IAC-09-B4.1.3

THE EVOLUTION OF SATELLITE PROGRAMS IN DEVELOPING COUNTRIES

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ABSTRACT

This paper analyzes the historical paths of eight countries – from Africa, Asia and Latin America – as they pursued technical capability in the area of space technology. Through this analysis, the paper provides three major contributions. The first contribution is an original framework called the Space Technology Ladder. This Ladder framework proffers an idealized path through four major technology categories, as follows: 1) establishing a national space agency; 2) owning and operating a satellite in Low Earth Orbit; 3) owning and operating a satellite in Geostationary Orbit; and 4) launch capability. The second contribution is a graphical timeline, created by mapping the historical achievements of the eight countries onto the Ladder framework. The results provide information about the similarities and differences in the technology strategies of the various countries. The third contribution is a discussion of the strategic decisions faced by the countries under study. By exploring their diverse strategies, we work toward developing prescriptive theory to guide developing country space programs.

INTRODUCTION

The international space community is growing. More countries are demonstrating interest and capability in space. In the beginning of the space era, the funding, expertise and accomplishments were dominated by the United States and Soviet Union. Gradually, however, many other countries have carved their own place in the space faring society. The first mission of the US Vision for Space Exploration, the Lunar Reconnaissance Orbiter (LRO), demonstrates this point. This unmanned spacecraft, which represents the US return to the moon, was launched in June 2009[i]. The LRO mission closely follows the launch of three other satellites that were sent into lunar orbit by India, China and Japan between 2007 and 2008. Currently, many developing countries are seeking to increase their level of space activity. Some of these countries, such as South Africa, Nigeria and Malaysia, are investing in their second generation of satellites. Others, such as India and Brazil, plan to drastically extend the capabilities of their existing space programs to include new capabilities.

This paper considers the policy choices made by countries as they pursue space activity. It uses historical summaries of developing country space programs to find models of technology procurement. It explores how closely their progress follows an idealized process based on progressive technical complexity and increased managerial autonomy. Countries are considered from Africa, Asia and Latin America. The trajectories of each country's space achievements are mapped and compared. The results highlight the various options that have been exercised in the past for achieving increased national space capability.

The paper is organized as follows. The next section outlines the theoretical framework that is the foundation for the analysis. This framework is called the Space Technology Ladder. The third section explains the data and analysis methods used in the study. The data describes national space technology milestones for countries from Asia, Africa and Latin America. The fourth section explains the results and summarizes the stories of national space projects that are expressed in the results. The fifth section discuses the variety of models used by countries for the procurement of new space technology. The final section summarizes the finding and offers conclusions.

THEORETICAL FRAMEWORK: THE SPACE TECHNOLOGY LADDER

There is very little literature that directly studies the technology and procurement choices made by developing countries in the area of space technology. This study builds on previous work by the authors, which examined the space activities of countries in Africa[ii,iii]. These space activities were subsequently ranked on metaphorical "ladders" that highlighted the different avenues through which countries accessed remote sensing, communication and navigation services.

The present work examines the policy choices made by developing countries in their pursuit of increased space technology capabilities. The analysis includes information about the order in which new technical milestones are achieved as well as the procurement model that is used to reach each new milestone. In order to make a comparison across several countries, we begin by establishing an idealized technology path that a country could follow as it develops space capabilities. Note that the assumed technology path is not meant to serve as a prescriptive standard. It merely provides a convenient way to compare all the countries against a consistent, fictionalized example. The technology path is summarized in the Space Technology Ladder. The ladder is developed by building a list of milestones that some countries achieve in space. These milestones are ranked according technical complexity. For each technical milestone, there are also procurement milestones that represent an increase in the level of autonomy of a country when executing a certain technical feat.

The Space Technology Ladder includes four major levels of space technology achievements. At the lowest technical level is establishing a national space agency or an office in charge of space policy at the national level. A country reaches the second technology level by owning and operating a national satellite in Low Earth Orbit (LEO). Level three is achieved when a country owns and operates a satellite in Geostationary Orbit (GEO). At level four, a country has independent capability to launch a satellite. The four levels are ranked to show an increase in technical complexity. These four technology milestones are chosen because, historically, they reflect the initial efforts of both developed and developing countries in space. Most developing countries are not currently involved in human space flight. Thus, the Space Technology Ladder focuses on milestones in space policy, satellites and launchers rather than human space flight. Table 1 shows the four major milestones of the Space Technology Ladder.

Table 1: The Space Technology Ladder – Summary View.

LAUNCH CAPABILITY
SATELLITE IN GEOSTATIONARY ORBIT
SATELLITE IN LOW EARTH ORBIT
NATIONAL SPACE AGENCY

The order of the colors in the Space Technology Ladder is drawn from the natural spectrum. The colors are used to distinguish the various levels of the Ladder. They also remind the reader that there is a broad spectrum of ways that countries currently participate in the use of space technology. Throughout the paper, red is used to refer to actions taken with regard to a national space agency. Yellow highlights projects for a satellite in low earth orbit. Green represents projects with geostationary satellites, while blue is used for launch capabilities.

Table 1 shows the summary view of the Space Technology Ladder. At this high level, it has four categories of space activity that are defined based on a technology milestone. Each of these four technology categories can be further divided into sub-categories. The sub-categories represent different options for procuring the relevant technology or different levels within the technology. The sub-categories of each level in the ladder are described below.

Level one on the Space Technology Ladder is establishing a national space agency. For some countries, there are several milestones within this category. Some countries establish a national office in charge of space policy or research before they later establish an official space agency. Therefore the expanded version of level one contains these two possible milestones, as shown in Table 2 below. Following the example from Table 1, the lower level sub-category in Table 2 is on the bottom. Note that Table 2 is red because it is an expansion of the red level from Table 1.

Table 2: Two National Space Agency Sub-Categories.

NATIONAL SPACE AGENCY
Establish Current National Space Agency
Establish First Government Space Office

Level two on the Space Technology Ladder is owning and operating a national satellite in Low Earth Orbit. There are many ways a country can achieve this milestone. For example, they can design and build the satellite locally; they can produce the satellite in partnership with another country; or they can buy the satellite from a foreign company. The sub-categories in level two reflect the diversity of ways that countries might procure a low earth orbit satellite. These sub-categories also represent different levels of technical autonomy in a country's ability to gain access to a satellite. Table 3 shows the sub-categories within owning a satellite in Low Earth Orbit. As before, the lowest level sub-category is on the bottom, and the yellow color corresponds to level two of the Space Technology Ladder.

Table 3: Five LEO Satellite Sub-Categories.

LOW EARTH ORBIT SATELLITE
Build Locally
Build Through Mutual International Collaboration
Build Locally with Outside Assistance
Build with Support in Partner's Facility
Procure with Training Services

Level three – in green on the Space Technology Ladder – is to own and operate a satellite in Geostationary Orbit. As with the LEO satellite, there are a variety of ways that countries procure a GEO satellite; these methods can also be ranked to show increasing technical autonomy. Four options for obtaining a GEO satellite are listed in Table 4. They range from straightforward procurement to building the satellite locally.

Table 4. Four GEO Satellite Sub-Categories.

GEOSTATIONARY SATELLITE
Build Locally
Build through Mutual International Collaboration
Build Locally with Outside Assistance
Procure

Finally, consider the fourth level of the Space Technology Ladder, launching a satellite. This is shown in blue in Table 1. This analysis considers two sub-categories within launching a satellite. The lower level milestone is to launch as satellite to the desired orbit in LEO. The higher level milestone is to launch a satellite to the desired orbit in GEO. To achieve these milestones, a country must launch based on locally mastered and controlled technology. Table 5 shows the expanded view of the launch category.

Table 5. Two Launch Sub-Categories.

Launch Capability
Launch Satellite to Low Earth Orbit
Launch Satellite to Geostationary Orbit

The Space Technology Ladder has four major categories of technical milestones. These are discussed separately above for clarity. Another view of the Ladder combines the four categories. Table 6 shows this view and highlights the thirteen distinct actions within the framework. Table 6 provides the version of the framework that will be referenced throughout the remainder of the analysis.

Note here a caveat about the philosophy behind the Space Technology Ladder as shown in Table 6. In general, the goal of the framework is to show a series of potential technology milestones in the area of space technology and to rank them according to their level of technical complexity and managerial autonomy. This is consistently done within each of the four major technology categories, but not necessarily across the categories.

Table 6: The Space Technology Ladder – Detailed View.

The Space Technology Ladder	
13	Launch Capability: Satellite to GEO
12	Launch Capability: Satellite to LEO
11	GEO Satellite: Build Locally
10	GEO Satellite: Build through Mutual International Collaboration
9	GEO Satellite: Build Locally with Outside Assistance
8	GEO Satellite: Procure
7	LEO Satellite: Build Locally
6	LEO Satellite: Build Through Mutual International Collaboration
5	LEO Satellite: Build Locally with Outside Assistance
4	LEO Satellite: Build with Support in Partner's Facility
3	LEO Satellite: Procure with Training Services
2	Space Agency: Establish Current Agency
1	Space Agency: Establish First National Space Office

Consider, for example, that action 7 (LEO Satellite: Build Locally) is ranked below action 8 (GEO Satellite: Procure). Action 7 represents a great deal of technical independence. It implies that a country has achieved the ability to locally design and build satellite. They have also established the facilities in their country needed for satellite integration and testing. Action 7 arguably demonstrates more technical autonomy than Action 8. We have chosen, however, to organize the framework as shown to emphasize the four major technology categories (Space Agency, LEO Sat, GEO Sat, and Launch). Thus, specific actions are ranked to show increasing technical autonomy within their technology category, but not necessarily across categories.

This section has discussed the theoretical framework that is the foundation of the analysis in this study. The Space Technology Ladder is defined by its four major levels and various sub-categories. This Ladder is proposed as a theoretical path that a country could follow in achieving national space milestones. The sub-categories within the various levels are chosen based on historical evidence of common technology strategies. The levels and sub-categories are ranked such that a country increases in technical complexity and autonomy as they go up the Ladder. The Ladder thus provides a theoretical basis by which to compare the actual choices made by countries as they pursued new space technology. We start by assuming that a country will work its way linearly up the ladder, achieving each major milestone in turn. That is, we assume they will achieve technically less complex milestones before doing more complex tasks. We further assume that they will choose some, but not all, of the sub-categories as methods toward gaining technology. In order to test this assumption, we collect historical data about developing country space programs on three continents. This historical data is graphed visually and compared to the theoretical path laid out by the Space Technology Ladder. The following section explains in detail what data is used and how it is organized for analysis.

DATA AND ANALYSIS METHODS

The goal of this analysis is to map the technical progress in the area of space technology that was achieved by countries from a variety of regions. The visual mapping tests the hypothesis that countries move linearly up the Space Technology Ladder as they increase their space capabilities. The historical milestones of select countries are graphed on a timeline showing the year that they achieved a specific milestone on the Space Technology Ladder. In order to provide scope to the analysis, the timeline only shows the first occasion in which a country achieves one of the thirteen milestones from Table 6. This avoids the need to find and visualize a complete timeline of events for each country. It also emphasizes the occasions in which countries take a major step forward in their level of technical autonomy in the area of space. Data about national space milestones is drawn from the space agency websites of various countries, conference papers and news articles.

The eight countries included in the analysis represent three geographical regions – Africa, Asia and Latin America – that are traditionally considered to be developing. The African countries are Algeria, Egypt and Nigeria. From Asia, the study includes India, Malaysia and South Korea. Argentina and Brazil are the Latin American countries. The countries are chosen because they have achieved – or they are actively pursuing – at least three of the milestones shown in Table 6. The eight chosen countries are not the only ones that meet this criterion. Other countries from these regions have demonstrated a commitment to space, including Indonesia, China, Iran, Israel, Pakistan, South Africa, Venezuela and Mexico. Several of these countries could also be considered to see if they had reached 3 of the milestones in Table 6. This initial exploration of data from eight countries thus provides a starting point that can inform further research based on the same framework.

The study focuses on developing regions. The countries currently span a wide range of development levels. One way to quantitatively measure their development is based on the rankings of the United Nations Human Development Report.[iv] This annual report provides a multi-faceted measurement of development that is summarized in the Human Development Index (HDI). The HDI takes into account development measurements related to money, health and education. A country's HDI score is a number between 0 and 1 that combines information about performance in these areas. The 2008 version of the report ranks 179 countries based on their performance in the HDI. The HDI rankings for the eight countries under consideration in this study are shown in Table 7. Note that a lower HDI rank corresponds to a higher development level.

Table 7: Summary of information from United Nations Human Development Report for Countries Included in Study.

Human Development Report Information			
Country	*HDI (0 to 1)*	*Rank (1-179)*	*Region*
Algeria	.748	100	Africa
Egypt	.716	116	
Nigeria	.499	154	
India	.609	132	Asia
Malaysia	.823	63	
South Korea	.928	25	
Argentina	.862	45	Latin America
Brazil	.807	70	

Development is clearly a continuous rather than binary concept. It is therefore fruitless to determine explicitly whether a particular country is "developed" or "developing." As Table 7 shows, the countries in the study are all at different points in their development process. It is still appropriate to consider them as a group in this study, however, because they have been pursuing space technology as part of their overall development process. Once the data is collected about the first time each of the eight countries achieves a milestone from the Space Technology Ladder, the information is summarized visually on a graphical timeline. The vertical axis of the timeline shows the number of the technical action taken; this ranges between 1 and 13, as on Table 6. The horizontal axis shows the year in which the action was completed. In the case of a space agency, the year refers to the date the office or agency was established. For a satellite or project, the year refers to the launch date. For a launch project, the year shows the first date in which a satellite is safely launched into the desired orbit.

In some cases, a project is currently underway, but the complete milestone has not been achieved. For example, if a satellite has been built and but has not yet been launched, the milestone has not yet been reached. Also, if a launch has been attempted unsuccessfully, there is clear evidence of the pursuit of this capability but credit can not be given for reaching the milestone. In these cases, the actions are shown on the timeline as "Future" milestones. The timelines are color coded following the pattern established in Table 6 to aid the reader in distinguishing which milestone is achieved at each point. Red shows space agency milestones; yellow refers to LEO satellite projects; green is for GEO satellites; and blue designates launch projects. The following section shows the results of graphing the first time milestones of each country on timelines.

RESULTS

The timelines for achievement of first time milestones from the Space Technology Ladder are shown in regional groups in this section. The regions are presented in alphabetical order: Africa, Asia and Latin America. In order to ensure visual clarity, the words describing each specific milestone are left out of the timeline. Instead, the reader can refer to the numbers along the vertical axis which correspond to the numbers in Table 6.

African Countries

Figure 1 shows the timeline results for the three African countries – Algeria, Egypt and Nigeria. Egypt's path, shown in white triangles, begins the earliest of the three countries. In 1971 Egypt established a government office related to space studies. It was a partnership with the United States that was affiliated with the Egyptian Academy of Scientific Research and Technology. In 1994, this precursor institution was reestablished as the current Egyptian agency that leads space in the area of remote sensing. This new agency is called the National Authority for Remote Sensing and Space Sciences[v]. Egypt's next milestone from the Ladder is at level 8. In 1998, Egypt procured a first geostationary communication satellite[vi]. Later in 2007, Egypt procured her first low earth orbit satellite. They bought Egyptsat-1 from a Ukrainian company and also paid for training of Egyptian engineers.[vii].

The timeline allows us to quickly see several aspects of Egypt's path. First, there was gap of about twenty years between the establishment of the first space office and the next milestone from the Space Technology Ladder. Second, they invested in buying a geostationary satellite to offer commercial communication services before they bought their first remote sensing satellite. There is more to Egypt's space story. They plan to procure other satellites for both communication and remote sensing.

Nigeria's path along the timeline is shown in black diamonds. Nigeria's first milestone came in 1999 with the establishment of the National Space Research and Development Agency[viii]. In 2003, Nigeria procured her first low earth orbit satellite. They bought a remote sensing satellite called NigeriaSat-1 from Surrey Satellite Technology Ltd. in England; they also paid for training of Nigerian engineers[ix]. The next milestone was 2007 when Nigeria purchased a communication satellite from China's Great Wall Company[x]. They plan to achieve another milestone when a satellite called NX Nigeria is launched. This will be the first satellite for Nigeria that is built by local engineers in a partner's facility[xi]. Nigeria's progress in the past decade shows a clear focus on building up local technical capability building, especially in low earth orbit satellites. Like Egypt, Nigeria has other satellite projects which do not represent new milestones on the Space Technology Ladder.

Algeria (purple squares) has three milestones from Table 6. In 2002, Algeria both established a national space agency (ASAL) and saw the launch of their first low earth orbit satellite (ALSAT-1)[xii,xiii]. This remote sensing spacecraft was purchased from Surrey Satellite Technology Ltd. along with a training package. Algeria is working toward gaining its next milestone with the launch of ALSAT-2B[xiv]. This will be the country's first

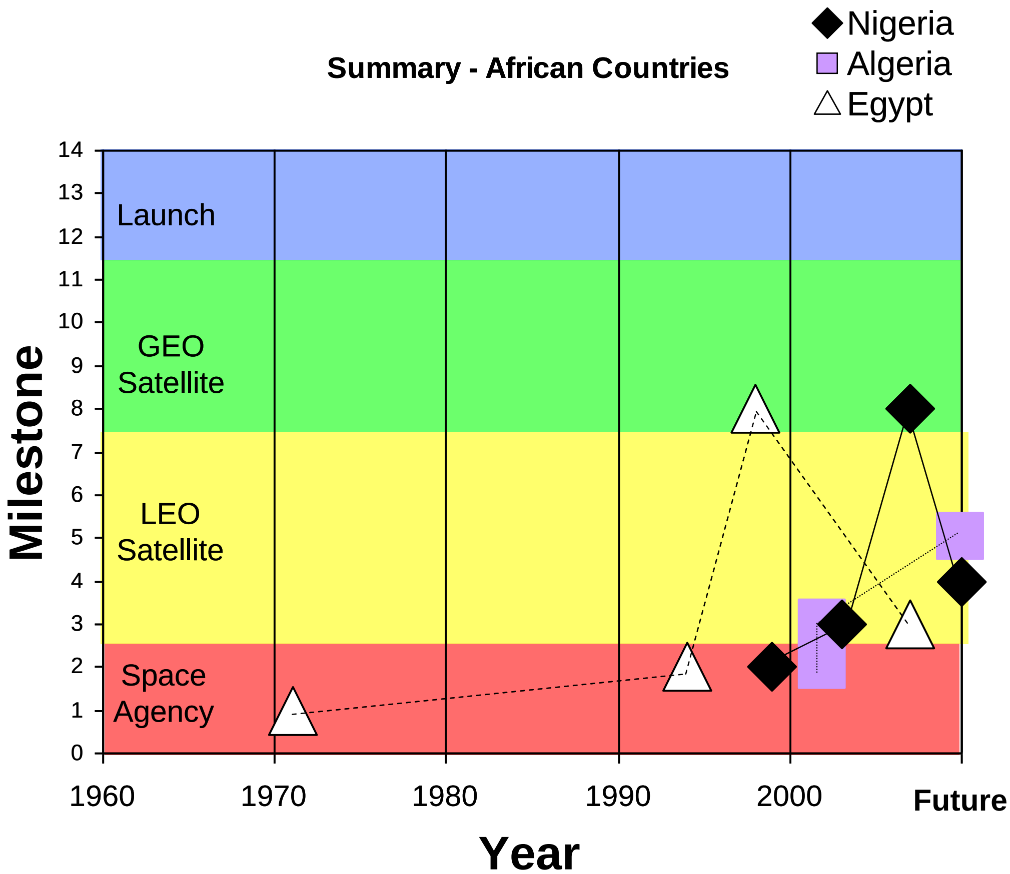

Figure 1: Timeline of Milestones - African Countries

LEO satellite built locally with outside assistance, and it is just one of the satellites that Algeria hopes to use in the future.

<u>Asian Countries</u>

Figure 2 shows the results for Asian countries. Again we start with the country with the earliest milestone; this is India.

India's path is in black diamonds connected by a solid line in Figure 2. Over the decades, India has had many space technology projects. Keep in mind that this is not a complete list; instead it shows the projects that represent milestones according the Space Technology Ladder. India formed the first government space office in 1962; it was called the National Committee on Space Research. Later in 1969, the current space agency (the Indian Space Research Organization or ISRO) was founded. In 1975, India launched Aryabhata, the first LEO satellite built with outside assistance from the USSR. India reached a launch milestone in 1980, with the first successful launch of their Satellite Launch Vehicle-3. It sent a satellite to LEO orbit. This was followed in 1981 by the launch of Baskara II, India's first locally built LEO satellite. The year 1981 also saw a milestone in terms of GEO satellites. India built her first GEO spacecraft with outside assistance from Europe; this was APPLE-I, an experimental communication satellite. In 1982, India saw the launch of INSAT-1, another GEO satellite which they procured from an American company. In 1992, the first locally built GEO satellite, INSAT-2A, was launched for India. The next milestone in 2001 demonstrated India's capability to launch their own geostationary satellites with the Geostationary Satellite Launch Vehicle.[xv,xvi]

India's record is impressive; they achieved nine of the 13 milestones on the Space Technology Ladder. Notice that they made major progress in several technology areas

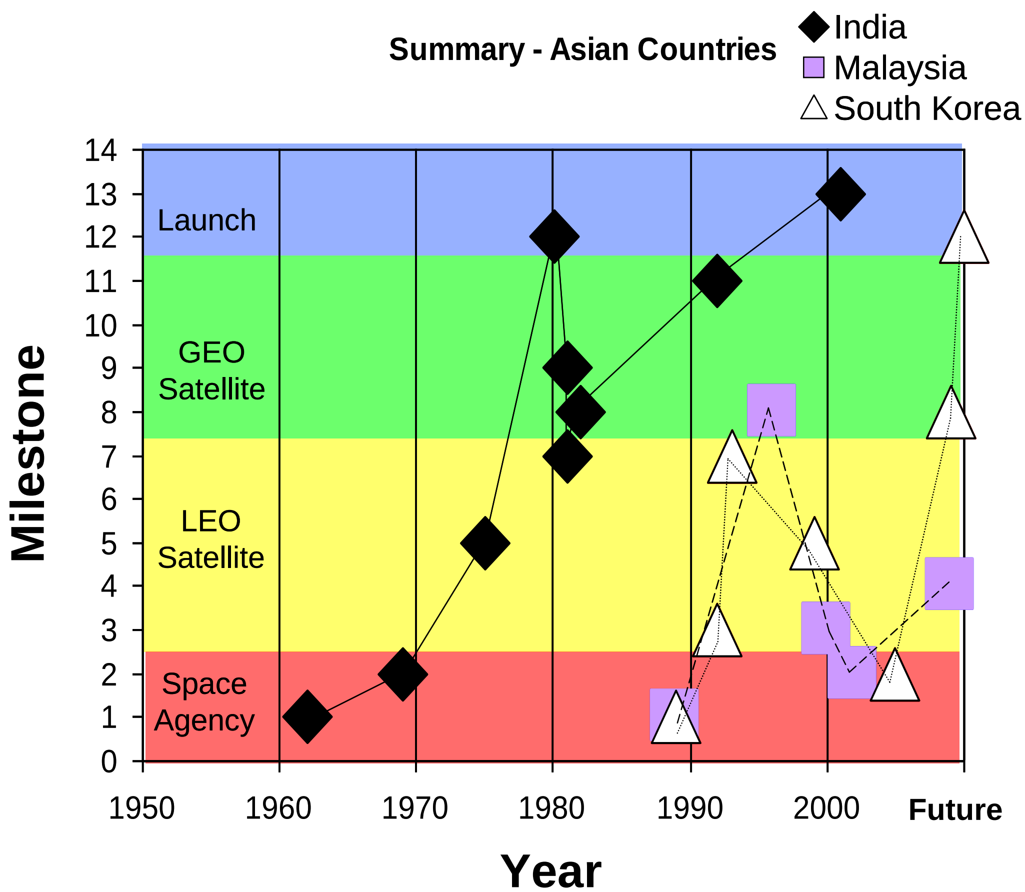

Figure 2: Timeline of Milestones - Asian Countries

simultaneously, especially in the 1980s. Between 1975 and 1985, India reached milestones in LEO satellites, GEO satellites and launch capability.

The second Asian country is South Korea, shown in white diamonds on Figure 2. An agency called the Korean Aerospace Research Institute was created in 1989, signaling Korea's first milestone. Later, in 2005, the National Space Committee was established as the leader for Korean space policy[xvii]. In terms of technical milestones, Korea procured KITSAT-1 (launched in 1992) and used the opportunity to train local engineers. Korea's first locally built LEO satellite is KITSAT-2 launched in 1993[xviii]. In 1999, KOMPSAT-1 was the first satellite built locally with outside assistance[xix]. Korea's first GEO satellite to be procured is COMS; it is scheduled for launch in 2009. As of the time of this writing, Korea is actively pursuing a local LEO satellite launch capability. An attempt in August 2009 almost reached this milestone[xx].

Malaysia's path is shown in violet squares in Figure 2. Like South Korea, Malaysia's first milestone is from 1989 at the establishment of the first government space office. For Malaysia, this was the Planetarium Division who pursed space-related educational outreach. Malaysia's next area of achievement is in geostationary satellites. They have purchased several; the first was in 1996. In 2000, TiungSat was launched for Malaysia. This was Malaysia's first LEO satellite to be procured. The process included training for local engineers. In 2002, the current Malaysian space agency was formed. It is called ANGKASA. The latest milestone is from 2009. The first Malaysian satellite to be built with the support of a partner in that partner's facility was RazakSat. Malaysia worked with South Korea to develop this satellite[xxi].

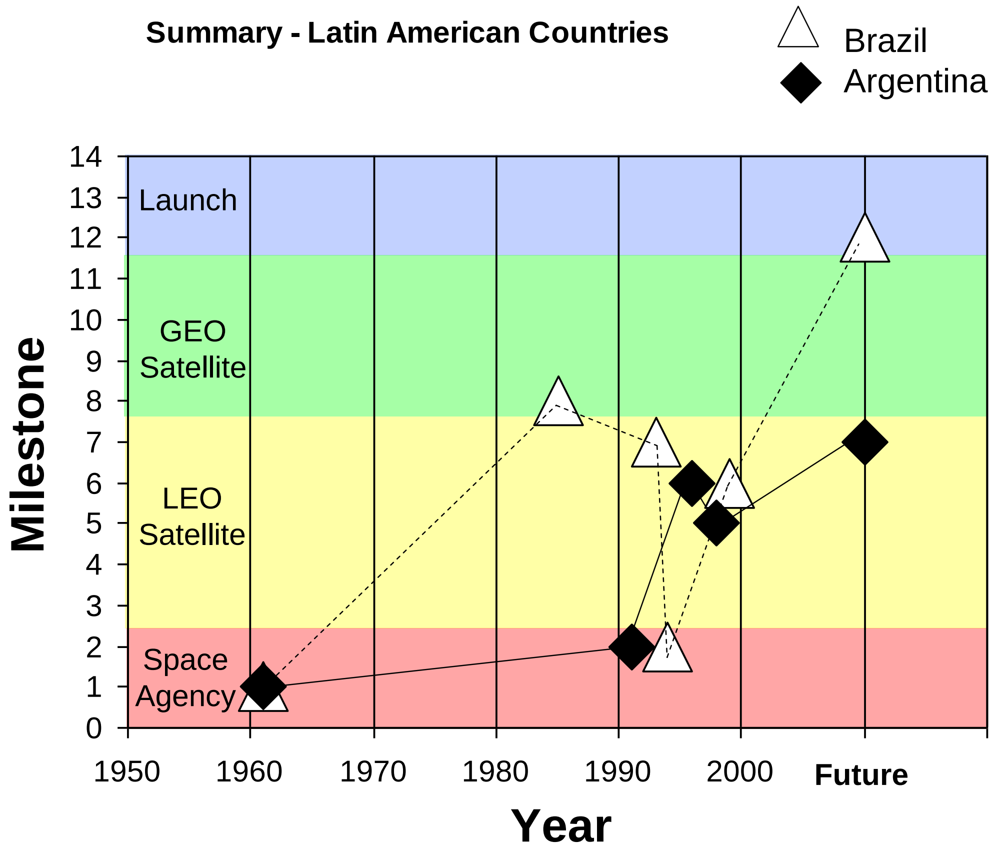

Figure 3: Timeline of Milestones – Latin American Countries

<u>Latin American Countries</u>
Argentina's path is shown in black diamonds in Figure 3. Both Argentina and Brazil started their first national space office in 1961. From there Argentina's next Ladder milestone came in 1991 when it established the current national space agency, known in Spanish as CONAE (Comision Nacional de Actividades Espaciales). In 1996, Argentina saw the launch of its first LEO satellite to be built through a mutual collaboration. This was the SAC-B mission. Later in 1998, the completed the SAC-A mission, which was the first LEO satellite built locally with outside assistance. SAOCOM is planned to be the first Argentinean satellite built locally.[xxii,]

Brazil's story is shown in white triangles on Figure 3. Brazil founded a group to lead national space activities in 1961. In 1985, Brazil procured her first GEO communication satellite. Brazil achieved a locally built LEO satellite in 1993 with SCD-1, which launched in 1993. The current national space agency of Brazil was established in 1994. Brazil's next milestone from the Ladder was in 1999. This was Brazil's first LEO satellite built in mutual international collaboration. The satellite was a remote sensing project with China called CBERS-1. Brazil is pursuing the capability to launch LEO satellites; this continues to be a goal for the future.[xxiii]

The next section discusses what can be learned from these explorations of the historical paths of eight countries in satellite technology.

DISCUSSION: STATEGIC DECISIONS

There are various angles by which one could view the information shown in the previous section. One approach could be to consider the historical and political context of each country and try to understand how these factors influenced their technology path. Another approach could be to consider the countries within each region and compare how these neighboring countries are similar or different. One might also group countries into cohorts based on the time frame in which their major space activities began. With these divisions, one could compare how strategies for achievement in space technology have changed over time. We propose these avenues of investigation for future work, as they are beyond the scope of this paper. The current paper will focus on the strategic decisions made by countries about how to achieve particular milestones on the Space Technology Ladder. These decisions reveal common issued faced by multiple countries. In some cases, it is instructive to see occasions in which two countries handled a situation in the same way. Other times, the stark differences between country strategies are revealing.

This work is directed to the community of people engaged in or supporting satellite programs in developing countries. The purpose of the following analysis is to extend the thinking of this community about the options that are available for countries to increase their local technical capability. The study achieves this purpose by laying out a number of strategic policy choices that countries made in the process of attaining milestones from the Space Technology Ladder, as described in the previous sections.

The discussion divides the policy decisions into three categories based on the context of the decisions. The three categories are as follows: Space Program Capabilities, National Context, and International Context. Decisions about space program capabilities relate to the specific human skills and technical facilities in which a country invests. The national context refers to the relationship of the space program to domestic government, industry and academic actors. The international context refers to the relationship of the space program to foreign government or commercial actors. The decisions that facilitated Space Technology Ladder milestones for the eight countries in this study can be categorized in one of these three areas. Each area will be explored in turn below.

Space Program Capabilities

The eight countries presented in this study made conscious policy decisions to achieve technology milestones in the area of space. As part of this process, priorities were set as to what specific technical investments would be made. These priorities may have been set by different players in different countries – players such as the central government or the technical specialists in the agencies. Research for this study revealed several specific examples of decisions about technical facilities and skills.

Make or Buy the Satellite?

In general, countries who want to engage in the independent use of space technology start by considering the option of having a national satellite. At this stage, a country may compare the costs and benefits of buying a satellite versus developing local capability to manufacture satellites. This decision is influenced by the kind of satellite services a country needs. Many countries begin with either a remote sensing imagery satellite or a communication satellite. Remote sensing satellites are typically flown in Low Earth Orbit and can be relatively small and simple. Communication satellites are normally larger, heavier and more complex than remote sensing satellites because they typically operate in GEO orbit, which is very far away.

Of the eight countries studied here, all of them have invested in owning and operating at least one LEO remote sensing satellite. All of these countries also show evidence that they are working toward developing a local capability to manufacture such satellites. All of the countries, except Argentina and Algeria, have chosen to own and operate a national GEO communication satellite. Argentina is an interesting exception. This country did not choose to build or buy a satellite independently. Rather, in the 1990's Argentina licensed a consortium of European companies to operate communication satellites over their territory and accessed satellite services in this manner[xxiv]. This is not considered a milestone on the Space Technology Ladder, but it is an effective way to access the satellite service. Although six countries in this study are investing in national communication satellites, only India has thus far succeeded in mastering the technology to produce communication satellites locally.

Make Satellites, Payloads or Both?

If a country chooses to invest in local technical capability to produce satellites, there are still several layers of decisions to be made. Should a country start by focusing on both satellites buses and instrument payloads? Or should they choose one of these on which to focus? Argentina provides an interesting story on this point. The SAC-B satellite was Argentina's first LEO satellite built in mutual international collaboration (Level 10 on the Space Technology Ladder). SAC-B was an astrophysical, science mission. Argentina leveraged its growing skills in manufacturing the satellite bus, but they did not try to provide all the instruments independently. Instruments and solar cells were added by the United States, Italy and Brazil. Through this collaboration, Argentina could achieve more than their own resources could provide[xxv].

What is the Program Purpose?

At the start of a satellite project that comes early in the space program, country must often also decide whether the goal of the project is primarily to learn, to test new technology or to produce an effective operational satellite. The outcome of this decision strongly affects the choice of how to obtain the satellite. Malaysia, for example, had a different purpose for their two LEO satellite projects. TiungSat (launched in 2000) was an opportunity for training of personnel in a new field. Malaysia worked with the English company SSTL to build this spacecraft and sent Malaysian engineers to Surrey for training. For their second satellite, RazakSat (launched in 2009), the goal was to develop a satellite that would provide specific imagery services. Malaysia partnered with Korea on this project, but took local responsibility for ensuring that the optical aspects of the satellite would function effectively.[xxvi] South Korea also provides an example of the ways that mission purpose shapes procurement philosophy. The KITSAT-2 mission was South Korea's first locally built LEO satellite. The primary purpose of the mission was to confirm the technical learning that Korea gained by working with the University of Surrey in KITSAT-1. Later the Kompsat-1 project became the first locally built satellite with outside assistance. Even though Korea had already achieved the milestone of building a satellite alone, they know move "down" the technology ladder and found a partner for Kompsat-1. This helped ensure the quality of the Kompsat-1 mission.[xxvii]

When to Build Satellite Facilities?

Another aspect of the decisions about building satellites locally regards the physical facilities required to execute satellite projects. For most countries, at the start of their pursuit of space capability, the requisite facilities for manufacture, integration and testing of satellites are not available. It may be the case that new facilities must be built or old facilities altered to enable the satellite projects to take place. Countries from this study faced a decision regarding when to build facilities locally to support various aspects of satellite projects. Consider several examples. Both India and Argentina started their satellite programs by building LEO satellites locally with outside assistance or partnership. Thus, they developed the facilities at the same time as they developed the human resources. In contrast, Nigeria and Malaysia procured their first satellites from a company along with a training program for their engineers. They later sent teams of engineers to build additional satellites in a partner's facility. Both of these countries are facing the issue of when and how to establish local facilities that will allow them to build future satellites locally. Nigeria and Malaysia focused first on training people and later on developing facilities.

Satellites and Launchers?

Finally, when a country pursues space technology, they face the choice of whether to focus on building satellites or extend their capabilities to include launching. Launching is a very different technical activity than manufacturing satellites; it is no small decision to invest in local launch capability. For the eight countries studied here, only India has successfully established an independent launch capability to LEO and GEO. Both Brazil and South Korea are actively working toward achieving the capability to launch LEO satellites.

Summary

To summarize this section, the historical paths of the eight countries revealed several strategic decision points regarding the process of building up capabilities in the space program. These are questions a country may face once they decide to pursue a satellite project. These decision points can be summarized as follows.

1) Will we acquire satellites through purchase or through manufacture?
2) Will we build the satellite bus as well as payloads or only build the bus?
3) What is the primary purpose of this satellite project – to test new technology, to train people, or to acquire a satellite that provides specific services?
4) When should we build local satellite processing facilities?
5) Should we invest in local launch capability?

The examples of these eight countries reveal a variety of ways to answer these questions. The answer will depend on the needs and resources of each country.

National Context

The section above discussed decisions faced by countries with regard to their space program capabilities, facilities and human resources. This section considers strategic choices made by countries with regard to the relationship between the space program and other players in the national context. These players may be within the government, industry and academia, for example. One area that differentiates the strategies of the countries in this study is the relationship between the space program and domestic commercial actors. In part, countries approach this issue differently due to variation in their levels of industrial development. Beyond that difference, however, countries still face a choice about how the procurement of space technology involves local industrial players and fits into overall national technology policy. Consider a few distinct examples. South Korea acknowledges the involvement of domestic industry as component suppliers for satellite payloads. This was an explicit goal of the KITSAT series of satellites. KITSAT-1 and KITSAT-2 were major milestones for Korea on the Space Technology Ladder[xxviii]. In a similar case for Argentina, a well-established company called INVAP was the prime contractor for the SAC series of satellites, which include Argentina's first two LEO milestones[xxix]. In both of these cases, the satellite projects were an opportunity to stimulate and include existing commercial companies. Malaysia's story is somewhat different. During their first satellite project, a new company was created to provide technical leadership and institutional structure for the newly established community of satellite professionals[xxx]. In the case of Nigeria, Algeria and Egypt, local commercial companies seemed to have played a less prominent role in past milestones.

A related question to that discussed above regards the type of institutions a country establishes or empowers to execute the space program. Such organizations can be government, commercial, academic or hybrids that combine various aspects. All eight countries in this study have some current government office that leads the national space effort. This government office may partner with external companies, universities or other government offices to execute projects. In Korea's case, policy is made by a National Space Committee, but projects are executed by a national research institute (Korean Aerospace Research Institute), a university (Korean Advanced Institute of Science and Technology), and a company that spun out of the university (SaTRec Initative), among others[xxxi]. Korea's story shows how satellite programs can lead to a complex network of institutional associations within a country.

In summary, this section points out that countries have established different strategies for organizing the institutions required to execute satellite projects.

International Context

A third area of decision making exhibited by countries in this study regards relationships with foreign companies and governments in collaborative space projects. These collaborations took various forms, but they affected every country. All eight countries obtained at least one satellite through a relationship with a foreign partner. More precisely, all eight countries achieved at least one milestone on the Space Technology Ladder between Level 3 (Procure LEO satellite with training) and Level 6 (Build LEO satellite with mutual international collaboration). This means all eight countries chose to depend on a foreign government or company to execute one of their early milestone projects. Although international collaboration on major technology projects is common, it is by no means a simple proposition. This section explores some of the questions addressed by countries as they managed their international space projects.

When to Partner?

One question a country faces is when to involve external partners during the process of building up capability in space technology. They can choose to establish partnerships early in their process. These relationships may be advantageous in terms of facilitating human resource development. They are difficult to manage, however, because the country that has lower technical sophistication may at a disadvantage in the relationship. Another approach is to work independently during the early stages to build up local capability and focus on partnering later as a technical equal. This discussion brings up another question – how does a country learn about space technology if they do not partner with outside companies or governments? Consider the following examples of partnership strategies. Brazil's first LEO satellite was SCD-1; it was built locally by the National Institute for Space Research and launched by the United States in 1993. After establishing this local satellite capability, Brazil collaborated with China on the CBERS series of satellites (first launched in 1999). In contrast to Brazil's independent start at Level 7, the other countries did their first projects in partnership. Argentina's first LEO satellite project was at Level 6 (Mutual International Collaboration); India started at Level 5 (build locally with outside assistance). Meanwhile, Nigeria, Algeria, Egypt, Malaysia and South Korea started their LEO work at Level 3 (Procure LEO satellite with training).

Of course, these brief outlines do not tell the whole story. Further research and description is needed to understand the mechanisms that enabled learning and cooperation in each case. These examples are presented to highlight the international aspect of space policy decision making.

Partnership or Purchase?

A final category of decision making relates to a country's choice about whether to form an international partnership on a commercial or political basis. Generally, this means choosing between partnering with a foreign firm or a foreign government. Examples of both kinds of partnerships are evident in the history studied here. A non-commercial partnership with a foreign government can be attractive as a way to build both technical and political capital. It may also be billed as a way to save money by sharing costs, though decreased expense is not guaranteed. The challenges of political partnerships come from the nature of government projects. They must be vetted by the political process at some level. They are subject to risk due to policy changes, and they may be designed based on interests that do not necessarily promote the technology objectives. A commercial partnership can benefit from the efficiency of a profit-driven company. If a country hires a foreign firm, they can exercise more unilateral control as customers than they can as political partners. There are also challenges to working with foreign commercial partners, however. Costs may be prohibitive, and regulation may affect international trade options. Consider now some examples of commercial and political partnerships among the projects studied here.

In the case of GEO satellites, most countries in this analysis purchased their communication satellites from foreign companies. Only India moved further up the ladder to develop GEO satellites locally. Several countries – including Malaysia, Egypt, Nigeria and Brazil – established commercial companies to own and operate the communication satellites for profit. This is logical in the case of communication. This facet of the satellite market is the most historically successful in the commercial sector. The case of LEO satellites shows more variety. Malaysia represents one extreme. Both of their LEO satellites have been developed through partnerships with commercial companies. This model of commercial partnership was also followed by South Korea, Egypt, and Algeria. Argentina is at the other extreme. All of their partnership milestones involve non-commercial partnerships with other governments. Meanwhile, India's long history includes a mix of milestones via government and commercial partnerships.

Summary

Just as a new space program must decide how to arrange an instructional structure to organize space efforts domestically, many countries manage the complexity of international partnerships. Countries have made distinct, strategic choices about when to pursue partnerships and the types of partnerships they pursue.

CONCLUSION

This study has made three major contributions to the community that supports space programs in developing countries. These contributions are the Space Technology Ladder framework, the graphical summary of historical milestones, and the description of strategic space decisions.

The Space Technology Ladder (see Table 6) is a framework that can be used to define the milestones reached by countries while pursuing national space technology capability. The framework has four major technical categories, which are as follows: 1) establishing a national space agency; 2) owning and operating a satellite in LEO; 3) owning and operating a satellite in GEO; and 4) launch capability. Within each of these four major categories are sub-categories that provide additional information about the level of technical autonomy achieved within the category. The Space Technology Ladder is not proffered as a prescriptive standard, but rather as a descriptive tool that facilitates comparison of countries with very different patterns.

The second major contribution of this paper is that it gathers together key information from the space history of eight countries. Each of these countries has pursued national capability in space technology as part of their overall process of development. The historical information is summarized and visualized in a graphical format. This original format provides instant insight about the order in which each country achieved major space milestones. This contribution is captured in Figures 1, 2 and 3.

The third contribution is highlighting strategic choices faced by the countries in this study. These decisions can be categorized into three areas, as follows: Space Program Capabilities, the National Context, and the International Context. The decisions in these areas determine the nature of each country's path through the Space Technology Ladder. Linking these decisions to the Ladder Framework reveals similarities and differences in the diverse stories. By outlining these key decision areas and the diverse strategies employed by the countries under study, this paper broadens the thinking of the community. Future research will include data about more countries. It will also look in greater depth at the contrasting decisions made by countries to understand their motivations and outcomes. Ultimately, we strive toward depth of understanding and prescriptive theory to support decision making in developing country space programs.

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