample Mars' environment is scheduled for launch in November 2013 and is expected to reach Mars in 2014. MAVEN will provide measurements from Mars' atmosphere, allowing for a more complete picture of the planet's environment.

3.3.9 Russia's Angara Rocket

Russia's Angara rocket, scheduled for launch from the Plesetsk Cosmodrome in 2013, seeks to secure Russia's independent access to space. This will be achieved by phasing out the Ukrainian rocket technology currently used for launches and also keeping future launches contained within the country.

3.3.10 China's Tiangong-2 Space Station

Tiangong-2 is a space laboratory expected to launch in 2013. The station is expected to succeed Tiangong-1, a prototype module launched in the last quarter of 2011. China's successful implementation of this project will establish them as a serious space power after lagging behind countries like the USA and Russia in recent years.

4. The Future

NASA through space programs i.e. Space Technology Program (STP) and Game Changing Development (GCD) has identified potential space technology development areas. These programs are aimed at improving future space explorations for realising spin-off technologies.
STP encompasses areas in space technology and application for advancing future space activities. They are further broken down into three separate technology readiness levels (TRLs) [5]:

4.1 Low TRL – Technology R&D

- Space Technology Research Grant Program.
- NASA Innovative Advanced Concepts (NIAC) Program.
- Centre Innovation Fund (CIF) Program.

4.2 Mid TRL – Technology Development

- Game Changing Development (GCD) Program.
- Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program.

4.3 High TRL – Technology Capabilities Demonstrations

- Flight Opportunities (FO).
- Technology Demonstration Missions (TDM) Program.
- Centennial Challenges Prize Program.
- Small Spacecraft Technologies Program.

More attention is drawn towards the GCD, as the link between the Low and High TRLs (intermediary between ideas and implementation). Before any further discussions, what the GCD represents is outlined as follows [5]:

- Transformative Technologies.
- Orders of Magnitude advancement enabling new missions and capabilities.
- Principal Investigator-led investment strategy.
- Planning for technology infusion to future NASA missions, other government agencies, the larger aerospace enterprise and national needs.
- Investing in High-Payoff Technologies.
- Changing the way a thing is done or made.

The program's goals are also outlined below:

- Formulate and implement high payoff, high risk technology projects that capitalize on:
  - Short development cycles (2-3 years).
  - Lean development strategies.
  - Competitive acquisitions.
  - Accountability through continuation reviews.
- Deliver technological knowledge and develop technology infusion plans that are used for supporting NASA missions, the aerospace community, and other government agencies.
- Effectively engage and partner within STP, across the Agency, and with industry to enable technology maturation from concept to flight.

4.4 GCD

GCD is overseeing 4 of STPS Big 9 Projects set up to facilitate future space missions as covered in the headers below [5]:

4.4.1 GCD: Human Exploration Tele-robotics & Human Robotic System

✓ Developing advanced systems capable of remotely operating robots to assist in future explorations.
✓ Maturing new robots capable of assisting humans in routine and tedious work.
Human and Science Mission.

4.4.2 GCD: CCTD

- ✓ Demonstrating large composite, light weight fuel that can reduce the mass and cost of the next generation Space Launch System (SLS).
  Human Mission.

4.4.3 GCD: HIAD

- ✓ Demonstrates new inflatable braking systems for use at hypersonic velocities enabling precise landing of large payloads on planetary surfaces, and returning payloads from the (ISS) to earth.
  Human and Science Mission.

4.4.4 GCD: Robotic Satellite Servicing

- ✓ Develops and improves technology to enable service, repair, refuelling and relocating satellites through the use of robotics.
  Human and Science Mission.

4.5 TDM

The remaining 5 STPs centre on Technology Demonstration Missions and are listed below [5]:

4.5.1 TDM: Laser Communications

- ✓ Increases space-based broadband, delivering data rates 10-100 times faster than today's systems, addressing the demands of future missions.
  Human and Science Mission.

4.5.2 TDM: Cryogenic Propellant Storage and Transfer

- ✓ Better fuel handling technology will improve spacecraft fuel economy. Required for cryogenic propulsion stage Space Launch System (SLS).
  Human Mission.

4.5.3 TDM: Deep Space Atomic Clock

- ✓ This tiny atomic clock is 10 times more accurate than today's ground based navigation systems, enabling precise, in space navigation.
  Human and Science Mission.

4.5.4 TDM: Large Scale Solar Sail

- ✓ This solar sail has an area 7 times larger than ever flown in space, enabling propellant free propulsion and next generation space weather systems.
  Science Mission.

4.5.5 TDM: Low Density Supersonic Decelerators

- ✓ Demonstrates new parachutes and inflatable braking systems at supersonic velocities enabling precise landing of large payloads on planetary surface.
  Human and* Science *Mission.

5. Conclusion

As the world becomes more aware of the advantages of the technologies realised through explorations; increased funds from government, international organisations and private bodies will be dedicated towards advancing R&D. The transition of space technologies over the years and the breakthroughs recorded, has elicited various interests, with more countries establishing their national agencies for this cause i.e. South Africa.

Eventually, continued investments towards increased space missions, will enhance the rate of space technology developments for humanity's long term interests and benefits.

6. Recommendation for Further Developments

This review paper will be alimented by addressing the following issues:

- Taking Nigeria into perspective, investments in Clean rooms and industrial/Technical parks should be prioritised for manufacturing semi-conductor devices employed during prototype, testing and final production.
- Africa should set-up a network of African countries in space, for better networking, support and monitoring of individual country's progress, as well as collectively.
- The world at large should sustain its continued investment in research and also follow-through on

implementation i.e. through the various agencies, bodies and committees set up. Leading agencies such as NASA is at the fore-front of this.

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References

[1] National Academy of Engineering (2000). *Greatest Achievements of the 20th Century.*
[2] International Space Station Guide (nd). *ISS International Facilities and Operations*. International Partners.
[3] Rosen S (2009). *How Space can Improve Life on Earth.* AD ASTRA.
[4] Nereus – Network of European Regions Using Space Technologies (2011). *Applications of Space Exploration Technologies in the NEREUS Regions.* Nereus Working Group.
[5] Balint T and Gaddis S (2013). *Innovation within NASA Space Technology and its Game Changing Development Program*. OPAG meeting Atlanta, GA.
[6]Policymic (2013) *10 Amazing Space Technology Developments to watch For in 2013* illustrated [online] available from http://www.policymic.com/articles/21505/10-amazing-space-technology-developments-to-watch-for-in-2013 [29th July 2013]
[7] Spin-Off Cases of Space Technology in Japan (2009). *Japan Aerospace Exploration Agency*. JAXA Special Publication.
[8] Down to Earth (2001). *Everyday Uses for European Space Technology*. ESA