Unlocking New Horizons: The Role of Kenya's Broglio Space Center in the Commercial Space Era

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Kenya's coastal region offers a strategic edge in space launch operations due to its equatorial positioning and Eastern-facing ocean, optimizing both fuel efficiency and satellite deployment trajectories, as well as adhering to existing safety requirements for potential debris field ellipses. The Broglio Space Center (in Malindi, Kenya), with a successful mission legacy dating back to the 1960s, stands at the forefront of this advantage, now pivotal in the Commercial Space 2.0 era. The center benefits from the aforementioned equatorial launch advantage, enabling cost-effective access to geostationary orbits and the following established infrastructure: repurposed offshore oil platforms acting as (flight-tested) small-to-medium orbital-class launch sites; the port of Mombasa – offering easy access to major nearby shipping lanes with direct channels to JAXA, India's increasingly active space industry, and ESA and NASA through the nearby Suez Canal; as well as established road and rail infrastructure direct from port to launch site - all in addition to low-wind, mild weather year-round. The potential benefits of a partnership between the Western "new space" industry as well as governmental bodies such as NASA and ESA and the already-poised Kenya Space Agency (KSA), (which has recently signed deals with commercial space giants such as SpaceX) have far-reaching ramifications, both for the aerospace sector and not. The low-cost renovations that are needed to modernize the Broglio Space Center and assert Kenya as a key player in the global space market are examined, taking into account the challenges faced by traditional launch sites such as ESA in French Guiana and NASA at Cape Canaveral, including logistical and environmental issues. In contrast, Kenya's location and KSA's proactive stance offer unparalleled operational advantages, cost-effective commercial space industry expansion, and extensive geopolitical benefits. This approach not only promotes innovation and collaboration but also strategically positions Kenya as an indispensable hub in the international space launch landscape. "Africa is indeed a Gateway for space."

I. Nomenclature

NASA	=	National Aeronautics and Space Administration
LEO	=	low Earth orbit
ELEO	=	equatorial low Earth orbit
GEO	=	geostationary orbit/geosynchronous equatorial orbit
JPL	=	NASA's Jet Propulsion Laboratory
Δv	=	change in velocity
Δm	=	change in mass
m_0	=	initial vehicle mass
m_0	=	final vehicle mass
I_{sp}	=	specific impulse
g_0	=	acceleration due to gravity ($9.81 ms^{-2}$)
USAF	=	United States Air Force
AFB	=	Air Force Base
JAXA	=	Japan Aerospace Exploration Agency
ISRO	=	Indian Space Research Organization
KSC	=	Kennedy Space Center
SGAC	=	Space Generation Advisory Council
CNSA	=	China National Space Administration
CSA	=	Canadian Space Agency

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II. Introduction

The space industry is rapidly undergoing a critical inflection point – commercial 'new space' companies are establishing control over previously-existing and innovative markets alike, and are ever expanding in the name of political, scientific, defense, or monetary gain. The next era of space exploration and innovation, the establishment of a cislunar economy and multiple permanent habitats in Earth orbit, as well as recent trends from SpaceX and other commercial launch companies, all point towards an immense spike in the launch cadence and spacefaring capability of humanity [1]. As an ever-increasing number of rockets are launched, the need for a modern, focused, and commercially-oriented launch site presents itself. 'Traditional' launch sites such as Cape Canaveral, Boca Chica, Vandenberg AFB, and more all come with significant technological, environmental, geographical, political, and financial challenges that are relics of past decisions and administrations.

A new location for the commercial launch industry, one that takes advantage of the rapidly-growing international space sector, including JAXA, the ISRO, and the expanding aerospace field in Africa and the EU needs to be established, while also considering the vital DoD contracts that revolve around threats from the Chinese and Russian theaters. This facility requires a carefully-crafted balance of political support from the hot country coupled with an environment that is open and supportive of the fast-paced, rapid development that has come to define the commercial space companies of today.

Any such launch facility has the potential to become the global hub of operations for the future of all Earth launches, and will undoubtedly result in the economic gain of billions, if not trillions of USD for the region it is constructed in [2]. As such, this spaceport requires extensive and immediate funding, planning, and construction to keep up not with the demands of today's aerospace industry, but with the face of the industry in 10 or 20 years.

This paper will explore the existing orbital launch site located in Malindi, Kenya, and illustrate why it is the ideal location when it comes to the criteria listed above, as well as the many other factors that play into the success of such a project.

III. Geographic Advantages

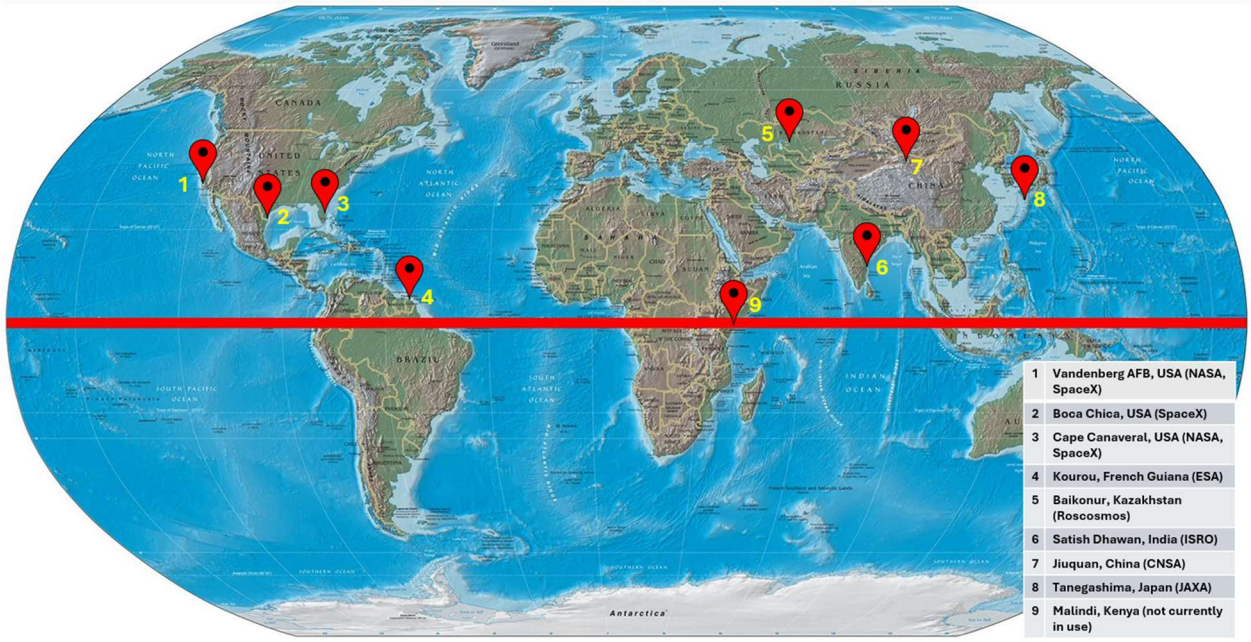

Fig. 1 Depiction of current launch facilities with relation to equatorial belt [3]

A. Equatorial Benefits

Malindi, located approximately 3.2 degrees south of the equator, offers an unparalleled geographic advantage when it comes to both the launch, recovery, safety, and monitoring of orbital missions.

Firstly, the equatorial belt has long been recognized as a prime region for space launch sites due to the inherent orbital mechanics advantages it offers. The high rotational speed of the Earth is at its maximum near the equator, and rockets launched eastward from equatorial locales harness this rotational speed to augment their initial velocity,

effectively reducing the energy required to reach orbit. At large scales and with expensive propellants and tanks, even a small fraction of savings like this means millions of dollars saved a year, and extreme cost-effectiveness when compared to launch sites that are at higher or lower latitudes, such as Cape Canaveral (28 degrees N), Boca Chica (18 degrees N), Vandenberg (34 degrees N), and Baikonur (45 degrees N). In addition to immense cost-savings in fuel, this geographic advantage gives way to higher payloads and lower environmental impact.

With a tangential surface speed at Earth's equator of ~456.1 m/s, the launch sites displayed above can be mathematically compared with Malindi in terms of fuel savings according to the following example calculations:

$$v_{Cape\ Canaveral} = 456.1\frac{m}{s} \times \cos(28.5°) = 401.16m/s$$
$$\Delta v_{savings} = v_{equator} - v_{Cape\ Canaveral} = 456.1 - 401.16 = 54.94m/s$$
$$\Delta v_{Typical\ low\ Earth\ orbit} = 9700m/s$$

Tsiolkovsky Rocket Equation:

$$\Delta v = I_{sp} \times g_0 \times (ln\frac{m_0}{m_f})$$

Payload capacity for a typical Soyuz final stage at the equator: 8.355 tons
Payload capacity for a typical Soyuz final stage at Cape Canaveral: 8.188 tons

Although this math is rough and makes some assumptions, a mass saving of roughly 151 kg, multiplied by the Soyuz's cost per kg of $5,000, would result in a cost savings of $755,000 per launch.

An additional advantage of launching from the equator is that near-equatorial orbiting satellites (such as GEO and ELEO orbits) will inherently pass over an equatorial monitoring station with every rotation, in contrast to the varying ground track of an inclined orbit. Therefore, a tracking station within this equatorial belt would easily facilitate and maintain with a higher factor-of-safety tracking and communication.

B. An Eastward-Facing Coast: Safety and Retrieval Advantages

One of Malindi's most important (and unique) geographic advantages lies in its eastward-facing coast along the Indian Ocean. This distinctive feature holds several key benefits for space operations:

1. Safe Crash Zones: The eastward orientation of Malindi's coastline provides a naturally safe crash zone in the event of launch accidents or intentional staging jettisons. Having the ocean to the east ensures that these stages can safely fall into the water and away from human populations, minimizing the risk to life and property.
2. Indian Ocean's Reliable and Calm Weather: Malindi benefits from the Indian Ocean's warm and relatively calm waters in this region. This climate attribute is especially advantageous for autonomous retrieval of booster stages, such as SpaceX's landing barges, enabling the recovery of booster stages from the ocean after launch. The Indian Ocean's warm and placid waters make these recovery operations more predictable and manageable, reducing risks and costs. Furthermore, these warm, calm conditions lead to an extreme decrease in the harsh natural disasters that are such a problem in some of the U.S. launch sites currently, such as the hurricanes, earthquakes, and tornadoes that frequent the shores of Florida and the Gulf of Mexico.
3. Trade Winds for Launch Schedule: The East Coast of Africa, especially Malindi, has long been renowned for its trade winds. These highly reliable winds blow predominantly north during certain months of the year, followed by a reversal to blow consistently south during others. Of particular significance are the periods of relative calm with low winds that occur between these seasonal shifts. These calm months present ideal conditions for launch windows, ensuring stable trajectories and reducing the risk of weather-related launch delays. Understanding and harnessing the seasonal wind patterns could lead to a highly predictable and efficient launch schedule from Malindi.

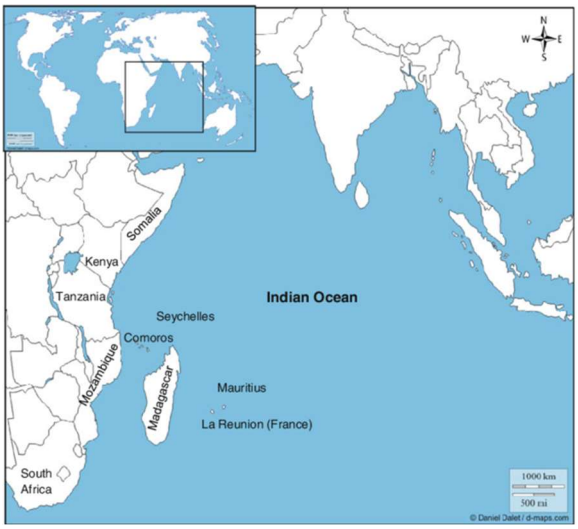

Fig. 2 Map of Kenya with Malindi, Mombasa, Nairobi, and Lamu highlighted (left) [4]
Fig. 3 Kenya with depicted available recovery area to the east (Indian Ocean) (right) [5]

C. Proximity to Aerospace Partners

In addition to easy access to the Kenyan coast through the nearby Suez Canal for both U.S. and EU launch agencies and companies, the geographic location that Malindi offers supports pre-established, safe, reliable, and cheap shipping lanes directly to both India's rapidly expanding launch industry, as well as JAXA's and CNSA's launch facilities.

IV. Existing Infrastructure

Fig. 4 San Marco Launch Platform, with a Scout orbital launch vehicle on the pad [6]

A. Broglio Space Center

The story of the Broglio Space Center begins in the early 1960s when the Italian government, in collaboration with NASA, recognized the need for a ground station outside the United States to support their growing space endeavors.

The remote location of Malindi, Kenya, was deemed ideal for this purpose due to its proximity to the equator, providing a significant advantage for launching spacecraft into orbit.

Funded by Italy but established in Kenya, the Broglio Space Center was named after Luigi Broglio, an Italian scientist and engineer who played a pivotal role in its inception. Broglio's vision was clear: to create a space center that could contribute to global space exploration efforts. The Italian Space Research Program (ARS) spearheaded this initiative, marking the beginning of Malindi's transformation into a space hub.

The first launch (from a converted oil platform) occurred in 1967 when the San Marco 1 satellite was successfully launched into orbit. [7]

B. Shipping Lane, Ports, and International Highway Project

In addition to the established small-and-medium-launch infrastructure at the Broglio space center, there are two major ports near the location, including the international shipping port of Mombasa less than 100km away, and the deep-water port of Lamu less than 120km away. Both ports and Malindi are connected by the LAPSSet Corridor commercial highway project, allowing easy transport from both ports to the launch location. Furthermore, the high-volume, high-reliability shipping lane already established to both ports allows for quick distribution of launch vehicles, components, and most importantly, materials needed to build out future spaceport infrastructure. Finally, the international airport located within Malindi hosts two runways, with Runways 17/35 and 8/26 measuring 1,400 meters long and 30 meters wide, and 1,082 meters and 23 meters wide respectively, with construction already underway to expand Runway 17/35 to 2,500 meters in length. This is compounded with the three other international airports in the immediate region, notably HKLU in Lamu, ICAO in Mombasa, and JKIA in Nairobi, each with longer, wider runways and shipping-specific infrastructure already set up. [8]

C. Notable Missions and Milestones Highlighting Capabilities

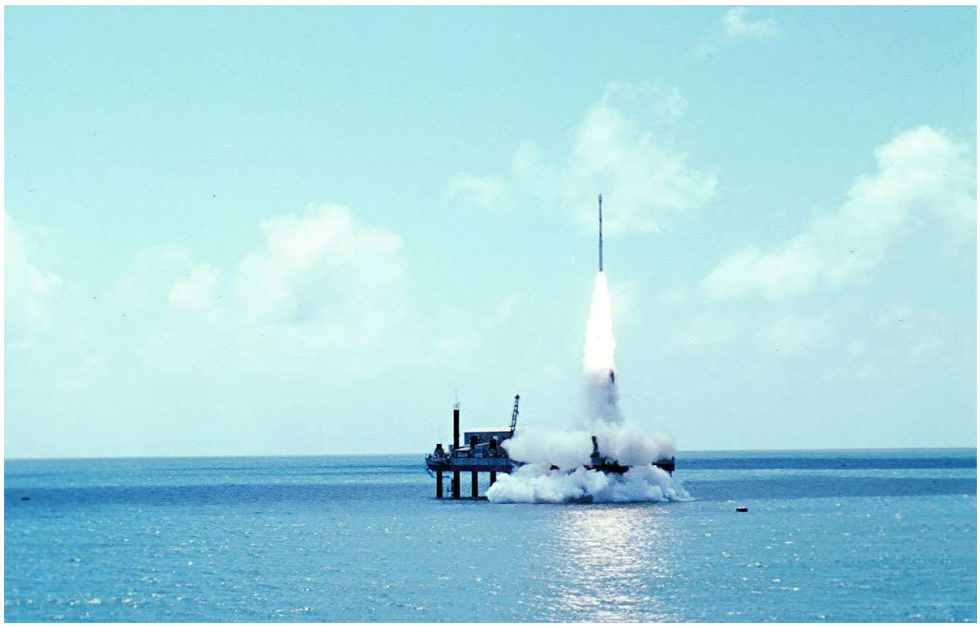

Fig. 5 Scout B-1 rocket lifting the UK-built Ariel 5 satellite to orbit from the San Marco Launch Platform

Throughout its history, the Broglio Space Center has been a witness to numerous historic missions. It has contributed to a wide range of projects, including satellite launches, scientific experiments, and international collaborations. Some of the most notable missions launched from Malindi contributing to its impressive track record include:

1. **San Marco Program**: Initiated in the late 1960s, the San Marco program involved launching satellites for scientific research. The Broglio Space Centre conducted a total of 27 launches, primarily of sounding rockets including the Nike Apache, Nike Tomahawk, Arcas, and Black Brant launchers. Low payload weight orbital launches were also conducted using the solid-propellant Scout rocket. Notable achievements include the successful launch of the San Marco 3 satellite in 1988, which conducted studies on Earth's magnetosphere.

2. **Uhuru X-Ray Satellite**: One significant launch was the first satellite specifically for X-ray astronomy, Uhuru, which was launched on a Scout B rocket in 1970, and identified the first good candidate for a black hole, Cygnus X-1.
3. **Galileo Navigation System**: Malindi played a crucial role in supporting the European Galileo navigation system by tracking and monitoring Galileo satellites during their critical early phases.
4. **James Webb Space Telescope**: As of the present day, the Broglio Space Center continues to provide ground station support for the James Webb Space Telescope, a testament to its enduring relevance in modern space exploration.

These missions represent just a fraction of the center's contributions to space science. Each launch and successful operation reaffirms Malindi's significance in the global space community. [9]

V. Benefits for the Region and the Western World

A. Benefits to the Local Region

The action of not only operating, but also constructing, a successful spaceport within the East African area has numerous, far-reaching benefits, both for the citizens and infrastructure of the region itself and the international aerospace community, including commercial launch services and all democratic governments participating in the industry.

Benefits to the region: As found in a case study conducted on the effects on the local community of the construction of the Wallops Island launch facility in Virginia, the construction and operation of a launch can bring multiple high-impact benefits to the region it's built in. A spaceport on the Kenyan coast would create tens of thousands of jobs in the construction, maintenance, operation, and organization of the launch facility, and would lead to a rejuvenation of the region (which is currently within one of the lowest-income counties in Kenya) through the generation of billions of dollars of revenue in both launch services and external grants. Real-world examples demonstrating the accuracy of these estimations are readily available when examining the history of launch locations such as Boca Chica, TX, and Korou, French Guiana. However, these facilities are (long-term) most likely to be both smaller and host less-frequent launches than any commercial launch infrastructure built in Kenya. [10]

B. Benefits to the Democracy of the Western World

In a move that transcends the continental boundaries of a Kenyan spaceport, a presence as massive as a multi-national, commercial and governmental launch and manufacturing facility would bring not only billions of dollars of trade, scientific discovery, and payload services to the region, it would also have profound and comprehensive soft-power influences across Africa. China's current approach of infrastructure construction and debt-collection from virtually all African countries is no different in the Eastern sector of the continent, and is only becoming more aggressive each year. The construction of a spaceport in Kenya is a far-sighted way for the Western community, including NASA, ESA, the CSA, and commercial space giants to establish a permanent, positive influence in the area, effectively pushing back against China's expansion. This is part of what makes this task so crucial, but also incredibly time-sensitive, as the more infrastructure, land, and regional influence that China claims, the harder it will be for any future players to break into the geographic region and take advantage of the existing support for a launch center that Kenya offers. [11]

VI. Challenges

The aerospace industry has (especially in recent years) shown an incredible determination and willingness to explore new ideas and areas in the pursuit of profit, exploration, and science. For this reason, the cost of constructing such a launch facility in the Malindi area is acknowledged, but assumed to have feasible solutions with the joint cooperation of the KSA, external funders such as The World Bank and the EU (established high-value funders to Kenyan infrastructure projects) and commercial space companies. [12]

With this in mind, challenges other than initial capital now rise to the surface. Issues facing any such project, regardless of region, are extensive and will take careful planning, immense funding, and industry-holistic determination. These include: infrastructure creation to both support the construction, and to actually construct, a spaceport; geopolitical obstacles, including the need for support from local and international governments, as well as

financially-rooted pushback from several players worldwide; and the time-consuming shift from already-established routines and launch facilities to a modern system.

These challenges are in no way new or unknown (or unsolvable) - as the acclaimed author Andy Weir explains in an interview focusing on the creation of a successful spaceport in the Kenya region:

> "Kenya is the center of the global space industry because they realized they can bring the space industry in, because they're on the Equator, which makes it cheaper to launch to low Earth orbit, because you've got the rotation of Earth helping you. And it gives you about one-fifteenth of the total velocity that you need just by being on the Equator. And then the other thing is that they — the fictional version of Kenya — made a bunch of laws to encourage the commercial space industry. They said, "We'll seize the land for a launch facility, you can come here, you can stay there for free. You still have to pay taxes, they're lower than you would pay anywhere else. We'll make all these special laws just for the Kenya Space Corporation such that they don't have to follow the union laws that the rest of the country has to follow." Literally everything they can think of to bring global space industry into Kenya. And it worked. And so now they have this multi-trillion-dollar-a-year industry that's centered right in their country, and it's brought them prosperity." [13]

This 'economic-driven political orientation' that Weir suggests is an already-existing phenomenon, and is currently being demonstrated in nearly all African countries (especially in Kenya). For example, the commercial benefits of facilitating a shipping lane as large as the port in Mombasa and the international airports in Nairobi, Mombasa, Malindi, and Lamu were recognized as outweighing the other problems the region faced, and enormous amounts of funding, both externally and internally-generated, was poured into these projects, much to the benefit of both the quality of life and income flow for the region. [14]

On this note, there is currently a vast and extensive network of international NGOs, governments, and private donors that are focused on establishing jobs, revenue streams, and better infrastructure in Kenya specifically, so the challenge of a lack on funding or initial push to begin planning and construction in the region can conceivably be mitigated with support from this sector.

VII. Involved Bodies and Established Efforts

Although the current time frame and complexity of the launch capabilities necessary to be successful outpace the capability that the KSA can provide with current funding, this is not to say that there are no current plans to this effect in place, or external funding being secured. As Charles Mwangi, the Acting Director, Space Sector & Technology Development at the KSA, states:

> "We at the KSA are focused on setting up the foundational layers for a space ecosystem in Kenya, so that we'll be able to build up the capability to complete launches from African soil." "Once we lay that foundation, we'll be able to build that environment of private companies and government-funded efforts that will build satellites and launch hardware from within the country." [15]

This sentiment illustrates the extensive efforts, planning, and level support that governmental bodies within the region are not only capable of providing, but are also planning on providing - contradicting the above challenge of resistance from agencies in the country itself.

A close cooperation between external funders, Western space agencies, large (and small) aerospace corporations, and the Kenyan government is crucial to the success of any project such as this. As a project lead at SGAC and a Space Applications Officer at the African Union, Meshack Kinyua, puts it, "step by step we are building the future, and seeing the writings transform into tangibles." While conducting the U.S.-Africa Commercial Space Workshop in 2023, he observed that:

> "the meeting unpacked the different layers of space administration and entry points for commercial engagements from both sides. The key outcome is that cooperation will thrive through mutual understanding and greater dialogue. The two regions have immense opportunities to leverage upon, with key emphasis on tailored services that make positive societal impacts." [16]

The KSA isn't the only organization in the region that is committed to the vision of building up a space industry in Kenya. International bodies such as the African Union, their committee, the African Space Agency, and private donors like Hayes Group International are all cooperating to the same effect, preparing the region to successfully host any external efforts to create a spaceport. As Selina Hayes of Hayes Group International (in partnership with the KSA)

says, “we have created [the framework for] a complete space economy, including hotels, ports, technology transfers, and the economic model for space as a service.” [17]

VIII. Significance Specific to SpaceX

The general reasoning presented above justifies the creation of a large-scale commercial spaceport in Malindi for the commercial space industry and the East African region as a whole. However, there are several reasons why such a launch facility would revolutionize SpaceX’s operations and business model as a whole, and lead to long-term security in launch operations and cash flow, as well as create room for expansion in the near future, aligning with short-term goals such as the commercial success of Starship and the NASA-SpaceX partnership. These reasons are now explored:

A. Risk Diversification

The current SpaceX business model revolves entirely around a single relationship – for better or worse, the collaboration of company representatives such as Elon Musk and Gwynne Shotwell with NASA and the United States government account for roughly 80% of revenue generated from Inception to May 2022 (excluding fundraising from investors). SpaceX has earned around $13.5 billion from NASA in the last two decades, and was recently awarded another 2 billion dollar contract (making them the second-highest receiver of NASA funding after JPL). [18]

In this way, SpaceX has proved to not be a commercial space company in all senses of the label – the company has relied almost solely on government funding and subsidies for the last 20 years, and is just starting to move away now, albeit extremely slowly.

Although the relationship between SpaceX and NASA is going strong, it’s never a solid long-term plan to receive a majority of income from a single, sometimes unreliable source. The US government has proven it won’t always be there for SpaceX’s needs – demonstrated by the repeated tensions between the FAA and SpaceX, as well as the periods of turmoil during recent government shutdowns and administration changes. Even if the Starlink business model unfolds according to plan, SpaceX still needs to diversify its income stream over the next few years, and be prepared to rely on other sources of funding. The aerospace industry within the United States, while massive, is almost entirely saturated already, and faces extreme competition with the rise of ‘new-space’ companies. One alternative to continuing to work with the FAA and NASA is to move a small portion of SpaceX’s business (whether for sources of commercial income or launch infrastructure) outside of the U.S., opening up SpaceX’s potential partners to many more governmental and commercial bodies, and ensuring that smaller government agencies like the KSA would be much more inclined to accommodate SpaceX’s fast-paced development and launch strategy.

B. Environmental Risk

Fig. 6 Satellite image of consistent weather patterns above Cape Canaveral (left) [19] Fig. 7 SpaceX Falcon 9 on Pad 39A at the KSC during launch attempt (top right) [20] Fig. 8 Lightning striking pad at Cape Canaveral, delaying SpaceX launch (bottom right) [21]

One of the biggest challenges that SpaceX has faced (both technologically and politically) is the environmental issues of the current launch and development sites that Falcon 9 and Starship vehicles utilize – namely Boca Chica, Vandenberg AFB, and Cape Canaveral. Florida is the number one place in the United States where thunder storms can be found. As of August 2022, 'roughly 16% of every launch attempt we have at Cape Canaveral gets scrubbed due to weather" stated Mark Burger, the USAF launch weather officer for the area. Pivoting to Boca Chica, "the Gulf of Mexico is especially vulnerable to hurricanes and storm surge because of its unique U-shaped coastline, which essentially traps a storm system into a populated region, no matter which way it turns" according to Ryan Truchelut, a chief meteorologist in the region. [22]

Kenya's year-round fair weather and predictable, low-intensity winds provides a relief from these disaster-prone (or at least storm-prone) environments, with a less than 5-degree Fahrenheit variation in temperature at the coast throughout all seasons. Although certainly still a consideration, the offshore ocean and craggy coastline near Malindi presents much less of an environmental hazard when launching or testing systems, especially when compared with the high-value protected marshes and grasslands that SpaceX has had numerous tensions with the FAA and environmental lobbyists in the U.S. in the past. [23]

C. Greater Tracking Coverage

As proven recently for the James Webb Space Telescope mission, the three tracking stations that the San Marco platform still utilizes (two 10-meter dishes and one 6-meter dish) are providing active, and crucial communication operations for high-value missions. The success of these tracking stations are of course limited to their current capabilities, which would be upgraded with the creation of a spaceport in the area. A tracking station with a unique placement across the globe from current SpaceX facilities would create a geographic advantage for vehicles such as Starship, ensuring greater coverage and tracking for longer missions, such as lunar and higher-orbit operations.

D. Starfactory Advantages

Finally, the creation of a Starfactory specifically tailored to manufacturing SpaceX hardware would provide an extreme geographical benefit by its proximity to nearby European, Middle Eastern and Asian partners, returning to the previous point of risk diversification, income expansion, and the rise of the aerospace industry in countries like India and Japan. Shipping and transportation costs of payloads or vehicles to and from a launch facility in Kenya and any of the major space organizations in the aforementioned countries would be significantly cheaper than comparable operations from the United States.

IX. Conclusion

The need for a new orbital-and-above launch facility, outside the United States and propelled by a joint cooperation between the growing commercial space industry, international bodies, and governmental space agencies is apparent, and will bring massive economic, political, social, and cultural benefits to the region it is constructed in. This paper established the multitude of justifications that defend the Malindi, Kenya site as an ideal position for a project of this scale. The benefits to all parties involved in the construction, operation, and commercialization of such a facility were explored, with a special emphasis on what a launch facility in Kenya would mean for SpaceX. Future investigations of this space would include a deeper dive into the risks associated with establishing such a massive project, as well as several mitigation procedures for these challenges. Through a collaboration between international partners, the KSA, and spokespeople from commercial space companies, an in-depth plan would be concretely established and published for the intent of generating interest and funding from public, private, and governmental sectors. Such a plan would include an extensive look into what a launch facility of this scale would look like, and establish milestones and action items necessary to achieve its successful construction and operation.

Acknowledgments

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