Master of Science – Aerospace Management at Toulouse Business School

Master's thesis

What is the impact of emerging technologies in the space launch services industry?

Benstaali Jawad

Cohort 2022 / 2023

Date of deposit : 11/07/2023

TBS Tutor : Victor Dos Santos Paulino

EXECUTIVE SUMMARY

The purpose of this research paper is to explore the transformative impact of emerging technologies in the space launch services industry. In today's competitive market for space launch services, understanding how these technologies affect innovation cycles is crucial.

Firstly, we establish a foundation by examining theories on innovation from Schumpeter and other scholars. We delve into concepts such as Schumpeter's theory of innovation cycles, the hype cycle, and technology readiness levels. These serve as tools to assess emerging technologies.

Next, we conduct an in-depth case study focusing on three up-and-coming technologies: 3D printing for rocket manufacturing, reusable rocket stages, and super heavy rockets. Each technology is thoroughly explained, described and analyzed based on its current level of technological readiness. This analysis reveals how companies like SpaceX, Blue Origin, and Relativity Space are revolutionizing the industry through these technologies by reducing costs and improving reliability while promoting sustainable practices.

Furthermore, this study explores the implications that these technological advancements have for different stakeholders in the industry including both new entrants and established players. We provide recommendations for both groups emphasizing the importance of adaptation, innovation, and strategic partnerships.

Looking ahead, the industry shows great potential for continuous innovation with shifts in competition and regulatory changes. With ongoing evolution in this sector, it becomes increasingly important to prioritize innovation, sustainability and cost-effectiveness. This thesis highlights the essential role that technological innovation plays in the space launch services industry. It offers insights into the current landscape as well as provides glimpses into future developments|

TABLE OF CONTENT

LEXICON

Innovation: The process of translating an idea or invention into a good or service that creates value for which customers will pay.

Emerging Technologies: Technologies that are currently being developed or will be developed within the next five to ten years, and which could substantially alter the business and social environment.

Space Launch Services Industry: The sector of the aerospace industry that is responsible for the logistical aspects of sending spacecraft into outer space.

3D Printing: A manufacturing process that creates a physical object from a digital design by laying down many thin layers of material in succession.

Reusable Rocket Stages: A type of rocket which can return to a landing site instead of falling into the ocean after launch, thus being refurbished and reused for later flights.

Super Heavy Rockets: Extremely large rockets capable of carrying more than 50t of payload into space, such as spacecraft and satellites.

Legacy Actors: Established companies in the space launch services industry.

New Space Actors: New entrants or startups in the space launch services industry.

INTRODUCTION

The importance of the space launch services industry cannot be overstated, as it plays a vital role in allowing for the exploration and utilization of outer space. By offering various launch vehicles and the necessary accompanying services, this crucial sector enables the successful deployment of satellites into orbit, supports scientific expeditions, promotes space tourism, and serves as an essential foundation for communication systems and global positioning technology.

However, similar to any other sector, the realm of space launch services faces its share of obstacles and interruptions resulting from the emergence of new technologies. These emerging technologies hold immense potential to completely transform the innovation cycles within this industry, propelling progress in various aspects such as designing spacecrafts for launch, streamlining manufacturing processes, enhancing operational efficiency, and diversifying customer offerings. In recent times, breakthrough innovations have shaped the field of space exploration by introducing transformative changes.

There has been a rise of companies in the space industry known as 'New Space,' which are focused on cutting down development and launch expenses. To achieve this objective, these companies have opted for new technologies like 3D printing, iterative design, and reusability of rocket stages. These technological advancements have greatly influenced the innovation cycles in the space launch services sector, resulting in enhanced efficiency, reduced costs, and improved capabilities. However, they have also led to intensified competition among players within the industry.

The research question for this master's thesis is: ***What is the impact of emerging technologies in the space launch services industry?***

In order to tackle this research query, we will delve into the established body of knowledge regarding up-and-coming technologies and their influence on the evolution of inventive processes across diverse sectors. Following that, our focus shall shift towards hand-picking a handful of these emerging technologies, wherein we will embark on conducting meticulous case studies pertaining to their integration within the realm of space launch operations. In regard to each specific technology studied, we aim to elucidate its potential utilization possibilities while simultaneously scrutinizing its present-day implementation efforts; identifying obstacles faced as well as advantageous prospects along the way.

In addition to our analysis, we will examine the effect of these technologies on innovation cycles. Do they speed up the process, create disturbances, open doors for new opportunities, or present unexpected obstacles? Additionally, we will compare how these various emerging technologies have impacted and endeavor to uncover any underlying patterns or shared factors. Lastly, we will explore the implications of our discoveries for leaders in the industry. Which strategies, policies, or practices should they contemplate in order to successfully oversee and harness these emerging technologies?

1. LITERATURE REVIEW

Upon initial observation, the innovation cycles within the space launch services sector appear somewhat unusual. In most cases, industries tend to follow a fairly consistent pattern in which incremental advancements progressively pave the way for significant breakthroughs over a period of time.

Nevertheless, the industry of space launch services stands apart as it has undergone a sequence of groundbreaking advancements within a concise timeframe instead of gradual ones. This extraordinary leap forward can primarily be attributed to the intense competition during the mid-20th century between superpowers, which spurred remarkable progress in both rocket technology and space exploration [1].

From the 1950s to the 1970s, a fervent race took place in the realm of space exploration, compelling scientists to delve into every technological possibility within the restrictions set by physics [2]. This period witnessed American and Russian researchers unleashing innovative technologies that continue to mesmerize us today, including full flow staged combustion cycle engines such as SpaceX's renowned Raptor engine. It is worth noting that these groundbreaking ideas were initially experimented with during this era with the Soviet RD-270 engine from the 1960s [3]. Despite having practically unlimited financial resources for their space programs at that time, constraints arising from materials and manufacturing techniques prevented many of these imaginative concepts from being fully realized beyond hypothetical scenarios. As subsequent decades unfolded, the industry underwent a maturation process wherein innovation shifted towards incremental enhancements rather than complete paradigm shifts.

1.1. WHERE DOES INNOVATION COME FROM?

In order to define innovation and understand its impact on the innovation cycles in the space launch services industry, it is important to consider from where innovation is coming from.

In 1985, Peter F Brucker outlined the Seven Sources of Innovation in his book "Entrepreneurship & Innovation [4]." These sources shed light on how innovation emerges and develops within various industries.

The first source of innovation are **unexpected occurrences or events**. Sometimes, innovation arises as a response to unforeseen situations or challenges that emerge within an industry.

Another source is **incongruities within an industry**. These gaps or inconsistencies create opportunities for innovative solutions to solve problems or fulfill unmet needs.

Process needs also drive innovation. When there is a need to enhance efficiency, cut costs, or streamline operations within an industry, it can spark opportunities for innovative advancements.

Moreover, **changes in the structure of an industry or shifts in market dynamics** can prompt innovation. Examples include alterations in competition landscapes, new entrants into the market scene, and changes in customer preferences and demands.

Changes in demographics and social patterns present another avenue for innovation. As population demographics evolve and cultural shifts occur alongside societal trends, they create new demands and prospects for innovative ideas and products.

Advancements in scientific knowledge contribute significantly to fostering innovation. New discoveries and progress made through scientific research open up unprecedented possibilities and capabilities for further development.

Lastly, **changes in perception and meaning impact the direction of innovation**. Shifts in people's interpretations of things as well as altering societal values influence the course of innovative concepts and practices across various industries.

These seven sources of innovation present a wide spectrum of pathways through which innovation can emerge and evolve within an industry. Each source holds the potential to significantly alter the current industrial landscape and shift it towards an environment ripe for innovation. The sources emphasize the dynamic, multi-faceted nature of innovation, underscoring its roots in an array of areas spanning from scientific advancements to changes in societal perceptions.

In the context of the space launch services industry, these sources are particularly relevant. For instance, the unexpected event of the Cold War led to significant advancements in rocket technology, sparking a wave of innovation in space launch capabilities. Likewise, process needs such as enhancing efficiency and reducing costs have been key drivers behind developments such as reusable rockets. Changes in the industry structure, particularly the entrance of private players in what was once a government-dominated domain, have significantly altered the competition landscape, driving further innovation. With the rise of interest in space exploration and the increasing accessibility of space-related activities, changes in demographics, societal patterns, and perception have also contributed to the surge in innovative developments in this industry. In conclusion, understanding the origins of innovation aids in predicting and preparing for future trends and directions of innovation within an industry.

Identifying the origins of innovation is essential, yet equally important is comprehending how these innovative ideas manifest and develop within an industry's framework. Hence, delving into the various types of innovation becomes imperative. These different forms, as we shall perceive, are impacted by their respective sources, ensuring that appreciating their subtleties permits a comprehensive understanding of innovation and its cycles within the space launch services sector.

1.2. WHAT ARE THE DIFFERENT TYPES OF INNOVATION?

Exploring the notion of innovation reveals that it is not universally defined. In order to encompass the wide range and significance of innovation, we can analyze it from three perspectives: its type, its level of novelty, and its cumulativeness.

In their influential work "***Managing Innovation: Integrating Technological, Market and Organizational Change***" [5] published in 1997, Joe Tidd and John R. Bessant have classified the concept of innovation into four distinct types.

Product innovation refers to the development of new or enhanced products/services by introducing fresh features, improved functionalities, or entirely novel offerings tailored to fulfill customer needs and preferences.

Process innovation focuses on enhancing the efficiency, effectiveness, and productivity of existing organizational processes. It entails adopting new methodologies, technologies, or techniques that streamline operations while reducing costs.

Position innovation involves strategically repositioning an organization within its industry or market. This type of innovation revolves around identifying and leveraging new market opportunities, targeting different customer segments, or creating unique value propositions that set one's organization apart from competitors.

On the other hand, **paradigm innovation** signifies a fundamental shift in how an industry operates or approaches problem-solving. It challenges established assumptions, beliefs and practices—effortfully reshaping the very foundations that define an entire industry.

In unpacking the concept of innovation through the lens of the four types identified by Tidd and Bessant, we set the foundation for a nuanced understanding of how change and progress materialize within organizations and industries. Each of these types represents unique mechanisms for value creation and competitive differentiation. In sum, these four types of innovation offer a multi-faceted view into the diverse mechanisms by which the space launch services industry, or any industry for that matter, can evolve and progress.

Understanding the range of change and the distinct routes to progress can be facilitated by identifying these classifications of innovation. However, it is crucial to acknowledge that innovation encompasses more than just these types. Hence, we move on to our next aspect of analysis: the '**level of novelty**.'

As we explore the spectrum of novelty in innovation, it becomes clear that not all innovations are created equal. The level of novelty provides a mechanism to evaluate the magnitude of change brought about by an innovation and its impact on existing technologies, processes, or markets.

Continuous or incremental innovation, as defined by Corso and Pellegrini [6], is characterized by a series of small, progressive improvements that enhance and refine existing products, processes, or services. These innovations work within the existing paradigm and leverage established knowledge and technologies to drive progress. In the context of the space launch industry, this could include advancements in materials used in rocket manufacturing, or improved fuel efficiency of engines, which increase performance without fundamentally changing the nature of the product or process.

In contrast, **discontinuous or radical innovation** is transformative in nature. It often brings about a significant shift in the status quo, introducing new technologies, products, or services that didn't exist before or improving existing ones in such a significant manner that they essentially become new. These kinds of innovations often disrupt established markets, overthrow incumbent players, and lead to the creation of entirely new industries. For instance, the development and successful deployment of reusable rockets by SpaceX is a prime example of discontinuous innovation in the space launch services industry.

The level of novelty in innovation is a key aspect to consider when evaluating the potential impact and significance of an innovation. Understanding whether an innovation is continuous or discontinuous can provide insights into its potential to drive progress and reshape industries.

While the level of novelty helps to delineate the scale and impact of innovation - from continuous or incremental changes that refine existing technologies to discontinuous or radical, industry-altering breakthroughs - this alone does not capture the full essence of innovation. It's crucial to understand that innovations don't exist in isolation; they are part of a broader tapestry of progress where each innovation is a piece of a larger puzzle. This brings us to the third key dimension of innovation - **cumulativeness**.

The dimension of **'cumulativeness'** in innovation presents a valuable perspective that emphasizes the interconnectedness and progression of innovative efforts over time. For Murray and O'Mahony [7], innovation is not a stand-alone event or phenomenon. Instead, it's a dynamic, continuous process where new ideas and solutions often emerge from the insights and foundations laid by previous ones.

The concept of innovation cumulativeness depicts the interconnectedness between successive innovations and their reliance on previous knowledge and technology. By recognizing this, we can acknowledge that even minor or gradual breakthroughs contribute as building blocks to the foundation of advancement. Within this cumulative process lies the tremendous impact that innovation has, as each new invention or improvement has the potential to unlock new opportunities for exploration and growth.

The term **'disruptive innovation**,' first coined by Clayton M. Christensen [8], indeed offers a unique perspective on the dimension of cumulativeness in innovation. Disruptive innovations are typically those that disrupt an existing market by creating a new market and value network. They often start by appealing to less-demanding customers and then gradually improve to the point where they displace established competitors.

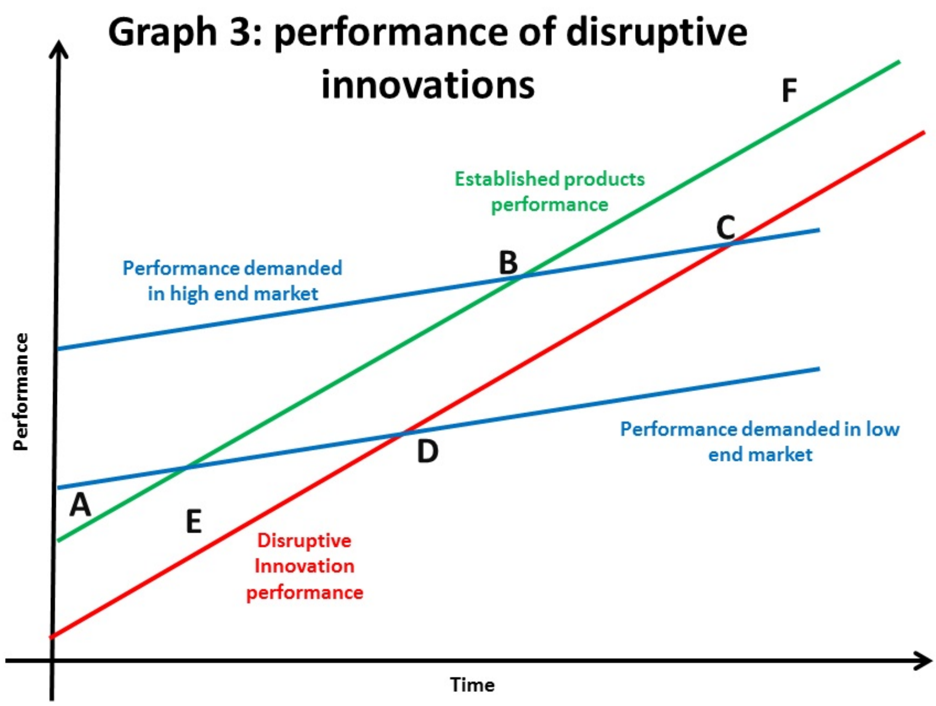
In the context of cumulativeness, disruptive innovations present an interesting conundrum. On one hand, they are non-cumulative in the sense that they don't just improve upon existing technology or processes; they create entirely new paradigms that can disrupt or even replace existing markets and industries.

However, it's important to note that even disruptive innovations do not occur in a vacuum. They are often built on the foundations of existing knowledge, even as they pioneer new paths. So, in another sense, they could be seen as cumulative, as they leverage existing knowledge to forge new directions.

In essence, disruptive innovation underscores the complexity of the innovation process, illustrating how it can both diverge from and build upon existing pathways of progress. This dual nature emphasizes the multifaceted nature of innovation and its ability to simultaneously drive continuous improvement and groundbreaking change.

In the context of the space launch services industry, a good illustration of this could be the development of reusable rocket technology. This innovation didn't emerge in a vacuum; rather, it was built upon decades of knowledge and advancements in rocket design, material sciences, computing, and aeronautics.

Thus, the cumulativeness of innovation emphasizes the trajectory of progress, highlighting how innovation today forms the steppingstone for the advancements of tomorrow. By appreciating this dimension of innovation, we gain a deeper understanding of the broader progression and evolution of industries.



In our analysis of innovation, we acknowledge that its complex character can be comprehended most effectively by exploring its various types, the level of novelty it embodies, and the extent of cumulativeness involved. By encompassing these aspects, we are able to shed light on the diverse elements of innovation that propel the development and advancement of industries like space launch services.

Tidd and Bessant's framework for categorizing innovation into product, process, position, and paradigm offers us a valuable tool to comprehend the various channels through which innovation can surface and bring about transformation. Likewise, the differentiation between continuous and discontinuous innovations as emphasized by Corso and Pellegrini assists in grasping the extent of change and its possible consequences.

The exploration of the cumulativeness of innovation underscores the importance of the innovation trajectory over time. It allows us to appreciate the interconnectedness of advancements, where each innovation, while unique in itself, builds upon the foundations of prior knowledge and technology.

The dynamic interplay of these dimensions showcases the intricacy of the innovation process. Notably, disruptive innovation exemplifies the complexity inherent in the cumulativeness of innovation, where new paradigms can diverge from, yet be rooted in, existing knowledge pathways.

As we unravel the dynamics of innovation within the space launch services industry or any other, we recognize that each innovation - whether an incremental improvement or a paradigm-shifting breakthrough, whether building upon existing knowledge or creating new value networks - contributes uniquely to the evolution and progression of the industry.

Understanding these facets of innovation provides valuable insights into the forces driving change and progress.

As we continue to delve deeper into the realm of innovation, this three-dimensional perspective - type, level of novelty, and cumulativeness - serves as a guiding framework to capture the breadth and depth of innovation's impact on industries and societies at large.

1.3. WHAT ARE THE CHARACTERISTICS OF THE CYCLES OF INNOVATION ?

Innovation, by its very nature, is an evolving process that unfolds over time. It is not a static event that happens in isolation but rather a dynamic continuum of ideas, discoveries, and advancements that go through various phases of development. This cyclical progression of innovation, from idea generation to commercialization and the further development of these innovations, forms the basis of what we term as **'cycles of innovation**.' Understanding these cycles is crucial for deciphering the patterns of innovation within industries, such as the space launch services sector.

In this next section of our literature review, we will delve deeper into the characteristics of these cycles of innovation. We will explore their various phases, the factors that influence their progression, and the interplay between different cycles. Furthermore, we will examine how these cycles shape and are shaped by the dynamics of the industry in which they occur. By understanding these cycles, we can gain a more comprehensive perspective on the innovation process, its drivers, its challenges, and its role in driving industry evolution and transformation. Let us commence our exploration of these innovation cycles and their characteristic features.

Joseph Schumpeter, a 20th-century economist, is widely regarded for his profound contributions to our understanding of economic development and its intrinsic relation to innovation. In his book from 1942, *Capitalism, Socialism and Democracy* [9], Schumpeter introduced a perspective on innovation that has since served as a cornerstone in the field of economics and innovation studies. Schumpeter's concept of "**creative destruction**," or the incessant product and process innovation mechanism by which new production units replace outdated ones, has proven influential in shaping our understanding of the innovation cycles.

In Schumpeter's view, the economic system is not in a state of static equilibrium but rather in a process of dynamic evolution. Innovation is a catalyst for this evolution and is both disruptive and transformative. It disrupts the status quo by rendering existing products, services, or processes obsolete and introduces transformation by paving the way for new methods, technologies, or practices. This dynamic process of creative destruction embodies the cyclical nature of innovation.

The cyclical pattern of innovation, as proposed by Schumpeter, manifests in what he termed "**business cycles**." These cycles are not steady, consistent patterns of growth but rather are characterized by periods of significant innovation and economic expansion followed by phases of consolidation, adjustment, and potential contraction. The cycles are self-propelling, driven by the continuous emergence and diffusion of novel technologies and practices.

Schumpeter's business cycles are punctuated by instances of radical, transformative innovations that disrupt existing industries and markets. These radical innovations often lead to bursts of entrepreneurial activity and rapid economic expansion, a phase Schumpeter referred to as a "swarm-like clustering" of innovations. This surge in innovative activity often comes with increased investments and substantial economic growth.

However, these periods of intense activity and growth are not sustained indefinitely. Following this expansion phase, the economy typically enters a period of digestion and assimilation. In this phase, the radical innovations that fueled the expansion are assimilated into existing systems and processes, leading to a period of consolidation. There may also be adjustments in the market, including potential downturns or contractions, as the economy absorbs and adjusts to the transformative effects of the innovation.

Despite the potential downturns or periods of slower growth, Schumpeter argued that these cycles are crucial mechanisms for economic development. They enable the creative destruction process where obsolete technologies or practices are replaced with novel ones, thus driving the continual evolution and progress of the economy.

Thus, innovation tends to unfold in cycles that reflect the dynamic interplay between technological advancements, market demand, entrepreneurial activity, and broader societal trends. These cycles can be broadly categorized into three phases: emergence, diffusion, and maturity.

1. **Emergence**: This is the beginning phase of the cycle, characterized by high levels of uncertainty and risk. It's during this phase that radical, transformative innovations are typically introduced, often by innovative entrepreneurs. These innovations can significantly disrupt established markets or even create entirely new ones. However, given the high levels of uncertainty associated with novel technologies or processes, this phase is also marked by intense competition, as various players vie to establish their solutions as the dominant design.

2. **Diffusion**: Once a dominant design emerges and gains acceptance in the market, the innovation enters the diffusion phase. The focus during this phase shifts from invention to improvement, with imitative and Fabian entrepreneurs playing a critical role. These entrepreneurs take the initial innovation and refine it, tailoring it to different market segments and customer needs, thus driving its widespread adoption.

3. **Maturity**: In the maturity phase, the pace of innovation slows down as the technology or process becomes standardized and widely accepted. During this phase, the market typically consolidates, with only a few major players remaining. Drone entrepreneurs, resistant to change, can thrive in this phase as the rate of technological change slows and the focus turns towards optimization and incremental improvement of the established design.

Each phase of the innovation cycle is critical and interdependent, with the actions and decisions made in one phase influencing the dynamics and outcomes of the next. Understanding these cycles can provide valuable insights into the evolutionary nature of innovation and help anticipate future trends and opportunities.

Therefore, Schumpeter's concept of innovation cycles offers a dynamic view of economic development. It depicts innovation not as a linear progression but as a cyclical process marked by periods of rapid change and slower consolidation. This perspective serves as an essential foundation in our exploration of the characteristics of innovation cycles.

The progression of innovation is heavily impacted by a multitude of factors interacting in a dynamic manner. Among these, the social aspects surrounding entrepreneurs hold significant sway. These individuals, with their distinct characteristics, abilities, and preferences, play a crucial role in shaping and propelling innovation cycles. To grasp this influence fully, it becomes essential to acknowledge the wide range of entrepreneurs who can be classified into different categories based on their inventive behavior.

Inventive entrepreneurs are the pioneers of innovation, originating innovative ideas, processes, or products. They have the ability to introduce original concepts that may initiate new cycles of innovation.

Once an inventive idea is established, daring and risk-taking individuals come into play as they become **innovative entrepreneurs**. These individuals transform the initial concepts into tangible and viable products or services, driving substantial changes in industries and markets.

In contrast, **imitative entrepreneurs** play a crucial role in diffusing innovations by adapting and enhancing existing innovations tailored to different markets or contexts. This ensures that new products or processes reach a wider audience.

On the other hand, **Fabian entrepreneurs** approach change cautiously and hesitantly compared to their more innovative counterparts. They only adopt new technologies or procedures when thorough proof of their utility and success has been obtained.

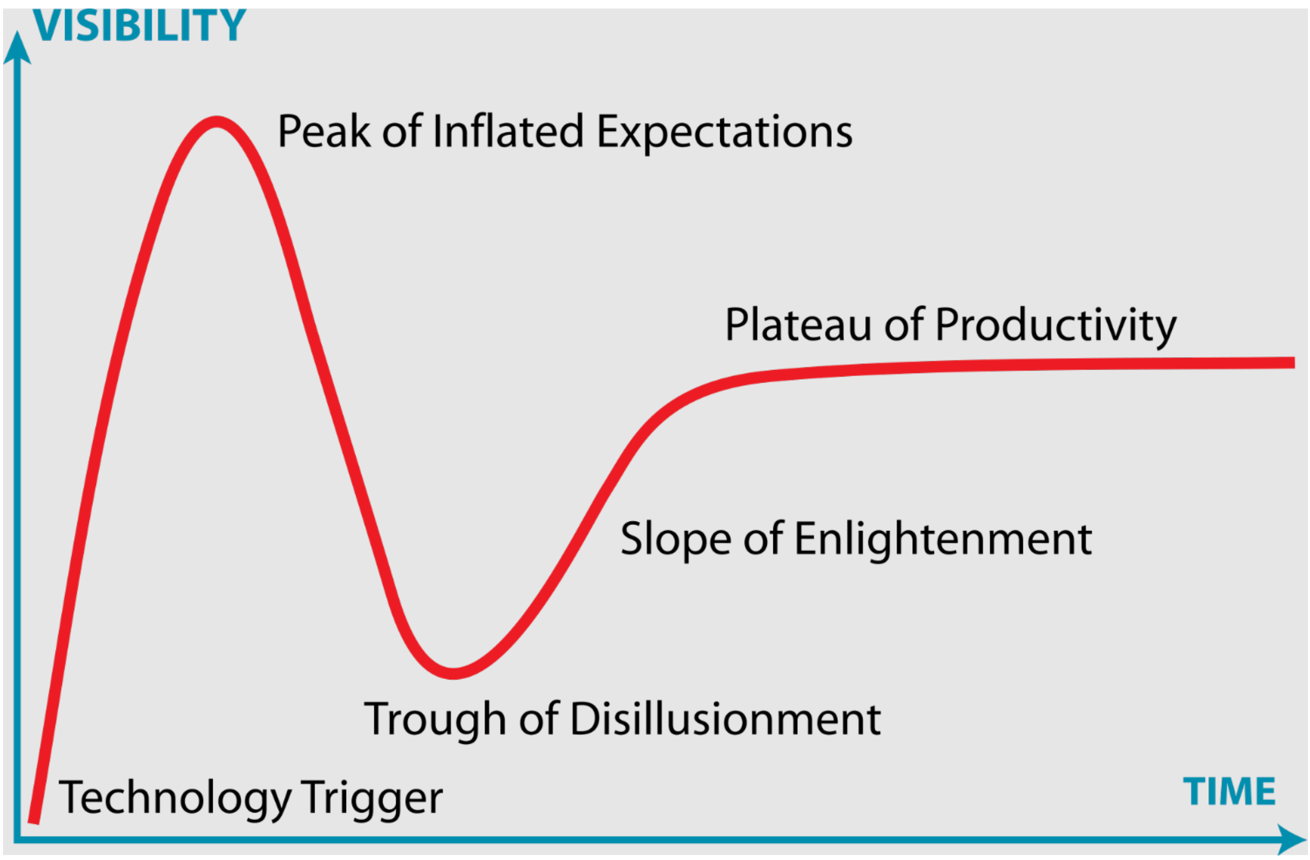
Lastly, **drone entrepreneurs** resist change even when clearly outdated methods and technologies are present. Their attachment to established norms can hinder innovation cycles but may also serve as motivation for others to innovate aggressively.

By considering the roles and behaviors of these different types of entrepreneurs, we can begin to appreciate the complexity of innovation cycles. Within this landscape, each entrepreneur has a unique contribution to make - either fueling the advancement or impeding the progress of these cycles. They serve as catalysts for change or act as obstacles that innovative entrepreneurs must overcome in their pursuit of success.|

1.2. THE IMPORTANCE OF THE HYPE CYCLE

If entrepreneurs have a crucial influence over innovation cycles, their behavior is also determined by another important macro factor: the concept of the **'Hype Cycle'**. The hype cycle was introduced by Gartner [10], a leading research and advisory company. The Gartner hype cycle provides a graphical representation of the life cycle stages that an emerging technology or innovation goes through from conception to maturity and widespread adoption. It aims to help understand the typical progression of an innovation, from overenthusiasm through a period of disillusionment to an eventual understanding of the innovation's relevance and role in a market or domain.

The Hype Cycle model comprises five key phases: Innovation Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment, and Plateau of Productivity.



The cycle commences with the "**Innovation Trigger**," wherein a potential technological breakthrough initiates the process. Anticipation begins to swell, even though practical applications of this innovation may still be scarce.

As the technology starts to be put into practice, early exposure gives rise to a multitude of success stories alongside numerous failures. Some companies take action in response, while many others do not. This results in what is known as the "**Peak of Inflated Expectations**."

Following that phase comes the "**Trough of Disillusionment**," during which interest diminishes due to failed experiments and unsuccessful implementations. Producers either consolidate or go out of business. Investments persist only if surviving providers can enhance their products adequately for early adopters.

In the subsequent stage referred to as the "**Slope of Enlightenment**," comprehension regarding how this technology can benefit businesses gradually solidifies, leading to more successful implementations and an increasing number of ways in which this technology can be applied.

Finally, we arrive at the perennial state called the "**Plateau of Productivity**." At this point, mainstream adoption gathers momentum as broad market applicability and relevance make it abundantly clear that investing in this technology has paid off handsomely.

The influence of hype cycles on entrepreneurs can vary depending on the type of entrepreneur and their approach to innovation and risk-taking.

Innovative entrepreneurs, often characterized by their risk-taking behavior and orientation towards fast growth, may be particularly attracted to the initial stages of the hype cycle - the innovation trigger and peak of inflated expectations. The promise of rapid growth and large potential markets associated with an emerging technology can appeal to their growth mindset and propensity for risk. They may seize the opportunity to ride the wave of hype, leveraging it to attract investors and customers to their ventures.

On the other hand, Fabian entrepreneurs with more conservative views tend to exhibit a preference for steady and predictable growth. Consequently, they may adopt a cautious approach when it comes to navigating through the hype cycle. These individuals may opt to enter the market during the slope of enlightenment stage, wherein there is sufficient evidence showcasing the potential of technology and enhanced predictability in market conditions. By carefully observing and learning from others' experiences during the earlier stages of this cycle, conservative entrepreneurs can capitalize on their acquired knowledge to minimize risks and uncertainties associated with new technological advancements.

Entrepreneurs with an inventive mindset, motivated by their profound faith in the revolutionary capacity of cutting-edge technologies, may not succumb to the sway of exaggerated expectations when embarking on a new business endeavor. Instead, they might wholeheartedly embrace an emerging technology right from its inception purely driven by their visionary perspective and recognition of its latent potential – unfazed by any surrounding frenzies. Furthermore, these aspiring individuals could endure through even the most disheartening phases characterized by disillusionment, fueled solely by their unshakeable belief that said technology carries immense intrinsic value over time.

Finally, imitative entrepreneurs, characterized by their critical and questioning approach, might engage with a new technology only after it has passed the trough of disillusionment and started climbing the slope of enlightenment. They might prefer to wait until the initial hype has subsided and the technology has demonstrated its practical value and reliability.

The hype cycle, in its essence, can function as a time-based guide for entrepreneurs to actively engage with emerging technologies. However, the distinct approaches to risk-taking, innovation, and value generation among different types of entrepreneurs can lead them on divergent paths while navigating this map.

1.3. THE ASSESSMENT OF EMERGING TECHNOLOGIES: THE TECHNOLOGY READINESS LEVELS

The concept of Technology Readiness Levels (TRLs) is a classification system initially developed by NASA in the 1970s to assess the maturity and readiness of a given technology for use in space missions [11]. This systematic framework serves as a valuable tool to gauge the maturity level of an emerging technology, effectively bridging the gap between scientific innovation and practical application.

TRLs are based on a scale from 1 to 9, where each level represents a specific stage in the lifecycle of the technology, from the initial idea to its full-fledged operation. This provides a structured and consistent approach to evaluate and compare the readiness of different technologies.

Level 1, representing the lowest tier, denotes the initial phase of technological advancement where fundamental principles have been observed and the concept remains purely theoretical. In this stage, the technology exists merely as an idea or hypothesis without any experimental evidence or comprehensive analysis to substantiate its potential.

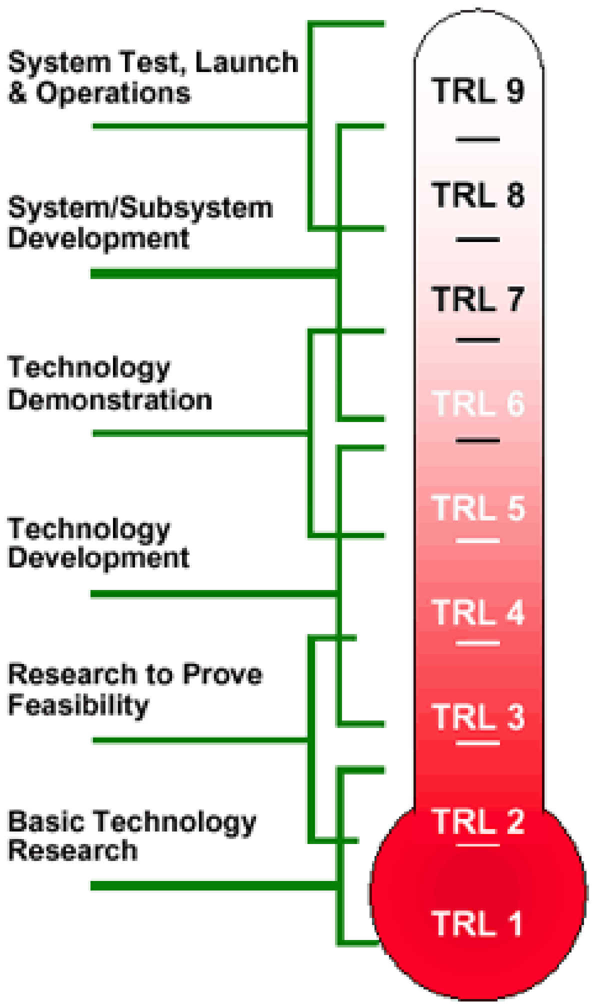
As we ascend through the levels, each subsequent tier signifies further progress in the development of the technology. At Level 2, the concept is formulated and implemented into a practical application. Levels 3 to 5 entail active research and development wherein the technology transitions from being an experimental proof-of-concept towards a validated component or system within laboratory settings.

Upon reaching Level 6, a relevant environment showcases a demonstrated prototype of the technology; examples include deployment in field scenarios or outer space for space technologies. System-level demonstrations take place at Level 7 within operational environments.

The completion and flight qualification of a technological endeavor are symbolized by Level 8 and 9 in our scale. The highest level achievable on this continuum is Level 9 which indicates that successful mission operations serve as irrefutable proof of effectiveness for said technology.

The TRL scale presents a straightforward and measurable depiction of the level at which a technology is prepared and developed. It furnishes individuals involved, such as scientists, business leaders, investors, and policymakers, with a shared vocabulary to analyze and assess advancements made in any particular technology. Moreover, the TRL framework aids in recognizing potential hazards, strategizing efforts towards progress, and effectively facilitating the movement of a technology from its experimental stage to commercialization.

In the context of the space launch services industry, understanding the TRL of an emerging technology can provide significant insights into its potential impact on the innovation cycles. It can help to identify the current position of the technology within the hype cycle and the role it might play in shaping the industry's future.



1.4. SUMMARY AND CONCLUSION OF THE LITERATURE REVIEW

In this literature review, we sought to explore and understand the intricacies of innovation and its pivotal role in shaping the landscape of the space launch services industry. We started by investigating the origins of innovation, revealing its multifaceted nature. As elucidated by Peter F. Drucker, innovation springs from seven major sources, such as unexpected occurrences, incongruities, process needs, changes in industry structure, shifts in demographics, advancements in scientific knowledge, and alterations in perception and meaning. These sources lay the groundwork for the birth and evolution of innovation within industries.

From there, we transitioned into characterizing the various types of innovation. Drawing upon the influential work of Joe Tidd and John R. Bessant, we identified four key categories: product, process, position, and paradigm innovation. Each type provides unique pathways for value creation, competitive differentiation, and the progression of industries. We then moved onto studying the two critical dimensions that shape the nature of innovation - the level of novelty and cumulativeness. These dimensions emphasized the scope of change an innovation can bring and the interconnectedness of innovative efforts over time, respectively.

The next section of the review examined the dynamics of innovation cycles. Taking inspiration from Schumpeter's work, we discussed the role of entrepreneurs, categorized into three types: Inventors, Innovators, and Imitators. Each of these entrepreneur types influences the rhythm and pace of innovation cycles, shaping the trajectory of industries.

Subsequently, we delved into the concept of the 'hype cycle,' which characterizes the phases of public expectation and disillusionment that new technologies often undergo. The hype cycle is a crucial element that impacts the behavior of different types of entrepreneurs and their decision-making processes.

Finally, to accurately gauge the potential impact of emerging technologies, we underscored the importance of assessing their maturity. Here, we introduced the Technology Readiness Level (TRL) – a metric initially developed by NASA – which provides a consistent approach to evaluate and compare the readiness of different technologies.

In summary, understanding the origins, types, and characteristics of innovation, alongside the dynamics of innovation cycles, is instrumental in comprehending the influence of emerging technologies on the space launch services industry. The assessment of the maturity of these technologies through TRL further enriches this understanding. The insights derived from this literature review will guide our subsequent investigation into the specific question of how these emerging technologies shape the innovation cycles within the space launch services industry.

2. CASE STUDY AND IMPACT ANALYSIS OF EMERGING TECHNOLOGIES IN THE SPACE LAUNCH SERVICES INDUSTRY

Transitioning from an extensive review of the literature on innovation and its cycles, we now delve into a more specific, context-rich exploration of the influence of emerging technologies in the space launch services industry. This sector, renowned for its swift technological progression and increasing strategic and commercial relevance, serves as the ideal backdrop for our investigation.

The focal point of this integrated study is threefold, encompassing three game-changing technologies poised to redefine the industry: 1) The use of 3D printing in rocket manufacturing; 2) The advent of reusable rocket stages; and 3) The introduction of super heavy rockets. Each of these innovations marks a significant divergence from conventional methodologies, carrying the potential to deeply affect the innovation dynamics within this space.

3D printing, the first of these, is transforming manufacturing processes with its unique capabilities in precision, scalability, and cost-effectiveness. The second, reusable rocket stages, signals a shift towards enhancing the economic viability of space launches through improved resource utilization. The third, super heavy rockets, represents a leap in payload capacity and performance, opening up unprecedented possibilities for missions beyond Earth's orbit.

These technologies, their current state of adoption, and the subsequent impacts on the industry's innovation cycles will form the heart of our analysis. We aim to scrutinize how these technological disruptions are shaping the patterns of invention, innovation, and imitation within the space launch services industry.

Our investigation goes beyond a narrow focus on individual technologies. Instead, we aim to delve into the interconnectedness and mutual influences of these technologies. By taking this comprehensive approach, we will gain better insights into how these technologies collectively shape innovation cycles within the industry.

Through an intricate analysis combining detailed case studies of emerging technologies with profound examination of their impact, our primary goal is to address the core question: "What is the effect of emerging technologies on innovation cycles in the space launch services industry?". Our research seeks to uncover how technology, innovation, and industry evolution intertwine to bring about transformative changes within this sector.

2.1. 3D PRINTING FOR ROCKET MANUFACTURING

At the forefront of revolutionary manufacturing processes that are transforming both construction and object design, additive manufacturing, commonly known as 3D printing, has made a significant impact in the aerospace industry, particularly in rocket production.

In its essence, 3D printing involves layering material successively according to a predetermined pattern outlined by a digital model. This enables complex geometries and intricate designs beyond what traditional manufacturing methods can achieve [12]. The implications for rocket fabrication are profound -- components that were once manufactured separately and then assembled together can now be produced as one single piece. This simplifies the building process, shortens the manufacturing time, and minimizes potential errors.

A compelling example of this is evident in the production of rocket engines. Conventionally composed of multiple parts manufactured separately before being joined together, incorporating additive manufacturing allows many of these components to be consolidated into one unit. In turn, this simplifies production significantly while also reducing engine weight - an essential advantage in an industry where every kilogram counts.

The space launch services industry has warmly embraced 3D printing due to recent technological advancements enabling materials capable of withstanding extreme conditions experienced during space flight to be utilized. Direct Metal Laser Sintering (DMLS), one specific type of 3D printing technique, employs lasers to fuse layers of metal powder together into a robust object able to withstand demanding circumstances encountered during a rocket's ascent.

The advent of 3D printing within the space industry signifies an era characterized by innovation on multiple fronts; it not only reshapes existing manufacturing methodologies but also contributes significantly towards rapid cycles of innovation often experienced within this sector.

2.1.1. CHARACTERIZATION OF THE TECHNOLOGY

Examining 3D printing for rocket manufacturing through the lens of our literature review, we see that it represents an intriguing case of innovation in action.

To begin, 3D printing in rocket manufacturing is a **process innovation**, as defined by Tidd and Bressant. Though rockets themselves are not new, the advent of 3D printing has fundamentally transformed the means of their production. Process innovations often lead to improved efficiencies and reduced costs, and in this context, 3D printing has indeed revolutionized the process, resulting in streamlined production and enhanced performance of rocket components.

The birth of this advancement can be attributed to a blend of factors, namely the pull from the market and the push from technology. Market-pull innovations arise in response to a specific need in the space launch sector: an urgent demand for rocket components that are less complex to produce, cost-effective, and lightweight. Conversely, technology-push advancements are propelled by progressions in technology. The evolution of novel materials suitable for 3D printing under extreme conditions, coupled with enhancements in 3D printing methods themselves, have played a critical role in facilitating its integration into rocket production.

From the perspective of Schumpeter's entrepreneurial typology, the players who are pioneering and championing the use of 3D printing in rocket manufacturing could be classified as inventive entrepreneurs. They introduce a disruptive process innovation into the industry, challenging the status quo of traditional manufacturing methods and changing the competitive dynamics in the space launch sector.

Lastly, the Gartner Hype Cycle serves as a useful tool for understanding the public perception and maturity of 3D printing in rocket manufacturing. After navigating the initial surge of inflated expectations and subsequent trough of disillusionment, 3D printing is seemingly on its path towards the 'plateau of productivity', where its benefits become widely recognized and accepted, indicating a maturation of the technology and its adoption into routine operational procedures.

Relativity Space, a prominent aerospace manufacturer, is an excellent example of an organization embracing 3D printing technology. Founded in 2015, this company is pioneering the use of 3D printing in the production of rockets with a mission to build humanity's future in space. Using their in-house developed Stargate 3D printers, which are among the largest in the world, Relativity Space has been able to automate and streamline their manufacturing process, constructing rocket components in days instead of months. [13] Their flagship rocket, Terran 1, is a testament to the potential of this technology, with nearly 95% of its parts being 3D printed. Their application of 3D printing to rocket manufacturing is breaking traditional industry norms and positioning Relativity Space as a 'creative destructor' in the space industry.

In summary, 3D printing in rocket manufacturing is a process innovation driven by both market demand and technological advancement. Its introduction and adoption are initiating a Schumpeterian cycle of creative destruction in the space launch industry, marking a paradigm shift in manufacturing methods.

2.1.2. ASSESSMENT OF THE TRL

The Technology Readiness Level (TRL) of 3D printing for rocket manufacturing is relatively advanced. As per the definitions established by NASA, the TRL is characterized by nine levels, with level 1 indicating the lowest level of technology maturity and level 9 indicating an actual system "mission proven" through successful mission operations.

As of now, 3D printing for rocket manufacturing could be argued to be at TRL 7 or 8. This assessment is based on the fact that system prototypes have been demonstrated in an operational environment. Companies such as Relativity Space have performed successful test firings of engines and other major components manufactured through 3D printing, showcasing system functionality in a simulated environment. Furthermore, SpaceX, has incorporated 3D printed parts in their operational rockets, demonstrating the practical feasibility of this technology.

However, the technology has not yet reached TRL 9 as a full launch vehicle, wholly manufactured through 3D printing, has not yet been demonstrated in mission operations. Nevertheless, with advancements in additive manufacturing and companies investing heavily in R&D, this milestone might be achieved in the near future. Therefore, while the technology has shown significant promise and has matured considerably, it still has to prove itself fully in the field of space launch services.

2.1.3. IMPACT ANALYSIS

3D printing has transformative potential for the space launch services industry. This impact can be analyzed from various perspectives, particularly in terms of cost reduction, design flexibility, and shorter production times.

The initial aspect to consider is the financial burden of production which directly affects both the feasibility and competitiveness of space launch services. The introduction of 3D printing technology has proven to be a cost-effective solution, primarily due to its ability to minimize wastage during the manufacturing phase. Unlike conventional methods such as milling or forging, which involve shaping objects by carving material from larger blocks, 3D printing facilitates layer-by-layer construction using only essential materials for the final product, resulting in reduced waste and subsequently lowering costs. Additionally, intricate components can now be printed as one cohesive unit without the need for subsequent assembly processes, further decreasing expenses.

Secondly, 3D printing brings unparalleled design flexibility. In traditional manufacturing, complex designs often translate into complex and expensive production processes. However, 3D printing is less constrained by design complexity. This capability allows engineers to create more efficient designs that would have been impossible or too expensive to manufacture using traditional methods. For example, intricate cooling channels can be printed directly into rocket engines, increasing their efficiency and performance.

Thirdly, 3D printing can significantly reduce production times. Once the design is finalized, 3D printers can operate around the clock, producing parts faster than traditional manufacturing methods. This rapid production capacity can increase the speed of iteration in the development process, allowing for faster innovation cycles. For example, a change in the design software can be quickly translated into a new physical prototype.

In summary, the utilization of 3D printing possesses the capability to completely transform the sector of space launch services. This transformation would occur through enhanced cost-effectiveness, adaptability and efficiency. Such advancement holds the prospect of shortened innovation cycles and reduced expenses whilst also allowing manufacturers greater design flexibility. As a result, this has considerable potential to drastically modify the competitive dynamics within this industry. Nonetheless, for these advantages to materialize fully, it becomes imperative that companies successfully and promptly incorporate this technology into their practices while concurrently adapting regulatory frameworks in response to these novel manufacturing methodologies.

2.2. REUSABLE ROCKET STAGES

The notion of utilizing previously launched rockets is not novel within the realm of space exploration. However, it has long been regarded as a complex technological hurdle and financially unviable endeavor. Under the traditional approach to space travel, rocket stages were engineered solely for singular deployment purposes – leading to discarding most components after each mission's completion. While technically simpler in design, this methodology proved cost-prohibitive due to its requirement for manufacturing fresh rockets prior to every launch.

The emergence of private space companies such as SpaceX has revolutionized the way we approach space missions. These companies have put forth the notion of reusability as a crucial method to mitigate astronomical costs linked with launching spacecraft. To be precise, their strategy revolves around creating rockets that can safely return to Earth after providing payloads to their intended destinations and can subsequently be revitalized and employed for numerous subsequent missions. An example of this groundbreaking concept is SpaceX's remarkable Falcon 9 rocket, distinguished by its first stage which is ingeniously engineered to make a triumphant return back to our planet post-separation, enabling it to take flight once again in future endeavors.

Reusable rockets necessitate a plethora of inventive technologies and design principles. These encompass potent and economical engines capable of enduring several ignitions, sturdy thermal shielding to withstand the searing temperatures during re-entry, and accurate navigation systems for the successful touchdown of the rocket on Earth. Furthermore, thorough consideration should be given to ensuring the rocket stages' durability so that they can endure the demanding strains imposed by multiple launches and re-entries.

The space launch industry stands at a critical juncture with the triumphant integration of reusable rocket stages. Should these promises of reusability prove to be justified - including substantial reductions in launch expenses, expedited turnaround times for launches, and expanded entry into outer space - we might find ourselves on the cusp of an epoch-defining era in space exploration and commercialization. Nevertheless, reminiscent of any groundbreaking revolution, there are obstacles and unknowns that necessitate overcoming for us to fully embrace these advantages.

2.2.1. CHARACTERIZATION OF THE TECHNOLOGY

The reusability of rocket stages or rocket parts, as practiced by SpaceX and others, can be categorized as a **process innovation**, given its radical departure from the traditional single-use approach to spacecraft. The concept doesn't introduce a new product but fundamentally alters how space launches are carried out by changing the lifecycle of a rocket. This makes the space launch process more efficient and cost-effective.

The innovation was driven by the visionary entrepreneur Elon Musk, founder and CEO of SpaceX. Musk, as an entrepreneur, certainly fits Schumpeter's description of an innovative entrepreneur who upsets equilibrium by introducing new ways of doing things. He set out with the explicit goal of reducing space travel costs and enabling the colonization of Mars, and reusable rockets are integral to this vision [14].

The source of this innovation is a mix of technological advancement, entrepreneurial drive, and economic necessity. The idea of reusable rockets isn't new; however, the development and successful implementation of the technology required significant advancements in various fields like materials science, propulsion, and control systems. It also needed an entrepreneurial push and a supportive market environment that saw the value in the promised cost reductions.

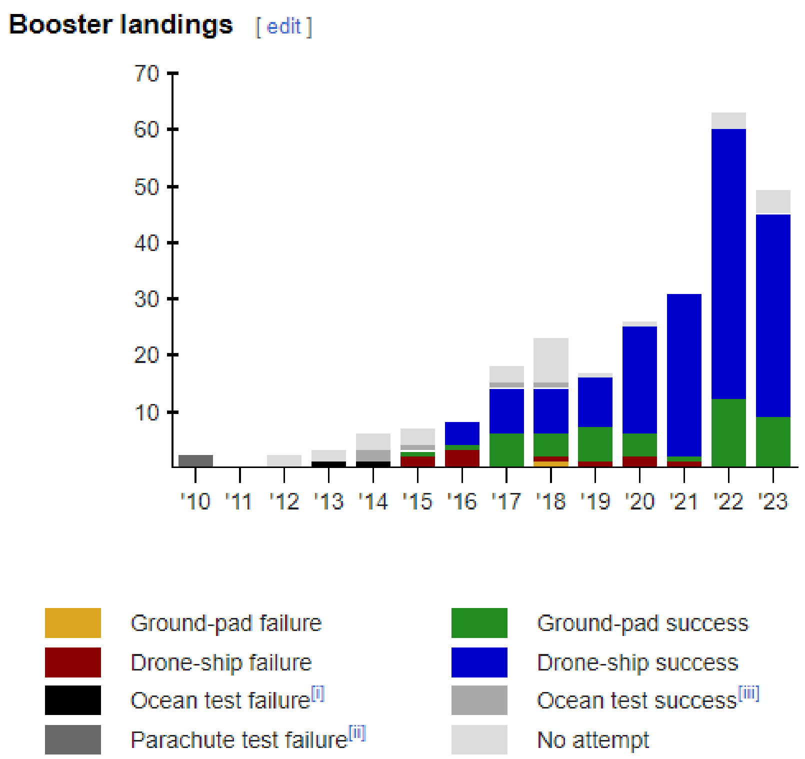
The notion of reusable rockets has already transcended the peak of inflated expectations and the trough of disillusionment, as depicted by the hype cycle. SpaceX's accomplished reuse of the Falcon 9 first stage offers concrete proof that this technology functions effectively, staying true to its commitment to decreasing launch expenses. To date, SpaceX’s record for the Falcon 9 booster with the most launches without major refurbishment is held by booster B1058 which has already flown sixteen times [15]. Consequently, it firmly places itself in the phase characterized by increased awareness and acceptance, known as the slope of enlightenment.

2.2.2. ASSESSMENT OF THE TRL

The technology readiness level (TRL) of reusable rocket stages, in the context of SpaceX's Falcon 9 and Falcon Heavy rockets, can be considered to be at TRL 9 - "Actual system proven through successful mission operations". This is the highest level on the TRL scale, indicating that the technology is mature and has been tested in real-world operational conditions.

SpaceX's Falcon 9 first stage has been routinely reused in multiple successful missions, significantly reducing the cost per launch. The first such successful landing occurred in 2015, and since then, SpaceX has landed Falcon 9's first stage more than 200 times with a success rate of 94.9% [15]. Falcon Heavy, which uses three Falcon 9 boosters, has also seen successful recovery and reuse.

Thus, the concept of reusable rocket stages is not merely experimental or theoretical. It is a tried-and-tested approach to space launches, with a proven track record of successful operational missions. It is also continually being optimized to improve its economic benefits and overall mission feasibility. Hence, reusable rocket stages have achieved a high level of technological readiness.



2.2.3. IMPACT ANALYSIS

The advent of reusable rocket stages has significantly influenced the dynamics of the space launch services industry. This innovation brought by SpaceX has caused a paradigm shift, shaking up the traditional space industry.

The **economic implications** of using reusable rockets are profound. The primary effect is seen in the affordability of space exploration. SpaceX has effectively diminished the expenses linked to launching rockets into space by employing reusable rocket stages, consequently widening access to outer space for a more diverse audience. Moreover, this cost reduction goes beyond mere incremental advancements; it holds the potential to revolutionize business strategies, enabling the creation of unprecedented ventures such as extensive constellations dedicated to providing global internet connectivity (for instance, Starlink). These innovative projects were previously deemed unattainable due to their exorbitant costs but can now become a feasible reality thanks to the development of reusability in rocket technology.

Reusable rockets also show a potential for **industry disruption**: SpaceX, through its remarkable achievement of cost reduction in launches and the successful demonstration of reusable rockets, has caused a significant disturbance within the space industry. This disruption has placed considerable pressure on other launch service providers, compelling them to invest resources into creating their own reusable launch systems; failure to do so would leave them susceptible to being overshadowed by SpaceX's capabilities. The consequences of this disruption have sparked an intensification in innovation across the entire industry.

The potential of reduced expenses and heightened launch frequencies facilitated by reusable rocket stages could conceivably result in the **increase of activity**. This encompasses a broad spectrum, including scientific investigations, exploratory missions, as well as commercial ventures like satellite deployment and space tourism. It introduces avenues for an expanded array of missions, increased participation from various entities, and an expedited pace in human endeavors throughout space exploration.

2.3. SUPER HEAVY ROCKETS

Super heavy rockets, also referred to as super heavy-lift launch vehicles (SHLLVs), represent the next significant frontier in rocket technology [16]. These launch vehicles are designed to carry extremely heavy payloads into space, surpassing the capabilities of current heavy-lift launchers (above 50t). Their increased lifting capacity is set to open new possibilities for space exploration, including manned missions to Mars and beyond.

SpaceX's Starship serves as an outstanding illustration of a super heavy rocket. This two-stage-to-orbit (TSTO) spacecraft is designed to be fully reusable, with the promise of boasting immense lifting capacity (100 to 150t to LEO). It encompasses various applications—from transporting satellites to Earth's orbit and beyond, servicing the International Space Station with humans and resources, to facilitating ambitious voyages to the Moon, Mars, or potentially even other celestial bodies [17].

Another notable super heavy rocket under development is NASA's Space Launch System (SLS). Designed as a powerful, advanced launch vehicle, the SLS will be pivotal to NASA's Artemis program, which aims to return humans to the Moon and establish a sustainable human presence there.

Developing super heavy rockets is a highly ambitious undertaking that presents numerous technological and engineering obstacles. Among these challenges are the necessity for stronger yet lighter materials, more robust engines, and state-of-the-art guidance and control systems. Additionally, substantial testing and validation procedures are essential to guarantee the safety and dependability of these vehicles.

The emergence of super massive rockets is poised to trigger notable transformations within the space sector. This development signals a shift in the industry's attention towards delving deeper into space exploration, potentially leading to the establishment of human settlements beyond our planet, while also bringing about a considerable decrease in the expense required for accessing space.

2.3.1. CHARACTERIZATION OF THE TECHNOLOGY

From the source of innovation perspective, super heavy rockets represent a fusion of both product and positioning innovation. SpaceX's Starship promises a rocket twice as powerful as the current tenant of the title the Saturn V that first brought humans to the Moon. In terms of positioning, SpaceX is seeking a blue ocean [18] with a super high-capacity rocket for a target price between 20 and 100$ per kilogram compared to 10200$ per kilogram for an Ariane 5 for instance [19].

In terms of the type of innovation, super heavy rockets embody both incremental and radical innovation. On one hand, they integrate and improve upon existing technologies, such as propulsion systems and materials. This reflects incremental innovation as it builds upon the already established foundation of rocket technology. On the other hand, the overall concept of a reusable, super heavy-lift vehicle that can transport large payloads to Mars and beyond is a significant departure from the current norms in the space industry, thus representing a radical innovation.

The Starship serves as a remarkable example of continuous innovation in the space launch services sector. This state-of-the-art spacecraft greatly surpasses the performance capabilities of its counterparts presently functioning in the market. With an unmatched ability to carry payloads, a reusable design, and potential for interplanetary voyages, the Starship not only stretches the limits of technical feasibility but also considerably boosts the operational efficiency and effectiveness of space missions. As a result, it elevates competition within the industry and establishes novel benchmarks, solidifying its status as an epitome of sustained innovation.

As of this moment, SpaceX's Starship can be observed to be at the peak of inflated expectations in the hype cycle of the space launch services industry. This ambitious project, while promising ground-breaking advancements, is currently amidst significant hype, fueled by its lofty objectives and SpaceX's consistent media presence. However, it is crucial to bear in mind that this position in the hype cycle often precedes a phase of disillusionment as the practical challenges of realizing such innovative leaps become evident.

2.3.2. ASSESSMENT OF THE TRL

Assessing the Technology Readiness Level (TRL) of super heavy rockets requires a deep understanding of the maturity of the underlying technologies and the system as a whole. Based on the descriptions provided by NASA and the European Space Agency (ESA), the TRL of super heavy rockets like SpaceX's Starship could be considered to be between 6 and 7.

TRL 6 is defined as "technology demonstrated in relevant environment." SpaceX has performed a variety of test flights with the Starship prototypes, including high-altitude flights, landing maneuvers, and heat shield tests. This has shown that individual components of the system are functioning in a relevant environment, satisfying TRL 6.

At the same time, TRL 7, defined as "system prototype demonstration in a space environment," seems to be within reach. SpaceX is aiming to perform orbital test flights in the near future, which would validate the system in a space environment. However, these tests have not yet occurred as of mid-2023, and thus the technology cannot yet be classified as TRL 7.

In conclusion, while there has been substantial progress, super heavy rockets are not yet fully mature technologies. Their exact TRL will depend on the successful completion of the upcoming tests and demonstrations. Despite this, the progress that has been made so far is quite promising, pointing to the potential of super heavy rockets to revolutionize the space industry.

2.3.3. IMPACT ANALYSIS

The emergence of super heavy rockets like SpaceX's Starship has the potential to stir up a revolutionary shift in the space industry and its patterns of innovation. This impact can be examined through three key lenses: the expense associated with reaching outer space, the magnitude of missions that become possible, and the transition towards embracing a vision of life across multiple planets.

Firstly, these rockets promise a dramatic reduction in cost per kilogram to orbit, primarily achieved by full reusability and high launch frequency. This could broaden the range of feasible space missions, enable new types of entrepreneurial activities, and induce a surge of creative, radical innovation in the sector. Given the cost-sensitivity of space projects, this impact cannot be overstated.

Secondly, super heavy rockets significantly increase the payload capacity to orbit and beyond. This not only enhances the scope of single missions but could also reduce the complexity of missions previously requiring multiple launches. It could push the boundaries of what's possible, paving the way for ambitious endeavors such as large-scale space stations, lunar bases, and even manned missions to Mars. Such a shift in potential mission size would undoubtedly accelerate the pace of innovation, as it allows for larger and more complex projects to be undertaken.

Lastly, the vision of making life multi-planetary, as advocated by Elon Musk, is inseparable from the development of super heavy rockets. By providing the capability to transport significant numbers of passengers and large amounts of cargo to Mars, it sets the foundation for the colonization of other planets. This vision adds a new dimension to the innovation cycles, inspiring not only incremental and radical innovations in related sectors but also the creation of entirely new industries.

To sum up, the immense abilities of super heavy lift launchers like SpaceX's Starship possess the power to revolutionize and reshape the patterns of progress prevailing in the space launch services sector. Nevertheless, it is crucial to acknowledge that these potential ramifications can only be realized if these technologies mature successfully and operate seamlessly.

2.4. COMPARATIVE ANALYSIS AND CONCLUSION

In conducting this comparative analysis of 3D Printing for Rocket Manufacturing, Reusable Rocket Stages, and Super Heavy Rockets, distinct patterns emerge in the impacts these emerging technologies have on the innovation cycles within the space launch services industry. Each of these technologies embodies varying forms of innovation, stemming from different sources and at different stages of readiness, yet they all share the potential to profoundly transform the sector.

3D Printing for Rocket Manufacturing is essentially a process innovation originating from established industries, demonstrating the disruptive potential of cross-industry technology transfers. It's at a relatively high technology readiness level (TRL 9), and its implementation has primarily influenced the industry's cost structures and production timelines, fostering efficiency-oriented incremental innovation.

Reusable Rocket Stages, on the other hand, represent both a product and a process innovation. The technology, although spearheaded by a single entrepreneurial entity, SpaceX, has now become an industry-wide focus. It's at an advanced stage of development and operation (TRL 9), and its main impact lies in dramatically reducing launch costs and increasing launch frequency, fueling both incremental and radical innovation.

Super Heavy Rockets embody an infrastructural innovation, aiming at reshaping the very parameters of space missions. Currently at a moderate technology readiness level (TRL 6), these rockets primarily inspire radical and architectural innovation, by pushing the boundaries of what's possible and enabling the pursuit of previously unimaginable goals like the colonization of Mars.

In conclusion, the case study of these emerging technologies reveals a dynamic and complex interaction between technology, innovation, and industry evolution. Their varied impacts on cost, scale, frequency, and scope of space missions are concurrently reshaping the competitive landscape and innovation cycles in the space launch services industry. As these technologies continue to mature and evolve, they are likely to induce further changes, leading to a more accessible, frequent, and ambitious era of space exploration.

3. IMPLICATIONS AND RECOMMENDATIONS FOR THE INDUSTRY

As we transition into the subsequent part of this master's thesis, our attention shifts from analysis to implementation. The aim is to investigate the consequences that the emergence of specific technologies such as 3D Printing for Rocket Manufacturing, Reusable Rocket Stages, and Super Heavy Rockets has on the space launch services industry. Grasping these implications will not only assist stakeholders in comprehending ongoing changes more effectively but also empower them to make well-informed decisions in light of these transformations.

In the following sections, we will present essential suggestions targeting different stakeholders involved in the industry. These recommendations will be built upon our earlier examination and will seek to offer practical approaches for a range of actors, including existing companies, fresh players, financiers, and policymakers. The goal is to successfully adapt to the changing environment by providing concrete strategies.

Lastly, we will explore the future outlook of the space launch services industry in light of these emerging technologies. In essence, we will paint a picture of what the future might hold, based on the trends we have observed and the trajectories these technologies seem to be following.

In this section, our aim is not just to predict the future but to provide industry stakeholders with a set of tools and perspectives to actively shape it. Understanding the implications, following the recommendations, and preparing for the future outlook will serve as guides to all stakeholders as they chart their course through the rapidly evolving space launch services industry.

3.1. IMPLICATIONS FOR THE INDUSTRY

The advent of 3D Printing for Rocket Manufacturing, Reusable Rocket Stages, and Super Heavy Rockets is reshaping the space launch services industry, engendering new paradigms and upending traditional models. These implications are multifaceted, affecting various areas of the industry in significant ways.

One of the most profound implications is the shift in manufacturing norms. 3D printing for rocket manufacturing represents a sea change in production models, introducing the potential for dramatic cost savings, increased customization, and reduced lead times. This reconfigures the traditional cost structures, allowing companies to operate more efficiently and respond more dynamically to market demands. It opens doors to smaller players who can now compete in what was once the realm of well-funded, large-scale enterprises.

The emergence of reusable rocket stages carries its own set of implications. The most significant among these is the potential for substantially reduced launch costs, potentially turning space accessibility from a privilege of a few to a commonplace reality. It may enable more frequent launches, leading to a surge in space-related activities - be it scientific exploration, satellite deployment, or space tourism.

The advent of super heavy rockets creates new possibilities in terms of payload capacity and mission scope. These mega-rockets are paving the way for more ambitious space exploration and colonization missions, possibly reigniting the public's interest and governmental support in space activities. This could lead to a surge in funding and innovation across the industry.

Each of these technologies, in their own way, is reshaping the competitive landscape, forcing established players to adapt and evolve, while providing new entrants with unique opportunities. In essence, the space launch services industry stands at the precipice of a new era, with these technologies serving as the catalysts for change. The implications are as profound as they are far-reaching, set to redefine the industry's trajectory for decades to come.

3.2. RECOMMENDATIONS FOR STAKEHOLDERS

Given the rapidly changing landscape of the space launch services industry, both new and legacy stakeholders must adapt and prepare for the impending disruptions. The following recommendations, while not exhaustive, offer a guide for navigating these tectonic shifts.

To thrive in the realm of space exploration, emerging players should max out on the possibilities presented by cutting-edge technologies. These revolutionary advancements, like 3D printing and reusable parts for rockets, possess immense potential to level the playing field by empowering new entrants to rival industry giants. It becomes crucial for these fresh actors to construct their game plans around these technologies while embracing adaptability, originality, and effectiveness as core pillars.

Embracing collaboration and fostering partnerships can also be an effective approach for new space actors. Given the complexity and high stakes of space operations, collaborating with other stakeholders - whether they are fellow startups, academic institutions, or even legacy actors - can help mitigate risks and accelerate growth. Additionally, seeking strategic partnerships with downstream industries could prove fruitful, such as satellite manufacturers, space tourism operators, or scientific research entities, to create an integrated, value-driven ecosystem.

On the other hand, legacy space actors face the challenge of maintaining their market position in the face of disruptive innovations. To this end, they must become more adaptive and receptive to change. Although these organizations have the advantage of extensive experience, large-scale infrastructure, and established relationships, the introduction of these emerging technologies necessitates a more innovative mindset.

Research and development hold significant importance for longstanding actors in the field. The incorporation of technologies such as 3D printing, reusable rockets, and super heavy rockets holds immense potential to provide crucial advantages and ensure their competitive dominance. Furthermore, it would be wise for them to explore collaborations with pioneering startups, blending their established assets with the fresh perspectives and nimbleness of these fledgling companies. This approach has the potential to cultivate an atmosphere of innovation, which is paramount for sustaining competitiveness in this rapidly evolving industry.

In conclusion, it is imperative for both emerging and established actors to remain vigilant regarding changes in regulations. The ever-changing technology field will inevitably lead to the development of new rules and obligations for compliance. Taking a proactive approach in influencing these regulations and being ready to fulfill them will significantly contribute to their sustained achievements within the industry.

3.3. FUTURE OUTLOOK

As we cast our gaze towards the forthcoming era of the space launch services field, a landscape characterized by ceaseless technological progress, heightened rivalry, and a greater stress on sustainability and economic efficiency becomes palpable in our minds.

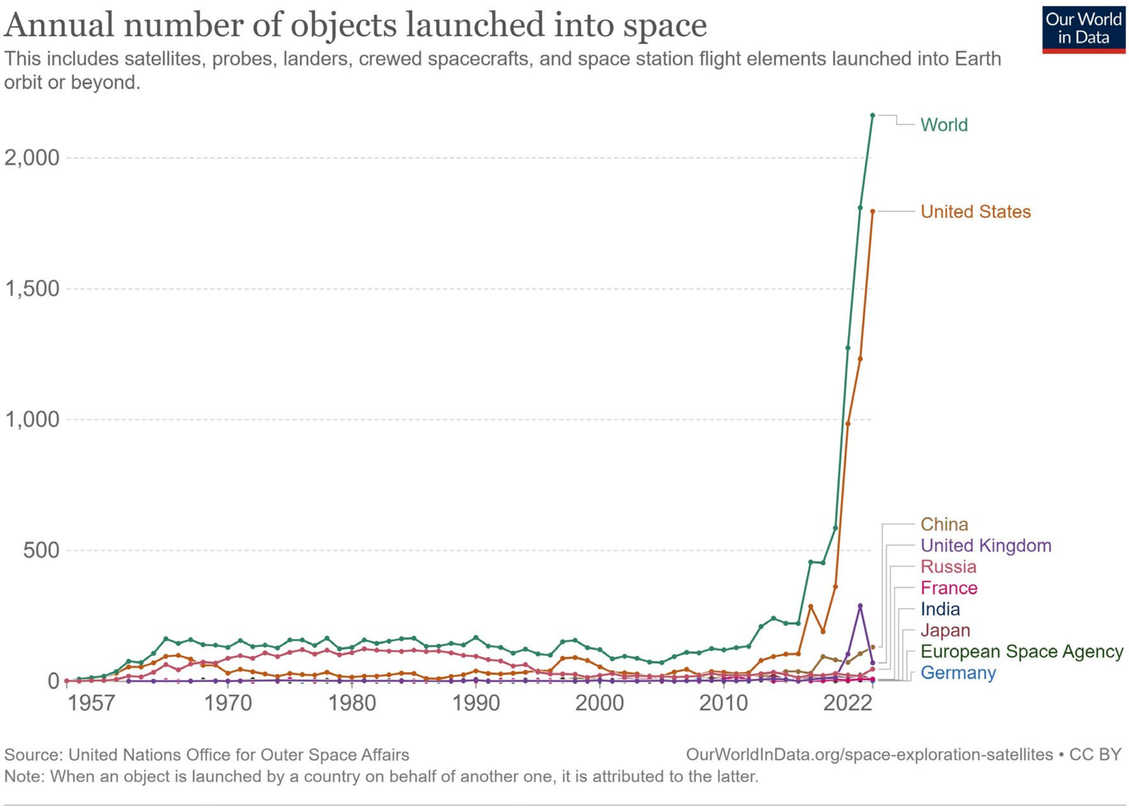
To begin with, it is highly improbable that the speed of technological progression will decelerate. The field is on the brink of experiencing further ground-breaking developments, fueled by emerging technologies like cutting-edge materials, artificial intelligence, and advanced propulsion systems derived from future generations. Furthermore, the drive to make space accessible to all will persist, resulting in heightened involvement from private companies, academic institutions, and even individuals who are passionate about the subject matter.

The sector will encounter heightened rivalry as well. The emergence of 3D printing, reusable rocket phases, and immensely heavy rockets has decreased obstacles to participation and raised the likelihood of disturbance. Up-and-coming players within the space domain will persist in challenging established operators, propelling innovations forward, reducing expenses, and enhancing services. As a result, this may trigger a transformation in market dynamics with new frontrunners potentially emerging in the field.

The future will witness an increasing emphasis on sustainability and cost-effectiveness. As the number of launches rises [20], the importance of sustainable methods to reduce environmental harm will also grow. The prominence of reusable rockets as a solution to this concern will continue to rise. Additionally, the pursuit for cost-effectiveness will endure, aided by technologies like 3D printing and the introduction of super heavy rockets. These innovations have the potential to dramatically decrease production expenses, subsequently reducing launch costs and expanding opportunities for space exploration and utilization.

In the near future, we anticipate a surge in the significance of regulations and standards. As the private sector's participation and global collaboration in space continue to expand, there will be an evolution in regulations aimed at guaranteeing safety, fairness, and sustainability. Both emerging players and existing operators must be willing to adjust to these shifting regulatory frameworks.

Essentially, the space launch services industry's trajectory is teeming with both promising prospects and formidable obstacles. Those capable of exploiting the potential of cutting-edge technologies, adjusting to ever-changing market forces, and maneuvering through regulations will find themselves excellently poised to take charge during this upcoming era of interstellar investigation.



[21]

CONCLUSION

To conclude, this thesis has delved into the intricate and diverse realm of emerging technologies and their influence on the cycles of innovation within the space launch services sector. Throughout this examination, we have observed how progress in technology, particularly in 3D printing, reusable rocket stages, and super heavy rockets, is not only altering the construction and operation methods of rockets but also molding the industry's strategic environment.

Our in-depth analysis illustrated the significance of Schumpeter's cycles of innovation theory, the hype cycle, and technology readiness levels as important frameworks to understand and assess the role of these emerging technologies in the industry. We characterized each technology according to its source, type, and TRL, allowing us to identify key implications for industry stakeholders, including new space actors and legacy operators.

We embarked on this expedition that guided us through captivating advancements made by groundbreaking enterprises like SpaceX, Blue Origin, and Relativity Space. Each of these companies employs various technologies in their pursuit to advance space exploration. Our investigation unveiled the significant influence of these technologies in lowering launch expenses, enhancing dependability, and fostering sustainable practices in space exploration. These outcomes have far-reaching implications for the entire industry as a whole.

In light of our findings, we provided recommendations for industry stakeholders. For new space actors, the necessity to embrace these technologies, innovate, and push boundaries was highlighted. For legacy operators, the need to adapt to these technological shifts and consider collaboration or strategic partnerships with these new space actors was stressed.

As we set our sights on the future, it is anticipated that there will be a persistent stream of new ideas and technological advancements in the industry. Alongside this, intensifying rivalry among companies and a growing focus on environmental responsibility and efficiency are poised to reshape the field. Moreover, alterations in regulations will wield significant influence in molding the industry's trajectory. This forthcoming period presents an array of prospects and difficulties for all those involved, guaranteeing an enthralling voyage ahead.

In essence, this thesis establishes a groundwork for forthcoming research to explore more deeply the ramifications of each burgeoning technology and their impact on various facets within the sector of space launch services. It emphasizes the pivotal role played by innovation in shaping industries, a concept that carries significant weight in our swiftly evolving world. As we persistently challenge the limits of space exploration, it becomes evident that innovation will continue to steer us towards a future previously envisaged only in the realm of speculative fiction.

AUTO-EVALUATION AND EXPERIENCE FEEDBACK

Embarking on this master's thesis journey has been an illuminating and enriching process for me. The exploration of the impact of emerging technologies on the innovation cycles in the space launch services industry has broadened my understanding of the field and equipped me with valuable insights into the intersection of technology, business, and industry evolution.

Initially, the vastness of the subject and the complexity of intertwining multiple concepts—innovation cycles, emerging technologies, and the specific context of the space launch services industry—seemed quite daunting. However, the research process became progressively less intimidating and more engaging as I delved deeper into the various facets of the topic.

Critically evaluating and integrating theories from a wide range of academic sources to build the literature review was a rigorous exercise that helped enhance my analytical and critical thinking skills. The case studies of 3D printing, reusable rocket stages, and super heavy rockets offered practical insights into how theoretical concepts manifest in real-world scenarios.

I found immense value in the process of interpreting these discoveries and converting them into implications and recommendations for industry stakeholders. This task compelled me to adopt a strategic mindset when considering the practical application of my research. It urged me to think from the standpoint of different stakeholders, taking into account not only the possible advantages brought by these technologies but also the obstacles they may encounter while adopting them.

Finally, the process of constantly re-evaluating and revising my research questions, as well as continuously updating my understanding of the technologies under study, has made me appreciate the iterative nature of research. It has taught me that our understanding of such complex phenomena is constantly evolving and being refined, much like the innovation cycles that I have been studying.

BIBLIOGRAPHY

[1] "Space Race - Wikipedia", en.wikipedia.org (Accessed 11 Jul. 2023).

[2] "The Space Race - Alpha History", alphahistory.com (Accessed 11 Jul. 2023).

[3] "RD-270 - Encyclopedia Astronautica", astronautix.com, (Accessed 11 Jul. 2023).

[4] P. F. Drucker. "Innovation and Entrepreneurship". perfectbound. Jul. 1985.

[5] J. R. Bessant and J. Tidd. "Managing Innovation: Integrating Technological, Market and Organizational Change". John Wiley & Sons. Jun. 1997.

[6] M. Corso and L. Pellegrini. "Continuous and Discontinuous Innovation: Overcoming the Innovator Dilemma". Creativity and Innovation Management . vol. 16. no. 4. pp. 333 - 247. Nov. 2007. https://doi.org/10.1111/j.1467-8691.2007.00459.x.

[7] F. Murray and S. O'Mahony. "Exploring the Foundations of Cumulative Innovation: Implications for Organization Science". Organization Science. vol. 18. no. 06. pp. 1006-1021. Nov. 2007.

[8] "Disruptive Innovations - Christensen Institute", christenseninstitute.org, (Accessed 11 Jul. 2023).

[9] J. Schumpeter. "Capitalism, Socialism and Democracy". Harper & Brothers. Jun. 1942.

[10] A. Linder and J. Fenn. "Understanding Gartner's hype cycles". Gartner. May. 2003.

[11] H. Mihály. "From NASA to EU : the evolution of the TRL scale in Public Sector Innovation". The Innovation Journal. vol. 22. pp. 1-23. Oct. 2017.

[12] B. Vayre, F. Vignat and F. Villeneuve. "Designing for Additive Manufacturing". Procedia CIRP. vol. 3. pp. 632-637. Aug. 2012. https://doi.org/10.1016/j.procir.2012.07.108.

[13] "World's Largest 3D Metal Printers", relativityspace.com, (Accessed 11 Jul. 2023).

[14] Jorge, "SpaceX – Lowering the Cost of Access to Space", d3.harvard.edu, (Accessed 11 Jul. 2023).

[15] "List of Falcon 9 first-stage boosters", en.wikipedia.org, (Accessed 11 Jul. 2023).

[16] "Super Heavy Lift Launch Vehicles: Global Status and European Perspectives", espi.or.at, (Accessed 11 Jul. 2023).

[17] "SpaceX Starship", en.wikipedia.org, (Accessed 11 Jul. 2023).

[18] J. Benstaali. "Système Starship et mode de croissance de SpaceX". Chaire Sirius. Mar. 2022.

[19] T. G. Roberts, "Space Launch to Low Earth Orbit: How Much Does It Cost?", aerospace.csis.org, (Accessed 11 Jul. 2023).

[20] A. Witze, "2022 was a record year for space launches", nature.com, (Accessed 11 Jul. 2023).

[21] U. N. O. F. O. S. Affairs, "Annual number of objects launched into space", ourworldindata.org, (Accessed 11 Jul. 2023).