ASSESSMENT OF THE POTENTIAL FOR DEVELOPING A MICRO-LAUNCHER INDUSTRY IN SOUTH AFRICA

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ABSTRACT

Small satellites have dramatically lowered the barriers to participating in space activities for many emerging countries, including South Africa. The rapid up-take of this facet of space technology has spurred the development of several micro-launchers dedicated to lofting small satellites to low Earth orbit. However, the majority of these micro-launcher initiatives and the majority of spaceports in use are located in the northern hemisphere, and there are currently no operational spaceports in Africa.

In this study the potential for developing a micro-launcher industry in South Africa is explored, building on the launch facilities established for the previous space programme of the 1980s and early 1990s, and existing capabilities in present-day academic institutions and industry. Potential markets, financial requirements, technical feasibility, available infrastructure, and regulatory and policy aspects of such a venture are reviewed with respect to South Africa's current political situation and attitude towards space activities. Several possible options for establishing small satellite launch capabilities in South Africa are used as a framework to assess the feasibility of a micro-launcher industry in South Africa. These range from a simple "ship and shoot" scenario with no indigenously developed technology to more complex cooperative arrangements which would, to varying degrees, require technology transfers and cooperation with potential international partners.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS AND ACRONYMS

AISI	Aerospace Industry Support Initiative
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science & Industry Corporation
DST	Department of Science and Technology
dti	Department of Trade and Indusrty
ESA	European Space Agency
GEO	Geostationary Earth Orbit
HCoC	Hague Code of Conduct
ISRO	Indian Space Research Organisation
ITAR	International Traffic in Arms Regulations
LEO	Low Earth Orbit
MBIE	Ministry of Business, Innovation and Employment
MEO	Medium Earth orbit
MTCR	Missile Technology Control Regime
NASA	National Aeronautics and Space Administration
OTR	Overberg Test Range
PLSV	Polar Satellite Launch Vehicle
SALT	Southern African Large Telescope
SANSA	South African National Space Agency
SKA	Square Kilometre Array
SMME	Small, medium-sized and microenterprises
SOC	State-owned company

1. INTRODUCTION

In 2016 the space launch market was estimated at approximately $5.5 billion, enabling a space industry worth $339 billion (Satelite Industry Association, 2017). Much of the existing launch industry has been developed off the back of a trend of using larger, more capable satellites, which require correspondingly larger launch vehicles. This need for an ever-increasing launch vehicle capacity has led to the development of costly launch vehicles with capabilities to loft payloads with masses of up to 64 tons to LEO. The escalation of costs associated with both developing and launching these larger satellites has amplified the barriers to entry into the space market for new actors.

The status quo is being challenged by a large number of new entrants in the space arena who are developing commercial space systems based on constellations of small satellites with masses in the range of 1- 50 kg. The advent of these small satellites has greatly lowered the barriers to entry for new space actors and as a result many new space actors are entering the market, with the potential to disrupt the established space industry currently dominated by a few large prime contractors and a larger number of medium-sized players.

Companies such as Skybox, Planet Labs and Spire have pioneered the use of smaller satellites in lower orbits to provide useful imaging data, which accounted for an 11% increase in revenue related to Earth observation from 2015 to 2016. There is also significant interest in using small satellites to provide Internet, with companies including SpaceX and OneWeb having confirmed their plans to launch sizeable constellations of 4,025 and 648 satellites, respectively. To date, the majority of small satellites are launched as secondary payloads, constrained to orbits selected by the launchers' primary payload customers. These tend to be high-altitude orbits, whereas most small satellites are short-duration missions that do not require the high orbits accessed by large launch vehicles.

Given that nearly half the satellites launched in 2016 had masses of 10 kilograms or less, the industry's emerging small satellite market is rapidly gaining traction. The proliferation of commercial small-scale satellites and the demand for more regular launches targeting specific orbits has stimulated the development of dedicated small launch vehicles. There are currently more than 25 launchers under development worldwide that have a carrying capacity of less than 500 kg to low Earth orbit. This is still a relatively untapped market as most of the new small launch vehicles are not yet operational and some are still sourcing funding (Klotz, 2017). This market has already garnered global interest; however, the majority of the launchers in development are coming from the US. The American launchers reaching an operational state include Rocket Lab's Electron, Virgin Galactic's LauncherOne, along with Vector Space System's Vector H and Vector R. Russia's Lin industries is also developing a dedicated launch vehicle family known as the Taymyr family, which has carrying capacities between 12 kg and 180 kg. China has also developed its own small launcher, Kuaizhou-1A, with a carrying capacity of 300 kg to LEO. To date, this is the only small launch vehicle that has been successfully used to launch a payload.

The small satellite trend has also encouraged the development of a new generation of spaceports. Launch complexes such as Wallops Flight Centre, Vandenberg Air Force Base and the Esrange Space Centre are proposing the development of their own in-house launchers for small satellites. Given the high capital outlay required to build new spaceports, several countries are considering adapting existing facilities into smaller launch complexes suitable for small launch vehicles. The UK in particular is investigating the possibility of using decommissioned airfields.

In this regard South Africa has two distinct advantages in that is has legacy spaceport infrastructure situated on the southernmost tip of Africa built for this purpose and it's in a prime location to launch into sun-synchronous orbits. Following South Africa's decision to develop a reconnaissance satellite in the 1980s, approximately R 5 billion was invested in the space programme over the decade that followed, the equivalent in 2017 purchasing power of more than $13 billion U.S. dollars. Some of the infrastructure from that initiative that remains functional today includes the Spaceteq (formerly Houwteq) satellite assembly, integration and test facility that was used in testing several South African satellites and the Denel Overberg Test Range (OTR), which was built to be a space launch complex (Gottschalk, 2010). With South Africa's growing involvement in small satellite activities, the question naturally arises; should the South African government consider permitting, encouraging, facilitating or even supporting the development of a local micro-launch industry?

This study considers the potential of developing a micro-launcher industry in South Africa by considering several scenarios in which the industry could be introduced. The challenges and opportunities associated with each scenario are discussed in relation to historical missions and the current state of scientific, technological, industrial and economic development in South Africa. The proposed scenarios focus on the level of external stakeholder involvement, the relative cost of initiating the industry, and the degree to which the technology will impact other sectors through knowledge sharing, industrial capacity enhancement, and direct spin-offs. The four scenarios discussed are:

I. **A lease agreement scenario**, in which a foreign entity is able to lease a launch facility under South Africa's jurisdiction but where there is no further interaction between South Africa and the foreign entity;
II. **A joint venture scenario**, in which there is active participation between South Africa and a foreign entity, with collaboration, positive investment cycles, skills transfer and the use of existing rocket technology, with South Africa acting as the launch country;
III. **An agile development scenario**, in which South Africa begins transitioning facilities towards space activities by supporting suborbital flights for scientific experiments and commercial applications using existing technology and strategic partnerships with foreign entities to develop or acquire additional industrial capabilities;
IV. **An independent development scenario**, in which there is active collaboration between government and industry within South Africa to develop a launch industry with indigenous rockets and South Africa acting as the launch country.

The analysis of these scenarios is limited to a review of historical space projects in other developing countries, and similar high-technology projects in South Africa and is based on publicly available information. The objectives of the present study are to:

- Assess the current demand for small launchers and the sustainability of such a demand;
- Examine the state of the overall launch industry, with a particular focus on the maturity and stability of the small launch vehicle industry;
- Assess the current availability of spaceports and their standard operation;
- Evaluate the relevance of South Africa's legacy infrastructure with respect to current launch requirements and the current state of spaceports;
- Assess the regulation governing space activities both internationally and within South Africa to establish weather launcher activities would be permissible;
- Assess the feasibility of developing a micro-launcher industry in South Africa for each of the scenarios described above.

2. MARKET AND ECONOMIC TRENDS IN THE LAUNCH INDUSTRY

The first satellite launched into space, Sputnik I, had a mass of only 83.6 kg. By today's standards this would have been considered a microsatellite, but in 1957 it was groundbreaking technology that initiated the U.S.-U.S.S.R space race. Since the launch of Sputnik 1, satellites have become incrementally larger as technology continues to allow for longer operational life, more instrumentation, power and capability. An example of this progression is illustrated with the development of Intelsat, a well-established communication satellite provider. The first satellite launched by the company in 1965 was Early Bird, which had a mass of 40kg. This was followed by Intelsat 3 in 1969 with a mass of 160kg, Intelsat 4 in 1975 with a mass of 800kg and Intelsat 5 in 1981 with a mass of 1900kg. This upward trend has continued, with Intelsat 35 launched in 2017 weighing in at approximately 6000kg (N2YO, 2017).

While these large satellite providers have continued with commercial success, the barriers to entry in the commercial satellite market and limited access to space for scientific research have driven the development of ever-smaller satellites. The most notable development in this trend has been the development of CubeSats. The CubeSat concept was initially developed in 1999 at California Polytechnic State University and Stanford University to facilitate educational and scientific space exploration by standardizing the size and form factor for a smaller type of satellite. The standard unit (1U) is 10x10x10cm, which can be extended into 1.5, 2, 3, 6 and 12U sized satellites (Mabrouk, 2017). The standardized sizes allow for standard sized launch pods, which in turn reduces the complexity of designing custom launch containers and reduces the overall manufacturing cost.

As technology advances there is more opportunity to develop miniaturized satellites that have some of the same functionality as larger satellites. In 2011, a NASA team successfully built and tested PhoneSat, a satellite using smartphone components, namely a phone camera and Google's Android™ operating system (NASA, 2013). The purpose of this mission was to demonstrate that modern electronics have the capability to survive in space and provide useful data at a low cost. However, given the low orbits used by these smaller satellites, larger constellations are needed to cover the same area as larger satellites placed in higher orbits. That being said, large constellations of smaller satellites could still prove to be more economical than a single large satellite. Using small satellites is advantageous to smaller companies as it is easier to improve iteratively on satellites already in use and losing one or more satellites is unlikely to hurt a company's financials as opposed to a business model that relies on a single, very costly satellite. This can be seen in upcoming companies such as Planet Lab, Spire and One Web, which are redefining the technology required to operate Earth observation and telecoms satellites.

There are many views on the current direction of the satellite industry, with some considering the new generation of smaller satellites a disruptive technology, while others view it as a passing fad. In order to assess the feasibility of a launch industry in South Africa to cater for these small satellites, it is necessary to establish if there is enough demand to sustain such an industry. In evaluating the demand for smaller launch vehicles, the current state of the global small satellite market and relevant trends with respect to current launch options and sectors utilizing these satellites will be discussed in more detail. The stakeholders within the existing launch industry will also be considered from a global perspective to assess and the current state of interaction between countries.

2.1. Trends in the small satellite market

The smaller size and lower mass of small satellites allow for the possibility of multiple small-scale satellites to be launched on a single launch vehicle as secondary payloads, or 'ride-shares'. In this case, the primary payload is the main customer that determines the launch schedule and orbital parameters. In February 2017 an Indian PSLV rocket launched ISRO's Earth observation satellite Cartosat-2, along with 103 considerably smaller secondary payloads. Small-scale satellites are typically classified according to mass, as shown in the Table 2.1.

Table 2.1 Small Satellite Nomenclature and Mass Categories.

Satellite class	Mass Range
Small satellite	100 – 500 kg
Microsatellite	10 – 100 kg
Nanosatellite	1 – 10 kg
Picosatellite	< 1 kg
Femtosatellite	10 – 100 g

The trend of having an increasing number of smaller secondary payloads per launch has risen over the last few years. In 2014 the number of payloads per launch averaged 1.77, increasing to 3.03 in 2015 (Ostrove, 2017). The increase in the number of payloads per launch is largely attributed to the proliferation of smaller satellites. The payloads-per-launch ratio in 2016 declined to 2.52, partly due to a lower launch rate and a change in operational vehicles (Ostrove, 2017). Of the launch vehicles previously favoured by small-scale satellite operators, the Dnepr did not launch in 2016 and the Antares only launched once. Going forward, the drop in number of payloads per launch is not expected to continue as the use of smaller satellites continues to evolve and the demand for dedicated launch vehicles aimed at small-scale satellites is expected to increase (Ostrove, 2017).

Figure 2.1, below, shows the total number of CubeSats in all categories launched since 2010 in the academic, commercial, military and agency sectors (Kulu, 2018). While there was a drop in the total number of orbited small-scale satellites in 2015 and 2016, the number of small satellites launched more than doubled by the second quarter of 2017. The impact that a launcher's schedule can have on small-scale satellites is more evident when noting that only two PSLV flights orbited approximately 70% of the small-scale satellites launched by June 2017. In a ride-share arrangement the secondary payloads are required to accommodate the schedule set by the primary payload, including delays. For academic institutions such launch delays are considered an acceptable risk, however this is more problematic for commercial operators. The frustration with sourcing timely launch opportunities is expressed in a statement made by Spire, a commercial small satellite operator, which stated in 2016 that the "main obstacle in getting the company's satellites to orbit has simply been launches not happening when they are originally scheduled" (Henry, 2016).

2.2. Trends in satellite use by sector

The increase in the total number of small satellites orbited suggests an increase in demand. However, to establish whether the increase would have any effect on a market based in South Africa it is necessary to analyse the various sectors that are contributing to the increase in demand for small satellite launch opportunities. Space activities can be broadly classified as civil, military, and commercial. National agendas may limit the market reach for an agency more than it would for a university, so for this particular study the civil sector has been separated into university actors and national agencies. Likewise, for the purpose of this study the military sector is not considered as part of the open commercial market as it is not considered a significant potential user of small satellites in South Africa.

Over the past few years there has been a shift among these sectors in terms of small-scale satellite use. Figure 2.1 shows the change in the dominant use from the university sector to the commercial sector as small satellites have been adapted by the commercial industry to provide marketable services such as communication and Earth observation.

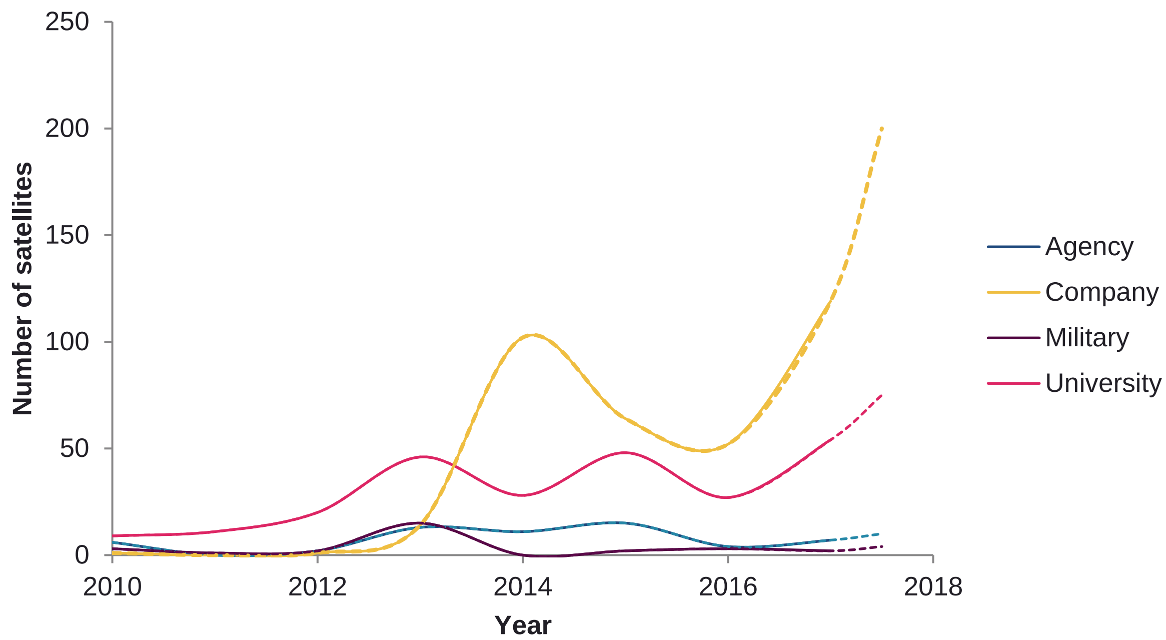


Figure 2.1 Number of small-scale satellites launched by sector between 2010 and 2017. (Kulu, 2018)

Historically, universities were a significant developer and user of small satellites. Many institutions still continue to develop and operate small satellites as a means to carry out scientific research to validate new space technologies, and to provide practical experience for students given the relatively low manufacturing and launching cost of these satellites. The low cost has also led some universities to use femtosatellites as 'beep sats', where the data produced does not yield much useful information other than telemetry, which can then be used as an educational tool (Swartwout, 2013). As mentioned, the CubeSat concept was developed by California Polytechnic State University and Stanford University to facilitate educational and scientific space exploration by standardizing the size and form factor in order to lower the development cost (Mabrouk, 2017). The use of these satellites and the ride-share concept benefited many universities, as specifying launch parameters was not a primary concern for them and early ride-share agreements were often free.

Although universities continue to make use of small-scale satellites, there has been a shift in user patterns and the predominant demand is now from the commercial sector. The development of effective compact technology has enabled companies to employ smaller satellites to yield marketable products. This shift is shown in Figure 2.2, where the commercial sector has accounted for more than 60% of the micro/nano satellites launched since 2016. In particular, the commercial Earth observation constellations, namely Planet and Spire, accounted for nearly half of those satellites (Kulu, 2018). With the increasing use of smaller satellites by the commercial sector for operational space applications, the demand for dedicated small launch vehicles is expected to increase as control over orbital parameters and launch schedules becomes more important. It is anticipated that the demand for launches is likely to increase for the sun-synchronous orbits, as many of these small-scale satellites are for Earth observation (Ostrove, 2017).

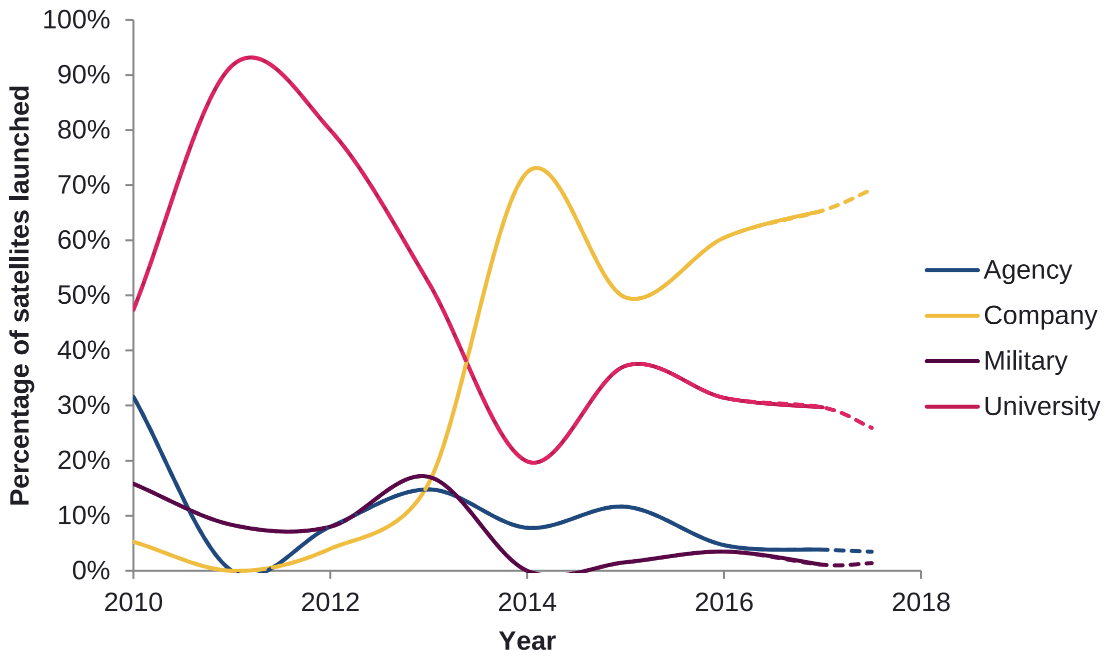


Figure 2.2 Percentage of small-scale satellites launched between 2010 and 2017. (Kulu, 2018)

Communications satellites made up 7% of the total number of micro/nano satellites (with a mass less than 50 kg) launched between 2009 and 2015, however SpaceWorks have forecasted this growth to completely cease by 2018 (Doncaster, et al., 2016). While there is still a drive in new telecoms companies using much smaller satellites in significantly larger constellations, the anticipated satellites are in the "small satellite" category, with masses in the range 150kg - 200kgs. In 2015, SpaceX and OneWeb confirmed their plans to launch sizeable constellations of 4,025 and 648 satellites respectively, with both companies having secured significant funding as well as launch arrangements (Moore, et al., 2016). While these constellations are out of the scope of the proposed micro/nano launcher industry given the larger aggregate mass, it is important to note that these constellations are considerably larger than those of the currently operational Earth observation companies, and could present a more consistent demand for a launch industry.

Spire is a commercial small satellite operator that provides information for global ship tracking and high-frequency weather forecasts using GPS radio occultation to infer temperature, pressure, and humidity at various altitudes. Spire recently secured a contract with the National Oceanic and Atmospheric Administration (NOAA) in the U.S to provide weather data to the value of $370 000 (Werner, 2017). The company is still developing the LEMUR constellation, which will be deployed in two phases. Phase I, which has been competed, consists of 29 identical CubeSats placed into different orbital altitudes and inclinations. Phase II follows a similar approach but with up to 175 CubeSats in a 400 to 650 km orbit.

Spire also requested authorisation from the Federal Communications Commission to launch up to 900 satellites in a 15-year period in order to replenish the in-orbit fleet, as necessary to maintain a constellation of 175 satellites (Spark, 2015). Spire launched the Phase I LEMUR satellites with a variety of vehicles including PSLV, Dnper, H-IIB and Antares along with contracting approximately 12 launches with Rocket Lab's Electron, which is not yet operational (Henry, 2016). GeoOptics, like Spire, also uses GPS radio occultation on CubeSats to monitor the weather and has also been awarded a contract with NOAA. GeoOptics has only just begun to establish their constellation, and to date they have been using the Soyuz and PSLV to launch their satellites (Werner, 2017). The company was referenced in relation to being a client for LauncherOne in 2012, however there has been no public reference to a contract since then.

Planet operates a constellation of CubeSats used for Earth observation for applications in agriculture, deforestation, and disaster relief. The constellation consists of 28 'Dove' CubeSats, which are collectively referred to as a 'Flock'. Despite their small size the Doves provide images with a resolution of 3 to 5 meters on a global scale with a revisit rate that is unprecedented among existing satellite systems. The orbital inclination of Planet's satellites is 52 degrees, thus providing data for the vast majority the world's populated and agricultural regions (Escobedo, 2016). Not all launches are successful; 26 satellites from Flock 1d were lost on Orbital ATK's Cygnus, followed by the loss of Flock 1f on SpaceX's Falcon 9. Planet has also contracted 3 launches from Rocket Lab, each of which is expected to launch 20 to 25 satellites (Krebs, 2017).

Another pioneering small satellite operator named Astroscale aims to ensure LEO remains commercially viable by removing space debris. This company has begun to develop a solution to address the issue of debris, particularly in LEO where the issue is most prevalent and where most commercial small satellites intend to operate. This company is still in the developmental stage, but once established, launches will be required as often as satellites need to be removed from orbit. Given the current trend towards small satellites and large constellations, Astroscale's services have the potential to be in high demand. The first of the satellites developed by Astroscale is the IDEA OSG 1, which has a mass of 22 kg and collects information on debris larger than 100μm within a given orbit. ADRAS 1 is the second satellite from Astroscale to be launched. With a total mass of 120 kg, ADRAS 1 will be responsible for deorbiting selected satellites (Astroscale, 2016).

ExactEarth, established in 2009, is a satellite operator that specialises in maritime vessel monitoring. This company has built up a small constellation of 9 satellites (ExactEarth, 2017). Partially funded by ESA's Business Applications, ExactEarth together with Satellite Applications Catapult, Pole Star Space Applications, TeamSurv and OceanWise, has developed a maritime machine-to-machine (M2M) platform that uses the satellites to upload sensor data from vessels. A direct competitor of ExactEarth is Orbcomm, which also offers remote ship tracking services. These companies both tendered for a Canadian government contract to the value of $14.5 million in 2016, which highlights the commercial viability of these small satellite constellations (Selding, 2016).

National space agencies have also acknowledged the benefits of smaller satellites, using them as technology test beds and to conduct scientific research. Although, it should be noted that even though there has not been a significant uptake of smaller satellites by national space agencies, it is interesting to note that NASA has outsourced several contracts to commercial micro/nano satellite operators. This is a positive indication that the commercial aspect of micro/nano satellites has a small but consistent client base, which may help drive its success in the long term.

The trend towards greater use of small satellites is being fuelled by the commercial sector, which is an auspicious base for a potential launch industry. However, the majority of these companies are based in the US and current forecasted demand suggests that 92% of the demand for small launchers will come from the US and Asia (Pultarova, 2017). US-based companies are subject to certain US technology transfer restrictions such as ITAR, which could hamper access to a global client base. Despite restrictive legislation internationally, the launch and satellite usage trends from a global perspective are indicative of trends that will filter down to countries such as South Africa, which are not yet actively participating in space activities but are fostering or seeking ways to foster their space industries.

2.3. Operational Commercial launchers

A typical launch vehicle comprises several basic subsystems including propulsion, guidance, navigation and control. The propulsion can be from an engine using solid or liquid propellant, or a hybrid of both. The choice of engine can be determined to a certain extent by the mission for which the launch vehicle is to be used. Solid propellants are simpler to operate and cheaper than liquid propellants, however once ignited the engine cannot be throttled or stopped, whereas the burn rate of liquid propellants can be controlled more effectively (FAA, 2016).

By the end of 2015, there were 112 variants of space launch vehicles operating globally. This includes the individual launchers that are differentiated within family groups, such as the Atlas V family, with different iterations of boosters, fairing diameters and upper stages. However, not all the currently operational launch vehicles are available on the commercial market (FAA, 2016).

There are a wide variety of launch vehicles on the market, which are able to launch into Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Sun-Synchronous Orbit (SSO) and Geostationary Orbit (GEO), depending on the size of the engine and the mass of the payload. The payload capacity for a given launcher is higher to LEO than GEO given the lower potential difference within the Earth's gravity field; consequently, a large overall satellite mass can be orbited to LEO for the same launch cost. Of the launchers available to the market and launched in 2016, the carrying capacity to LEO ranged between 450 kg to 25 000 kg. Figure 2.3 shows the carrying capacity and launch cost per kilogram for each launch vehicle in 2016, where prices have been disclosed in publicly available sources. While the larger launch vehicles are considerably cheaper per kilogram, the orbital parameters are not always suitable for small-scale satellites as most require launches to LEO.

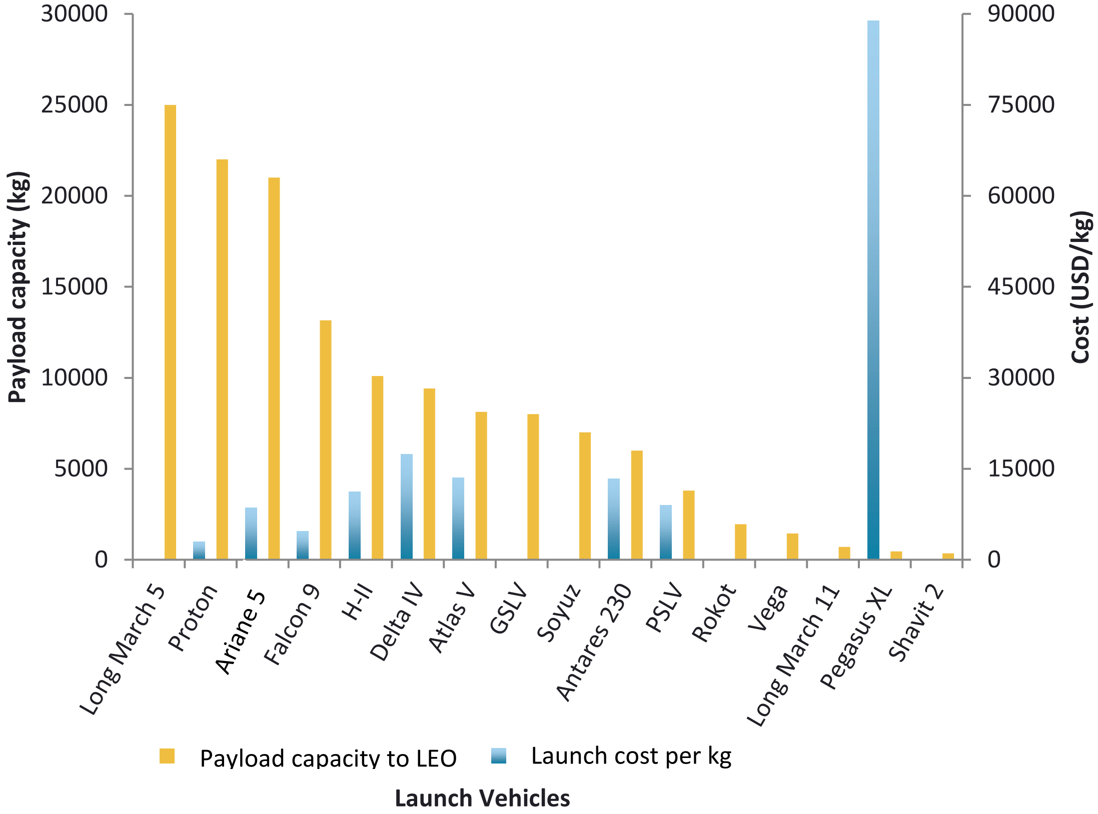


Figure 2.3 The carrying capacity and launch cost per kg by launch vehicle. (FAA, 2016)

Excluding the Long March 5, most of the larger launch vehicles were targeting orbits higher than LEO. As they were designed to primarily serve the satellite telecom market in GEO, launch prices to LEO are therefore often not that competitive for these launchers and hence the associated providers do not often offer these launchers for LEO missions. The Proton had the lowest cost per kilogram but crucially did not launch into LEO in 2016. In comparison, the smaller vehicles were almost entirely launched to LEO but cost more per kilogram. Falcon 9 is the second cheapest operational vehicle, and 40% of its launches were to LEO.

Figure 2.4 shows the frequency with which each of the launch vehicles was launched into LEO in 2016. Not surprisingly, the heavy-lift launchers, with the exception of Long March, were not widely used to loft payloads to LEO.

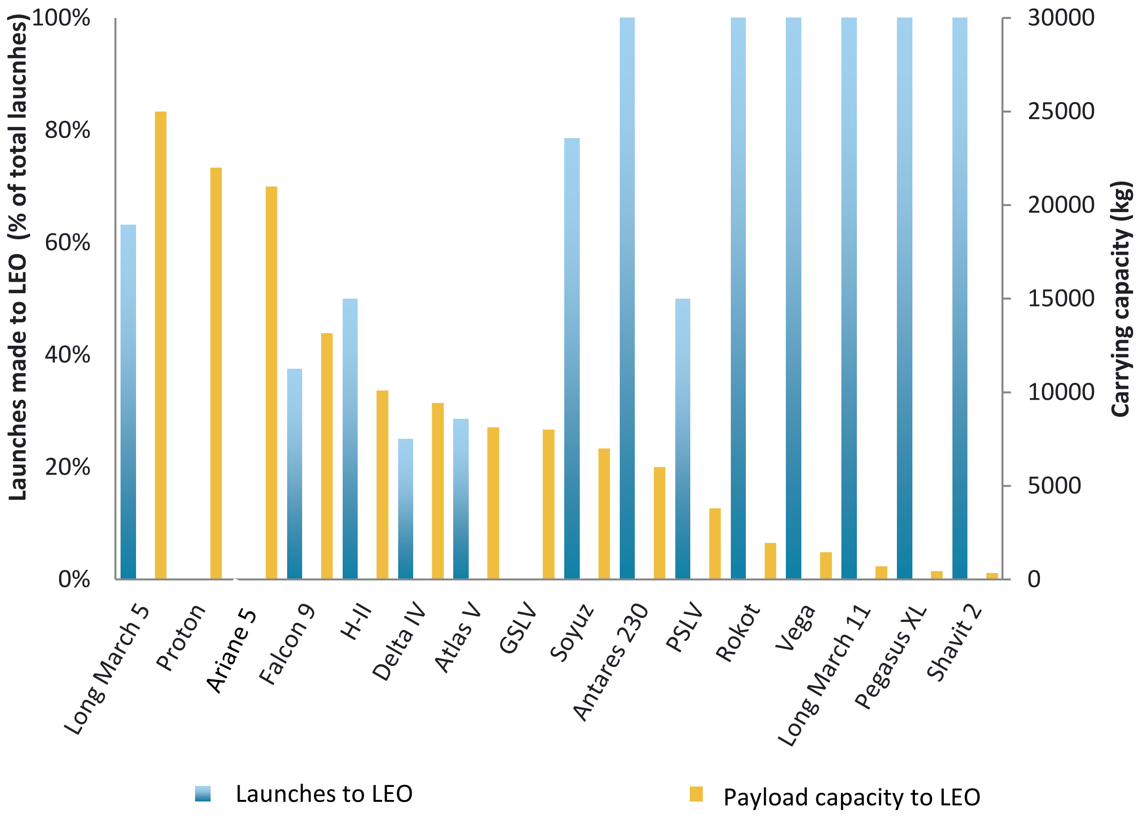


Figure 2.4 Percentage of launches to LEO by launch vehicle. (Kyle, 2017)

Antares, Falcon 9, Soyuz, Atlas and H-II have all been used to deliver cargo to the International Space Station (ISS) and are expected to continue to be used in this manner. Falcon 9 has become the most utilized launch vehicle in the US due to its lower prices and NASA contracts. This vehicle is expected to increase the launch rates into LEO over the next year, given the current demand for US launches (Ostrove, 2017).

The Long March 5 is the largest vehicle in operation in China, built to enable the country's plans to develop Tiangong 2 into a multi-module space station (Ostrove, 2017). This is also driving up the number of launches into LEO, which is uncharacteristic for such a large launch vehicle. China also still faces the issue of the US ITAR technology safeguards regime, which limits their international customer base for commercial launches considerably as US components cannot be lofted using Chinese launch vehicles. So while this vehicle is likely to be cheaper per kilogram it is not accessible to many commercial operators who utilise US components in their satellites.

As an alternative to these larger launch vehicles, Pegasus XL has marketed itself as the "world standard for affordable and reliable small launch vehicles". With a launch capacity of only 443 kg to LEO, it is the smallest operational launch vehicle, but arguably not the most affordable, as illustrated in Figure 2.3.

Pegasus uses an air launch technique, where the rocket is carried under Orbital ATK's Stargazer L-1011 aircraft to an altitude of 40 000 ft, where it is then released and the first stage ignited (Orbital ATK, 2016). The most recent launch of Pegasus XL was in December 2016, when the vehicle was used to launch the 29kg CYGNSS weather research satellite developed by the University of Michigan and the Southwest Research Institute. This was the first launch of Pegasus since 2013, as Orbital ATK has struggled to get contracts for this launch vehicle due to the cost per kg, which is considerably more expensive than alternative launch options. Pegasus is not likely to withstand the influx of small launchers that are aiming at the same target market but at considerably lower prices, as discussed in Chapter 3.

2.4. Launch Events from a Global perspective

In 2016, the global space economy was estimated at $339 billion worldwide (Satelite Industry Association, 2017). Of the total global space economy, only $5.5 billion accounted for the launch industry. The launch market, although comparatively smaller in market size than other segments of the space economy, is necessary to enable all other space activities. This market is generally considered to be a captive market, as the majority of payload operators have existing agreements with launch service providers, and countries have been traditionally somewhat bound by various national policies and legislation into restricted launch options. Only a third of the launch market is made up of commercial transactions in which launches were tendered in a competitive global market (FAA, 2016).

In 2016 there were 85 launch attempts by 8 nations that were operating through indigenous launch industries. These were USA, China, Russia, Europe, India, Japan, Israel and North Korea (SpaceFlight101, 2016). However, there are a few countries that are in the process of developing their own launch vehicle technology. These countries include Argentina, Brazil, and Indonesia (FAA, 2016). With the progression of several space programmes the pattern of number of launches by nation has begun to shift. Russia, which has had the majority of launches since 2004, lost part of its market share in 2016 to the USA and China, launching on only 19 occasions, while the USA and China carried out 22 launches each (FAA, 2016). Figure 2.5 shows the change in orbital launch patterns by country over the past decade.

The US market share has increased since 2014 with the entrance of SpaceX's Falcon 9 and Falcon 9 Heavy launch vehicles, which offered slightly more competitive pricing than existing American launch vehicles (FAA, 2016). Japan's Mitsubishi Heavy Industries (MHI) Launch Services and India's Antrix (the commercial branch of ISRO), have also increased their market share, having started an aggressive campaign to market themselves as commercial operators (FAA, 2016). The Indian Polar Space Launch Vehicle (PSLV) launched more regularly in 2016 given its low price, high reliability and the strong local demand. The PSLV has also become a popular launch vehicle for secondary payloads. Small-scale satellite operators from the US, including Planet Labs, specifically got waivers from the SPACE Act[1] to launch with this ISRO vehicle.

Based on the current trends and national objectives, it is expected that the US and China will continue to dominate the industry in 2018. The Chinese space industry, which has been heavily supported by the national space programme, showcased Long March 5 and Long March 7 in 2016, each with a launch capacity of 25 tons and 13.5 tons respectively. China also opened a new spaceport in Wenchang, Hainan province and carried out their longest crewed space mission in 2016 (SpaceFlight101, 2016). The China Great Wall Industry Corporation has also actively been pursuing commercial international contracts, which include both manufacturing and launching satellites (FAA, 2016).

[1]The SPACE act of 2015 that supersedes the CSLAA still bars US commercial satellites from launching on Indian vehicles.

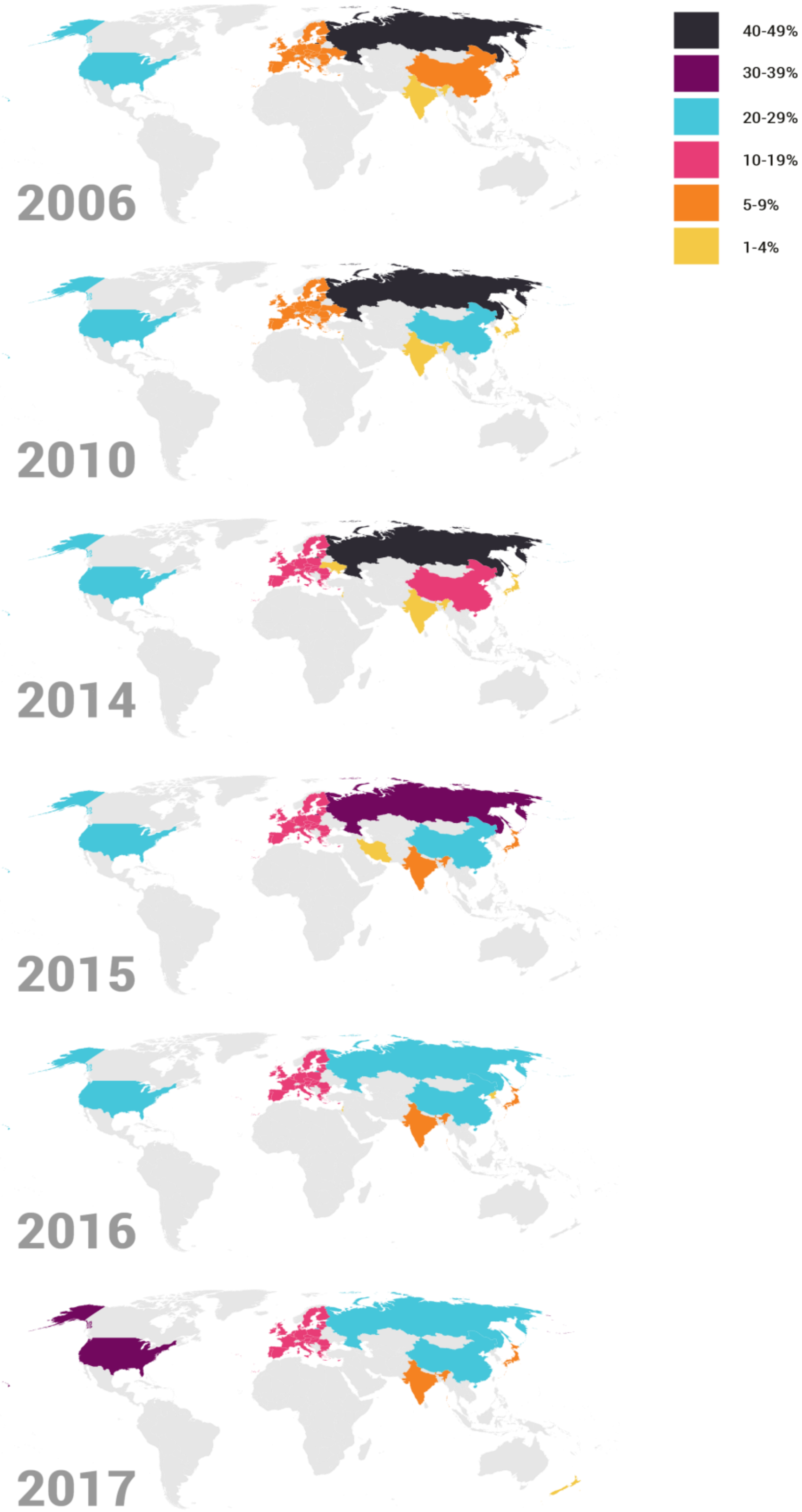


Figure 2.5 Percentage of orbital launches by country between 2006 and 2016.

While there has been a move towards commercialization, there is still a strong link between the countries manufacturing launch vehicles and the countries from which they are launched. This is illustrated in Figure 2.6. ESA and Russia are an exception, with the Russian-produced Soyuz rocket being launched from ESA's launch site in French Guiana. There is also an ITAR agreement between New Zealand and the US that allows for US vehicles to be launched from New Zealand, such as Rocket Lab's Electron, which is manufactured in the US but launched from New Zealand's Mahia peninsula.

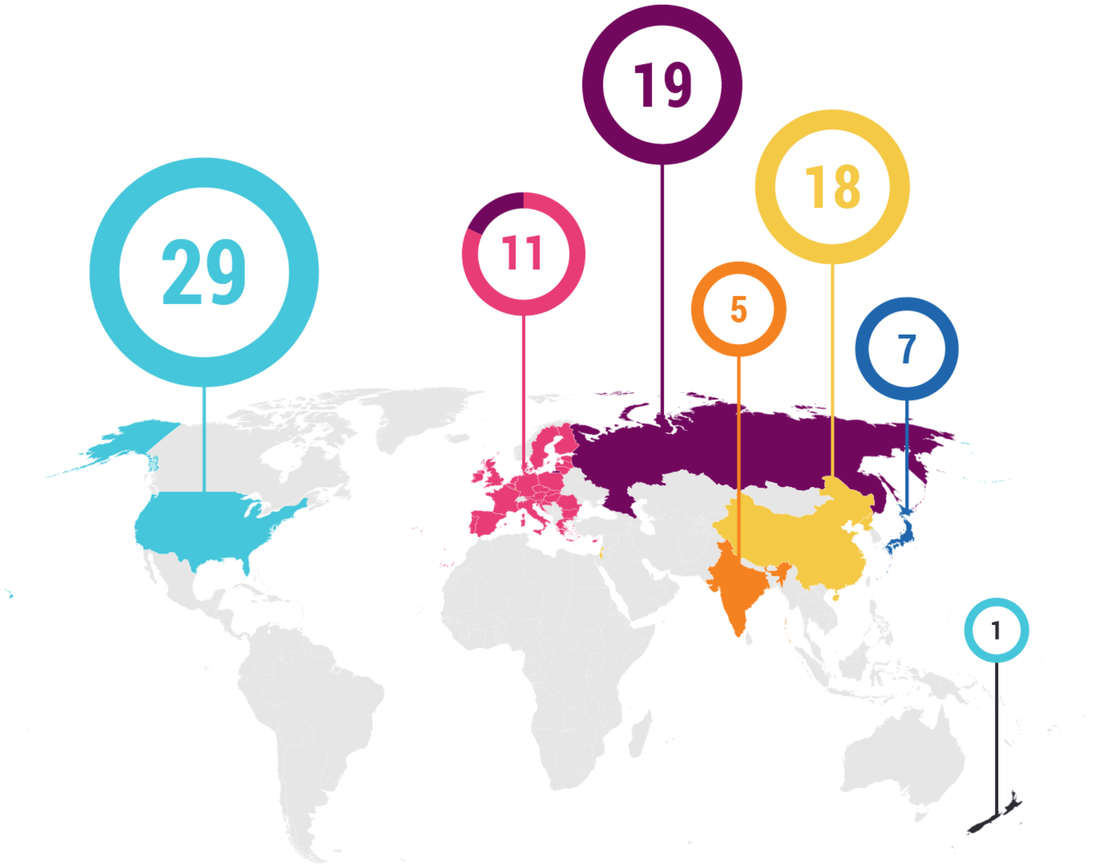


Figure 2.6 Number of launches in 2017, mapped by launch and manufacturing country.

In China's state-owned enterprise system, the China Aerospace Science and Technology Corporation (CASC) produced both the most launch vehicles globally along with all of the launch vehicles launched in China (Ostrove, 2017). With the majority of funding for the Indian space industry being supplied by the government, India has also developed a monopolistic launch vehicle provider in the Indian Space Research Organization (ISRO).

In the US a more competitive industry has developed, however, this could be considered a protectionist market as opposed to a free market because of restrictive US legislation that includes:

a. the **International Traffic in Arms Regulations (ITAR)** that restricts trade of space technology with a number of countries, one of which is China (Howell, 2016);

b. the **Commercial Space Launch Agreement of 2005 (CSLAA)**, which prohibits the launch of US commercial satellites on the Indian vehicles, as the price was thought to "distort the conditions of competition" given that Antrix is an Indian state owned company (de Selding, 2017);
c. the **SPACE act of 2015** that supersedes the CSLAA, which essentially still bars US commercial satellites from launching on Indian vehicles (de Selding, 2016).

Currently US-based companies ULA, SpaceX, and Orbital ATK are supplying launch vehicles into the US market, and while they may be private companies they are also the sole providers for government launches since the National Aeronautics and Space Administration (NASA) has a policy of outsourcing launches to commercial launch operators. As a result, these companies are deriving substantial revenue from government contracts in what could be considered a subsidised operation.

As noted, the European Space Agency and Russia have been the first to make use of shared resources. ESA has been launching the Russian Soyuz 2 rocket from their launch site in French Guiana since 2008, supplementing it with their rockets Ariane 5 and Vega. This arrangement has been beneficial to both parties as Russia receives additional income through the launch of satellites and use of the Soyuz spacecraft, and ESA has the benefit of having a dependable and proven medium-class launch vehicle at its disposal. This partnership allows the use of existing technology to satisfy ESA's requirement for a medium launcher without the development and production costs of new launcher systems (ESA, 2005).

Other major launch vehicle manufacturers include the state-owned Russian companies TsSKB (which produces the Soyuz) and Khrunichev (which produces the Proton); Japan's Mitsubishi Heavy Industries, which produces the H-II launcher and the European company Airbus, which produces the Ariane 5 launcher for ESA (Ostrove, 2017).

As the launch industry expands to cater for the rapid growth and popularity of smaller satellites, the number of launches is expected to increase. While these small-scale launch vehicles are not yet operational, there are several launch vehicles being designed specifically to cater for orbiting small satellites with masses less than 500kg to LEO, while others have become more bespoke in catering only for micro-satellites with masses under 100kg launching into LEO. On average the price per kilogram for the smaller launch vehicles is still higher than the available larger vehicles; however the smaller launch operators are gaining traction in the market by offering flexible scheduling and providing small-scale satellite operators with control over orbital parameters (FAA, 2016). As already mentioned, the companies Planet, Spire and GeoOptics have already secured launches on these smaller vehicles.

2.5. Trends in the BRICS countries

As the focus of this dissertation is to assess the potential feasibility of developing a micro-launcher industry in South Africa, it is instructive to consider launcher activities in the political groupings of which South Africa is a member, namely BRICS and IBSA. As the IBSA countries (India – Brazil – South Africa) are all members of BRICS, this discussion will focus on BRICS.

What is known today as BRICS, started in 2001 as the BRIC partnership comprising Brazil, Russia, India, and China. At its inception in 2001 these countries were considered to be the largest emerging market economies that would play an increasingly important role in world economics. However, in 2010 the decision was made to include an African country to validate the group's representation of the emerging world. That country was South Africa, hence the acronym BRICS (The Economist, 2013). Of the BRICS countries, all except South Africa have made moves towards developing space launch capabilities and have already started to influence the global space economy.

Russia was the first of the BRICS nations to develop space capabilities with a successful launch in 1957 from Baikonour in what began the space race between the then USSR and the USA. Since then it has been a key actor in the global space industry, accounting for the majority of launches until 2016, when it was superseded by the USA and China. Russia has a number of operational launch sites, including the Plesetsk launch site, which is considered the northernmost launch site globally. This launch site, built in 1957, has been used since 1966 for testing rocket equipment and launching satellites into orbit. Vostochny, which is operational but still in the process of being completed, was built to reduce the dependency on Baikanour, which Russia rents from Kazakhstan and allows for eastward launches with the possibility of more orbital inclinations than Plesetsk. Another smaller launch site, Yasny, in Orenburg Oblast had its first launch in 2006 using repurposed intercontinental ballistic missiles to put civilian satellites into orbit (BRICS magazine, 2016). GLONASS, Russia's global navigation satellite system (GNSS) has included both South Africa and Brazil as partners in the overseas network segment. The first station was commissioned in Brazil in 2014, and the second in South Africa in 2017 (GPSWorld, 2017). More recently Russia has built and launched the 'Kondor-E' satellite for the South African military, although it may not be mutually beneficial to pursue this partnership as the cost for the project was approximately R1.4 billion (Maynier, 2014).

China also has an internationally recognized space programme operated by the China National Space Administration (CNSA). Unlike the majority of space faring countries which are partners in the International Space Station (ISS), China has been categorically excluded from participating due to American national security concerns (Howell, 2016). However, this has not stopped China from developing its own space station, Tiangong 1. The CNSA has several significant accomplishments in space, such as the first soft landing on the moon in decades, launching manned missions to Tiangong 1, and undertaking periodic launches with its Long March rocket series (Kluger, 2015). As with Russia, China has partnered with South Africa for a ground station network. The China-Brazil Earth Resources Satellite

(CBERS) collaboration is a technological partnership between China and Brazil that operates remote sensing satellites. China’s Centre for Resources Satellite Data and Application (CRESDA) has installed a terminal that is operated by the South African National Space Agency (SANSA, 2015). China is also supporting the space ambitions of other African countries. China recently signed a memorandum of understanding between Ethiopian’s Mekele University and the Chinese National Space Science Center (NSSC) in Beijing, which acknowledged the specialized help and material support that NSSC has previously provided (Mekelle University, 2017).

In a similar manner to China, India has developed a fully-fledged indigenous space programme as a result of technology embargos applied after a nuclear test in 1974 (Misty, 1998). During the 1980’s India developed the Satellite Launch Vehicle -3 and Augmented Satellite Launch Vehicle, simultaneously developing the design, manufacturing infrastructure and pre/post-launch services and facilities. Through these initial experiences ISRO was able to develop the Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV) to meet the national agenda of providing space services to the country, including remote sensing, weather monitoring and telecommunications (Gupta, 2007). The reliability and affordability of the PSLV has made it a commercially viable launch option for small satellite operators around the globe. In June 2017 PSLV-C38 launched 29 Nanosatellites from 14 countries, in addition to India’s own Earth observation satellite Cartosat-2E (ISRO, 2017).

Brazil is currently in the process of developing technology to manufacture a domestically made satellite with the intention of launching it on a domestically made rocket in the next decade. This comes after the launch of a French-designed geostationary satellite, which will provide broadband Internet to remote parts of the country while providing secure communication channels for military and government personnel. The necessity of this satellite was partially motivated by revelations in 2013 that the U.S. National Security Administration had tapped the communication of Brazil's president at the time, providing the rationale behind the prompt financing of the satellite. Visiona, a joint venture with state owned company Telebras and the aerospace manufacturer Embraer, orchestrated the launch and were optimistic that they would be able to provide the content for a microsatellite (100kg) within 2-3 years for government missions such as tracking hydroelectric reservoirs and deforestation. However, the ongoing recession in Brazil has led the government to embark on an austerity programme, which has curtailed the defence and research spending (Haynes, 2017). Brazil already has existing space infrastructure, notably, the Alcântara Launch Center, which the government is planning to use as a launch site for foreign-made booster rockets. In particular, there have been discussions about using the Ukrainian Cyclone, Israeli Shavit and Russian Proton launch vehicles as well as Chinese rockets (BRICS magazine, 2016).

3. NEW LAUNCHER INITIATIVES

The surge of commercial interest in smaller satellites has spurred the development of smaller dedicated launch vehicles. Where previously secondary payloads were priced into large-scale launches as a cost per unit mass, now there is an opportunity to purchase an individual launch, allowing ownership and control of all the launch parameters.

Unlike large satellites, small-scale satellites are intended to have shorter life spans, allowing one to iterate the design and features of satellites while constellations are active. This new method of operation requires more frequent and timely launches. The developers of the smaller launcher vehicles have acknowledged this need, and many have proposed launch schedules involving one or more launches per week. This is considerably more than the current market is offering, having only achieved 85 launches globally in 2016. Figure 3.1 shows the total number of successful launches during the past 20 years, where it can be seen that the number of launches per year has increased steadily since 2004. The current launch rates are still considerably lower than in the heyday of the space race, when there were consistently over a hundred launches per year.

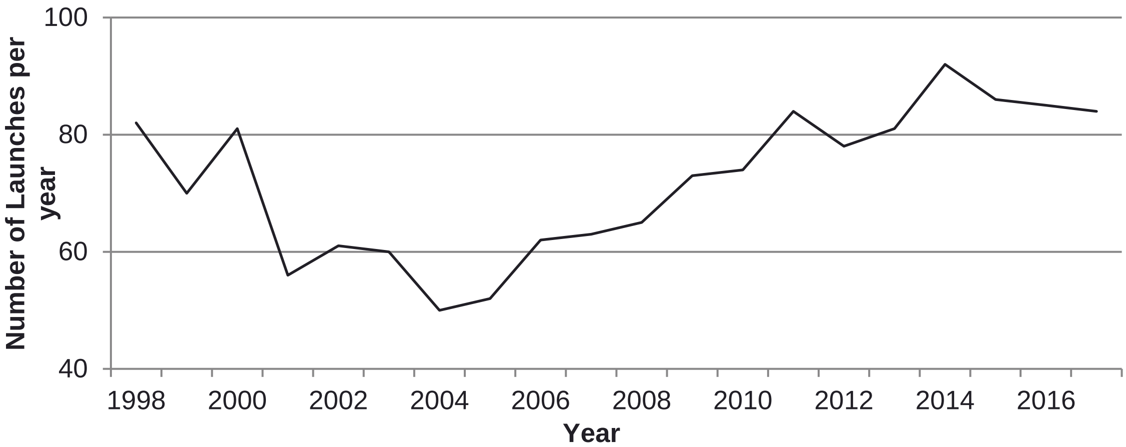


Figure 3.1 Total number of successful launches between 1998 and 2017. (Kyle, 2017)

While it is still cheaper per kilogram to launch as a secondary payload on a larger launch vehicle, the smaller launch vehicles are better suited to the needs of the small-scale satellite market. Will Marshall, co-founder of Planet Labs, stated that they are prepared to utilize less expensive launch vehicles with lower success ratings that launch more frequently (Werner, 2015). The Electron launcher's 3D printed engine can be built in 24 hours and the payload modules can be integrated within hours, enabling Rocket Lab's aim to launch weekly. Recognizing the need for more frequent launches, Virgin Galactic's

LauncherOne vehicle intends to launch every two weeks and Vector Space System's Vector-R aims to launch twice per week (Messier, 2016).

As small satellites are now being used for commercial services, timely launches and the choice in orbital parameters are imperative for continuity of business operations. Launching with smaller vehicles allows the parameters to be set within the range determined by the launch site, most of which offer launch opportunities into a sun-synchronous orbit.

The developers and operators of large launch vehicles are inherently more risk adverse as the primary satellites are generally large, expensive and need to be handled with care, resulting in more intensive and time-consuming launch schedules. In contrast, smaller satellites are relatively inexpensive to build and have considerably shorter life spans; consequently, the more important consideration for small-scale satellites is the launch frequency.

3.1. Developing small launchers

Following the greater use of small satellites by commercial operators, the developers of small launchers are starting to attract more attention from investors and are already being awarded commercial contracts while still in the process of developing the technology for their launch vehicles. In 2015, NASA granted over $17 million in contracts to three micro-launcher developers: Virgin Galactic, Rocket Lab and Firefly Space Systems.

Globally, there are several launch vehicles under development with carrying capacities between 4 kg to 760 kg, in comparison to the operational launch vehicles that have a carrying capacity between 443 kg to 23 000 kg. The average mass targeted by the smaller launch vehicles is approximately 200 kg to LEO; however, the most common capacity is 400 kg. Table 3.1 is a list of small launchers currently under development compiled by Niederstrasser and Frick in 2015, appended with several additional launch vehicles, although this list is not exhaustive.

Table 3.1 Small launch vehicles under development. (Adapted & extended, Niederstrasser, Frick, 2015)

Organization	Launch Vehicle	Country of Origin	Est. Launch Date	Carrying Capacity (kg)	Est. Launch Cost ($ Millions)	Est. Cost Per Kg ($ Thousand)	Launch method
Ventions LLC	SALVO	USA	2015	4			Air
CubeCab	CubeCab	USA	2018	5	0.25	50	Air
Lin Industrial	Таймыр	Russia		9	0.18	20	Land
XCOR Aerospace	Lynx Mark III	USA	2017	15			Air
Garvey Spacecraft Corporation	Nanosat Launch Vehicle	USA		20			Land
Generation Orbit	GO Launcher 2	USA	2016	30	2.5	56	Air
Interorbital Systems	NEPTUNE N5	USA	2015	40	0.25	13	Sea
Celestia Aerospace	Sagitarius Space Arrow	Spain	2016	<25	0.24		Air
Boeing	ALASA	USA	2016	45	1	22	Air
Open Space Orbital	Neutrino 1	Canada		50			Land
zero2infinity	Bloostar	Spain		75			Balloon
PLD Space	Arion 2	Spain	2021	150		38	Land
Rocket Lab	Electron	USA	2015	100	4.9	49	Land
Scorpius Space Launch Company	Demi-Sprite	USA		160	3.6	23	Land
Swiss Space Systems	SOAR	Switzerland	2017	250	<10	40	Air
Firefly Space Systems	Firefly α	USA	2017	200	8-9	20	Land
Virgin Galactic	LauncherOne	USA	2016	200	<10	<20	Air
ARCA Space Corp.	Haas 2C	Romania/ USA		400			Land
MISHAAL Aerospace	M-OV	USA		454			Land
Orbital ATK	Pegasus XL	USA	1990	468	40	88	Land
Lockheed Martin	Athena Ic	USA		470			Land
Vector space systems	Vector-R	USA		60		54	Land
CASIC	Kuaizhou-1	China	2017	300			Land
LandSpace	LandSpace-1	China	2018	400	8	20	Land
Rocket Crafters	Intrepid-1	USA	2019	376	9	23	Land
EU SMILE project	SMILE	EU	-	115	-	-	Land

*Shaded rows in the table indicate companies listed by Niederstrasser & Frick in 2015 that are no longer in this business as of this writing in May 2018.

Within the past three years, six of the vehicle projects listed by Niederstrasser & Frick in 2015 have cancelled due to financial and technological reasons. Of the remaining launch vehicles listed, only Kuaizhou-1 has been successfully launched, despite the majority of these companies' anticipated launch dates falling within the 2016-2017 period.

The Kuaizhou-1A, launched on the 9th of January 2017, is a small launcher with a 700km sun-synchronous orbit carrying capacity of 200 kg. Kuaizhou-1A was developed by China Aerospace Science and Industry Corporation and it is marketed though Expace Technology Co. Ltd, China's commercial rocket company (Barbosa, 2017). Another notable launcher coming out of China is LandSpace-1, developed by China's first private space launch company, Landspace. This launch operator has partnered with Gomspace, a Danish satellite builder, in a joint nanosatellite project (Lin & Singer, 2017).

Rocket Lab's Electron, which was poised to be the next operational small launcher, failed to reach orbit in its inaugural test flight in May 2017 due to issues with ground support. However, Rocket Lab has already signed contracts to launch for NASA, Planet and Spire Global (Clark, 2017). As noted, New Zealand has signed an International Traffic in Arms Regulations agreement with the US that allows the transfer of technology between the US and New Zealand, which is where Rocket Lab's launch site is located.

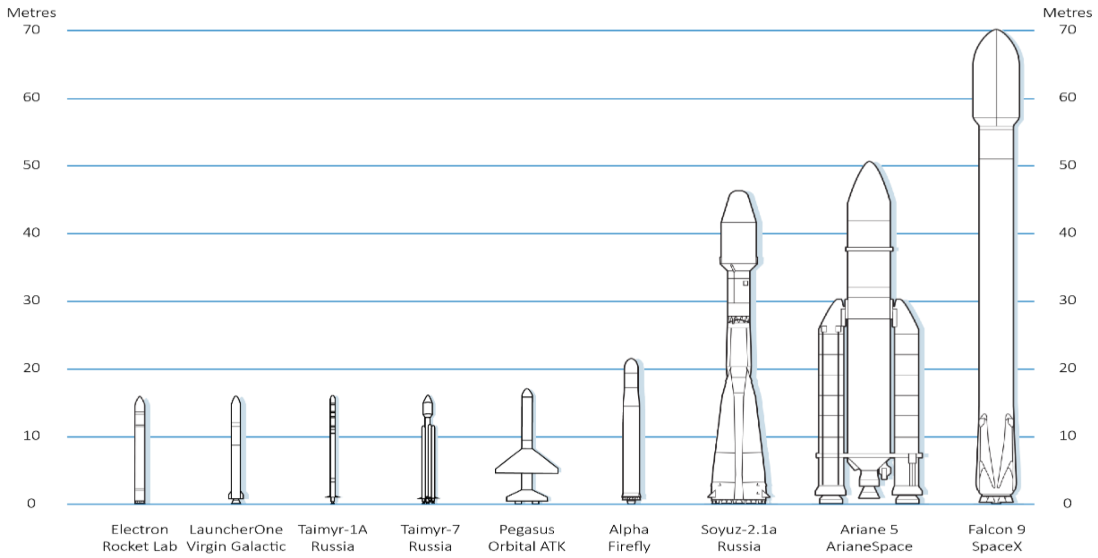


Figure 3.2 Scale of various launch vehicles.

Bloostar, developed by the Spanish company Zero 2 Infinity, was successfully prototyped in 2017. Slightly unconventional, this rocket is a launched using a high-altitude balloon and only ignites its engines at 25km. While this is not yet operational, tests have proven the technology and the launch sequence is capable of delivering 75 kg to approximately 600km (Henry, 2017). This technique also provides more flexibility with respect to the launch site, as the launch facilities would not require a safety buffer zone to the same extent as a ground launched rocket.

Virgin Galatic's Launcher One rocket has the highest capacity of the small launchers currently under development. This rocket system uses an air launch technique similar to the Pegasus XL. A carrier aircraft named Cosmic Girl releases the rocket at approximately 10 000m, after which the first stage of the two-stage LauncherOne rocket is ignited. This launch method allows more flexibility for the choice of launch location, as there is no need for a dedicated traditional launch facility. All the carrier aircraft requires for ground support equipment is a runway. The use of an aircraft to move the launch to a predetermined location has the added benefit of being able to manoeuvre away from adverse weather before the rocket is launched (Virgin Orbit, 2017).

The US micro-launcher CubeCab, with a carrying capacity of only 5 kg, has been designed specifically to launch CubeSats. Many of the small launchers still have slightly higher payload capacities averaging around 100 kg, which is still disproportionately larger than the smaller micro, nano and pico satellites. CubeCab adopted the use of standard components that can be 3D printed and fuels that can be stored at room temperature to keep the overall cost down. As part of the standardisation, this vehicle only caters for payloads that fit the CubeSat specifications. Similar to LauncherOne, CubeCab will be air launched from a privately-owned F-104 Starfighter aircraft (CubeCab, 2017).

The Russian company Lin industrial has proposed the Taymyr family of launch vehicles, designed to carry satellites between 10 kg and 180 kg to LEO, depending on the launcher model. The project's prototype Taymyr-1A, with a capacity of 10kg, was first exhibited in 2015 and after receiving funding the first launch is anticipated in Q1 of 2020 (Lin Indiustrial, 2016).

The US company Firefly Space Systems had proposed the Firefly α rocket with a carrying capacity of 400 kg to LEO, but after two years of legal disputes with Virgin Galactic over the use of confidential information the company ran out of money. However, the company had already received letters of intent for 42 anticipated launches from the initial launch through to 2021 valued at $300 million, and a further 35 launches were requested between 2021 to 2025 to the value of $280 million (Messier, 2016). The company has now been bought out by Noospace and has refocused its efforts towards a sub-orbital rocket, which is not in the scope of this dissertation.

The small launchers are priced per launch as opposed to the larger vehicles which are quoted as cost per unit mass. It is assumed that the small-scale satellites will be the only payload, or at least the primary payload. Based the estimated costs shown in Figure 3.3, Pegasus XL is not competitive in the market for satellites under 200 kg as the increased carrying capacity defeats the purpose of using a small launcher since it would result in a ride-share arrangement. The cost per kg of mass for Pegasus is $ 88 000, which is much higher than any of the launchers under development that average at approximately $ 40 000/kg, meaning that it does not lend itself well to sharing the additional capacity. The cost per kilogram, shown in Figure 3.4, demonstrates the price disparity between the small launch vehicles and the existing larger vehicles, however, as mentioned, the additional cost incurred by using smaller launch vehicles is justified by the benefit of being able to control the launch parameters.

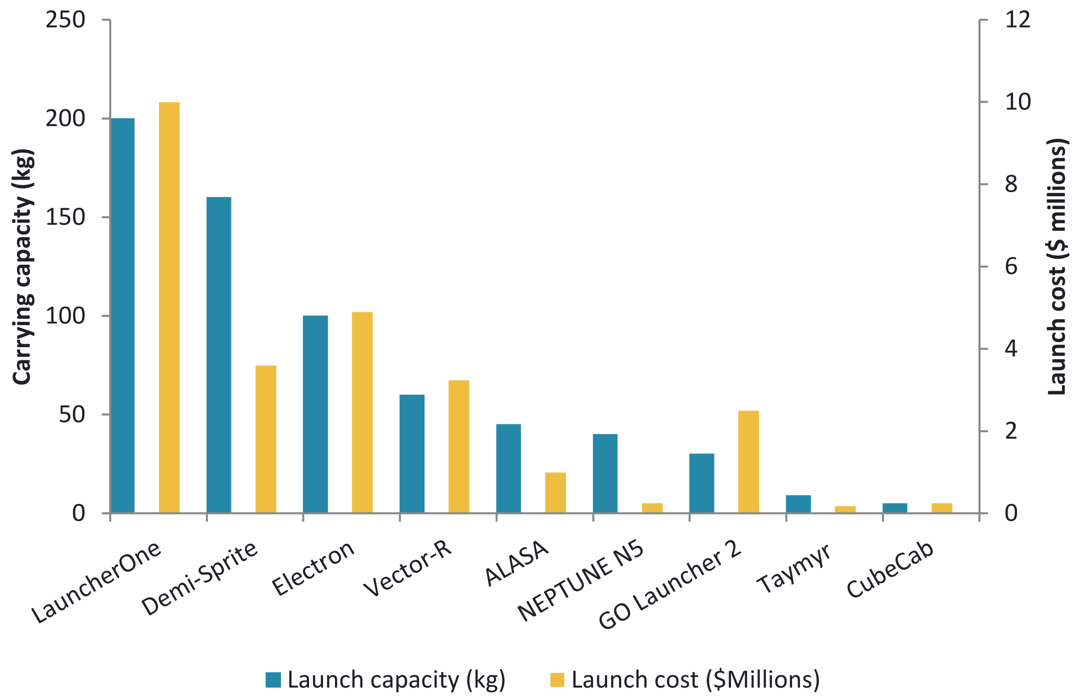


Figure 3.3 Launch cost of small launchers under development.

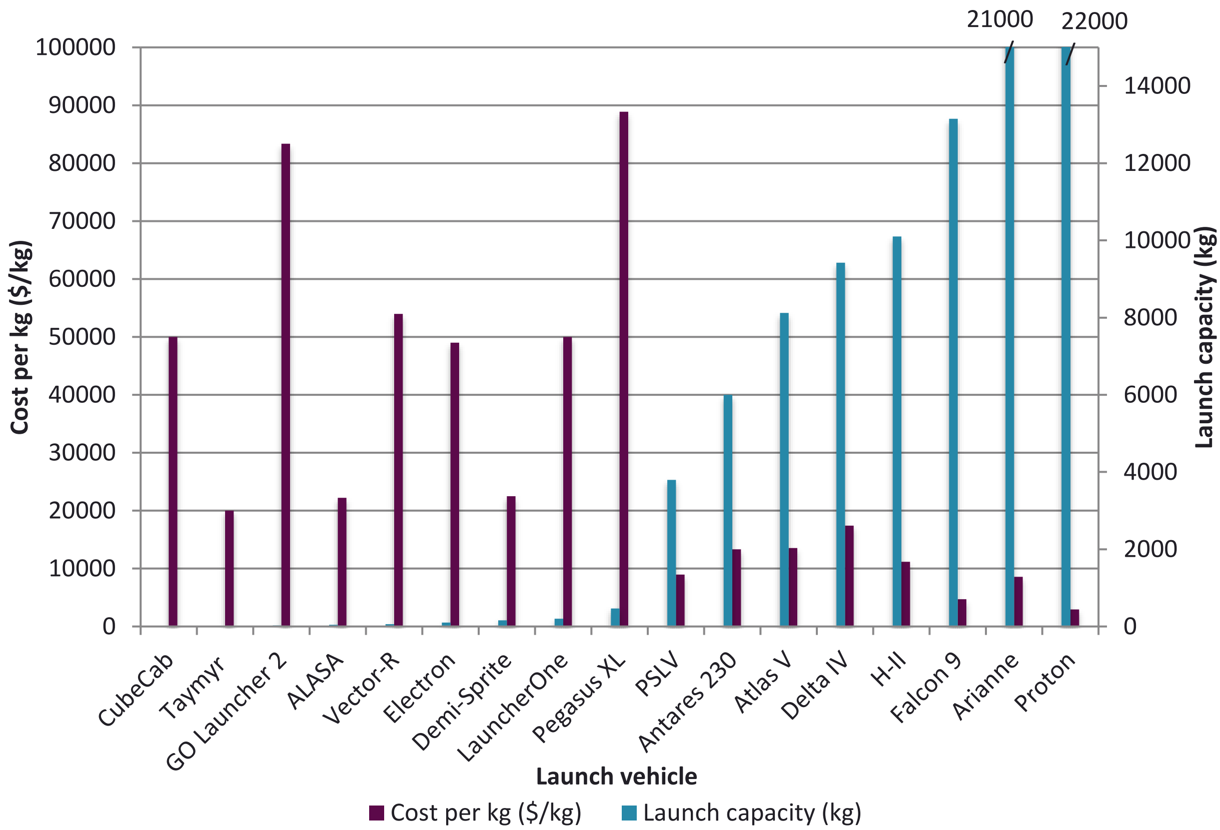


Figure 3.4 Launch cost per kg of various launchers. (FAA, 2016)

Other launch options under development include repurposed intercontinental ballistic missiles, though these have limited public use due to military restrictions. CubeSats can also be launched from the International Space Station using the NanoRacks Japanese Experiment Module (JEM) Robotic Manipulator System (JEMRMS) (Rainey, 2017). NanoRacks has deployed over 170 satellites from the ISS, however the company is now expanding to include deployment from the PSLV as the ISS orbit is not always ideal for smaller satellites. NanoRacks is anticipating 3 to 4 launches per year on the PSLV, a considerably lower launch frequency than predicted by the developers of dedicated micro-launch vehicles (Foust, 2017).

Spaceflight offers a ride-share service, called SHERPA, that matches the currently operating launchers to small-scale satellite operators based on the required launch date and desired launch parameters. Using this service the cost to launch is approximately $50 000/kg, which is comparable to that of small launchers under development but it is far more expensive than the published cost of large launch vehicles, which can be as low as $3 000/kg (SpaceFlight, 2017). SHERPA itself is not a launch vehicle; it is simply an adapter that is used to manage the deployment of secondary payloads from larger launch vehicles such as the Falcon 9. Companies using Spaceflight to source launches as secondary payloads are likely to switch to using the smaller vehicles once operational, given the additional flexibility, control and frequency for comparable costs.

Along with all these new launch options is a new company called Precious Payload. This company intends to create a database of launch options as well as a matching system between prospective satellites and launch providers. So far the company has connected with 12 launch providers, however they have not disclosed them (Foust, 2017). This company also does not disclose the cost of the matching service; however, this is likely to improve the process of sourcing optimal ride-shares on the larger launch vehicles.

3.2. Financial considerations for launch providers

Designing and manufacturing launch vehicles is an expensive and time-consuming venture. As a result, a number of new ventures have collapsed financially, while others have attracted some support from public funding sources and assurance from future dated contracts.

In 2013 PLD Space raised € 1.2 million to fund the development of a liquid propulsion engine. Following the success of the initial investment, the company opened a new round of investment in 2016, aiming to secure approximately € 6 million which was expected to come from both private and public investment. The Spanish government now funds approximately 25% of the start-up (Pultarova, 2017). The need to appeal to both public and private funding stems from a lack of investor confidence in Europe with regard to space technology. Torres, the founder of PLD Space, noted that American investors appeared to be more comfortable with space-focused business plans than Europeans (Henry, 2016).

Another small launcher being developed in Europe is the ‘Small Innovative Launcher for Europe’ (SMILE) project. This project is a joint initiative by the Netherlands Aerospace Centre (NLR), German Aerospace Centre (DLR), Norway’s Nammo Raufoss AS, Andøya Space Centre (ASC), Denmark’s Terma, Romania’s National Institute for Aerospace Research, The Netherlands Airborne Composites Automation, and Heron Engineering from Greece. The SMILE project has been granted € 4 million from the EU for over a 3-year period for the development and proof-of-concept for a small launcher (SMILE, 2016). Despite the financial support from the EU, the project is struggling to attract sufficient funding (Pultarova, 2017).

After successfully prototyping a launch vehicle, start-ups generally require additional funding to enhance their manufacturing process and for up-scaling of the business model. Rocket Lab has raised $75 million worth of investments, which will be used to expand manufacturing facilities in the US and New Zealand to produce the Electron launch vehicle (Klotz, 2017). In addition to up-scaling the manufacturing process, there is also a need to expand on human capital. Astroscale, the satellite start-up, has stated that the latest series of funding of $25 million will partly be used to hire a Chief Operating Officer (Henry, 2017). Similarly, PLD Space intended to use part of the funding received to increase their team, which at the time comprised of only 11 staff members (Henry, 2016).

An example of a space launch vehicle developer that had been based in South Africa is Marcom-AS. While operating in South Africa the company managed to secure seed funding from the national Department of trade and industry (dti) to the value of R3.5m to design, manufacture and test fire a liquid rocket engine. Despite successfully demonstrating the engine test fire no more funding was allocated to the project due to follow-up proposals being lost within the government systems. This inefficiency and lack of commitment to develop what was then South Africa’s only active space launch vehicle company shows the lax attitude of the government towards space activities and their lack of real commitment to achieving the objectives in the South African Space Strategy. This is discussed in more detail in Chapter 5.

3.3. The Hype

The exponential interest in small launchers can be likened to the trends modelled by the Gartner Hype Cycle. The Gartner Hype Cycle comprises of five stages that represent the emergence, maturity and adoption of emerging technologies. The cycle can be used to understand how a technology may evolve and allows for informed risk management when investing in new technology. While this concept technically applies more to disruptive technologies, such as blockchain and machine learning, it can also be applied in the space industry to show the evolution of small satellites and their launchers. Figure 3.5 shows the Gartner Hype cycle.

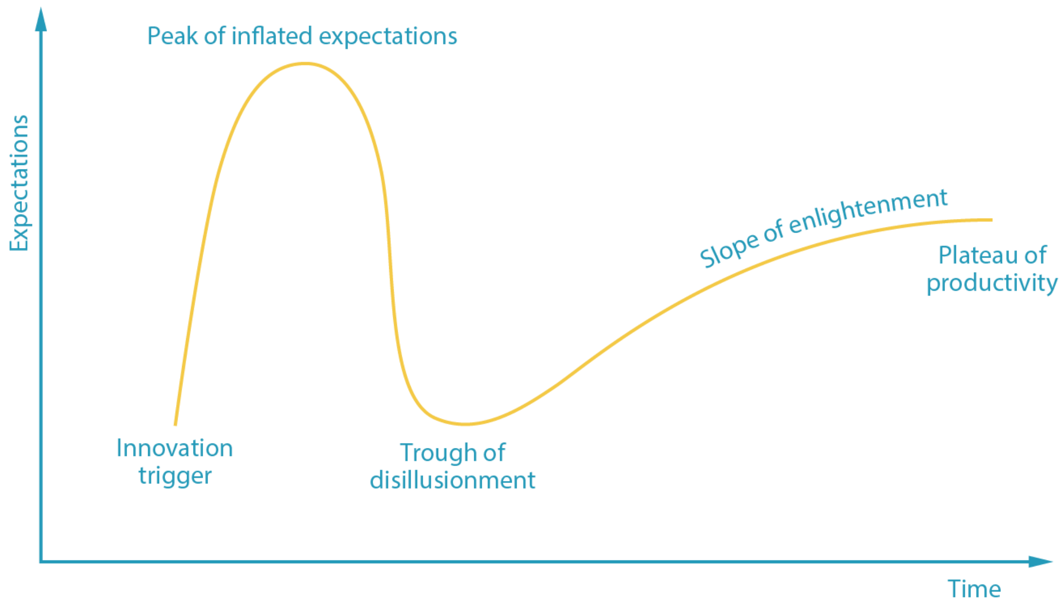


Figure 3.5 The Gartner Hype Cycle. (Gartner, 2017)

The first phase of the cycle starts with an innovation trigger. This is when a potential technology or proof-of-concept gains media interest, which generates publicity and initiates the hype. At this stage the innovation often isn't yet a working product.

The next phase is in the Peak of Inflated Expectations. Early interest in the technology or concept will result in some workable product. Given expected failures in the initial development some companies pursue the concept, however many do not.

Following the expectations peak, the hype around the concept drops into the Trough of Disillusionment, as interest in the promised performance and expectations of the product decline when implementations fail to deliver. In this phase the technology needs to improve the product to the point at which it is functional for early adopters.

Then there is the Slope of Enlightenment. This phase can be used to describe the current state of the small launch vehicle sector. Of the launch vehicle companies that were active in 2015, approximately 25% have been dissolved and of the companies still in the development phase none of them have achieved their intended initial launch dates. Rocket Lab did launch in 2017, two years after the initial anticipated launch date, and the test failed. As already mentioned, Rocket Lab already has commercial contracts from the 'early adopter' companies such as Planet Labs that are willing to take the risk of launching satellites with a new technology in return for the benefits of frequent and constant launch schedules, control over orbital parameters and a lower launch cost.

The number of new entrants forecasted in the Hype Cycle is expected to increase as the technology or concept becomes more established and the benefits of the technology become better understood. New generations of the technology start being developed, which attracts more investment and more adventurous companies enter the market. Once there are a number of successfully operating enterprises the hype cycle reaches the Plateau of Productivity, where the technology is adopted by the mainstream and the viability of maintaining operations is more clearly defined (Gartner, 2017).

As the commercialization of small satellite products increases, the requirement for frequent access to launches into specific orbits becomes more important. Small launch vehicle operators have acknowledged this need and generally aim to have schedules involving one or more launches per week. This still presents an advantage over ride-sharing agreements, even with the introduction of adaptors such as SHERPA and NanoRacks or the convenience of Precious Payload's matching utilities, as they will always be constrained by the larger launch vehicle's infrequent launch schedules. However, the introduction of reusable larger launch vehicles as well as the development of launch aggregators is likely to put some downward pressure on the demand for smaller launch vehicles.

This is an opportune time for South Africa to enter the market, as the current state of the market is turning towards the 'Slope of Enlightenment'. The larger appetite for risk in the small satellite market lends itself particularly towards developing industries, as satellite operators are less likely to be concerned with sourcing launches from established launch sites and launch vehicles. The initial cost to enter the launch market could also be minimized through the use of existing South African facilities, as will be discussed in Chapter 4.

However, given the time and cost required to develop a launch vehicle, it is unlikely that South Africa would be able to compete with the launchers that are close to market. It is worth noting that PLD Space struggled to source financing in Europe for their launch vehicle. As a result the Spanish government funds 25% of the company. It is not uncommon for new launch vehicle operators to file for bankruptcy, as highlighted in Table 3.1. Should South Africa consider the in-house development of a launcher, the financial burden would have to be assessed realistically against the available budget for space activities and the potential benefits of having such a launcher. As noted, Marcom-AS had been making significant progress towards developing a local engine, but lacked adequate financial support required from government to continue developing the launch vehicle.

4. MARKET AND ECONOMIC TRENDS IN THE SPACEPORT INDUSTRY

With the ever-increasing interest in space activities, countries are assessing the need for and viability of building spaceports and, given that the construction of a new spaceport can be a costly outlay, many are looking to refurbish existing facilities. In 2014, the United Kingdom sent out a consultation notice to assess the viability of converting an existing airfield into a suborbital launch site. Similarly, the USA has slowly expanded on the use of existing federal space complexes and allowed for the co-location of commercial spaceports with government facilities, some with particular attention to the growing small-scale satellite market. More recently, New Zealand has entered the spaceport market, albeit with a very small launch complex. With regard to existing facilities, South Africa has legacy launch complex infrastructure in what is now the Overberg Test Range.

In this chapter we provide an overview of typical characteristics of spaceports such as the location, safety requirements and cost factors. The current state of the sector is then discussed in relation to the target client base and possible motivations for development of micro-launch capabilities. South Africa’s previous involvement in space activities is summarized to provide the context in which the infrastructure exists and currently operates. Lastly, we discuss the condition and suitability of the exisiting facilities to support micro-launch activities.

4.1. Typical Launch site characteristics

There are numerous launch complexes around the world and, while they are built to suit a particular set of needs, they share several common characteristics. Typical factors to consider when selecting a spaceport include access into the required orbit, designated areas for integration of the launcher and the payloads and capacity for a suitably sized launch vehicle. As part of launch operations, specific documentation is drafted to detail the operational and safety requirements of the launch site. This typically includes information on the communication, transportation and processing facilities, along with consumables, safety processes and mechanical and electrical procedures. In commercial launches the launch services contractor would generally produce this documentation (Gates, 2011).

The geographical considerations of a launch site include the proximity of the site to towns as the site would need supplies and the site staff would require accommodation and access to standard conveniences such as shops, schools and hospitals. The legalities of moving equipment across international borders can also motivate the choice of location as the transfer of dual-use technology is closely monitored and regulated. The choice of location can also be influenced by environmental concerns such as sensitive ecosystems, the prevalence of lightning or whether the area is prone to earthquakes (Gates, 2011). In 2014, the British Government, in conjunction with the Civil Aviation Authority (CAA), carried out a consultation open to both the public and industry specialists to review the requirements for a suborbital UK spaceport. They posed the question of how criteria regarding a spaceport's location should be weighted. Respondents including Virgin Galactic, HE Space, Foster & Partners and Spacemiles proposed various weighting strategies with a focus on the site's potential for commercialization, deliverability, weather, and in the case of commercial suborbital flights, the area's intrinsic tourist appeal was also given a strong focus (U.K Department for Transport, 2014).

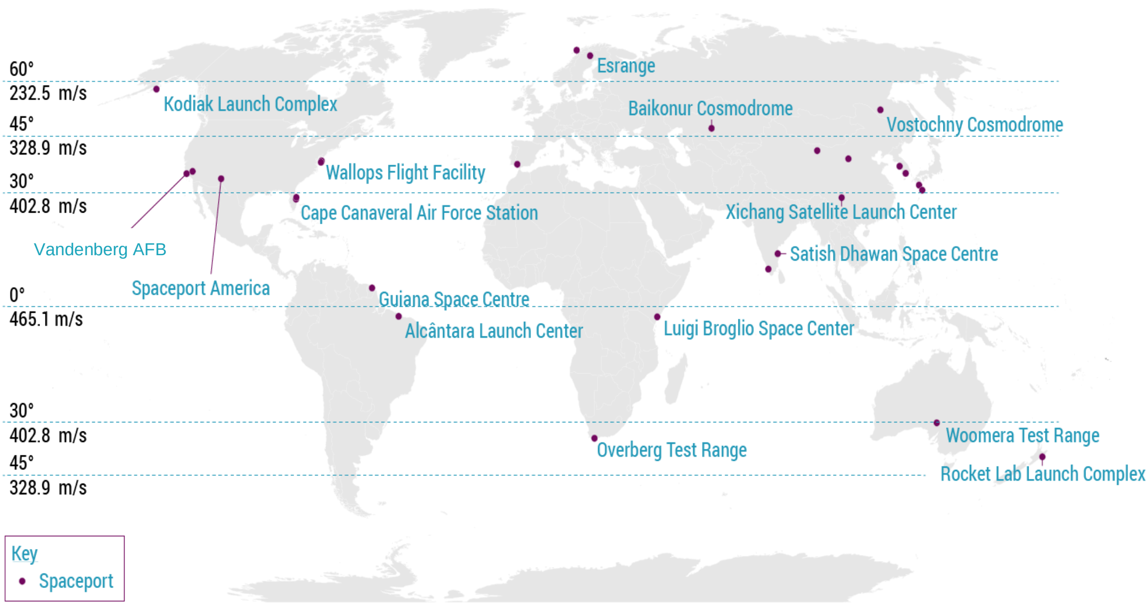


Figure 4.1 A selection of launch complexes from around the world.

The location can also benefit the positioning of a satellite into particular orbits without the need for additional manoeuvres, an example being equatorial launch sites, which are ideal for launching geostationary satellites. The general advantage of launching eastward allows launch vehicles to use the Earth's rotational speed towards the total velocity increment needed to achieve the required orbital velocity. This tangential velocity gain is 465m/s at the equator, and it decreases as the cosine of the latitude of the launch site. Figure 4.1 shows the tangential velocity at various launch locations. It is clear that South Africa has the similar range of launch azimuths to Rocket Lab's launch complex in New Zealand and the Woomera Range in Australia.

The European Space Agency (ESA) launches from Kourou in French Guiana, situated in North-Eastern South America. This site was chosen in 1964 by the French government, despite the complication of being on a different continent, due to its isolated equatorial location. Kourou is conveniently close to the equator at latitude 5°3', making it ideally situated to launch into the geostationary transfer orbit as minimal orbital plane change manoeuvres are needed once in orbit. From a safety perspective French Guiana is also advantageous as it has a very low population, with 90% of the land covered in forest, lowering the risk of injury or damage to property. There is also a low risk of natural disasters such as cyclones or earthquakes (ESA, 2017).

For highly inclined orbits, equatorial launch sites confer no particular advantage. In such cases the main consideration is that the downrange areas should be sparsely populated. In practice this means that most launch sites are on the coast with vast expanses of ocean downrange. Equatorial positions are not always an optimal launch location. Rocket Lab has built a new private launch complex in New Zealand on the Mahia Peninsula at a latitude of 39° S. This site was specifically chosen as the company's primary objective is to launch payloads into a sun-synchronous orbit. Like Kourou, the low volume of marine and air traffic in the area allows for frequent launches (Rocket Lab, 2016). Much like ESA's arrangement in Kourou, the head office, manufacturing plant and the majority of clients for Rocket Lab are based in the US, despite New Zealand being used as the launch location. The flexibility of operations, lower costs and location-specific advantages can motivate the decision to launch from another country.

Infrastructure at the launch site, such as clean rooms, fuel and access to telemetry, tracking and command facilities are also key factors when deciding on a launch site. The ground support equipment, launch vehicle and payload processing areas are not normally housed in the same location, although the storerooms are generally located in close proximity to each other. The facilities' storerooms may have different clean-room ratings and safety standards, which is determined by the equipment and payload. Using facilities that are above the required cleanroom standard can inflate the cost of a launch. As such, it is important to assess the required cleanroom rating in relation to pre-launch operations as a given standard may only be needed for particular instruments that could be catered for differently. For example, portable 'clean tents' of higher ratings than the available clean room facilities could be used (Gates, 2011).

The cost of building and maintaining infrastructure at spaceports has been a key driver in the decision of several commercial ventures to extend and adapt existing facilities. NASA's Wallops Flight Centre is now hosting the commercial Mid-Atlantic Regional Spaceport (MARS) on the southern section of Wallops Island (MARS, 2017). Cecil Spaceport, which was licensed by the FAA in 2010 for horizontally launched vehicles, was built out of the decommissioned Naval Air Station Cecil Field (Cecil Airport, 2017). This trend is evident in the British CAA's recommendations for the proposed UK spaceport, suggesting that the location for the sub-orbital launch facility should be an existing UK commercial or military aerodrome that is still active but that has low level of activity (U.K Department for Transport, 2014).

Tracking the launch vehicle is an important aspect of the launch. The most widely used system for tracking launch vehicles is C-band radar, commonly known as skin tracking, which does not use a signalling device on the launch vehicle, although some launchers have C-band transponders to increase the tracking range (Gates, 2011). During a launch the range safety officer monitors the ascent trajectory using the tracking devices. Should the vehicle deviate from the anticipated course and cross a predetermined boundary, the range safety officer will activate the flight termination system, which effectively destroys the launch vehicle before it can cause harm. Rocket Lab's first test flight, named 'It's a Test', was terminated due to a data loss time out, which was caused by misconfiguration of telemetry equipment (Rocket Lab, 2017). After analysing data collected during the launch, Rocket Lab confirmed that the vehicle had been following the intended trajectory, and that the flight termination was solely due to a lapse in communication.

The location of the chosen spaceport will have an effect on the launch schedule, as transportation to the launch site needs to be accounted for, particularly when launches are anticipated to happen weekly. The amount of time taken to orchestrate a launch once the launcher arrives at a launch site also affects the overall cost. The degree to which the vehicle requires re-testing once at the launch site can have a substantial impact of the budget, as will the class of cleanrooms required on site and the installation of launcher-specific hardware. The duration of the launch operation depends on the launch scenario, which could include (Gates, 2011):

- **Quick ship-and-shoot launch**, where little to no testing or mechanical changes are required at the launch site; this could start as early as T-11 days in Table 4.1;
- **'Limited' processes launch**, where some testing and mechanical work may be needed on the spacecraft at the launch site;
- **'Full blown' mission launch**, where a complete set of testing and extensive mechanical work is needed on arrival at the launch site.

Table 4.1 Typical launch schedule. (Gates, 2011)

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
T-20	T-19	T-18 S/C Arrival / Setup EGSE at PPF	T-17 S/C Aliveness Test	T-16 Thermal Closeouts	T-15 S/C fuelling	T-14 RCS & Leak Test
T-13	T-12	T-11 S/C & Vehicle Elec. and Mech. Checks	T-10 S/C Mate to Vehicle Upper Stage	T-9 Fairing Installation	T-8 Transport to Pad/ Mate to Vehicle	T-7 Comm. Checks
T-6	T-5	T-4 S/C Functional	T-3 Final Vehicle Closeout	T-2 Launch Rehearsal	T-1 Management Review Crew Reset	T+0 Launch

The longer the time required at a launch site, the more expensive the launch is likely to become, with an increased need for personnel, resources and more complex facilities. Time spent at the facility can be managed by limiting the necessary tests on the spacecraft and integration at the launch facility to only what is deemed essential to the launch. Minimizing on-site mechanical operations can also reduce the time required at the launch facility. This would also inform the rating of the cleanroom facilities needed at the facility (Gates, 2011).

4.2. Operational Spaceports

There are many operational spaceports in the world, several of which are shown in Figure 4.1. While many of these are well established, as the nature of space missions has changed so have the spaceports. Complexes such as Wallops Flight Centre, Vandenberg Air Force Base and the Esrange Space Centre are proposing the development of their own launchers for small satellites.

Baikonur Cosmodrome is the largest spaceport and is currently one of only two launch facilities used for human space flight, the other being Jiuquan Satellite Launch Centre[2]. The cosmodrome is well connected to other cities and countries via train, air and road transport links and there is an extensive network of roads and railways connecting the various hubs within the cosmodrome. However, the Baikonur Cosmodrome was built during the Soviet Union era in what is now Kazakhstan. As a result, Russia has to lease the cosmodrome for approximately $115 million a year from the Kazakhstan government (Kosmotras, 2017).

The situation with the Baikonour Cosmodrome prompted the decision by the Russian government to build the Vostochny cosmodrome in Russia. Like Baikonur, the new cosmodrome will have its own city, accomodating 30,000 people, an airport, train station, hotels, and schools. Notably, Vostochny was designed with a complex that would be used for training both cosmonauts and space tourists. The move allows the Russian government full control over the facility and its operation, along with a further motivation being job creation within Russia. According to Russian media reports, Prime Minister Dmitry Medvedev had said that it would “upgrade the industrial base in the region” (Zak, 2014).

As previously mentioned, China has the only other spaceport that currently supports human space flight, which is necessary to support the Chinese Tiangong-2 space station. China has four fully equipped launch complexes allowing independent end-to-end space capabilities. The country has opened some of its

[2] The Kennedy Space Centre can support human space flight; however, the USA is not currently launching astronauts from US soil.

facilities to promote its launch industry to international clients. The Taiyuan Satellite Launch Centre (TSLC) was partially declassified in the late 1980s in an attempt to provide launches to the commercial sector, and between 1997 and 1999, a total of 12 Motorola Iridium global wireless communications satellites were launched from the centre (China Space Report, 2017). More recently, the small launch vehicle Kuaizhou-1A was launched from the Jiuquan Satellite Launch Centre in a bid to attract more customers in the small satellite launch market.

India, like Russia and China, has state-sponsored spaceports and like these countries, has also developed independent end-to-end space capabilities. The Satish Dhawan Space Centre recently launched the Geosynchronous Satellite Launch Vehicle Mark III (GSLV Mk III) and as mentioned in the market overview, India also holds the current record for launching the most satellites in a single launch on the PSLV. The Satish Dhawan Space Centre was built to cater for a variety of launch vehicles developed by ISRO (Bennett, 2017).

As opposed to Russia, China and India, where spaceports are entirely state run, in America the drive to develop spaceports has come from the commercial sector. After the Space Shuttle Challenger accident in 1986 the US government ruled that launch customers should solicit launchers from launch vehicle providers and that the providers would facilitate the launch by leasing launch facilities (United States Department of Transportation, 1998). This move towards commercialising the space launch industry, coupled with legislation promoting the use of government assets for access to space, spurred the development of privately-operated launch activities co-located with federal facilities (Rogers, 2015).

Wallops Flight Center and Vandenberg Air Force Base have engaged in hosting commercially licensed operators who make use of existing government facilities. These spaceports have also begun to focus on small satellites and smaller dedicated launch vehicles as they try to attract more of the launch market for small satellites.

Wallops Flight Centre, located on Virginia's Eastern Shore, was established in 1945 by the National Advisory Committee for Aeronautics as a centre for aeronautics research. Today, Wallops is NASA's principal facility for the management and implementation of suborbital research programmes and educational programmes by flying experiments on NASA’s suborbital rocket programmes such as RockOn! and RockSatC (Black, 2017). Wallops Flight Centre also hosts the commercial Mid-Atlantic Regional Spaceport (MARS), which independently operates its own small-class and medium-class launch facilities using launch pad 0B and 0A (MARS, 2017). Wallops is now also engaging the commercial sector through the Small Launch Vehicle Research (SLVR) Project that aims to develop an end-to-end solution for access to space with payload preparation, integration, test, launch and on-orbit ground support for small payloads between 1.8kg – 180 kg (Black, 2017).

Harris Spaceport Systems, operating from launch complex 8 at Vandenberg Air Force Base, is also targeting the smaller satellite market. Harris Spaceport Systems programme manager, Dan Gillen, suggested that this spaceport would be ideal for providing an affordable space launch opportunity for smaller satellite classes that do not require the larger, more expensive rockets, or who would prefer a dedicated launch as opposed to being a secondary payload in a ride-share arrangement (Gillen, 2017).

Mojave Air & Space Port was originally built in 1935 as a rural airfield to serve the surrounding mining industry. However, after being used by the military during World War II, the airfield was obtained by Kern County and renamed Mojave Air & Space Port. This was the first facility licensed by the FAA for horizontal launches of reusable spacecraft, becoming certified as a spaceport in 2004 (AirplaneBoneyards, 2018).

The Pacific Spaceport Complex - Alaska (PSCA), formerly known as the Kodiak Launch Complex, has changed its strategy of targeting large government defence contracts and is now trying to provide a cheaper launch location with fewer scheduling constraints to smaller micro-launch companies and commercial suborbital flight operators. Given its high latitude, PSCA is in a prime position to launch polar and sun synchronous orbits. Alaska Aerospace Corp President and CEO Craig Campbell stated, that "… the emerging small, ultra-small and very low-cost industry has a need that is not being met by the traditional facilities because of cost, [and] because of scheduling, etc. We are looking to carve a niche to provide the services they need at very low cost" (Van Wagenen, 2016).

Like PSCA, Spaceport America was built independently of the federal government to support a complete range of space launch activities. This spaceport is targeting the "pioneering new breed of commercial space entrepreneur", with tenants including launch companies Virgin Galactic and SpaceX (Spaceport America, 2017). Spaceport America was developed in 2005 through an agreement between Virgin Galactic and the State of New Mexico, in which the State contributed $200 million to build the spaceport and Virgin Galactic agreed to use the facilities as its headquarters and operate space flights from the site (Jacksonville Aviation Authority, 2012).

Through the formation of ESA, Europe has been able to include countries in the development of the Guiana Space Centre, a fully-fledged spaceport catering for large commercial satellites, space exploration missions and delivering cargo to the ISS. Given the location and different sized launchers available, including the Ariane 5, Soyuz and Vega, the spaceport has been commercially successful, with various clients for industries based in the USA, Japan, Canada, India and Brazil and Europe (ESA, 2017). French Guiana, although politically stable in the past, has been become a point of contention between the Guyanese people and French government. The Guiana Space Centre was used to highlight issues facing the territory as the launch facility is a pressure point for the French government (D'Auria, 2017). Strikes around the facility delayed the launch of an Ariane 5 with two satellite payloads, Brazil's SGDC defence communications satellite and South Korea's KoreaSat-7 commercial communications satellite, for over six weeks (Phys.org, 2017). While this is an established spaceport and the delays do not seem to have affected the customer base, there has now been more interest in developing localized launch capabilities for small satellites in Europe.

The Esrange Space Centre based in northern Sweden was founded in 1966 by the European Space Research Organization (ESRO), one of the precursors to ESA, whose members were Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom. The purpose of the Esrange Space Centre was to support space research and technological development. Since its inception, the centre has launched over 550 sounding rockets for scientific research. These missions are primarily for the support of member states of ESA, while non-member states may use the facilities on a lower priority basis (SSC Group, 2017). The centre also offers programmes for students to test payloads on either rockets (REXUS) or balloons (BEXUS). However, these student opportunities are only open to member States of ESA.

Currently, the Swedish Space Corporation only provides sounding rocket and balloon launches from the Esrange Space Centre; however they are now developing the capability specifically for launching small satellites, called the SmallSat Express, scheduled to be operational in 2021. This service is aimed at the scientific community as well as commercial customers, launching satellites with masses between 1-150kg, although the primary target for payloads would be CubeSats. The centre has also standardized the launch profile to a sun-synchronous orbit at 500km and inclination of 97.4°. The centre has also begun to transform itself into becoming a ‘green’ launch site, with the intention to ban Hydrazine in the SmallSat Express project (Pahlsson, 2017).

Africa also hosts an operational spaceport. The Luigi Broglio Space Centre is located in Malindi, Kenya. While this spaceport has not launched a rocket since 1988, it is still maintained and managed by the Agenzia Spaziale Italiana (2009). In accordance with a bilateral agreement between Kenya and Italy, the site may be used by Italy to carry out launches, provide ground support, manage remote sensing data and carry out training. As part of the agreement, Italy has the authority to define the programmes and is responsible for equipping the site and training local employees, while Kenya is entitled to royalties from commercial launches. In addition to this, the equipment on the site becomes the property of the Kenyan government after 15 years (Agenzia Spaziale Italiana, 2009). The centre is at 2.99 degrees latitude, making it an ideal launch site for launching geosynchronous satellites. The site is also located on the coast allowing for launches over the sea.

As mentioned, the UK is also investigating the possibility of establishing a local spaceport to cater specifically for suborbital spaceflights of scientific payloads and customers wanting a suborbital spaceflight experience (U.K Department for Transport, 2014). The UK stated that this would not only benefit the local economy but also afford the country more independence regarding space activities.

The most recent spaceport development targeting small launch vehicles is on the Mahia peninsula in New Zealand. The launch facility was specifically designed with minimal market-specific equipment to cater for the cheaper, basic ‘ship and shoot’ launches (Rocket Lab, 2016). This launch complex configuration could be replicated using South Africa’s existing infrastructure, as will be discussed in section 4.5.

4.3. Financial considerations for spaceports

The cost of maintaining a spaceport is also a consideration for new developments. Generally, commercial spaceports rely on launches for income, although several also receive income through renting workspace and hangers, while others have maintained operations with government support. PSCA, in particular, does not have any substantial sources of revenue besides launch services, which makes the complex vulnerable to fluctuations in the market. PSCA’s cash reserves dropped by approximately 75% in 2016 as no launches were carried out on the site. To date, the federal government has provided $167 million in grants to maintain the facility and a further $33.7 million towards reconstructing parts of the facility that were damaged as a result of a failed launch in 2014 (AAC, 2017).

The Australian government also provides financial support for its spaceports. The Woomera complex is a focal point in South Australia’s space innovation and growth strategy. The government has supported this strategy by awarding an AU$297 million contract to refurbish the facilities and a further AU$50 million to upgrade obsolete equipment and systems (Government of South Australia, 2017). Spaceport America also has roots in government funding, as already mentioned; the State of New Mexico contributed $200 million towards the spaceport’s construction (Jacksonville Aviation Authority, 2012).

Renting commercial space in the spaceports does provide some constant income, although this alone is not entirely sufficient to support the operation of a spaceport. A typical lease fee at Mojave is around $50,000 per month, but this does vary based on the area required (Sheetz, 2017). Leasing space can also lead to further launch contracts. For example, Spaceport America hosts Virgin Galactic’s headquarters and under the hosting agreement Virgin Galactic is mandated to launch using this spaceport, guaranteeing regular launches.

To only consider micro-launchers and the anticipated lower cost to launch, it is important to note the lower price that spaceports would need to offer in order to make the micro-launch vehicle model viable. PSCA has estimated an all-inclusive launch service being charged between $200,000 and $500,000. This would need to be factored into the anticipated launch profits and minimum required launch frequency to maintain a profitable spaceport.

The above discussion shows there are several spaceports to choose from, each of which has similar features. However, the legalities, political stability, launch cost, launch vehicle availability, scheduling and the orbital inclinations accessible are factors to be considered when choosing a spaceport for a given launch. The choice of rocket might dictate the location. India has become the leader in launching multiple small-scale satellites in single launches, making it a cost-effective choice, although in a ride-share agreement the secondary payloads have less control over their orbits. This is in contrast to a marginally more expensive launch by Rocket Labs' Electron launch vehicle, which is launched in New Zealand, but offers dedicated launches.

The legalities of launching in a particular country might also restrict options. As already mentioned, US companies have had to apply for waivers to launch with the PSLV in India and there is a standing ban on NASA entering into any bilateral agreements with Chinese entities, preventing launches through them. As noted, bilateral agreements are necessary to facilitate launching in another country, such as Italy's agreement with Kenya, the US's agreement with New Zealand, and Russia's agreement with Kazakhstan. New spaceports should be contrasted against the existing and anticipated spaceports to assess the viability of operating in the current landscape.

The cost of developing new spaceports and maintaining existing facilities should also be a key consideration. The operational aspect of the spaceport would also have to be assessed, as single-purpose spaceports such as PSCA may require financial support from government during market fluctuations. Alternative sources of income such as renting space within the complex and weapons testing should also be explored in evaluating a spaceport's viability, as these activities have allowed several spaceports to remain profitable when not participating in space launches. In the South African context, to understand the current situation regarding space activities, it is important to understand the country's space history.

4.4. South Africa's historical space activities

Like many countries, South Africa's introduction to space activities was through the military. In 1963, the build-up of the Apartheid military started in earnest with the parastatal arms company Armscor manufacturing tactical missiles with French cooperation. This progressed with the technology of the time to the development of air-to-air missiles with supervision and support from both France and Israel. In 1980, after two decades of dealing with missiles, the decision was made to develop a reconnaissance satellite to monitor neighbouring countries for intelligence-gathering purposes. With the isolation of the Apartheid regime the government decided to develop its own launch vehicle to support the satellite programme.

The South African government acquired launcher technology in the form of Israel's Shavit launcher. The Shavit space launch vehicle was based on the French Intermediate Range Ballistic Missile, named Jericho, and modified by the Israeli aerospace industry to carry a payload as opposed to a warhead. Once in South Africa, the launch vehicle was rebranded as the RSA-3. It had a mass of 23 tons and was capable of launching a 330kg satellite into LEO (Gottschalk, 2010). Following the development of the launch vehicle, two suborbital tests were completed. However, under diplomatic pressure the De Klerk administration agreed not to resume space launch activities until South Africa had joined the Missile Technology Control Regime (MTCR). However, even after South Africa joined the MTCR in 1995, the space programme was not resumed.

At the peak of the South African space launch programme about 1500 people were employed and, in its entirety, the programme cost the government approximately R 5 billion, the equivalent in 2017 purchasing power to more than $13 billion U.S. dollars. As a result of the investment in this programme, South Africa still has existing space infrastructure that remains functional today. These facilities include (Gottschalk, 2010):

I. The **Spaceteq** (formerly Houwteq) satellite assembly, integration and test facility, which can cater for satellite integration in a clean room and has test facilities for mechanical mass properties, vibration, an anechoic chamber and thermal vacuum test chambers. This facility was used for the development of both of South Africa's indigenous satellites programmes: SunSat (launched 1999) and Sumbandilasat (launched 2009) (Anon., 2014).

II. The **Denel Overberg Test Range** (OTR) was built as an eastward and polar space launch facility. It has a control centre, launch pads, tracking antennas and radars. This facility's telemetry station is still operational and has been used for testing missiles, averaging 50 tests per annum (Denel OTR, 2017). The test range operates commercially with 42% of the revenue coming from foreign customers testing military equipment and around 8% from providing commercial satellite launch support services (Martin, 2015).

III. The **South African Air Force Test Flight and Development Centre** (TDFC) was moved from Waterkloof Air Force Base, Pretoria to Bredasdorp in 1987 to be closer to the OTR. This centre, which was originally for military R&D, has also moved into more commercial business, carrying out test flights for British Aerospace, Russian affiliated Marvol and Vodochody L-59, among others (TDFC, 2015).

South Africa's transition to a democracy was coupled with the process of demilitarization. The defence industry, which had been built up as a result of arms embargos, was forced to downsize and diversify into civilian products in the wake of severe defence budget cuts. This also led to the restructuring of the military industrial complex, commercializing part of the state-owned enterprise Armscor into Denel, which retained the majority of Armscor's R&D and production facilities and was to operate under the Department of Public Enterprises. Houwteq, one of Denel's inherited facilities that had been involved in developing military satellites, was repositioned for civilian purposes in 1992 and started the development and marketing of LEO Earth observation satellites, known as the GreenSat programme. However, the GreenSat programme was not commercially viable and was terminated in 1994 (Batchelor & Dunne, 1998).

Subsequent satellite developments in South Africa have been limited to universities. SunSat, a 64kg microsatellite with an amateur radio communication payload and a multispectral imager was developed at Stellenbosch University. In 1991, the Computer and Control Systems Group of the electrical and electronic engineering department of the university established a post-graduate research group in satellite systems. More than 100 students, in conjunction with engineers, were involved in the development of the SunSat satellite and over 50 Masters and PhD degrees were awarded during that time (CVP, 2014).

SumbandilaSat, South Africa’s second satellite was developed by SunSpace in conjunction with the University of Stellenbosch, funded by the South African Department of Science and Technology. The satellite has a mass of 80kg and contained multiple payloads, with the primary one being a multi-spectral imager. The satellite also contained a number of experimental payloads from Stellenbosch University, Nelson Mandela Metropolitan University and the University of KwaZulu-Natal. For the Department of Science and Technology (DST), the SumbandilaSat project was intended for the development and growth of people and institutions, providing relevant satellite data for society at large, to develop regulatory capacity in government, and to inform the space policy process in South Africa (Spaceteq, 2014). Many of the engineers involved in the development of SunSat became the core team that formed SunSpace, which built SunbandilaSat for the DST. Sunspace was acquired by Denel in 2013 and rebranded as Spaceteq.

The French-South African Institute of Technology (F’SATI) at the Cape Peninsula University of Technology (CPUT) built South Africa’s third satellite, ZACUBE-1, launched in 2013 (F'SATI, 2016). This satellite was made using a combination of off-the-shelf components from Clyde Space and Innovative Solutions In Space (ISIS), with an innovative transceiver that was developed and built at F’SATI/CPUT. The success of the technology demonstration for the transceiver led to the design for a CMC UHF/VHF transceiver, which is now commercially available from Clyde Space. While Clyde Space and ISIS are based in Europe, ISIS has established a presence in South Africa with a local office in Somerset West.

There are also two privately funded CubeSats that originated from South Africa and form part of the QB50 mission. The CubeSat ‘nSight1’ was designed and manufactured by SCS Space, a subsidiary of the private SCS Aerospace Group, while ‘ZA-Aerosat’ was designed and manufactured by SCS Space in partnership with CubeSpace, Cape Peninsula University of Technology, Stellenbosch University, Nelson Mandela Metropolitan University, Pinkmatter Solutions, AMSAT SA and NewSpace Systems (AMSAT-UK, 2017).

CubeSpace, together with the Electronic Systems Laboratory (ESL) at the University of Stellenbosch, developed a unique small satellite attitude determination and control system, which was supplied to 15 other satellites in the QB50 project. The funding raised from the sale of the control units was invested into developing another satellite, ZA-AeroSat (Van de Groenendaal, 2016).

Both nSight1 and ZA-AeroSat made use of local technology and manufacturing opportunities, with more than 70% of nSight1 being made from components supplied by South African space industry enterprises (BusinessTech, 2017). These small satellites have been used as a platform for both technology demonstrations and to showcase the capabilities of the South African space industry. SCS Aerospace Group has facilities to design, integrate and test small satellites, while NewSpace Systems is able to assemble them in an ISO compliant class 10 000 clean room by ESA-certified technicians (Van de Groenendaal, 2016). NewSpace also provides components to order for small satellites, with clients including NASA, ESA, Mitsubishi, ISIS and Spaceflight (NewSpace Systems, 2018).

While South Africa has remained somewhat active in the satellite industry, there have been no government initiatives to revive the launch programme from the 1990's. However, given the rise in small satellites being developed in South Africa and the existence of launch facilities that are still operational, there is a possibility of re-establishing an active space launch site in South Africa.

4.5. Denel - South Africa's Space Parastatal

The majority of South Africa's space-related facilities operate under the parent company, Denel. Denel is a South African state-owned company (SOC) operating in the defence, security and related technology domains. It operates as an investment holding comprising various specialized business entities, each of which operates under its own management structure. The group structure is shown in Figure 4.2 (Denel, 2017). Of these business entities that fall under Denel SOC Ltd, the units relevant to space activities are the Denel Overberg Test Range, Denel Dynamics and its subsidiary Denel Spaceteq facility.

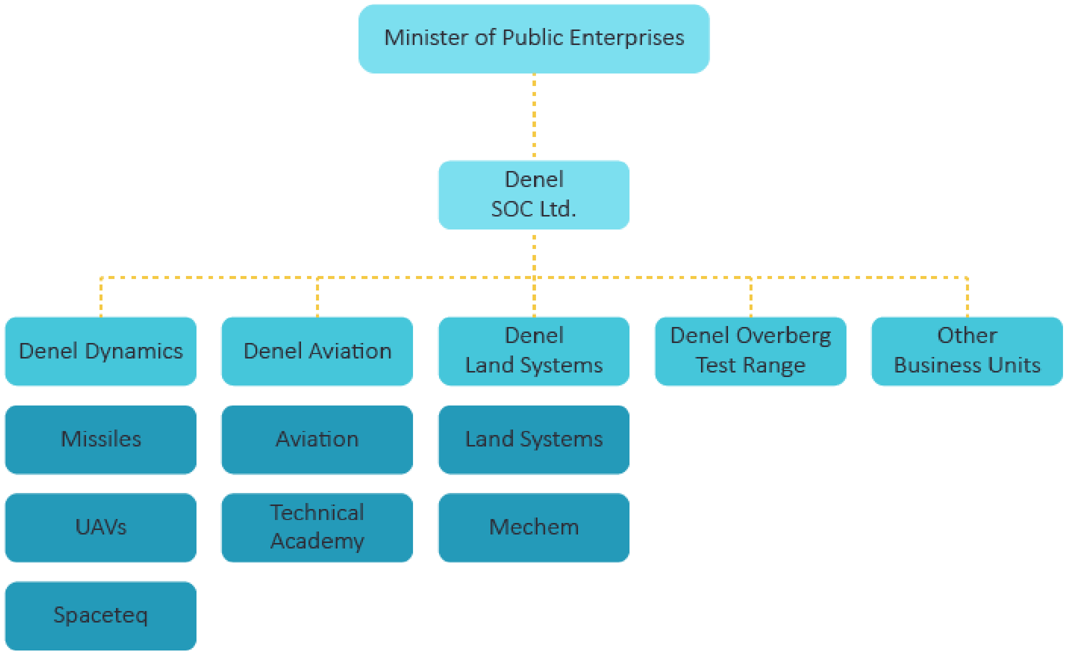


Figure 4.2 Denel Group structure. (Denel, 2017)

4.5.1. Overberg Test Range

The location of the Overberg Test Range (OTR) was specifically selected during the GreenSat project due to its isolated southerly location, providing opportune conditions to launch the GreenSat reconnaissance satellite. However, as Denel became established as a commercial entity, the Overberg Test Range became a centre for testing weapons developed for the South African Defence Force, and the need for diversification of the business has led the OTR to target international clients that lack the space or a suitable environment for weapons testing. The German Air Force and Navy, as well as several German defence companies, including Diehl, have used the facilities at OTR. Other notable international clients include: the Republic of Singapore Air Force (RSAF) that primarily uses the range to conduct defence exercises; the Swedish aerospace and defence company (Saab Group); the Italian Air Force; the British multinational defence, security, and aerospace company BAE Systems; Singapore Technologies Aerospace (ST Aerospace); the Turkish Navy and the Spanish Air Force.

A considerably smaller aspect of the commercial operations at OTR is the support provided to foreign space programmes. OTR has provided support to various launches that have been carried out by NASA, the United Launch Alliance, the Centre National d'Etudes Spatiales (CNES) and Space X. OTR uses a 10-meter tracking antenna that works with both the S and X Band, as well as two mobile S-Band telemetry tracking stations that can be deployed to remote locations. This system has already been deployed in Ghana, Namibia, New Zealand, Australia and French Guiana.

Given the work OTR does with foreign entities, it has developed an end-to-end operation that can include assistance with importing and exporting the necessary equipment as well as accommodation and transport to the site. OTR is able to facilitate access to organizations such as the Council for Scientific and Industrial Research (CSIR), which can help with client projects, as well as specialized South African subcontractors (Martin, 2015). Expanding the customer base to include space launches would also improve to profitability of the test site, which has decreased over the past few years (Martin, 2016). Features of OTR are discussed in more detail below:

a) Location

One of the reasons OTR is suited to weapons testing is its remote location. The OTR is situated in the Western Cape of South Africa between Arniston and Cape Infanta, with an overland area of approximately 43 000 ha separated by the De Hoop Nature Reserve, which can with prior arrangements be designated as part of a safety area. The overland safety area spans approximately 70 km along the coast when the De Hoop Nature Reserve is included. The South African Air Force controls the air space over this area; consequently there is no altitude limitation at any time, and maritime traffic along the coastline is light in this area. Located adjacent to OTR is Air Force Base Overberg, which has a 3000m main runway and 2000m secondary runway that can be used at the request of OTR clients to fly personnel and equipment directly to the site (Denel, 2017). However, OTR is also accessible by well-maintained roads and Cape Town, which hosts an International Airport and cargo port that are about 200km from the range. Figure 4.3 shows the range location and layout.

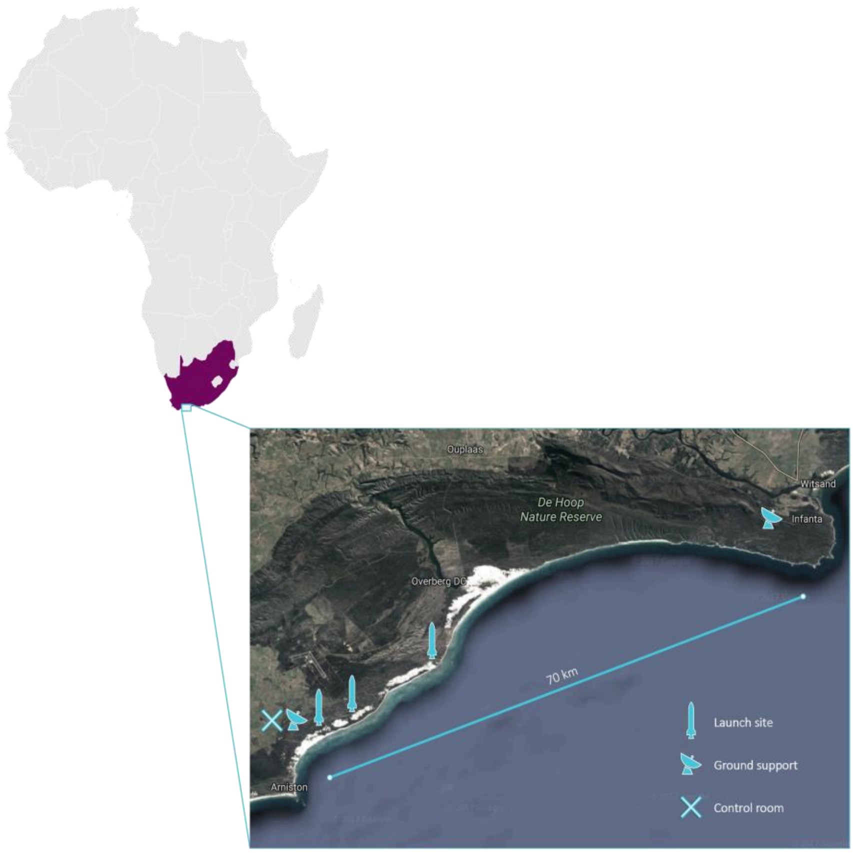


Figure 4.3 Layout of Overberg Test Range.

This region of South Africa has a typically Mediterranean climate with mild winters and warm summers. Rainfall is spread throughout the year, although the peak rainfall is generally in spring (October and November) and autumn (March and April). This area is also known for strong winds, with the prevailing wind in summer from the south-east and from the north-west in winter.

b) Facilities

OTR has two self-contained preparation buildings, which include an integration area, laboratory and office area that can be access-controlled by the client. The OTR has a central control centre that houses the command and control infrastructure, and there are mobile control centres available should the launch happen in a remote location on the test range. The range has a centralized computing system that comprises a Communication and Computation System (CCSYS), Graphic display system (GRDIS) and a Range Safety Display (RSDIS).

- The CCSYS provides a real-time communication link with all the equipment on the range as well as certain client-specific equipment. This computer system also relays real-time state vectors to GRDIS and client instrumentation and calculates the projected impact point used for Range Safety.

- The GRDIS provides a visual display of the launch with the Instantaneous Impact Point (IIP), safety volume, and telemetry information. This system also provides the inputs for execution decisions and countdown logistics.
- The RSDIS monitors air and maritime traffic around the site and uses this information to ensure range safety.

The control centre has a flight termination system that follows the specifications set out in the American Range Commanders Council document RCC 319-92.

OTR uses cinetheodolites, mobile tracking mounts and high-speed video cameras to provide telemetry and capture the flight test data for off-line analysis. The test range has four mobile Skytrack units and two mobile Askania units. The Skytrack units have an off-line trajectory accuracy of 30 micro-radians.

The range also has a mobile track mount that is used to provide high-resolution in-flight photographic and trajectory data, in conjunction with the cinetheodolites. The mount that can move in two axes, azimuth and elevation, and can support automated tracking. There is also the possibility to adapt it with client-specific video and infrared sensors using the five available stations on the mount.

The OTR has two primary telemetry facilities at fixed locations as shown in Figure 4.3 that are used to provide real-time reception, recording and relay of telemetry data. These facilities can be supplemented with two mobile secondary telemetry facilities, which are also available for integration purposes. These facilities are in compliance with IRIG 106-93, the Inter-range Instrumentation Group document for 1993. This document serves as a telemetry standard that aims to ensure interoperability between aeronautical telemetry applications at ranges affiliated with the Range Commanders Council. The latest revision of the IRIG 106 is IRIG 106-17, released in 2017.

The main station (MS2), located on the western edge of the range, is equipped with telemetry workstations, communication, video links and versatile interfaces to allow integration between the range user equipment and the telemetry systems of the station. Three radar systems provide real-time tracking over the entire testing area with a real-time range error less than 2.5m and angular error less than 100 micro-radians. The site also has a Weibel Ranging Radar System that uses multi-frequency Doppler to track objects. The design of the equipment is such that it has a high reliability and resistance to blast vibrations.

The test range also has some experience in supporting space operations. Since 2003, the OTR has provided telemetry launch support to various international entities including NASA and ESA, supporting missions such as the Mars Exploration Rover I launched in 2003, the Deep Impact spacecraft launched in 2005 and ESA's Automated Transfer Vehicles in launched 2008, 2011 and 2012. For the purpose of launching space vehicles, the OTR has two dedicated mobile S-band telemetry tracking stations available for quick deployment at remote locations, which have included various southern African countries, Australia and New Zealand. Given that the OTR is currently operational, employees are likely to already have some experience in launching and operating missiles. This knowledge could be readily expanded upon to include space launch vehicles, which have similar attributes.

The financial considerations for using OTR would also have to include possible upgrades for out-dated equipment. While the extent of an upgrade would not necessarily be on the same scale as that of Woomera, which is costing the Australian government over $300 million, it is worth noting that infrastructure on these facilities is costly. Despite the maintenance costs, the diverse use of OTR further supports its use a launch site, as current operations are sufficient to maintain operational standards without additional financial support as other spaceports may require.

4.5.2. Denel Dynamics

This entity specializes in missiles, guided weapons and UAVs, having had more than 45 years' experience in the design, development and production of such systems. In 2013 a division for space technology was added when Denel assumed control over SunSpace, which was the company responsible for designing and manufacturing SumbandilaSat. This new division was branded as Spaceteq (Anon., 2014). The Spaceteq head office is based at the former Houwteq facility near Grabouw.

Spaceteq offers a range of products for small satellites including reaction wheels, flight computers, transmitters and transceivers. The facility also has (Spaceteq, 2018):

I. A thermal vacuum chamber, which is suitable for testing on both a satellite and component level.
II. A vibration facility that can use be for items up to 1 tonne in mass.
III. An electromagnetic compatibility testing centre with an anechoic chamber of dimensions 8m x 7m x 8m.

While this facility is being used as a base to build and test satellites Amal Khatri, an executive director at SANSA, has noted that the technology available at the facility is old and in need of an upgrade (Campbell, 2018).

In the South African context, Spaceteq has emerging competition from private companies that have already designed and manufactured small satellites. As mentioned, SCS Space and CubeSpace have both been contracted to design the South African QB0 satellites nSight1 and ZA-AeroSat. Should South Africa pursue end-to-end commercial capabilities in the construction, launch and operation of small satellites processing, SCS Space and CubeSpace have the knowledge and facilities to build small-scale satellites.

4.6. Hartebeesthoek Radio Astronomy Observatory

In 1961, NASA built Deep Space Station 51 outside Johannesburg, South Africa. This station was used to send and receive data from several of NASA's unmanned probes including Ranger, Surveyor and Mariner programmes. Then in 1975, the station was converted to a radio astronomy observatory and handed over to the South African Council for Scientific and Industrial Research. Following this, in 1988 the observatory became a National Facility.

Since then, it has been used for TT&C support on a continuous basis by companies operating satellites in space, such as the French Space Agency (CNES), Boeing, Hughes and Intelsat (SANSA, 2012). Should OTR be used as a spaceport Hartebeesthoek would be a significant partner in launches. Knowledgeable ground support can determine a mission's success; an obvious example is Rocket Lab's test flight that was ultimately terminated due to a misconfiguration of telemetry equipment (Rocket Lab, 2017).

Given the infrastructure available at OTR, the support of Hartebeesthoek, satellite-testing facilities at Denel Spaceteq and the satellite development possibilities with SCS Space, CubeSpace and universities including CPTU and Stellenbosch, South Africa has the potential to support small-scale missions as well as end-to-end launch services with existing facilities.

5. Policy and Regulatory Aspects of Space launches

The focus of this chapter is around the governance framework for outer space activities, particularly in relation to space launching activities and launching states. South Africa's legal framework is also contrasted against the legislation governing other space faring countries and assessed in terms of the degree to which it adheres to the relevant UN space treaties. South Africa has stated its intention to move towards a knowledge-based economy, setting expectations for science and technological sectors. This has prompted the government to formalize the National Space Strategy and the National Space Policy, which are explained in more detail in this chapter.

5.1. International Space Law

The international governance framework for space activities has been developed by the United Nations. The first instrument to be agreed by UN was the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space in 1963. In 1967, this declaration was followed by the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, commonly referred to as the Outer Space Treaty. The treaty was largely based on the declaration, with several additional provisions. Since international treaties are one of the sources of international law, the outer space treaty is widely regarded as the Magna Carta of international space law.

International law applies only to States and not entities within a State; as such it is the State's responsibility to ensure that the legislative entities within the State abide by the principles by ratifying the treaties and incorporating the principles into domestic law. Figure 5.1 shows the number of treaties and national space regulations passed each year between 1957 and 2013. This highlights the increase in national legislation as States incorporate international treaties into their domestic law.

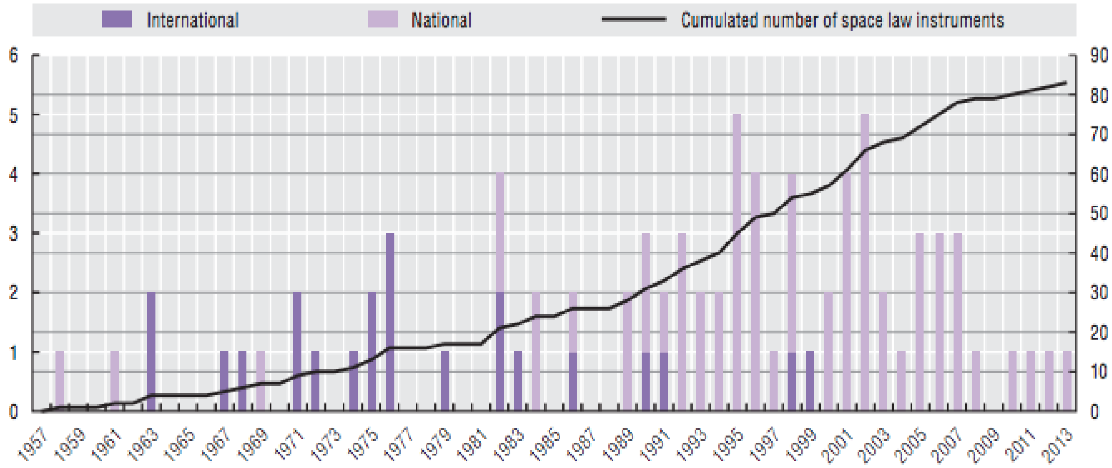


Figure 5.1 Number of treaties, national space laws and regulations per year between 1957 and 2013. (OECD, 2014)

Key aspects of international space law include international conventions, such as the United Nations treaties on space activities, and international custom, in the form of general practices becoming accepted as law. For customary law there are two elements that need to be identified: general, consistent practice over time and that a number of States consider the practice to be obligatory, such as some of the guidelines and recommendations laid out by the UN working groups.

The basic framework of international space law comprises five broad multilateral treaties developed by the United Nations. The first of these was the Outer Space Treaty, after which four more treaties were adopted to elaborate on the text contained within the Outer Space Treaty (UNOOSA, 2013):

1. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, which entered into force on 3 December 1968 (Rescue Agreement);
2. Convention on International Liability for Damage Caused by Space Objects, which entered into force on 1 September 1972 (Liability Convention);
3. Convention on Registration of Objects Launched into Outer Space, which entered into force on 15 September 1976 (Registration Convention);
4. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, which entered into force on 11 July 1984 (Moon Agreement).

Of these, the most pertinent to a 'launching state' are the clauses on liability, dual use technology and the Registration Convention. Figure 5.1 along with Table 5.1 demonstrate a decrease in countries prepared to ratify the space treaties as they became more restrictive, particularly the Moon Agreement, which only attracted 17 signatories.

Table 5.1 Number of countries to ratify UN Treaties. (UNOOSA, 2017)

Outer Space treaty	Rescue Agreement	Liability Convention	Registration Convention	Moon Agreement
105	95	94	63	17

As the first of the treaties drafted, the Outer Space Treaty addresses most of the issues of space activities with a high-level approach, reiterating the principle that space should only be used for peaceful purposes. Article I of the Outer Space Treaty states that the exploration and use of outer space including the moon and other celestial bodies shall be free for all States, and shall be carried out without discrimination, on the basis of equality, and that States should both facilitate and encourage international cooperation in this regard. This article supports the concept of knowledge-sharing and technology transfer, which to some degree has been hindered by the international arms control regimes like MTCR and HCoC.

Further to this, articles III and IV state that all States party to the treaties must conduct themselves in accordance with international law in the interest of maintaining international peace and that no weapons of mass destruction may be allowed in space. In keeping with this, the moon and other celestial bodies may not be used for military purposes, including establishing military bases and testing weapons. However, the use of military personnel, equipment and facilities that may be required for peaceful exploration are not prohibited in these articles. This is relevant to the issue of dual-use space technology and the Missile Technology Control Regime (MTCR), as military equipment is not prohibited from use in space as long as it is not used in a harmful manner. The control regimes noted here are addressed in more detail later in this chapter.

Article VI states that Parties to the treaty are responsible for national activities in outer space and for ensuring that both governmental agencies and non-governmental entities under their jurisdiction adhere to the international conventions set out by this Treaty. Further to this, the activities of non-governmental entities require authorization and continuous supervision by the appropriate State Party. Should the entity be an international organization, the responsibility for compliance is borne by both the international organization and the States party to the Treaty.

Article VII highlights the issue of liability in space activities, stating that the States party to the treaty that launch or procure the launch of an object into outer space, as well as the State from whose territory the object is launched, are internationally liable for any damage caused by the space object. Article VIII states that the objects will remain under the jurisdiction and control of the state with whom it is registered, and that the ownership of these objects is also not affected by their presence in space.

The Convention on International Liability for Damage Caused by Space Objects expands further on the issues of liability regarding space activities, describing how compensation for the damage shall be apportioned. Given that these treaties have been ratified by South Africa, any damage caused by persons under South African jurisdiction results in South Africa as a State becoming liable for the damage. Pertinent to launching space objects, in Article V the State from whose territory the object is launched is regarded as a participant in a joint launch, and therefore is jointly liable under the convention for any damage caused.

Article XXII states that, if an international inter-governmental organization is liable for the damage, the compensation claim should first be presented to the organization. However, should the organization not pay within a period of 6 months, the Claimant State may invoke the liability of the member States party to this treaty to cover the compensation. Although there is no requirement for it, in Resolution 68/74 the UN General Assembly recommends that States introduce insurance requirements for space activities operating within their jurisdiction to ensure entities are able to cover these potential costs.

The Convention on Registration of Objects Launched into Outer Space addresses how space objects should be registered in the event that multiple States are involved in a launch. Article II states that when a space object is launched into orbit or beyond, the launching State, which includes the State from whose territory it was launched, and the States that procured the flight or the State launching the object, must register the object on an appropriate registry. When the 'launching state' comprises multiple states, only one of the states is required to register the object.

There is also a requirement for all space objects to be registered with a registry maintained by the launching State. Further to this, the onus is on the state to inform the Secretary-General of the United Nations of all items on its registry. The content of the registry, which is maintained on a national level, is decided by the State, with consideration of the reporting requirements of the given state to the UN, which include the: a) name of launching State, b) registration number; c) date and location of launch; d) basic orbital parameters and e) general function of the space object. States that have not ratified this treaty are encouraged to register their space objects with the Untied Nations accordance with resolution 1721 (XVI) B (UNOOSA, 1961).

South Africa has domesticated its international obligations flowing from the Outer Space Treaty under the Space Affairs Act (Act of 1993). While South Africa had not ratified all these UN space treaties when the national law was drafted, it does reference the UN treaties as the law on which it is based.

5.2. International Technology Control Regimes

The Missile Technology Control Regime (MTCR) and Hague Code of Conduct against Ballistic Missile Proliferation (HCoC) are both soft laws based on an informal political understanding among States aiming to limit the proliferation of missiles and missile technology. They depend on a common export policy applied to an agreed list of items, voluntary political compliance and a self-imposed code of conduct for their enforcement (Kasprzyk, et al., 2016). While neither of these soft laws are intended to inhibit the development of space programmes, the dual-use nature of the technology inevitably blurs the division of its use.

5.2.1. Missile Technology Control Regime

The Missile Technology Control Regime (MTCR), established in 1987, is a set of guidelines aimed at minimizing the proliferation of weapons of mass destruction through adherence to a common export policy. The MTCR divides equipment and technology into two categories. Category I items are considered to be of greater sensitivity in terms of transferability to WMD. The transfer of the Category I items is authorized on a case-by-case basis, such as when there are government-to-government undertakings that an item is assured to be put only to its stated end-use. The design of technology or equipment listed in the MTCR Annex is also subject to scrutiny.

When evaluating the transfer of items listed in the Annex, the capabilities and objectives of the missile and space programmes of the recipient State are considered, as well as the significance of the transfer in relation to the potential to develop it into a weapon delivery system, along with the end use of the transfer and the applicability of relevant multilateral agreements. The transferred technology may not be replicated or further transferred under the MTCR guidelines (Missile Technology Control Regime, 2010).

The MTCR does not aim to impede national space programmes or international cooperation; however, the technology used in space launch vehicles and equipment is practically identical to that in ballistic missiles, and while the regime's export policy guidelines are not legal commitments, there is an underlying political commitment for South Africa to adhere to these guidelines, which adherence will affect the ease with which the country can gain access to space technology.

The annex is divided into two categories; military and dual-use technologies. The greatest restraint in export controls is shown in 'Category I' items, which includes complete rocket systems such as space launch vehicles and sounding rockets, production facilities for these systems, major sub-systems including rocket stages, re-entry vehicles, rocket engines and guidance systems with capabilities exceeding a 300 km/500 kg range/payload threshold. 'Category II' provides for greater export flexibility. It includes items similar to Category I, but the assumed capability is a maximum range equal to or less than 300 km (Missile Technology Control Regime, 2010).

Despite the intention not to impede space programmes, the MTCR technology embargoes do impact on the space programmes of developing nations seeking to develop capabilities for independent access to space. The ISRO incurred delays and increased cost on their programmes, but the MTCR has not ultimately prevented them from developing, manufacturing and operating their own indigenous space launch vehicles. On the contrary, the restrictions actually promoted the development of indigenous technology, including shell catalysts for rocket fuel, radiation-hardened integrated circuits for satellites and maraging steel for rocket motor casings. The reaction to the embargo has made India somewhat less reliant on imports and more immune to international pressure. However, in 2016 India signed the MCTR, having already developed an indigenous space industry.

South Africa, like several other countries, relinquished their space programmes in the early 1990's, having been heavily influenced by the MTCR embargoes and political-economic considerations (Misty, 1998). However, there are likely to be more opportunities to cooperate in this sector with countries that are aligned with respect to international conventions and technology controls, as illustrated above by India joining MTCR in 2016.

Figure 5.2 Member States of the MTCR in 2018. (Daily GK Affairs, 2018)

In preparation for South Africa joining the MTCR, the Non-Proliferation of Weapons of Mass Destruction Act (Act 87) was passed in 1993. This act provided for the establishment of the South African Non-Proliferation Council, which is responsible for the control over weapons of mass destruction and to manage matters relating to the proliferation of such weapons. It is noted that in the definitions of this Act a 'delivery system' includes a space launch vehicle capable of delivering a payload of at least 500 kilograms over a distance more than 300km (dti, 2010). This delivery system is listed as a category I item in the MTCR annex. However, Category II items have less stringent controls placed on them and launch vehicles with a carrying capacity of less than 500kg to LEO fall into this category. In addition to this, in the South African context, these smaller launch vehicles are not explicitly restricted in the Non-Proliferation of Weapons of Mass Destruction Act.

5.2.2. Hague Code of Conduct

The Hague Code of Conduct against Ballistic Missile Proliferation (HCoC), which came into effect on 25 November 2002, aims to reduce the proliferation of ballistic missiles, supplementing the Missile Technology Control Regime (Kasprzyk, et al., 2016). HCoC attempts to address regional and global security challenges, which are caused by the on-going proliferation of Ballistic Missile systems through the promotion of mutual trust between countries and the implementation of political and diplomatic measures.

A requirement of the HCoC is that the signatories must have ratified the Outer Space Treaty and that space activites should only be carried out for peaceful purposes. As with the MTCR, the HCoC is not intended to impede national space programmes but it emphasizes the need to not contribute to proliferation of ballistic missiles. To further this goal, there is a general measure in HCoC to exercise vigilance in the consideration of assistance to Space Launch Vehicle programmes in any other country, “considering that such programmes may be used to conceal Ballistic Missile programmes”.

Given the similar nature of space launch vehicles to ballistic missiles, the end-use is what would define the difference between these, which is why HCoC emphasises the need for more ‘transparency’ in ballistic missile programmes and space launch vehicle programmes. This has culminated in a registry of prelaunch notifications and an annual declaration noting the number of ballistic missiles and space launch vehicles launched, but this has not led to any open sharing of information.

It was noted in a study of the HCoC’s relevance to African states that there has been an interest in developing space capabilities given the surge of small satellites between 100 or 150 kg. The new interest in small satellites has also led to development of smaller launchers making the possibility of space more accessible to Africa than ever before, which may give the opportunity for African countries to increase their presence in the space-launch sector (Kasprzyk, et al., 2016). While the HCoC and the MTCR are not intended to impede space programmes they do restrict access to certain necessary components. Countries may impose their own restrictions on certain components or simply not wish to sell such components to other countries.

Mark Comninos, CEO of Marcom-AS, commented on the difficulty of importing into South Africa components required for developing their liquid propulsion engine, namely sourcing carbon fibre rocket casings and cryogenic ball valves. The difficulty of importing goods despite having signed these agreements suggests it may still be necessary to become self-sufficient in producing the core components that may be seen as ambiguous within the restriction criteria. While other South African space actors echoed this sentiment, it was also noted that South Africa's export control has also rejected the export of components from South Africa based on these regulations, despite them not actually falling within the controlled criteria. Improving the understanding of the technology as well as the law regarding these items within the current export control regime would likely improve the consistent and rational application of the regulations by South African customs authorities.

5.3. South African Space Legislation: South Africa's Space Affairs Act

With regard to national space law, South Africa has been quite progressive. While the country is currently only regarded as an emerging space nation, an appropriate authority to regulate space activities has been in place since 1993, established through the South African Space Affairs Act of 1993. The Act provides for the establishment of a council to manage the regulatory functions and advise the Minister of Trade and Industry on all space-related matters. As noted, national space legislation is required to ensure nationals of a particular state are adhering to the international laws and obligations as well as reducing the international liability associated with space activities.

The Space Affairs Act defines space activities as, inter alia, contributing to the launching of a spacecraft and the operation of such a space craft in outer space, where launching is defined as the placing or attempted placing of a space craft into a sub-orbital trajectory, an orbit, outer space or the testing of a launch vehicle. However, the scope of 'space activities' covered in the Act can be understood from section 11 of the Act to include design and manufacturing of space objects, operation and control of space objects, re-entry of space objects and operation of launch facilities (Department of Trade and Industry, 1993).

As the government would be held responsible for activities carried out in space with regard to international law and in particular, under the United Nations treaties on outer space, authorization by a national authority is required for the actions of both governmental and non-governmental entities in outer space. South Africa has an authorising body, the South African Council for Space Affairs (SACSA), which covers the licensing of space activities. SACSA does not specifically define the jurisdiction of South Africa as a launch state or make provision for transferring ownership of space objects, but it does outline situations when South African licenses are required. Sections 11- 15 of the Space Affairs Act provide the legal framework for the licensing process. Section 11 of the Act expands on the definition of 'space activities' to include launching from the Republic, launching from a different territory on behalf of a person in the Republic's jurisdiction, and the operation of a launch facility (Department of Trade and Industry, 1993).

All space activities can only be performed under a space license issued by SACSA. As such, participating in any space activities without obtaining prior authorization from the Council is an offence punishable by law. The licensee is responsible for fulfilling the obligations under the UN treaties for the safe use of outer space. As provision has been made in the Space Affairs Act for amending, suspending and revoking of licenses, the Council can effectively regulate the issue and content of licenses through legal procedures to ensure that activities carried out are compliant with international obligations.

The licenses are also used to moderate the liability of the State regarding space activities. There is no explicit requirement for insurance in the Act, however, the State, through the Council, may decide what securities are suitable as collateral for covering the liabilities incurred. The dti is in the processes of reviewing the Act and has proposed the inclusion of insurance, third-party liability, and limiting the liability of non-governmental entities to encourage industrial development in the private sector (dti, 2015).

One aspect of the national law that would need to be reconsidered is the need for a registry. The current South African legislation does not make provision for the registration of space objects. There are also no clear reporting requirements for entities participating in space activities to inform the Council of any changes, other than those that may affect the license. However, the South African Council for Space Affairs does keep a registry of South African satellites.

South African space law does not explicitly regulate payloads, although it does specify that the launch license shall only be granted after due considerations of all pertinent facts, including international obligations and responsibilities – so no weapons of mass destruction will be permitted, but other than that, the payloads would not be regulated. This legal framework allows for transparency when engaging with South African entities in space activities.

5.3.1. National Space Legislation from several countries participating in space activities

As noted in Chapter 4, Sweden aims to introduce the SmallSat Express into the Esrange Centre by 2021. However, the Act on Space Activities that governs Swedish space activities does not include any cap on liability of operators, nor does it require any form of third-party insurance (Government of Sweden, 1982). In this sense South Africa's law provides marginally more control over the State's exposure in the event of damage, as there would be predetermined collateral held by the State.

The Spurring Private Aerospace Competitiveness and Entrepreneurship Act (SPACE Act) in the US was put in place to support the developing commercial space industry by limiting the liability of space operators, amongst other issues. The adjustment to the liability clause was to encourage private sector investment as insurance requirements were reconsidered to find a balance between not exposing the Federal Government to undue risk and not requiring operators to purchase more insurance than necessary (U.S. Government Publishing Office, 2015).

Much like the US, the UK has included a liability cap in their Outer Space Act to encourage the commercial sector (UK Government, 1986). For the most part the liability cap for the UK would be set at €60 million, however this amount could be adjusted depending on the outcome of the risk assessment performed during the license application. While the liability cap is an improvement, there is still a requirement for third-party insurance, regardless of the size and cost of the satellite, which is less favourable for the small satellite launch market (Newman & Listner, 2015).

In Austria there is a requirement to take out a minimum third-party insurance to the value of €60 million and the liability is solely on the operator, unless the space activity is considered to be in the public interest. Should the activity be deemed to be in the public interest the Minister for Transport, Innovation and Technology might determine a lower amount at their discretion (Government of Austria, 2011). Whilst this clause is to moderate the requirement for insurance, there isn’t a distinction on what qualifies as ‘public interest’. Much like the US and the UK, this liability cap may be debilitating for commercial small satellite launchers as well as operators, as the cost of the insurance seems disproportionate to the cost of constructing and launching a small-scale satellite.

New Zealand, interested in developing a domestic launch industry, has already signed a Technology Safeguard Agreement (TSA) with the USA in order to launch the American-owned Rocket Lab Electron rockets. The FAA licenced the first launch of Electron given that the national legislation was still evolving. The aim of developing this legislation was to encourage a new industry while ensuring the country was compliant with international laws and obligations, basing the proposed legislative framework on the permissive regime used in UK space legislation (Ministry of Business, Innovation and Employment, 2016). The proposed legislation should be sufficient to meet international obligations without posing any unnecessary barriers to operation, which may be seen as a deterrent to development in the space industry (Joyce, 2016).

A noticeable difference in the New Zealand legislation is the number of licenses required in comparison to South Africa. In addition to the launch and facility licenses, which are common to both, there is a:

- License for payloads, which requires the Ministry of Business, Innovation and Employment to consult with the security ministers before granting a payload permit,

- High-altitude license, which is required when launching a vehicle that is capable of travelling above controlled air space, where they are not in possession of a launch license.

Unlike New Zealand, South Africa does not have a technology safeguard agreement with the US, which may limit allowable technology transfers from the US to import equipment related to space activities, including satellites and space launch vehicles. South African requirements include a compliance certificate from the Recycling and Economic Development Initiative of South Africa (REDISA) and a specifications document from the Non-Proliferation Council. This type of import is subject to the authority of the Waste Act of 2008, the Non-Proliferation of Weapons of Mass Destruction Act 87 of 1993 (SARS, 2017) and the non-proliferation agreements including the Missile Technology Control Regime and the Hague Code of Conduct. Despite South Africa having fewer direct blocks and the relevant legal framework, actors in the South African space industry have described the governance around the import/export of ‘high-tech’ goods as lengthy, slow and inefficient.

5.4. South Africa: National Space Strategy and Policy

While South Africa had heritage space infrastructure predating 1994, and had ratified the Outer Space Treaty and the Rescue Agreement in 1968 and 1969 respectively, the government only relatively recently adopted a national space policy and strategy to inform and direct the national agenda with regard to space activities. In response to the need to transform the South African economy into a knowledge-based economy and the recognition of science and technology as a potential engine for economic growth, the Department of Science and Technology drafted the Ten-Year Innovation Plan in 2007 (Munsami, 2014). Having adopted the national space policy, which aims inter alia to ensure that South Africa upholds its international obligations, South Africa then ratified the Liability Convention and the Registration Convention in 2012.

The Ten-Year Innovation Plan outlines the challenges for the decade between 2008 and 2018. The grand challenges outlined for space science were to have (Department of Science and Technology, 2008):

- Independent access to high-resolution Earth observation satellite data available for all of Africa from a constellation of satellites designed and manufactured in Africa;
- Undertaken at least one launch from South African territory in partnership with another space nation, and have in place a 20-year launch capability plan;
- Specified and co-built a domestic/regional communications satellite and secured a launch date and ITU slot for its operations;
- Become the preferred destination for major astronomy projects and associated international investment in construction and operations;
- Constructed a powerful radio-astronomy telescope and used it for world-class projects.

Of the five challenges outlined, only two have been achieved. The Department has succeeded in placing South Africa internationally on the map in the area of astronomy, having established observatories such as the Southern African Large Telescope, Hartebeesthoek Radio Astronomy Observatory and MeerKat, the precursor to the Square Kilometre Array (SKA), which will be the world's largest telescope (SKA, 2017). The SKA project is a joint venture with a number of other countries, although it is primarily located in Australia and South Africa.

As for the remaining grand challenges, Africa does not have a constellation of Earth observation satellites, although the UK-led Disaster Management Constellation (DMC), of which several other African countries are involved, does provide imaging under contract (DCMII, 2017). South Africa has also been included in a possible BRICS Remote Sensing Satellite Constellation, although this is still under development. Of the Challenges yet to be completed, South Africa has legacy facilities to launch space vehicles, however the country does not have indigenous launch vehicles, intentions to develop a launch vehicle, or technology cooperation agreements with space-launching states.

Identifying space science and technology as one of the five grand challenges marked the beginning of a formal effort to consolidate and develop the South African space sector. This effort culminated in two key government documents, namely the National Space Strategy, which provides the national strategic goals and the National Space Policy, which was to provide the policy framework necessary to achieve these strategic goals (Munsami, 2014).

South Africa adopted its National Space Policy in 2009 following a four-year process of consultation with a wide range of stakeholders in the South African space arena that began in 2005. The primary focus of the policy was to improve the level of coordination and governance in the space sector while leveraging the benefits of space science and technology for socio-economic growth and sustainable development. As a result, the South African space policy is not a primary policy, but rather ancillary policy in support of primary policy goals.

In 2010, the Department of Science and Technology officially launched the National Space Strategy and the South African National Space Agency (SANSA). Three priority areas were highlighted as part of the national strategy, one of which was the need to boost innovation and economic growth (Department of Science and Technology, 2010). This falls under a larger national mandate in the National Industrial Policy Framework and the Industrial Policy Action Plan to move South Africa towards a knowledge-based economy, which has been supported by involvement in high-tech projects such as the Square Kilometre Array (SKA). The National Space Policy, as well as the National Space Strategy, emphasise the need for South Africa to develop space-related products and services in order to strengthen international trade and industry on a larger scale while developing an indigenous knowledge base. The dti also highlighted the need for more coordination in assisting industries to leverage their competitive potential allowing them to become part of hi-tech global supply chains (Department of Trade and Industry, 2009).

5.4.1. National Space strategy

The Department of Science and Technology set out the National Space Strategy to formalize key areas in which space activities could contribute towards the national priorities relating to socio-economic development. The objectives of the national space strategy were to develop (Department of Science and Technology, 2010):

- The local private space science and technology industry sector;
- Services and products that can respond to user needs;
- An export market satellite or services offered from existing facilities;
- Organized strategic programmes using current space science and technology activities;
- A roadmap for future space activities that would respond to opportunities with international industrial partners or international space agencies;
- Partnerships with established and developing spacefaring countries for industrial and capacity development purposes.

In order to build on existing competencies, in 2008 the Department of Science and Technology commissioned a SWOT analysis to determine the current state of the sector. Through this exercise, they established that South Africa has a heritage of companies working in space activities with practical experience in microsatellite design and development, and substantial experience in image processing and satellite telemetry, tracking and control operations. It was also noted that there are high technology sectors, which are not necessarily in space activities but could possibly support new innovation in an industrial context in the future. However, the continued emigration of highly skilled South Africans and the retirement of aging personnel will start to reduce this knowledge base. The organization of the space sector is also a concern as the public entities driving the space programme are dependent on multiple governmental departments for funding and there is little research and development in the private sector given the lack of incentive to enter into the South African space industry (Department of Science and Technology, 2010).

As part of the strategy several key performance indicators were established and categorized into 'readiness factors' or inputs, 'intensity factors' and 'impact factors', which represents the intended impact on society. These are shown in the Figure 5.3 (Department of Science and Technology, 2010):

Figure 5.3 Key performance indicators for South Africa's Space Strategy.

The target readiness factors for 2017 fell shy of the expectations and the focus is still largely in the astronomy sector as opposed to space technology. With regard to the human capital target, the Council for Scientific and Industrial Research (CSIR), which falls under the Department of Science and Technology, is considered a centre of competence. Although, that is also the only centre that is regarded as a 'centre of competence'.

The capital stock has also not reached the intended target. In 2012, there were no operational satellites and as of 2018 there is one classified military Earth observation satellite (KONDOR-E, manufactured and launched by Russia) and two CubeSats, which were manufactured privately in South Africa (Maynier, 2014). KONDOR-E should not necessarily be considered an achievement. The manner in which the project was conducted was questionable as the development of the satellite was largely kept from the public domain, while the total cost of the project was excessive at approximately R1.4 billion. Another unfortunate example of mismanagement is the development of South Africa's locally developed Earth observation satellite, EOSat-1. SANSA allocated R500 million to Spaceteq to develop the satellite, commissioned in 2013 for an anticipated launch in 2017/2018. However, the satellite is still not complete and the launch has been moved to 2020, while Spaceteq have now stated that the programme is being restricted due to lack of funding (Martin, 2018).

On the other hand, two privately developed small satellites have had an overall positive impact on the science and technology sector in South Africa. These projects financed by the DST through the AISI have created a base on which to up-skill a younger generation of South Africans in the satellite design and manufacturing process. These privately operated projects have also allowed for international partnerships with companies such as Clyde Space, ISIS, Surry Space Centre, and the von Karman Institute. The benefits of local developments have already been realised as the funding raised from supplying several QB50 satellites with a locally designed control system partially funded the development of ZA-AeroSat (Van de Groenendaal, 2016). Another example of commercialisation of academic space technology from South Africa is a CMC UHF/VHF transceiver developed at the Cape Peninsular University of Technology (CPUT). The transceiver was demonstrated on ZACUBE-1 and is now commercially available from Clyde Space (F'SATI, 2016).

The budget for research and development in South Africa is generally lagging behind that of other countries of a similar level of development as South Africa. Naledi Pandor, the former Minister for Science and Technology, targeted R&D funding to be approximately 1.5% of the gross domestic product by 2020. Currently it is benchmarked around 0.76% of the gross domestic product (Wild, 2017). The CSIR was allocated R916 million for the 2017/2018-year but this is also not dedicated to developing any sector in particular. The Aerospace Industry Support Initiative (AISI) that operates within the CSIR to manage Aerospace projects, only received approximately R21 million in 2016 to finance over 30 ongoing Aerospace projects (AISI, 2016). This is contrasted to the support given to the SKA project, which received R693 million in the 2017 fiscal year, marking 5 years of financial support since South Africa won the bid to co-host the telescopes with Australia (Pandor, 2017). As part of the 2018 budget allocation SANSA received R131 million, considerably lower than the target of R500 million as stated in the 'readiness factors'. While there is a stated intention to support and develop space technology in South Africa, the lack funding coupled with mismanagement of projects and a larger focus on astronomy projects has hampered the implementation of the strategic space plan.

The objectives stated in the national space strategy are starting to become realised, however this is largely due to the privately manufactured satellites that originated in South Africa. The AISI managed a number of projects relating to the space industry in the 2017 year primarily in alignment with the National Industry Policy, as opposed to the Space Policy informing AISI objectives set by the dti (AISI, 2018). These small satellite programmes, funded by the DST and AISI, have yielded constructive relationships with several well-regarded international entities such as Clyde space, ISIS, Surrey Space Centre, and the von Karman Institute. These satellites were also recognised for their part in the QB50 constellation. The development of these satellites has also resulted in marketable products such as the transmitter and control system.

SANSA has been less involved in realising the industry development objectives, contributing to the development of only one satellite (EOSat-1) that has so far taken several years longer than originally planned and is yet to be completed. The development of this satellite has also not engaged the industry to the same degree as the smaller satellites that have formed numerous partnerships within and out of South Africa, in spite of the considerably larger budget allocated to EOSat-1. However, SANSA has been involved in other goals set out in the National Space Strategy, namely using space technology and Earth observation effectively for the benefit of rural and urban planning, coastal and ocean monitoring and land management. In this regard, developing the space sector through the AISI and the promotion of University projects that engage local suppliers has proven more successful in promoting industry growth than initiatives introduced by SANSA.

5.4.2. National Space policy

While the Department of Science and Technology was drafting the national space strategy, the Department of Trade and Industry was concurrently drafting South Africa's National Space Policy. The strategy provides a strategic context for a national space programme and defines the high-level objectives for the space programme, while the policy sets out the framework and governance mechanisms which enable the strategy (Munsami, 2014).

South Africa has a variety of institutions and programmes in academia, science councils, government departments and private industry that are involved in the study, exploration and utilization of space. However, there was a lack of coordination between these initiatives as they were managed by different administrative entities. The South African National Space Policy was developed in order to address these issues by providing a guiding framework in the form of policy principles, as mandated in Section 2 of the Space Affairs Act (Department of Trade and Industry, 2009).

The main directives within the policy are detailed in 8 objectives underpinned by a number of policy principles that aim to provide guidance during implementation of the policy to achieve its objectives. The principles include:

- The use of outer space for peaceful purposes and the benefit of humankind;
- Building, developing and maintaining a robust set of space capabilities, services and products to support national priorities,
- Responsible use of the space environment, in accordance with national law, international treaties and best practises,
- Promotion of research and development in South Africa,
- Improving the levels of self-sufficiency in South Africa and international competitiveness through the use of domestic space capabilities and services,
- Cooperation with other nations in mutually beneficial and peaceful uses of outer space, with a focus on benefits that can be derived for the African contentment through cooperative activities with other African countries.

The policy objectives intend to inform both public and private sector stakeholders' participation in the space sector. The first objective is to improve coordination between these sectors and stakeholders. Prior to the introduction of the National Space Policy, South Africa had a number of smaller entities within the government and the private sector working in isolation in the utilization and development of space related products (Munsami, 2014). This purpose of this objective is to: (a) orchestrate space activities so that there is less duplication of resources and efforts between entities, (b) achieve maximum benefits out of current space activities, and (c) create a coherent network for stakeholder interaction.

The second objective is to promote capacity building. A significant proportion of the space engineers, technicians and scientists currently active in the space sector hold legacy knowledge from the Apartheid era, and with the subsequent lack of investment in the space sector, there has been limited development of human capital (Munsami, 2014). This is highlighted in the National Space Strategy's objective to initiate technology transfer and capacity building programmes with spacefaring countries.

The third objective aims to facilitate the provision of appropriate and adequate space capabilities to support South Africa's domestic and foreign policy objectives. As South Africa has ratified all the international treaties pertaining to space and related international agreements such as the Hague Code of Conduct (HCOC) and the Missile Technology Control Regime (MTCR), there is potential for facilitating the development of an indigenous space sector through knowledge and technology transfer transactions with foreign partners.

The fourth objective, to create a supportive regulatory environment, enables South Africa's participation in the space sector. South Africa has established national legislative and regulatory bodies such as the South African Non-Proliferation Council, the National Conventional Arms Control Committee and the South African Space Council in order to regulate the industry and ensure that participation falls within international legislation and obligations.

The fifth objective is fostering research and development in South Africa. Having had a fragmented space sector affiliated with a variety of uncoordinated institutions and programmes in academia, science councils, government departments and private industry, there has been little direct investment into research and development in this sector since the Apartheid era. In developing this sector, more effort should be expensed in raising the R&D base within public sector institutions and higher education institutions (Department of Trade and Industry, 2009).

While there has been an effort to coordinate research and development within the space sector, there are still several government entities which are running separate programmes, namely SANSA and AISI, which both approach projects slightly differently. AISI follows requirements set out by SANSA, however the primary policies that it adheres to are set out by the dti. These include the Industrial Policy Action Plan, National Development Plan and the National Industry Policy Framework, as opposed to the National Space Policy, which is ancillary to these (AISI, 2016).

The sixth objective is to promote a competitive domestic sector. South Africa's intention to transition to a knowledge-based economy necessitates the development of more indigenous high-tech sectors, of which the space sector has potential for commercialization. As with the fifth objective, this largely supports the goals set out by the dti in the Industrial Policy Action Plan that is largely being addressed through the AISI.

The seventh objective is to promote mutually beneficial co-operation with other nations in the uses of outer space. International co-operation provides opportunities for South Africa to improve on technologies and applications through strategic partnerships that are in keeping with foreign policy objectives and international obligations. In particular, international co-operation will be pursued in accordance with the strategic foreign policy objectives of strengthening the African Agenda, South-South co-operation, North-South co-operation and global governance (Department of Trade and Industry, 2009).

The eighth and final objective is to promote awareness of the societal benefits of space activities. Given that the national space programme has transitioned from a military to a civilian focus, it is imperative that the general public have some appreciation of the benefits of space activities (Munsami, 2014). Achieving public approval for a national space programme can be leveraged by the socio-economic and public outreach benefits such a programme would bring. Awareness of this sector also has the potential to encourage learners to pursue and complete their education, which aligns with the objective to improve human capital.

5.4.3. South African National Space Agency

In support of national objectives such as the promotion and use of space and co-operation in space-related activities, improved human capital in engineering and science research and the creation of a domestic space industry operated within the national policy framework, the Department of Science and Technology drafted the South African National Space Agency Act of 2008, which mandated the establishment of the South African National Space Agency (SANSA). The agency was formally established in 2010. SANSA is responsible for implementing space programmes that are in line with the National Space Policy and informed by national developmental objectives.

In terms of its governing Act, SANSA is at liberty to collaborate with any entity, hire or purchase any property and acquire an interest in, or establish a company for the purpose of achieving its objectives (Department of Science and Technology, 2014). However, there has been limited direct interaction between SANSA and other entities within the space industry in South Africa in comparison to the AISI. The ties between the government's space agency and the government's parastatal Denel have, to date, proved ineffective and could largely be described as a wasted funding opportunity. The budget allocated by SANSA to Denel's Spaceteq has been the largest funded civilian space technology project in South Africa to date, yet there is still no satellite to show for it.

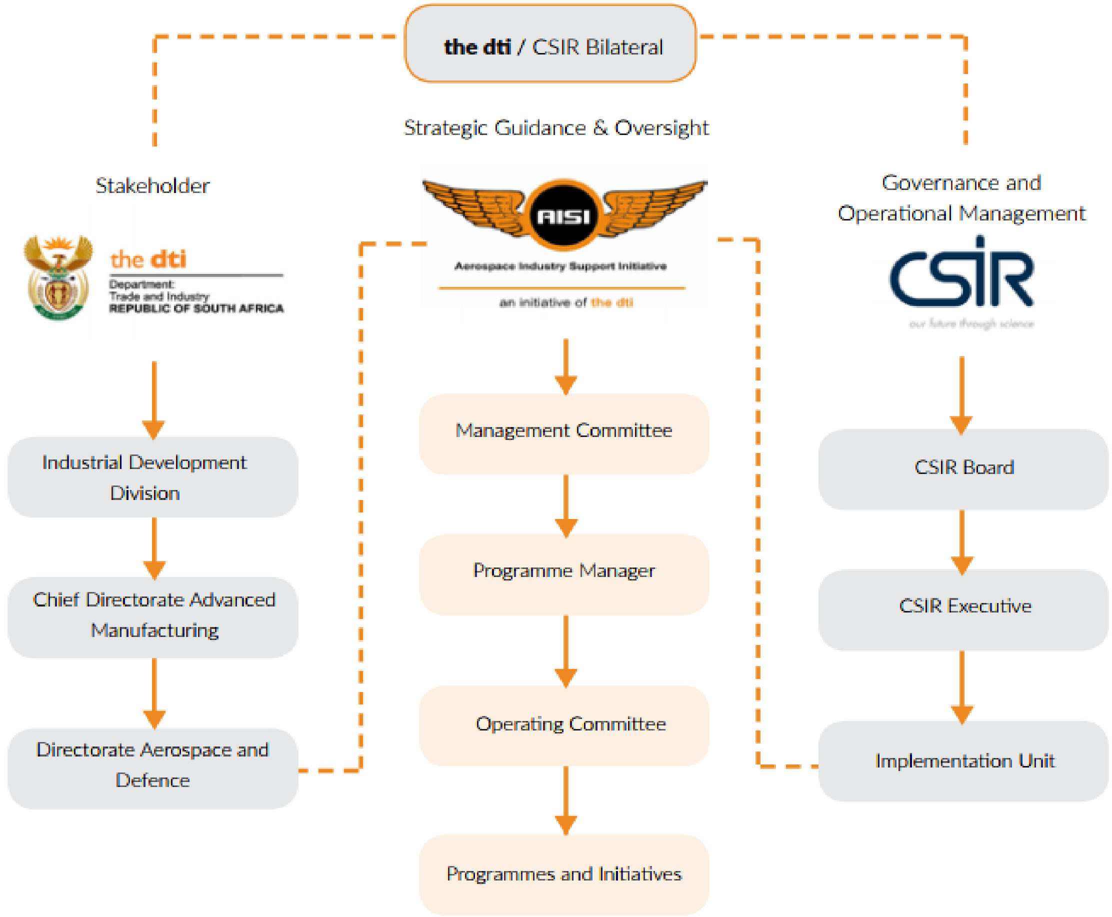
5.4.4. Aerospace Industry Support Initiative

The Aerospace Industry Support Initiative (AISI) was established by the Department of Trade and Industry in order to support the South African aerospace industry to improve its competitiveness. This entity operates within the CSIR framework, which is overseen by the Department of Science and Technology (AISI, 2015). This governance structure is shown in Figure 5.4.

The purpose of the AISI can be summarised as improving the global competitiveness of the South African aerospace and defence industry through:

- development of relevant industry capabilities and suppliers;
- facilitation of technology transfers to the industry; and
- facilitating collaboration between both local and international government entities, industries and academia.

Figure 5.4 Governance of the Aerospace Industry Support Initiative. (AISI, 2018)



During the 2015/16 financial year, the AISI provided industry support to the value of R21 million. This was used to fund a number of projects, three of which were in the space sector, namely, a nanosat imager, hyperspectral focal plane and mass storage to be used with a space imager and a stellar gyro. These projects were aligned with the requirements of SANSA and were evaluated on their relative impact on the industry, including factors such as intellectual property, import substitutions and marketable products (AISI, 2016). These impacts relate to the key performance indicators in the National Space Strategy.

Table 5.2 AISI Space projects for the 2015/2016 year. (AISI, 2016)

Project	Intellectual property	Import substitution	Marketable Products	Jobs created or retained
Nanosat Imager	x	x	x	8
Hyperspectral focal plane and mass storage			x	8
Stellar Gyro		x	x	

While these projects have been successful in producing marketable products or suitable import substitutions, the investment into industry development would need to be scaled up considerably to create a self-supporting a local industry. However, the funding towards these projects is limited with a budget of approximately R21 million. AISI funds a number of projects in order to support the growth of small, medium and micro-sized enterprises along with original equipment manufacturers in the Aerospace and defence industry. In comparison to the development costs of a small launcher such as the EU SMILE project, which is receiving € 4 million for 3 years, the AISI is inadequately funded to support a project on that scale.

Within South Africa's space strategy and space policy, there is a drive to push the country towards a knowledge-based economy, however this has yet to gain much traction. The government is investing in the space sectors, though cautiously and primarily focusing on astronomy, which has already been established in the South African sphere with international projects such as SKA. The lack of focus in space engineering is evident in the number of projects SANSA is involved in that fall under space engineering. The government has also yet to achieve the readiness factors set out in the space strategy in terms of capital stock, human capital and general investment into R&D in the space sector. Despite the positive industry stimulation from AISI, there is not sufficient funding to support an entirely indigenous space industry.

While the Department of Science of Technology highlighted the space sector as a grand challenge in South Africa's Ten-Year Innovation Plan, the country has not put enough focus into alleviating basic operational issues facing space industry companies currently operating in South Africa. As noted by several stakeholders in the space industry, the current processes followed within the government regarding import/export of space technology is a basic issue that is blocking the growth of space businesses within South Africa. In addition to that, allocation of funding is not supporting projects that would have a material and sustainable impact on the South African space industry.

The AISI has successfully created opportunities for universities to collaborate with local space industry players as well as international partners and in doing so has supported the development of products that can be used as ITAR-free import substitutes or as South African marketable products. This type of strategic investment, into academic research supported by industry experts, is at the moment the most effective way to make an impact in the South African space industry. The success of several of the small satellite projects in the past few years may be largely due to the fact that the projects were not affiliated with the South African parastatals, such as Spaceteq, and were able to reach out to other local and international partners where required.

6. ASSESSMENT OF THE POTENTIAL FOR A SMALL LAUNCHER INDUSTRY IN SOUTH AFRICA

Several elements of a small-launcher industry have been examined, including the demand for launchers, the development of similar vehicles, the legalities of becoming a launching state and the facilities required for such an activity. In order to assess the viability of a micro-launch industry in South Africa, various scenarios and the relative impact and implications of such scenarios will be discussed. The premise is that South Africa could act on any of the four broad scenarios listed below in order to achieve a micro launch industry:

I. **A lease agreement scenario**, in which a foreign entity is able to lease a launch facility under South Africa's jurisdiction but, other than regulatory compliance issues, there is no further interaction between South Africa and the foreign entity. Profits from the launch activity are solely for the foreign entity and South Africa earns rental income;

II. **A joint venture scenario**, in which there is active participation between South Africa and a foreign entity, with collaboration, positive investment cycles, skills transfer and the use of existing rocket technology. Profits from the launch activity are primarily for the foreign entity, although some would be allocated to South Africa;

III. **An agile development scenario**, in which South Africa begins transitioning facilities towards space activities by supporting suborbital flights for scientific experiments and commercial applications using existing technology and strategic partnerships;

IV. **An independent development scenario**, in which there is active collaboration between government and industry within South Africa to develop a launch industry with indigenous rockets and South Africa, as a State, being solely responsible for the launch activities;

In order to contextualize these scenarios within South Africa, an overview of the country's present situation is provided, together with an assessment of previous engagements by developing countries into the space sector and the success of those endeavours. The possibility of strategic partnerships is discussed in relation to achieving scenarios requiring external stakeholders. The introduction of a new industry is also considered from a 'lean start-up' perspective to inform processes to make this venture a success.

6.1. Social and economic trends in a South African context

South Africa is considered a developing country, however it has characteristics of both a less economically developed country (LEDC) and a more economically developed country (MEDC). LEDCs characteristically have lower standards of living, fewer educational opportunities and typically rely more on primary industries such as mining and agriculture, while MEDCs have a better quality of life, more educational opportunities and higher a percentage of the population in the secondary and tertiary sector, such as manufacturing products using raw material imported from LEDCs.

As of 2016, the top four sectors contributing to the South African GDP were finance (20%), government (17%), trade (15%) and manufacturing (13%), demonstrating the move towards being a MEDC and towards a knowledge-based economy (Stats SA, 2017). However, the unemployment rate of 27.7% in 2017 increased from 26% in 2016. The majority of the decrease in employment is coming from primary sectors, with the largest drop in employment coming from construction, agriculture and mining. The unemployment rate is considerably higher for people with education below matric level at 33,1%, while the unemployment rate for graduates is still high at 7,3% (Stats SA, 2017).

Mcebisi Jonas, South Africa's former finance minister, noted that while there has been marginal growth in the primary sector, there is still a need to diversify the economy into areas where South Africa has a comparative advantage - these include manufacturing and high-tech services (Jonas, 2017). Development of these sectors serves to improve national income and also to increase job opportunities across the spectrum of educational levels. There has been a drive to improve the ease of conducting business operations in South Africa, with the then President Jacob Zuma acknowledging the institutional impediments facing new businesses in the State of the Nation address in February 2017, stating that unnecessary barriers to businesses such as delays in issuing of licenses and visas needed to be removed (Zuma, 2017).

However, after an impromptu cabinet reshuffle in April 2017, South Africa's foreign-currency debt rating was downgraded by Standard & Poor's credit rating agency, followed by Fitch. In June 2017 Moody's also revised their rating of South Africa downward to Baa3, assigning a negative outlook. The key drivers for these downgrades included the uncertainty around economic policy, the lack of progress towards implementing economic reforms, the increasing government debt and the breakdown of institutional integrity (Moody's Investors Service, 2017). The rating agencies mirror the low level of investor confidence, and although it could be argued that the uncertainty was already priced into the market, government debt was becoming more expensive. There is already a lack of long-term fixed capital investment, an important requirement for the mining sector and as would be needed for any large-scale infrastructure development (Jonas, 2017). One such development in South Africa is the previously mentioned Square Kilometre Array telescope (SKA).

Under these financial pressures, the budget for the South African leg of the international SKA project was cut by approximately R90million in 2016 (Hemily, 2016). However, given that the project has a number of external stakeholders, the 2017 budget review has ensured enough financing to complete MeerKat, the precursor to the SKA array, as well as a provision for the completion of SKA (Hemily, 2017). Funding for research and development is currently at 0.76% of GDP, although the Minister of Science and Technology has targeted an increase to 1.5% by 2020 in spite of recent budget allocations not even keeping up with inflation. The Minister has suggested that collaboration with international partners may boost the spending on research projects.

Specifically regarding space activities, of the R7.5-billion allocated to the Department of Science and Technology for the 2017-18 financial year, only 1.7% of this was allocated to the South African National Space Agency, which is approximately $10 million (R131 million) at the current exchange (Wild, 2017). Not accounting for inflation, this is considerably less than the budgets of nations invested in developing space capabilities, as seen in the Figure 6.1, which shows the budget allocated to several countrys' national space agencies in 2013, represented in US dollars (OECD, 2014).

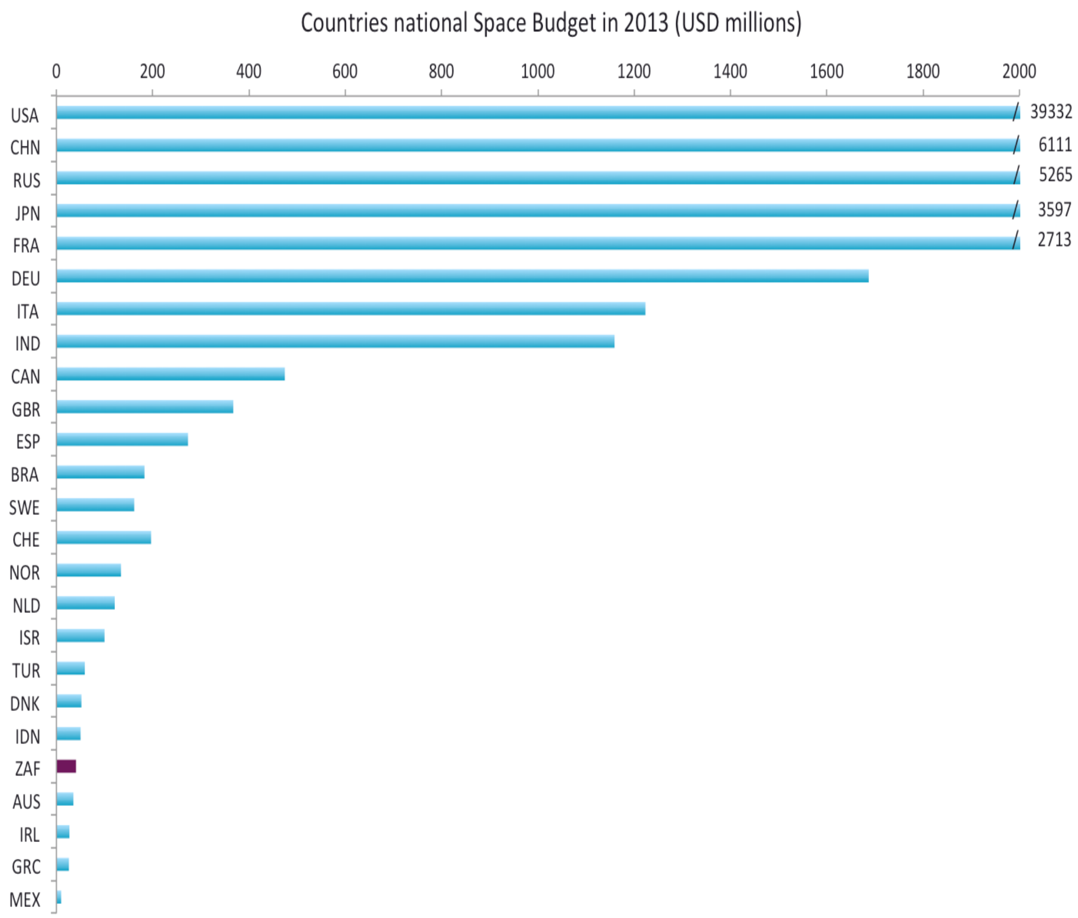


Figure 6.1 National space budgets in 2013 represented in USD. (OECD, 2014)

Despite the development cost, the SKA project has already had a net positive effect on the socio-economic level in South Africa. As a direct result of the SKA Human Capacity Development Programme, there has been an increase in students studying mathematics, engineering and astrophysics at South African universities as it supported South African students with an interest in these fields by providing grants and bursaries to over 700 people (SKA Africa, 2017). The SKA's global appeal has also led to more interest in students and academic exchanges coming from around the world to South Africa. The construction of the ground infrastructure created 618 jobs between 2008 and 2010, which accounted for a R9 million salary boost into the local economy of the Northern Cape (Atkinson, et al., 2017).

The then President Jacob Zuma commented on the impact of the Square Kilometer Array telescope (SKA) and its precursor, the MeerKAT telescope, during the State of the Nation address in 2017. He highlighted the contributions that the projects have made to the socio-economic development of the Northern Cape in South Africa, and the success of a localized implementation strategy which ensured that 75% of the R2 billion cost to build was spent locally, boosting the economy in the region (Zuma, 2017).

Another astronomy project in South Africa is the Southern African Large Telescope (SALT). This is the largest single optical telescope in the southern hemisphere, founded by a consortium of international partners including the United States, Germany, Poland, India, the United Kingdom and New Zealand (SALT Foundation, 2017). It has been fully operational since 2011 and has had a significant effect on the town of Sutherland and the surrounding area. In a recent study of tourism in the area it was noted that the number of guesthouses in towns close to SALT had increased. Between 1998 and 2015 Sutherland experienced an increase in the number of guesthouses by about 900%, and in the neighbouring towns of Victoria West and Brandvlei there were 300% and 100% increases, respectively (Atkinson, 2016).

While these examples of science and technology projects have proven to have net positive impacts on the economy, they have also required substantial funding from the government. Of the scenarios listed, it is unlikely that South Africa would be able to sustain an independent development of a micro-launch industry, as there is currently insufficient funding in the space sector to support a project of that scale. As illustrated in Figure 6.1, SANSA receives considerably less financial support from the government than its counterpart space agencies in other space-faring countries, and while initiatives such as AISI also provide some support, the allocated budget of approximately R21 million was spread to over 30 projects within its jurisdiction, only three of which were space related (AISI, 2016). Mismanagement of funding including the procurement of KONDOR-E and the development of EO-Sat1, do not support the idea that South Africa would be able to sustainably manage that scale of project.

Further to this, while Marcom-AS (the only company positioned towards developing space launch vehicles in South Africa) was active, there was little support from the government to develop a launch vehicle even after successfully demonstrating an engine test firing. Given the investment outlook for South Africa, it is unlikely that investors would choose to support such a costly high-risk project within the country. As a result of lack of investor confidence and government interest, the development of launchers is not likely to materialise in the foreseeable future.

As with the example of SKA, and noted by the Department of Science and Technology, international projects tend to be awarded more funding and have some guarantee of sustained funding given the reliance on external stakeholders. Joint ventures also ensure more international credibility, validating the knowledge base in South Africa. The secondary effect that MeerKAT, SKA and SALT have had on the Northern Cape should also be acknowledged as this encouraged local support for economic development. Should the space programmes result in similar secondary benefits, the support in South Africa for a space programme is likely to increase, as would general awareness of the societal benefits of space activities.

Incremental development of a space facility as described in the agile scenario would also be a possibility, as a large outlay of funding would not be required. Smaller projects from different sectors could contribute to this development with collaborations between manufacturing and aviation sectors and universities, as is currently being facilitated through the AISI. However, for this scenario to be a success there would need to be more focus on the space sector to increase the rate of product development and the local client base. Strategic investments into developing controlled components would also be necessary to support growth in the local aerospace industry and provide some autonomy from the established international space industry. Placing an emphasis on introducing modern manufacturing techniques such as additive manufacturing, which is becoming increasingly common in aerospace designs, could also promote the local industry through improved access to required components.

Given South Africa's current unpredictable economic and political situation, investors may not wish to invest in developing a launch sector, however the weaker currency can be beneficial in lowering the cost of procuring services from vendors in South Africa, such as use of the Overberg Test Range. The lower cost for services coupled with the need for cheaper launch sites for micro-launches could allow for beneficial partnerships in which South Africa can promote the use of the existing facilities while limiting their financial risks associated with being a launching state.

6.2. Assessment of Technology Transfer Projects in Developing Countries

The joint venture and agile development approach make use of technology transfer and the use of existing technology. To assess the method of transfer and the viability of the scenarios, previous technology transfer projects have been considered. There are a number of African countries that have initiated national space programmes off the back of small satellites that have used a technology transfer model whereby the more experienced party builds a satellite with active participation from engineers from the developing country. The concept is to use the knowledge gained during the development of the satellite to initiate a regional space industry. These satellite programmes, for the most part have similar objectives, namely to introduce developing countries to the technology used in space and its applications (Argoun, 2011).

Various mechanisms have been established for such technology transfer programmes. One method is the joint development of a space system in which the cost, experience and infrastructure is shared. However, depending on the partnership arrangements, there can be some prerequisites for the funding and level of capability. Examples of this method are:

I. The **World Space Observatory**, a UN facilitated project that involved a number of organizations and countries, namely: Argentina, France, Germany, India, Israel, Italy, Mexico, Baltic-Nordic Countries, China, Poland, Russia, South Africa, Spain, The Netherlands, UK, Ukraine, ESA and United Nations to develop an international ultraviolet astronomy satellite to allow observations in this wavelength region once the Hubble telescope is retired,

II. The **China–Brazil Earth Resource Satellite** (CBERS) Programme, a partnership between China and Brazil signed in 1988, to develop two remote sensing satellites (CBERS-1 and CBERS-2) to be jointly owned and used. The success of the initial phase led to an expansion of the project to include additional satellites (CBERS-2B, CBERS-3, CBERS-4, CBERS-4B),

III. The **small multi-mission satellite** (SMMS) project by the Asia-Pacific Multilateral Cooperation in Space Technology and Applications (AP- MCSTA). Constituents include China, Pakistan, Thailand, Republic of Korea, Mongolia, Iran and Bangladesh as members. This project demonstrated a workable collaborative framework in which AP- MCSTA held developing countries in equal regard when deciding policies, mechanisms and direction of the projects carried out (Leloglu & Kocaoglan, 2008).

Another method of technology transfer is a more direct combination of training courses, practical implementation of design and manufacturing and limited licensing. Typically, developing countries using this method have been encouraged to develop Earth observation capabilities rather than space research capabilities and R&D in launching capabilities. As a result, the majority of these satellites are small remote sensing satellites that are relatively low cost and have shorter development time as they use already established technology (Leloglu & Kocaoglan, 2008).

An example of this type of technology transfer is the BiLSAT project carried out between 2001 and 2004 by Surrey Satellite Technology Limited (SSTL) of Surrey University, UK and the Space Technologies Research Institute of the Scientific and Technological Research Council of Turkey (TUBITAK UZAY). The scope of the collaboration was the design, manufacture and launch a remote sensing satellite; establishment of a ground station; on-the-job training of core staff; limited licensing of all sub-systems of the satellite; and the development of two payloads. TUBITAK UZAY is now building a satellite called RASAT on its own, based on the experience gained in the BILSAT project.

Another project involving SSTL is the KITSAT-1 satellite built with the Satellite Technology Research Centre (SaTReC) of Korea's Advanced Institute of Science and Technology (KAIST). Evolving from the initial success of KITSAT-1, several more satellites were built by SaTReC, leading to the establishment of a successful company, Satrec Initiative, which became a commercial success.

Launching in particular requires a higher level of space technology and expertise as the risk failure has far-reaching consequences, including danger to personal on the ground and destruction of the client's payloads. As such, new entrants should not expect customers until the technology has been proven and the reliability of the launcher has been demonstrated. It could take several successful launches to convince potential customers that a new launch technology is safe. Circumventing this, developing countries are entering the market through partnerships that have the possibility to skip some intermediate developments using proven technology and established practices (Leloglu & Kocaoglan, 2008). Also, particularly regarding small launch vehicles as noted in Chapter 3, small scale satellite operators have a larger appetite for risk and are more willing to fly with 'new' technology with lower success rates, a trait that lends itself well to being an entry-level option for access to space.

A number of developing countries have motivated their participation in turn-key technology transfer projects as a means to expose local scientists and engineers to space technology in the hope that it might stimulate an interest in the domestic market and lead to commercial success. However, the success of these projects has largely been limited by the human capital of the country, level of infrastructure and the commitment to which they approached the project. Given the continuous technological advances in the space industry, the success of the technology transfer in transforming a given country's space industry relies on the continuous development of their own capacity for innovation. In addition to this, given the high technological standards of operating in space and the largely protected markets in the United States and Europe, newly established capabilities have to generate a demand in the domestic market until services are proven and competitive enough to join the international market. Space systems and sub-systems are already offered by established companies that have sustained several decades of non-competitive tenders, supported largely through government funding and protectionist economies. The United States space industry, in particular, draws support from national security and defence budgets that are closed to foreign suppliers (Leloglu & Kocaoglan, 2008).

While many of the satellite technology transfers were successful, the longevity and sustainability of the space prgrammes depended more on the stimulation of a local demand for space products. The development of a space programme needs to be supported by the nation building the technological base for manufacturing and design of such products, as well as the development of a domestic user group that will make use of products generated through the space programme. Mohamed Argoun demonstrates this in a study on the design and utilization trends of small satellites in developing countries. The study also showed that the lack of government support for continuing projects past the initial satellite development led to waning interest in the space programmes. To this end, he noted several keys attributes to sustain the momentum in the developing of national space programmes (Argoun, 2011):

I. International programmes

International projects can increase the technology base while lowering the overall cost of a project. Contributing to larger multilateral projects helps maintain the interest in developing space prgrammes regionally. The level of political maturity, technical abilities and industry cooperation of the countries involved can reduce unnecessary competition while promoting the unique regional industry developments and objectives. For the African continent there are some common objectives that lend themselves to motivating joint space programmes with international participation including:

(a) the desire to maintain the momentum in regional space industries,

(b) improving access to a more advanced technology and knowledge base,

(c) to be involved in low-cost initiatives for countries that lack funding,

(d) to improve regional and international collaboration and establish possible future partnerships.

II. Local Manufacturers and Service Providers

In order to maintain the industry, there must be some regional manufacturing or service capability to supply the market. With varying levels of expertise, the country should be able to manufacture some aspects of the subsystem or contribute to the service provided using local expertise.

III. Local Use

For the sustainability of space programmes in these regions, the authorities need to dedicate some resources into spreading the use of the technology, the products available and the possible spillover uses to non-space domains and encourage a domestic demand for the products until the programme becomes internationally recognized. The direct utilization of space products in developing countries, primarily in the form of images and data, is generally not as high as in developed countries.

South Africa's Department of Science and Technology has already acknowledged the benefits of international programmes in maintaining both funding and interest in larger programmes. This supports viability of the scenarios in which South Africa participates to various degrees in a joint venture with external stakeholders to launch space vehicles. The joint venture scenario also suggests that there should be some skills and knowledge transfer from an external stakeholder to South Africa, who would act as the launching state. Given South Africa's independent development in space activities, there is heritage space infrastructure and an aging pool of human capital that could be leveraged to develop launch capabilities. Figure 6.2 shows the maturity of various developing countries space programmes relative to their space capabilities including knowledge and infrastructure.

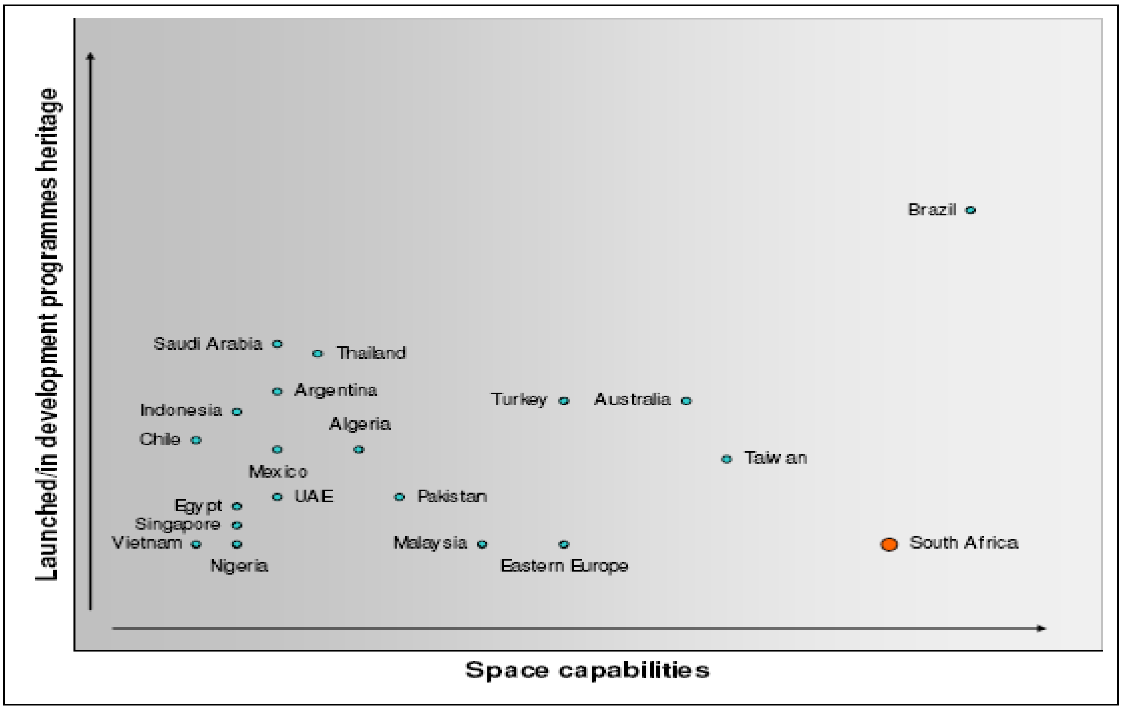


Figure 6.2 South Africa's Space capabilities in comparison with those other developing nations. (Department of Science and Technology, 2008)

While the knowledge base in South Africa may not be as advanced as that of the leading space powers, it is not comparable to a greenfield technology transfer project. Figure 6.2 illustrates that South Africa's space capabilities are disproportionately more advanced than its space programme when compared to other emerging space nations. As noted in Chapter 4, this is due to the legacy apartheid-era infrastructure and human capital development.

The technology transfer involved in a launch is also not entirely comparable to that of building a satellite, however the lessons for maintaining a sustainable industry are relatable. Given that there is almost no local demand for space launch vehicles, the South African industry would need to be supported by international satellite operators and, in this event, a joint venture with a recognized or trusted service provider might be necessary to encourage current operators to consider South Africa as a launch site. The indirect effect of this industry could include manufacturing and development of satellites, as well as raising the profile of South Africa as a producer for other high-tech manufactured goods.

The leasing scenario proposes to simply lease the launch facilities from South Africa, much like the agreement between Italy and Kenya for the Broglio Space Centre. In this case, the benefit of the partnership would be limited to the launch complex, but the cost of the project would be considerably lower from the South African perspective. This scenario would be beneficial in creating awareness within the general public about space activities and their societal benefits. However, the indirect economic effects would be more constrained, as this scenario would not require technology transfers. In leasing out the land for the launch site, the risk associated with being the ‘launch state’ would be moderated by the State acting as the lessee, who would also be responsible for damages caused by a launch as stated in the UN treaties.

6.3. Identification and Assessment of Strategic Partnerships

As two of the suggested scenarios include external collaboration, both strategic partnerships and the feasibility of these partnerships are central to the viability of those scenarios.

As mentioned, South Africa is part of the BRICS partnership of which India, China and Russia all have working commercial launch operations. India currently holds the record for the most micro-satellites released in a single launch, however it has not yet developed a micro-launcher and does not seem to be in the process of designing one. China and Russia have both moved towards introducing several small launchers into their operational range. China successfully launched its first small-scale launcher, Kuaizhou-1A, and is offering it for commercial use through China’s commercial company Exspace Technology Co. Ltd. There is the possibility that there could be an agreement between South Africa and China, however it is unlikely to include a technology transfer component and would probably focus on simply utilizing launch facilities as China has relatively new technology.

Russia has yet to bring a micro-launcher into service, but they are in the process of developing the Taymyr family of launch vehicles, covering a range of 12kg -180kg to LEO. As this is also new technology it is unlikely that a technology transfer would be viable. There has been mention in the past of partnerships between Russia and South Africa, however it was noted that the legal aspects between the two country’s space operations were not consistent and somewhat incompatible (Campbell, 2005). There was also some discussion in 2007 by the Aeronautical and Astronautical Societies of India of a possible collaboration with South Africa, however, nothing has yet come of those discussions (Gottschalk, 2010).

Another prospect would be to engage with countries that have the means but not the geographical possibilities or infrastructure to carry out launch activities. The United Kingdom has shown interest in developing a local launch facility, however given the constraints with land and air congestion the current proposal is only to establish a suborbital facility. Partnering with a country in a similar disposition could be beneficial for both parties, as they would have easier access to launch facilities based in South Africa, while South Africa could benefit from the experience of partners with more advanced space technology.

There are also possibilities of building relationships within Africa. The common rhetoric remains that Africa is not yet ready to be involved in space activities given the large outlay of capital that is required when the benefits can be derived through purchasing satellite imaging and broadband at a lower cost from established companies and countries operating in space (The Economist, 2017). However, continuing in this regard will perpetuate Africa's dependency on other countries for new technology, space-derived information and render the continent internationally inconsequential. There can also be no assurance of access to space or satellite resources when entirely dependent on single international partnerships, as with South Africa's Sumbandila satellite, whose launch with a Russian vehicle was held up for two years due to South Africa's Defense Ministry withdrawing from a provisional agreement to use a Russian military satellite (Gottschalk, 2010).

The main issue plaguing space programmes in Africa is the lack of funding and human capital, factors that do not lend well to developing an African Space Agency, a project only foreseeable in five to ten years as African countries are still focusing on developing their own national space agencies (Firsing, 2015). Nevertheless, South Africa should not rule out the possibility of collaboration between countries whose agendas are aligned. The benefit of satellites in Africa has been acknowledged by most of the continent, particularly in the area of telecommunication satellites, which are able to provide Internet connectivity to rural populations, and Earth observation satellites for land and resource management.

While none of the African countries currently have launch capabilities, Ethiopia is interested in developing its own launch vehicle and Nigeria has expressed its intent to develop their own independent access to space and would possibly be open to collaboration with other African countries.

Ethiopia has intentions to build an indigenous medium-sized space launch vehicle as well as domestic capabilities to build satellites within the next 3 years, aided in part by China (Mekelle University, 2017). In 2015 the Mekele Institute of Technology launched their own rocket, Alpha Meles, to an altitude of 30 kilometres. This sounding rocket was thought to have cost $2.3 million to develop, build and launch, which in a slowing economy does not improve confidence in the national agenda of developing a larger rocket. However, given the resilience of the programme during political and economic uncertainty, it may provide an opportunity for a reliable African partnership. In order to facilitate space activities, the Ethiopian government has established a Space Science Council as well as the Ethiopian Space Science and Technology Institute, both of which are chaired by the Ethiopian Prime Minister (Spacewatch, 2017).

Despite space being described as a free market, because of the restricted nature of dual-use technology, the high cost of research and development and the responsibility of states over their constituents, the market is still largely operated by States. As such, the South African government is also responsible for supporting companies by forging these relationships and through establishing bilateral agreements between countries.

6.4. The Lean Start-Up: Introducing a New Industry

When undertaking the creation of a new industry there is an initial distrust in the legitimacy of the industry as there is typically nothing to reference directly as successful business examples. Moreover, such initiatives are often driven by new actors without established track records. Their conformity to established institutional rules may also be called into question as they occasionally straddle legal boundaries. Aldrich and Foil (1994) have categorized the legitimacy of a new industry into cognitive legitimacy, which describes how a new concept may be taken for granted, and socio-political legitimacy, which describes how a new concept may fit into a set of standardized principles and rules.

New industries initially lack the public awareness and credibility, which amplify their constraints. Space launch is not a new industry globally, however, it could be argued that micro-launchers are a new industry as it has yet to prove its cognitive legitimacy. South Africa in particular has no form of space launch industry, therefore locally a micro-launch industry in this context would need to overcome the socio-political and cognitive legitimacy hurdles to succeed. Socio-political legitimacy is considered to be achieved when key stakeholders and government officials acknowledge the possibility of the concept existing within the current norms and laws of a country. In South Africa, the institutionalisation of the South African Space agency, the review of the Space Affairs Act and the inclusion of space activities in the national strategic goals can be viewed as the government's acknowledgment of the industry.

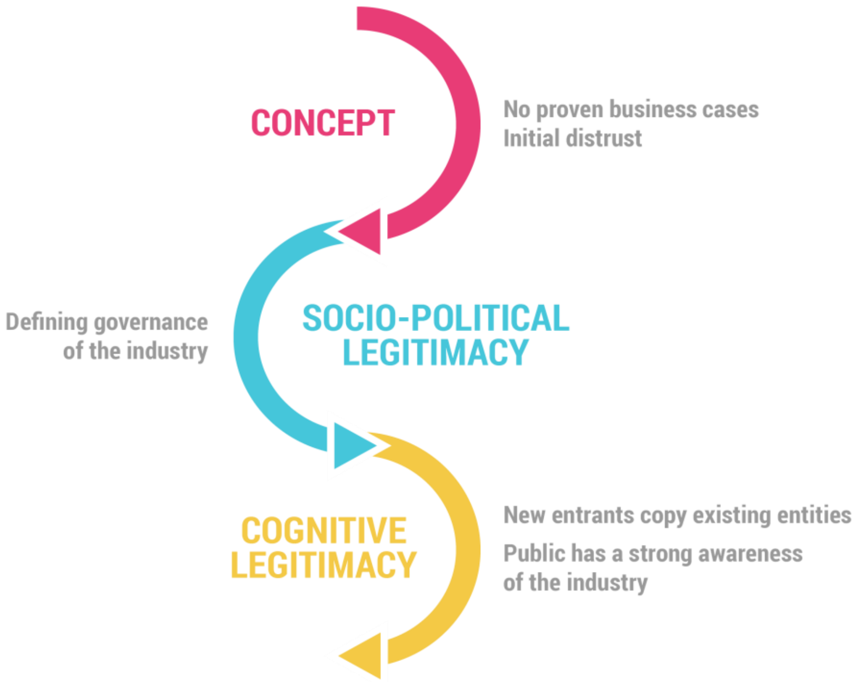


Figure 6.3 Establishing new Industries through socio-political and cognitive legitimacy.

Cognitive legitimacy is achieved when the general public has such a strong awareness of the industry that it is taken for granted, to the point that developing it locally makes economic sense. This comes from the dissemination of information to the public and government, where this becomes an understood area of interest and part of standard conversation. In South Korea, during the 1987 presidential race, Roh Moo-hyun differentiated himself from other candidates by making the development of national space activities a government priority through the promotion of independent satellites and technologically advanced industries (An, 2015). It would, however, be unlikely to have been used during an election campaign if the general populace had no interest or knowledge of Space activities or the related benefits. The notion that space programmes are perceived as a sign of technological proficiency within a country is also not unique to South Korea. Countries such as China, India, Japan and Brazil have also made a link between nationalism and technological advancement in space, incorporating it as part of a national identity (An, 2015). As the concept of space activities becomes linked to the national identity the cognitive legitimacy of the industry is realized.

In reference to South Africa, there is a space agency, however it does not receive much media attention and knowledge of its existence among the greater population is debatable. South Africa's space law is also not specifically covered in the top universities and South Africa's history regarding space is also not well known. Generally, space activities are not a part of standard conversation in South Africa. The consideration of cognitive legitimacy also extends past national borders. In the developed world there would also appear to be a stigma associated with interacting with 'Africa'. As mentioned by several stakeholders within the South African space industry, the perception is that products from South Africa would be inferior, while business operations have been tainted by reports of corruption.

New industries need to strike a balance in creating a competitive advantage and uniqueness while collectively appearing similar enough to convince stakeholders that the new industry has a critical mass of legitimate players (Aldrich & Fiol, 1994). While the Chinese micro-launcher has been the only successful vehicle so far, there were over 20 companies listed in 2015 attempting to develop the technology and there are more still aiming to join by 2020. The interest in micro-launchers has also prompted spaceports to adapt their business models to cater for these micro-launchers. This demonstrates that micro-launchers have established this critical mass of legitimate players on a global scale. In this sense it is possible for South Africa to get involved in the industry as it has achieved cognitive legitimacy globally and existing concepts could be replicated locally.

Timing the initiation of a start-up or new industry is also quite important; one aspect to consider would be the economic mood. South Africa is currently going through an economic slump with the primary sector growing 4.6% since the previous year, the secondary sector manufacturing down by 3.6% and wholesale trade in the tertiary sector down by 8.7% (Stats SA, 2017). Unemployment in South Africa is exceptionally high and increasing. While this is not an ideal situation in which to develop a new industry, the timing could provide the necessary boost into the economy to revive the secondary and tertiary sectors and drive South Africa towards a more knowledge-based economy. Stimulating growth may also reduce the unemployment rate by creating more job opportunities for both the educated and uneducated people in the general workforce. As noted in the case of SKA and SALT projects, there are indirect benefits from new industries that can benefit an area locally, such as the surge in guest houses in the Northern Cape and the salary injection received from newly employed people returning more money into circulation in that region.

The UK is intending to build a suborbital spaceport, stating in the proposal that the UK economy could currently only support one spaceport but that the benefits of building this spaceport could include factors such as the advancement of science and innovation, growth in the aerospace sector and supporting industries, improved economic activity around the spaceport's location and the promotion of high-level skills (U.K Department for Transport, 2014). The initiation of the entire space industry in New Zealand was motivated by the increased revenue stream from the launch industry as well as the supporting manufacturing industries, increasing the job opportunities for qualified engineers and an overall reputational benefit by being seen as a country capable of delivering reliable high-tech products that can indirectly improve other high-tech industries (Moore, et al., 2016). Similarly, the Russian Federation and the US State of Alaska have also expressed that the benefits of developing their spaceports was to increase the industrial base, create jobs and up-skill outlying areas.

Timing the introduction of new industrial capabilities also depends on the desired outcome; in this instance the industry itself is still new. This means technology is yet to be proven and early development can be costly, however, it is also important to embrace new technology in order not to be left behind. Given the higher risk appetite of the small satellite community and the lower cost to enter the market in comparison to the larger satellites this would seem to be an appropriate point of entry into the space launch sector.

Given that this is a new industry that has yet to be fully realized in South Africa and that it has a low level of cognitive legitimacy and public acceptance, a scenario in which South Africa operates independently is unlikely to be successful. A technology transfer launch complex lease agreement or an incremental development approach is likely to be more successful as these scenarios introduce the South African public to concept of a launch industry and initiate a conversation around space activities in general. Once public support has been established, government funded projects for space activities are likely to become less contentious.

6.5. Heat Map

In order to assess which of the scenarios may be best for South Africa to pursue, each is evaluated qualitatively on several factors including the capital required to see the scenario to completion, the time until 'value-add' in the industry is realised, the time it could take to deliver a micro-launcher, the ease of access to technology transfers and knowledge gain, the possibility for industry expansion and finally the reliance on external dependencies. The assumptions for each scenario are described below.

The first scenario is a lease agreement scenario, in which a foreign entity is able to lease a launch facility under South Africa's jurisdiction but there is no further interaction between South Africa and the foreign entity. In this scenario South Africa would be considered the launching state although exposure to liability could be moderated through the lease agreement. This scenario is the fastest to realise a micro-launch industry, as the assumption is that the leasing entity would be of a similar echelon as the second scenario and have an operational launch vehicle or at the very least a prototype. However, as this would primarily be a leasing contract there would no requirement for any technology transfers and the interaction between South African industry and the foreign entity would be far more limited than the second scenario. As such there would be little in the way of capacity building within South Africa. An example of this is Italy's agreement with Kenya: the organization of the Broglio Space Centre facility is owned and managed by Italy, while Kenyans are employed to carry out the day-to-day operations.

The second scenario is similar to the first in that there is some reliance on external stakeholders, whereas this scenario is a joint venture as opposed to a leasing contract. This would include a mandate to source certain components from South African companies and some pre-agreed expectations for technology and knowledge transfer. As with the first scenario, the assumption is that the foreign entity in the joint venture is established, therefore, the development of a launch vehicle should already be complete or close to completion.

The time this scenario takes to return a micro-launch industry depends on the participants in the joint venture. Furthermore, should the partnership be with another emerging space nation then the time taken to realize the scenario will be considerably longer. In particular, should the partnership be with another African country, the cost fronted by South Africa is likely to be much higher given its prominence on the continent. This perspective of the joint venture scenario can be likened to the third and fourth scenarios in which South Africa performs a larger role.

The third scenario follows an incremental development approach, in which South Africa begins transitioning facilities towards space activities by supporting suborbital flights for scientific experiments and commercial applications using existing technology and strategic partnerships. The assumption is that the government would provide funding through subsidies or sponsored projects to the commercial sector to enable the development of supporting industry. Partnerships would be advantageous, but not required to the same degree as the first two scenarios. Technology transfer would primarily take place through supported university projects supplemented with international cooperative projects involving South Africa and foreign industry.

The last scenario is a proactive, independent scenario in which there is active participation within South Africa to develop a launch industry with indigenous rockets, with South Africa acting as the launching country, with little to no external help. This scenario requires the most capital and is the least feasible of the options presented. However, should the capital be made available for the development of a launch vehicle, it would be faster than the agile approach to realise a working launch vehicle. In this scenario the development of the industry is driven by the government, using state-owned facilities and all development fully funded by the state[3].

These scenarios can be illustrated as a spectrum of South Africa's involvement and the relative benefits, capital requirement, time, knowledge gain, anticipated industry expansion and the dependency on external stakeholders. This is shown in the form of a heat map in Figure 6.4. As the development of the launch industry begins to rely more heavily on the South African government, the time and cost to completion increases. However, the time to completion has an inverse relationship to the benefits derived through industrial expansion capacities built and knowledge gained.

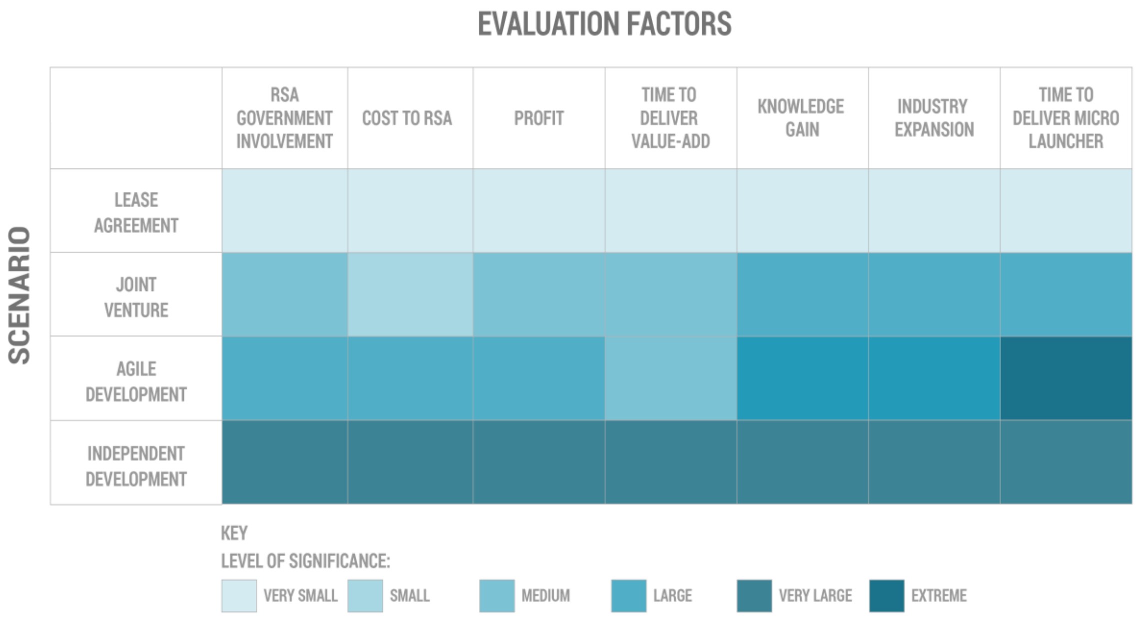


Figure 6.4 Heat Map of the four micro-launcher Industry development scenarios.

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[3] South Africa already demonstrated in the late 1980's and 1990's that it could successfully implement this scenario. However, the current geopolitical context and the domestic political environment are very different to that of the late 1980's.

As illustrated in Figure 6.4 the lease agreement scenario would be the fastest to realise an industry, but it also has the least economic impact. This is compared to the other extreme, the independent scenario, that has a significantly better economic impact but that also requires more resources from the South African government. Figure 6.4 could be used to identify a scenario which optimises the social and economic outcomes within the constraints specific to South Africa, including relative availability of funding, government support and desired results.

6.6. Assessment of Scenarios

As noted, it is still a common rhetoric that Africa is not yet ready to be involved in space activities given the large outlay of capital that is required. Launching, in particular, is only considered a suitable activity for more established space nations, as a higher level of space technology and expertise is required for success. Of the scenarios considered, the lease agreement would be the most cost and time efficient as it demands less knowledge and technical support from South Africa. The weaker currency also lowers the cost of procuring services from South African vendors, making the country a cost-effective to alternative basic launch sites. As noted, there are already basic operational facilities including Heartesbeeshoek, OTR and Spaceteq, which could be used pilot this scenario as a test case.

As the South African government becomes more involved in space activities it would also become responsible for more of the cost. The concept of a joint venture is intended to allow for some skills and knowledge transfer, while moderating the liability of South Africa as a launch state. In this scenario, it is assumed the partnership is with an established entity, and as such there would be an almost immediate opportunity for investment into up-skilling locals and further development of facilities.

Both the lease scenario and the joint venture scenario provide South Africa with respite from the capital necessary to develop and operate a launch facility, and this is a notable benefit as it is unlikely that South Africa would be able to cover the full cost of independently developing a micro-launch industry. As with the example of SKA and noted as by the Department of Science and Technology, international projects tend to be awarded more funding and have some guarantee of sustained funding given the political commitment international stakeholders. International partnerships also provide a level of credibility for the competence of the operation, possibly promoting a larger client base. This would also raise the profile of South Africa's industry in general given the association of space activities with a country's technological sophistication, which could have positive effects on the manufacturing industry. The use of existing facilities for space activities would promote the cognitive and socio-political legitimacy of the space industry, which is still required to some degree in South Africa.

A mutually beneficial partnership with a country with geographical constraints but experience with this technology, such as the United Kingdom for example, could provide that country with access to launch facilities based in South Africa, while South Africa could benefit from that country's experience. However, partnering with another developing country has a closer approximation to the Agile or independent approach in which most of the knowledge base would have to be developed from the ground up and the funding would be primarily from the South African government. As stated, the main issue plaguing space programmes in Africa is lack of funding and human capital, and this does not lend itself well to entering joint ventures with other African countries.

The Agile and Independent scenarios require the much more input from the South African government than the lease or joint venture scenario. The benefit of these approaches is the development of an indigenous knowledge base and more independence to carry out the space activities. The Agile approach uses government funding to enable commercial operations from existing industries in South Africa to develop the supporting infrastructure before propositioning the micro-launch industry, resulting in a more resilient commercial space programme that would be more responsive to market demands than a monopoly.

Collaborations between manufacturing and aviation sectors and universities on smaller, less costly and more manageable projects would contribute to the knowledge base and provide workable intermediate products. For this scenario to be a success there would need to be effective coordination of a project that spans different government departments. Historically this has been a challenge for the government to achieve, but the inclusion of the private sector could provide the necessary momentum to maintain the project. This has been successfully demonstrated by the projects funded by the dti through the AISI that included academic institutions and the private sector.

Investing more into universities and academia with a view to improving manufacturing techniques and processes, such as additive manufacturing within South Africa, would improve access to components that would otherwise be subject to import/export controls. As noted, a major challenge in manufacturing Marcom-AS's liquid propulsion engine was not having access to necessary materials and components such as cryogenic ball valves. Marcom-AS CEO, Mark Comninos, stated that importing these items had proved so challenging that the design had to be changed. In supporting an industry such as this, it is imperative that the business environment is conducive to growth. For that, access to necessary materials and components is essential.

The independent scenario has the highest cost to the South African government. This scenario illustrates an extreme case in which South Africa independently develops a micro-launcher; in reality this is very unlikely. While indigenous launch vehicle development has happened in the US, China, India and Russia, these projets were heavily supported through government funding and military operations for specific reasons including technology embargos and the cold war. At the present time South Africa has no requirement to develop this technology other than national independence in space activities. However, South Africa also does not recognise space launching as a legitimate industry, so it is unlikely that this would gain traction among politicians.

Although for simplicity of the arguments the scenarios are defined in this chapter as being finite, however there are potentially other alternative approaches that could be used to develop the industry depending on which aspect of the micro-launch industry is the most coveted based on the spectrum of different national priorities.

7. CONCLUSION

The number of satellites launched annually with a mass less than 10kg has increased from 141 in 2014 to 295 in 2017, and this is expected to increase to 419 in 2018 (Kulu, 2018). The proliferation of small-scale satellites and the demand for regular launches targeting specific orbits has been driving the development of dedicated small launch vehicles. The change in the dominant user of the small satellites from the university sector to the commercial sector will further support the commercial viability of a launch sector that caters for small satellties.

The number of satellites to be launched in the mass class between 100kg – 200kg is considerably higher than those with mass less than 100kg. With the hype around developing small communications satellites, SpaceX and OneWeb expect to launch constellations of 4 025 and 648 satellites respectively (Moore, et al., 2016). This would provide a more robust demand from commercially viable satellites in which to operate a niche launch industry.

There are several launch options with existing launch vehicles that provide LEO carrying capacities between 450 kg to 23 000 kg, however small satellites are usually the secondary payloads on such launches and are not able to dictate the launch parameters or launch frequency. Small satellites are typically short-duration missions that do not require the high orbits accessed by large launch vehicles. The operators of smaller satellites are also not as risk adverse as the operators of larger satellites, so proven reliability of the launch vehicle is not as important as with larger satellites. As such, these small satellite constellations are well suited to using the smaller launch vehicles in which they can define the launch parameters and have access to more frequent launches.

With the consistent increase in the demand for small satellite launches there has been an increase in the number of small launch vehicles under development, however most are not yet operational. The majority of the launchers are being developed in the US, however, companies in China, Russia and Spain are all in the process of developing small commercial launch vehicles. As of writing this (June 2018), China's small launch vehicle, Kuaizhou-1A, is the only operational small launch vehicle on the global market.

The small satellite trend has also stimulated the development of a new generation of spaceports. Several spaceports intend to incorporate end-to-end development capabilities to cater to the small satellites market, which is novel in the current launcher market. Wallops is running the Small Launch Vehicle Research (SLVR) Project for satellites between 1.8 kg – 180kg, the Esrange Space Center has initiated a project called the SmallSat Express for satellites between 1kg – 150 kg, whilst the Rocket Lab spaceport was purpose-built to support micro-launches. Further to these existing spaceports, some countries are considering adapting existing facilities into launch complexes for smaller launchers. The UK in particular is investigating the possibility of using decommissioned airfields. While still in development, these new ventures would be in competition to a potential South African micro-launch industry.

However, South Africa's heritage infrastructure could be leveraged to develop a launch industry at a lower cost than a Greenfield development and its location is ideal for sun-synchronous launches. Hartebeeshoek Ground Station has been used on a continuous basis by satellite operators for TT&C support, and Denel's Spaceteq satellite facility can cater for satellite integration in a clean room environment and the Denel OTR facility has the potential to be used as a space launch facility. Given the facilities are already available, this capability could be brought to market ahead of other developments. In addition to the infrastructure, South Africa also has an established space agency, national legislation governing space activities and has signed the HCoC and MTCR agreements as well as ratifying four of the five UN treaties on Outer Space.

The demand for South African launches would be limited by the country's access to an international client base. The majority of the companies contracting small launchers such as Spire and Planet are based in the US, which limits them to using launch operators linked to the US through technology safeguard agreements. Should South Africa wish to enter this market an ITAR agreement would need to be arranged. There is also almost no demand from within South Africa for a launch industry, and the success of space programmes has been linked to the support of the space programme from local sources, especially the government. The success of a launch industry in South Africa would be dependent on spurring a local demand for launches or ensuring access to the international markets through the necessary legal agreements.

In assessing the feasibility of developing a micro-launcher industry in South Africa, four different scenarios were evaluated based on the level of external stakeholder involvement, relative cost of initiating the industry and the degree to which the technology will impact other sectors within the country. The scenarios assessed were:

I. **A lease agreement scenario**, in which a foreign entity is able to lease a launch facility under South Africa's jurisdiction but there is no further interaction between South Africa and the foreign entity;
II. **A joint venture scenario**, in which there is active participation between South Africa and a foreign entity with collaboration, positive investment cycles, skills transfer and the use of existing rocket technology with South Africa acting as the launch country;
III. **An agile development scenario**, in which South Africa begins transitioning facilities towards space activities by supporting suborbital flights for scientific experiments and commercial

applications using existing technology and strategic partnerships with foreign entities to develop or acquire additional industrial capabilities;

IV. **An independent development scenario**, in which there is active collaboration between government and industry within South Africa to develop a launch industry with indigenous rockets and South Africa acting as the launch country.

The lease agreement scenario and joint venture scenarios both rely on partnerships with foreign entities, while the agile and independent development scenario depend on South Africa driving the industry's development.

Of the scenarios considered, the lease agreement and, to varying degrees, the joint venture are the most cost and time efficient options as they demand less knowledge, financing and technical support from South Africa. This also supports the improvement of the socio-political legitimacy of space activities within South Africa through the use of existing infrastructure to pilot the launch industry. The weaker currency also lowers the cost of procuring services from South African vendors, making the country a cost-effective alternative to using micro launch sites elsewhere in the world. Partnerships with established entities will also provide the necessary credibility for the competence of the operation, which could promote a larger client base.

Partnerships of South African entities with entities developing launch vehicles in Europe could be advantageous as South Africa has flexible insurance requirements, which are specific to a launch rather than a set insurance value of €60 million that is required by many European countries with legislation on space activities. As noted, South Africa also already has some infrastructure and a suitable launch location, which is not available to several of the smaller countries that are land-locked and do not have entirely safe, optimal launch angles for accessing a wide range of orbital inclinations.

There are various different international partnership options. Russia has a partnership with ESA in which Russia is able to use the European launch site in Kourou, while ESA has access to their Soyuz launcher. Similarly, though less beneficial to both sides, the US has an agreement with New Zealand which allows US launch vehicles to be launched from New Zealand, with limited liability. Likewise Italy and Kenya have an arrangement in which Italy has jurisdiction of a launch site based in Kenya. In more of a partnership agreement the Danish satellite builder Gomspace has partnered with China's LandSpace-1 launcher company to launch their satellites. A partnership such as the US/New Zealand or Italy/Kenya agreement would present a feasible industry model. However, given South Africa's current position within the space industry and its current economic situation, not all partnerships will be successful. Partnering with other developing countries in which there is insufficient funding, lack of technological experience and lack of government motivation is unlikely to result in a successful joint venture.

The secondary benefits of a joint venture may outweigh those of the lease agreement, as there would more flexibility to include stipulations on sourcing materials and labour. However, benefits derived from auxiliary business opportunities such as hotels and restaurants would benefit from either scenario. Both the lease agreement and the joint venture present feasible industry development options.

The agile and independent scenarios are the most demanding, but also likely to be the most profitable in the long run if they were to succeed. In its current situation, South Africa does not have the resources to successfully achieve either of these scenarios; most notably the funding and technical knowledge base are inadequate. Further to this, there is not enough local demand to support this type of industry, which has, in previous space technology transfer projects, been indicative of failed projects. The need for cross-department collaboration has also not proven successful in South Africa due to the lack of coordination. The low level of cognitive and socio-political legitimacy regarding space activities would also undermine efforts to develop this industry. As noted in other developing countries, the need for basic infrastructure is often used to discourage efforts to invest in space activities, which are seen as comparatively frivolous in relation to other areas of economic activity.

Taking all these factors into consideration and given the current political and economic climate and industrial capabilities in South Africa, the most suitable course of action would likely be the lease agreement coupled with the agile scenario. Requiring no technology transfer may improve South Africa's appeal as a chosen launch site, as opposed to the joint venture scenario in which countries would have to forgo some technology for the benefit of launching from South Africa. Carrying out launches from South Africa without the capital outlay offers the opportunity to raise the profile of space activities in the country, thereby improving the cognitive legitimacy of the industry in South Africa without negative funding connotations.

The agile scenario initially develops the industrial base that would be able support a space industry. The focus would be primarily on developing independent SMME's within the private sector through government-funded collaborative projects, much like is being done currently through the AISI. The collaborations between the private sector and universities in South Africa have yielded innovative products while developing the country's human capital. Given the current funding allocations and the National Space Strategy, the primary focus of the country is specifically not to develop an indigenous launcher. As a result, funding the development of local launch capabilities is unlikely to draw sufficient support from government to maintain the research and development needed to develop a working product, as was the case with the Marcom-AS launcher initiative.

Ultimately, the reputation of the country and the association with the launch industry resulting from the lease agreement is likely to improve the perception of South Africa's capabilities, and with that a better regard for locally developed components promoted through the agile scenario. Once South Africa becomes established in the space launch industry with a self-sufficient industrial base, the country could look towards developing an indigenous micro-launcher.

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