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ALINA ORLOVA

THE CURRENT STATE OF THE SPACE INDUSTRY AND THE RISE OF SPACEFLIGHT ASTROPRENEURS

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Master’s dissertation presented to COPPEAD Graduate School of Business - The Federal University of Rio de Janeiro, as part of the mandatory requirements in order to obtain the degree of Master of Science in Business Administration (M.Sc.).

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Master of Science in Business Administration dissertation presented to the Full-Time MBA of COPPEAD Business School – The Federal University of Rio de Janeiro.

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“Every vision is a joke until the first man accomplishes it;
once realized, it becomes commonplace”

Robert Goddard

Abstract

Despite its unlimited potential, the space sector has not become the driver of the global economy with relatively modest annual revenues in comparison to other markets, neither the space exploration has significantly advanced over the past decades, failing to turn humans into a multiplanetary species. The reason for these disappointing efforts in the final frontier is the space launch cost. Although, rocket technologies originated more than 60 years ago – a mature age for a technology, the average price of US$15,000 - $20,000 per kg to deliver payload into orbit continues to deter the large-scale exploration and exploitation of space.

Started in the early 2000s, an increasing participation of private companies in the space sector became known as the New Space movement. These companies' major focus is on building low-cost space launch vehicles. Their ultimate goal is to give customers of all types the opportunity to access space at a much lower price and with greater flexibility, thus dramatically changing the traditional model of the space economy.

New technologies, new services, new business models, new frontiers constitute the very core of the New Space movement. All of these elements have combined change the Space Business Ecosystem.

This work provides the readers with the first draft of this Ecosystem and also a detailed analysis of its core actor - Rocket Launchers, both in terms of their market success and rocket performance. Several research questions are also proposed in order to advance this study.

Keywords:

Space industry, Space Ecosystem, New Space, Rocket, Space Launch Vehicle, Spaceflight

List of contents

List of figures

List of tables

List of acronyms

ELV	Expendable Launch Vehicle
ESA	European Space Agency
ETO	Earth-to-orbit
FAA	Federal Aviation Agency
GEO	Geostationary orbit
GTO	Geostationary transfer orbit
ICBM	Inter-Continental Ballistic Missile
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
RLV	Reusable Launch Vehicle
SSO	Sun Synchronous Orbit
VTHL	Vertical Take-off and Horizontal Landing
VTVL	Vertical Take-off and Vertical Landing

I - INTRODUCTION

Initial interest to the space exploration was evoked by humanity's unfulfilled dreams in the final frontier. Though space was of a particular interest since our very early ancestors, humanity is still doing only first steps in the space exploration, timidly standing on the threshold of the space edge, not getting out beyond the Low Earth Orbit on a permanent basis.

Over the whole 20th century, science fiction writers were creating breathtaking stories about the outer space exploration in the new millennium. Not only space enthusiasts but scientists and engineers made optimistic forecasts regarding the new horizons that will open at the dawn of the new century. However, supersonic passenger transportation (Concorde and Tupolev 144 experienced a very brief existence)[1;2], asteroid and lunar mining, space tourism and colonization of outer planets – are still humanity's unrealized aspirations.

Modern rocketry started on March, 1926, when an American physicist and engineer Robert Goddard designed and launched the world's first liquid-fueled rocket, powered by gasoline and liquid oxygen (Launius et al. 2012). In 1927, inspired by Herman Oberth's publication "The Rocket into Planetary Space", German space enthusiasts founded an amateur rocket association - the Verein für Raumschiffahrt, better known as VfR, the organization that pioneered rocket manufacturing (Swenson Jr., Grimwood and Alexander 1989). Soon after Adolph Hitler came to the power, German army became a benefactor for the VfR. The partnership with Nazi turned exploratory rockets into war missiles (Weingardt 2012). Back those times the Germany army's interest in rockets as weapon was fairly unique (Teitel 2016; Weingardt 2012). Rocket-powered weaponry was one of few German military forces not restricted by the Treaty of Versailles.

The young rocket engineer Wernher von Braun became the leader of the VfR. Under his leadership was designed the A-3, better known as V-1 flying bomb and later a truly standout technological achievement and the direct antecedent of modern rockets - the A-4 missile, better known as V-2, renamed by the Nazis for "Vengeance Weapon Number 2" (Weingardt 2012) - the world's first long-range guided ballistic missile powered by a liquid-propellant rocket engine. The V-2 rocket became the first man-made object to travel into space by crossing the Karman line with the vertical launch on June 1944 (Neufeld 1995), and de facto the first space rocket. It was a turning point when the world realized the potential of the long-range rocketry and starting point for the rocket supremacy race between countries.

One of the most large-scale past-war scientific collaboration effort was the International Geophysical Year, from July, 1957 to December, 1958. Sixty-seven countries participated in IGY projects that encompassed a wide spectrum of Earth sciences including the upper atmospheric

[1] https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-062-DFRC.html last access August 2018
[2] http://www.tupolev.ru/en/aircrafts/tu-144 last access August 2018

research. Putting a scientific satellite into Earth orbit would enable to make experiments free of the Earth atmosphere and explore wholly new regions of space all at once. A satellite would travel around the planet at 28,164 Km/h without ever falling back to Earth, extending its mission as long as its instruments had power to continue working.

Eager to become the first country to launch a satellite into space, the United States failed to comply with the terms and launch a satellite on time. On the 4th of October, 1957 the world witnessed the launch of a first artificial satellite named "Sputnik" accomplished by the Soviet Union. The genius behind this historical launch was Sergei Korolev, a secret Chief Designer of the Soviets. In the 1950s, he developed the R-7 booster, which propelled a 5-ton dummy warhead 6,400 Km to Kamchatka, thus making it the world's first intercontinental ballistic missile (ICBM) (West 2001). The R-7 rocket would become known as Soyuz rocket and propel most of Soviets and Russian spacecrafts.

Less than in a month after the launch of "Sputnik", the Soviets put into the orbit the second satellite "Sputnik 2" to commemorate the 40th anniversary of the Bolshevik Revolution. "Sputnik 2" was more advanced than its predecessor and aimed to collect engineering and biological data from space. It was a 4-meter high cone-shaped capsule with a base diameter of 2 meters that weighed around 500 kg and that was carrying a first living being on its board, a Soviet space dog named Laika.

The importance to be the first nation to develop the Earth-to-Orbit launch capabilities could not be overestimated in the context of ideological and political confrontation between communism and capitalism in the era of de-colonization. The launch of "Sputnik" and "Sputnik 2" was a devastating blow to American national prestige and raised serious apprehensions about its national security. *"American newspapers carried headlines saying that the Soviets had won the race. International newspapers went as far as calling "Sputnik" the Pearl Harbor of American Science"* (Teitel 2016, p.227).

According to Bulkeley (1991), the launch of "Sputnik" and "Sputnik 2" were one of the most disruptive events in the history of the United States. Its success spelled crisis and rose a question on the current state of American science and technology. Having recognized the need to advance science in that country, America devoted its best efforts to improve national technology to the cutting edge. The year following the "Sputnik" launch saw the formation of the Advanced Research Projects Agency (ARPA), the President's Science Advisory Committee (PSAC), the transformation of the National Advisory Committee for Aeronautics (NACA) into National Aeronautics and Space Administration (NASA), and the National Defense Education Act (NDEA) (Dick 2008).

Next phase in the space exploration became the Earth's permanent natural satellite, the Moon. After some false starts, in fall 1958 the Soviet Union succeeded in launching several successful lunar probes. After lunar programs, followed the outer planets and space bodies programs. Starting from the first planetary mission to successfully return telemetry from the vicinity of Venus in 1962, the U.S. Mariner 2 mission, humanity successfully encountered with all planets in the Solar system and significantly advanced in its exploration. Among some notable engineering achievements were the mastering of soft landing on extra-terrestrial surface, robotic sample return probe, on-site analysis of another planet and exploration rovers.

Achieved progress in rocket science had been running almost parallel to the developments of its "blood brother" – aviation, with jet-powered aircraft replacing propeller planes and becoming state of the art, strategical resource. In 1950s aviation was challenging itself in breaking speed and height record. The Bell X-1 became the first manned airplane to break the speed of sound, Mach 1, in level flight.[3] In the 1960s, the X-15 hypersonic rocket-powered aircraft set speed and altitude records, Mach 6.72 at 31,120 m, a speed of 7,274 km/h[4], reaching the edge of outer space and returning valuable scientific data on aerodynamic and other technical fields.[5] Experts were conducting high-attitude controlled balloon flights that carried men to a near-space environment, such as Project Manhigh, to probe biomedical questions regarding human tolerance for high-altitude flights.

However, the time for methodical exploration of human side of hypersonic and high-altitude flights came to its end on April 12, 1961, when the Soviet Union stroke the world again by launching the first man into space, Yuri Gagarin, who completed one orbit of the Earth in the Vostok spacecraft. In 1963 Valentina Tereshkova was propelled into space, which enabled the Soviets to make propaganda mileage by claiming that under communism women were treated equally to men.[6] It was Korolev's greatest triumph followed by another feat - the first extravehicular activity in space or space walking performed by Aleksey Leonov in 1965 in the spacecraft called Voskhod (West 2001).

As a response to Gagarin's successful mission, President Kennedy delivered his famous speech "We choose to go to the Moon" at Rice Stadium in Houston, Texas on September 12, 1962. The speech was intended to intensify American efforts in space and persuade the American people to support extremely costly Apollo program - national effort to land a man on the Moon. Kennedy's goal was accomplished by the Apollo 11 mission when astronauts Neil Armstrong and Buzz Aldrin landed a lunar module on July 20, 1969, and walked on the lunar surface, while Michael

[3] *First Generation X-1 (fact sheet), Dryden: NASA, retrieved May 8, 2010.*
[4] *"North American X-15 High-Speed Research Aircraft". Aerospaceweb.org. 2010. Retrieved 24 November 2008.*
[5] https://en.wikipedia.org/wiki/North_American_X-15 last access August 2018
[6] https://www.historytoday.com/richard-cavendish/soviet-union-first-moon last access August 2018

Collins remained in lunar orbit in the command and service module. Wernher von Braun was the chief architect of the Saturn V launch vehicle in which Apollo crew reached the Moon. Five subsequent Apollo missions also landed men on the Moon - the last in December 1972. Eugene Cernan, the last man to walk on the Moon said as he prepared to climb up the lunar ladder for the last time: *"As I take man's last step from the surface, back home for some time to come – but we believe not too long into the future – I'd like to just say what I believe history will record. That America's challenge of today has forged man's destiny of tomorrow. And, as we leave the Moon at Taurus–Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17."* The promise that hasn't been fulfilled.

That was the period known as the Golden era of space exploration. The impressive accomplishments of the humanity, some of which haven't been repeated ever since. After decades of stagnation, the space industry has been awaking and drawing to itself considerable attention started from the beginning of the 21th century. Traditionally controlled exclusively by governments, today we are witnessing dramatic changes in the global space landscape toward greater involvement and empower of the private sector. Since 2000, more than 80 angel and venture-backed space companies have been founded, and attracted more than $13.3 billion of investment. The interest from investors accelerated and in 2015, the amount invested got higher than in the previous 15 years combined (TauriGroup 2016). This became known as the New Space movement (Brady 2016; Denis and Pasco 2015; Frischauf et al. 2017; Paikowsky 2016). New Space companies aspire to take advantage of infinite commercial opportunities that space can offer for eligible business models grounded in operational efficiency and technological advances.

In the beginning of the 1980s, the space economy accounted for a few billion dollars of the world's economy. In 2016, this figure totaled $329 billion worldwide. Commercial space activities made up 76% of the global space economy, totaling $253 billion.[7] So far, the main driver of the commercial space market has been the telecommunication industry, specifically satellites that relay television signals from the geostationary orbit directly to the viewer's location (Petroni and Santini 2012). Satellite TV accounts for 77% of all satellite services' revenues, totaling $97,7 billion and 220 million satellite Pay-TV subscribers worldwide (Bryce space and technology 2017). In the civilian domain, established spaced-based services include meteorology, operational oceanography, navigation and positioning systems. A recommenced interest from space entrepreneurs and private companies holds out hopes for space market further growth and creation of brand new space services addressing environmental, technological, and humanitarian problems (Olla 2008).

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[7] https://www.spacesymposium.org/media/press-releases/space-foundation-report-reveals-global-space-economy-329-billion-2016 last access August 2018

The space sector has a potential to influence many other spheres and radically change the life we live. The models, approaches and motivations for spacefaring activities are changing (Suzuki 2007). New services, new frontiers, and explorations constitute the very core of the New Space movement. All of these elements have combined to create a new Space Ecosystem for global space activities (Paikowsky 2016).

Despite the media buzz from the so-called New Space, this industry remains poorly studied from a business perspective. There is an apparent lack of scholarly research on the space domain from business and strategic perspectives. This research aims to contribute to the understanding of the space sector by studying it through the ecosystem theory lens, as it provides a comprehensive view of the contemporary business environment (Wadovski, Nogueira, and Chimenti 2018). In accordance with Teece (2007), the ecosystem represents the environment that the firm must monitor and react to in order to build sustainable competitive advantage. It encompasses all relevant actors and their relationships, across industries and reaching the final users.

To date, studies in the ecosystem area have mainly focused on companies in internet, high-tech, and ICT sectors (Jacobides et al. 2018). No studies have been conducted to examine the space sector. By implementing the ecosystem framework, this Master dissertation fills the need of a comprehensive analysis of the space sector: identifying and describing its relevant actors and connections among them, as well as its hubs and core activities.

Ecosystem's hub is essentially the "keystone" organizations in the ecosystem. Iansiti and Levien (2004) defined its role as providers of stability. Dhanaraj and Parkhe (2006) argued, hub firms manage knowledge mobility, innovation appropriation, and network stability.

Our assumption is that the hub of the Space Ecosystem consisted of companies that design and manufature space launch vehicles. This assumption is based on the critical role of space launch vehicles for any space activities. We also observed an apparent lack of scholarly research on market and performance analysis of space launch vehicles.

There have been conducted general overall comparisons of launch vehicles, usually focusing on solely technical factors such as improvements in structural systems, payload systems, guidance systems, and propulsion systems (Sackheim 2006). Some gross market estimations have been made in the past, usually for the purpose of developing parametric models for launch vehicle performance and cost evaluation. (Boone and Miller 2016; Hermann and Akin 2005; Watson 2014). These still lack a comprehensive market and performance analysis of the space launch vehicles, a deficiency that limits understanding competitiveness and economic viability of the whole Space Ecosystem.

To sum up, the objectives of the current research are:

Research Objective (1): To identify, chart and analyze the Space Ecosystem and its hubs ;

Research Objective (2): To identify key elements of space launch industry and to analyze its evolution ;

Research Objective (3): To describe, compare and analyze operational space launch vehicles.

II - THEORETICAL FRAMEWORK

Ecosystem perspective arrived to offer a comprehensive view of the contemporary business environment (Wadovski et al. 2018). Borrowed from biology, the term ecosystem generally refers to "an economic community of interacting actors that all affect each other through their activities, considering all relevant actors beyond the boundaries of a single industry" (Jacobides et al. 2018, p.2257).

Despite the increasing significance of the ecosystem concept in the field of strategy, and management of technology and innovation (Adner and Kapoor, 2010; Kapoor and Lee, 2013; Teece, 2007), many authors refer to the lack of a common ground of the ecosystem concept and its theoretical backing. In the field of management, the term "ecosystem" is used in various formulations such as industrial ecosystem, business ecosystem, service ecosystem, innovation ecosystem, platform ecosystem, digital ecosystem and IT ecosystem.

These differences in ecosystem concept have been addressed by Tsujimoto et al. (2017), who distinguished and described the main streams of ecosystem concept in management literature. They categorized the studies into four major research streams based on differences in theoretical background. The first stream is the "industrial ecology" perspective, which is based on the concept of industrial ecosystems. The second is the "business ecosystem" perspective, which is based on the theory of organizational boundaries. The third is "platform management". The fourth approach is the "multi-actor network" perspective, which contributes to dynamic behavioral relationship analyses based on social network theory (Tsujimoto et al. 2017).

The variances in ecosystem concept have been also addressed in other researches. Jacobides et al. (2018) stated that scholars emphasized different aspects of an ecosystem depending on the unit of analysis. In their study they identified three research streams on ecosystem: a "business ecosystem", which centers on a firm and its environment; an "innovation ecosystem", focused around a particular innovation or new value proposition and the constellation of actors that support it; and a "platform ecosystem", which considers how actors organize around a platform (Jacobides et al. 2018, p.2256).

We can resume that the choice of the ecosystem approach and the very definition of the ecosystem depend on the unit of analysis and the scope of the research. In our research we aim to explore the space sector from macro perspective, encompassing several interconnected industries. The unit of the analysis is an ecosystem's actor, which includes all participants engaging in the similar activities or performing similar roles. Thus, we consider that the "multi-actor network perspective" is the most appropriate ecosystem concept for the objectives of this research. The "multi-actor network perspective" expands the range of analysis to include a variety of actors in addition to private firms such as government, investors, regulators, consumers and others. This approach implies indirect, complex, and non-linear relationships among actors (Tsujimoto et al. 2017). Variables are not limited to contract or monetary relationships, and comprise non-tangible aspects such as power, knowledge, reputation, and historical relationships.

As stated by Tsujimoto et al. (2017), the "multi-actor network perspective" does not have a clear theoretical background. However, we can highlight some common features with other ecosystem streams such as the emphasis on **co-evolution** and **multilateral dependences** in the community (Iansiti & Levien, 2004; Jacobides et al. 2018) — individual members' performance is tied to the overall performance of the ecosystem; focus on **relationships** amongst actors as a base for the ecosystem survival and development as opposed to value creation process in traditional strategic models. Much of the literature suggests that networks naturally possess **"key players"** or **"hubs"** that enhance the ecosystem survival and development.

The benefit of the ecosystem perspective rests on its capacity to depict an entire competitive environment by highlighting all relevant actors playing in a market set and relationships among them. For Teece (2007), the ecosystem represents the environment that a firm must monitor and react, which affects its dynamic capabilities and thus its ability to build sustainable competitive advantage.

If a firm would like to know the complex dynamics intercepting its ecosystem or if it would like to enter and live in a new one, it has to rely on a deep knowledge and analysis of the ecosystem itself (Battistella et al. 2013). It is a matter of identifying the ecosystem components and examining the nature, directionality, and intensity of relationships amongst them; understanding what guarantees their existence and taking advantage from the balance of power.

III - METHODOLOGY

Currently, the majority of the ecosystem studies are focused on the discussion of ecosystems per se, i.e. comparisons between natural and business ecosystems, differences between value chain and ecosystem, ecosystems properties, and discussion of strategies of single ecosystems, etc. Literature on methodologies for ecosystem's charting and analysis is still in its infancy (Battistella et al. 2013). Among the proposed modelling approaches of value networks and business ecosystems are e3-value modelling (Gordijn et al. 2000); c3-value model (Weigand et al. 2007); Value network model of intangibles (Allee 2002); Agent based methodology (Marin et al. 2007); BEAM: business ecosystem analysis and modelling (Tian et al. 2008). Overview of these methods with main critique points have been presented in the paper by Battistella et al. (2013), who also proposed its own Methodology of Business Ecosystem Network Analysis (MOBENA), aiming to provide a theoretical and operational framework for charting and analyzing business ecosystems (Battistella et al. 2013).

The method allows to systematically study the structure and fluxes of a business ecosystem and is based on four steps of analysis: (1) ecosystem perimeter, elements and relationships; (2) ecosystem model representation and data validation; (3) ecosystem analysis; and (4) ecosystem evolution. The scope of this Master dissertation doesn't imply the deep analysis of the behaviour of the entire Space Ecosystem, and it doesn't include foresight of possible future scenarios. Therefore, we didn't perform the last two steps of MOBENA methodology in this research. Instead, we chose to examine the Space Ecosystem's hub – space launch vehicles, and conduct the comparative analysis of operational space launch vehicles.

▪ 1st Phase - Ecosystem perimeter, elements and relationships

The aim of the 1st phase was to identify and describe each element and ties among them. The main categories of elements are actors and enabling technologies. The results are to be synthesized in the so-called connection matrix.

To collect relevant information, we reviewed the literature, gathering, synthesizing and appraising the findings of already conducted studies on space sector in the area of business and strategy. The choice of the method is justified by the research's objectives and the space sector's specifics. Literature review provides a way to gain a comprehensive view of the space sector, its history, past and current actors, technologies, trends and challenges. The choice of method is also dictated by the existing information access restrictions on companies due to the dual usage of rocket technologies and its military implications.

Our literature review was based on peer-reviewed articles at Elsevier's Scopus, the cross-discipline platform with the largest abstract and citation database of peer-reviewed literature.[8] Scopus provides user-friendly and convenient sorting and refining features for multidisciplinary scientific literatures. The database also ranks journals based on their impact, prestige or influence, as well as articles in terms of the total citations.

To refer to commercial initiatives and capture a recent trend toward an increase participation of private companies in the space sector, we searched for the terms "New Space" or "commercial *space" or "private *space" or "*space competition". We also add industry-defining terms "spaceflight" or "spacecraft" or "satellite" or "launch" to improve the search results due to multiple meanings of the word "space" (without industry-defining terms, Scopus returns 8,502 articles, most of them on spatial studies).[9]

The next step was to apply inclusion and exclusion criteria. We chose only peer-reviewed articles in English or in Russian. For this, we applied filters: (1) Language ("English" or "Russian"); (2) Source ("journal") and (3) Document type ("article"), generating 319 references.[10] All journal titles considered at Scopus database are both peer-reviewed and have a description of the peer-review process available publicly (Elsevier: Content Policy and Selection s.d.). Peer-reviewed articles on the research topic published in Russian were not found.

Continuing the use of inclusion and exclusion criteria, we specified the subject area to business, management and economy. Applied filter: (4) Subject area ("Business, Management and Accounting" OR "Economics, Econometrics and Finance"). 54 articles constituted the final list of articles to support the 1st phase of MOBENA methodology.[11]

We conducted the data collection by reading the 54 articles highlighting companies, technologies, products/services and environment (market, constraints and regulation forces) and connections among them. The following step was to code and classify the collected data into categories, including grouping companies and other elements into what would become the actors of the Space Ecosystem. For a more efficient textual analysis, we used the NVivo 12 software.

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[8] https://www.elsevier.com/research-platforms last access September 2018

[9] TITLE-ABS-KEY ("New Space" OR "commercial *space" OR "private *space" OR "*space competition") AND TITLE-ABS-KEY (spaceflight OR spacecraft OR satellite OR launch)

[10] TITLE-ABS-KEY ("New Space" OR "commercial *space" OR "private *space" OR "*space competition") AND TITLE-ABS-KEY (spaceflight OR spacecraft OR satellite OR launch) AND (LIMIT-TO (SRCTYPE , "j ")) AND (LIMIT-TO (DOCTYPE , "ar ")) AND (LIMIT-TO (LANGUAGE , "English") OR (LIMIT-TO (LANGUAGE , "Russian"))

[11] TITLE-ABS-KEY ("New Space" OR "commercial *space" OR "private *space" OR "*space competition") AND TITLE-ABS-KEY (spaceflight OR spacecraft OR satellite OR launch) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Russian")) AND (LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "BUSI"))

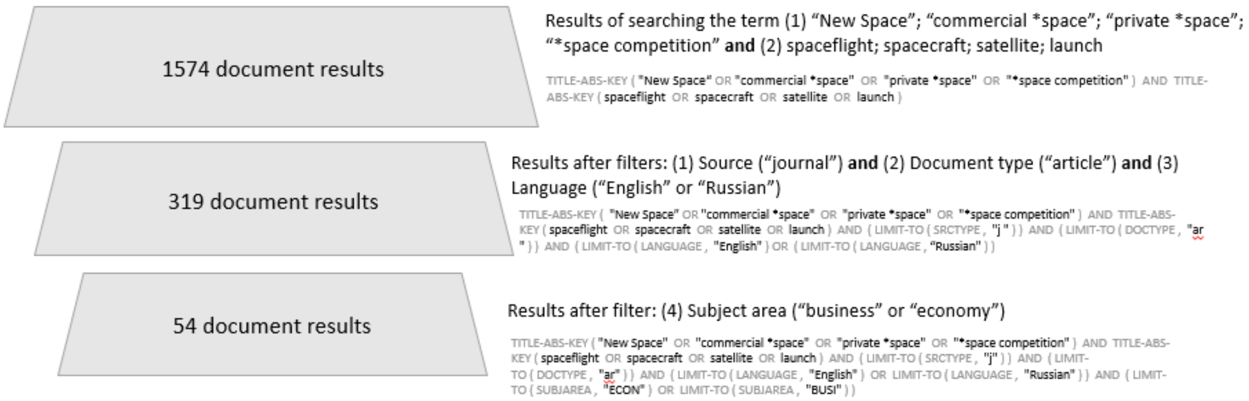


Figure 1. Filter and selection process at Scopus Platform.[12]

▪ 2nd Phase - Ecosystem model representation and data validation

The objective of this step is to develop a representative model of the ecosystem (Battistella et al. 2013). An ecosystem is essentially a vast network of players, products, services and technologies, representing nodes and relations between them. The information obtained in the previous step helps to identify and classify nodes, characteristics and links. Produced connection matrix serves the basis for the network representation in the form of the ecosystem chart. The visualization provides a broad understanding, insights for designing and executing strategies, and a common basis for communication among people (Wadovski et al. 2018). Through this approach, we can visualize which actors have a central role, which may have a disruptive potential and if there are parts of the ecosystem that are still under way to be occupied.

The Space Ecosystem is reported in “results and discussions” section. The chart was obtained using the open source software Gephi, a free tool that allows graphic visualization and analysis of complex networks. For nodes, color and dimension codes are used to represent the weight of each actor in the ecosystem. Actors that have more weight have larger size and more saturated color.

A parameter for the weight factor can be based on financial indicators (i.e. revenue, investments, market capitalization), technologies (i.e. innovations, patents), geographical presence, etc., depending on the research purpose. In our study we selected the number of connections as the weight factor. The logic is: the more established relationships has an actor, the more power it possesses in the ecosystem. This approach helps to take into consideration tangible and intangible aspects.

▪ 3rd Phase – Central hub analysis

[12] The first search was conducted on July, 2018. The search was repeated on December, 2018 and newly published articles were added to the selection process and analysis.

In this research, we chose to examine not the overall ecosystem's behaviours as proposed by MOBENA methodology, but particularly explore its hub – space launch vehicles. Our objective was to describe, compare and analyze all operational space launch vehicles on their launch history, performance characteristics and price.

To accomplish this objective, we gathered data about all orbital class space launch vehicles that have been operational from January 1st 2006 till December 31st 2018. We define an operational rocket as one that had been launched at least once, successfully or not, over the past 13 years. The time interval has been set from January 1st 2006 till December 31st 2018. The year 2006 was chosen as a symbolic starting point of private spaceflight due to a historical launch of Falcon 1 (though unsuccessful) - first privately-developed orbital liquid-fuel launch vehicle.

The final list consists of 72 orbital class launch vehicles. This figure includes variants of a rocket family. For example, there are 10 Atlas V variants defined by the number of solid rocket boosters used, type of fairing by diameter, and type of Centaur upper stage (Federal Aviation Administration 2018). Eight of them has been launching between 2006 and 2018 and are included in the list. Rockets Atlas V-511 and Atlas V-521 didn't fly any single time in this time period, and so are excluded from the analysis. Some vehicles that are not available for commercial use or do not represent significant value for the research were grouped together under "Several" and excluded from the analysis. The group "Several" includes Iranian Safir rocket, North Korean Unha rocket, Ukrainian rocket Tsyklon and the U.S. Minotaur-V. The most numerous rockets` families are Long March, Soyuz, Atlas, Delta and, most recently Falcon. Visual representations of these rockets are provided in Appendix-B. Short explanations on Delta and Atlas naming convention are presented in Appendix-C.

Data screening revealed considerable discrepancies on rockets` declared characteristics and launch prices among information sources. To drive accurate and comparable results, of critical importance is to ensure the most relevant and reliable data. In our research, we made a decision to use data from two sources:

- Rocket manufacturer's manuals and/or datasheets on their own official websites;
- U.S. Federal Aviation Agency`s annual reports

The use of these two reputable data sources also serves the verification purposes. In case of divergence, the data from official manuals and websites was used. Data on the 72 orbital class launch vehicles was carefully collected and systematized. Metadata included general information on rocket name, family, launch provider, country, and the following numerical parameters:

- Year of the first flight
- Operational status*

- Lift-off mass (Kg)
- Category **
- Payload capacity to Low Earth Orbit (LEO) (Kg)***
- Payload capacity to Geosynchronous Transfer Orbit (GTO) (Kg)***
- Mission type ****
- Accumulated number of flights prior 2006
- Annual number of flights (from 2006 to 2018)
- Total number of flights
- Reliability index (%) *****
- Price per launch (US$M) ******

** Currently operating or retired*

***Category: light ≤211000 Kg, medium 211001-699999 Kg, and heavy ≥ 700000 Kg*

****Rocket performance for a reference orbit is a function of altitude. In the current analysis, performance computations are based on the following orbital parameters:*

*Standard GTO: 27.0 deg at 35,786 Km * 185 Km*

LEO: 28.7 deg at 200 Km circular

If a rocket performance for given orbital parameters was not stated, the proximate were used.

*****As a rule, light class launch vehicles are designed to transfer payloads only to Low Earth Orbits due to the intrinsic performance limitations.*

******Ratio of successful launches to total number of launches*

*******Price of a launch in 2017 or the most recent available.*

We also calculated performance and efficiency parameters of a rocket. A common term in rocketry is "payload ratio". A measurement of price-effectiveness is a "price per Kg into orbit".

$$Payload\ ratio = \frac{Payload\ to\ orbit}{Lift\text{-}off\ mass};$$

$$Price\ per\ Kg\ into\ orbit = \frac{Price\ per\ launch}{Payload\ to\ orbit}$$

The result of the data collection, cleaning and matching is a comprehensive table with launch history, performance characteristics and price of all operational space launch vehicles. The table is presented in Appendix-D.

After the data on the space launch vehicles was collected and systematized, we aimed to group a set of related space launch vehicles in a meaningful, systematic, and standard format. We decided to group space launch vehicles based on their launch statistics. The creation of rocket groups was based on number of launches per periods: "period 0" comprehends rocket launches since the start of its operational activity up to 2005 year; "period 1" - launches since 2006 up to 2008; "period 2" - from 2009 up to 2011; "period 3" - launches from 2012 up to 2014; "period 4" - launches from 2015 up to 2017; and "period 5" – launches in 2018.

Identifying patterns in launch history can be performed by clustering methods. Hierarchical clustering is one of the most used methods. Hierarchical clustering methods put the elements into clusters based on similarities among the clusters (Kaufmann and Rousseeuw, 2008). The most well-known methods are single-linkage, complete-linkage and average linkage. A more complex, but accurate method is the Ward method (Ward, 1963). This method was used for classification of space launch vehicles and creation of rocket groups. This was our choice for classification of space launch vehicles and creation of rocket groups. By applying Ward method (Everitt et al. 2011) the aim was to join elements into clusters so that the variance within clusters is minimized. We chose four clusters and checked their difference by running a discriminant analysis with cluster number as dependent variable and the launch periods as independent. The three discriminant functions were significant at $p < 0.01$ and all cases were correctly classified by them.

To graphically track and assess the relationship between a set of variables for different rocket clusters we applied to linear regression analysis. Dependable variables are “number of launches”, “number of rockets” and “market share” and a predictor is a “year”.

Market share for a cluster was calculated as sum of launches performed by all rockets in a cluster divided into total number of launches performed worldwide.

$$Market\ share = \frac{Number\ of\ launches\ per\ cluster}{Number\ of\ launches\ total}\ ;$$

Parameter estimates (also called coefficients) are the change in the response associated with a one-unit change of the predictor, all other predictors being held constant. The F and Sig. columns summarize results of the F test of model fit. The R Square statistic is a measure of the strength of association between the observed and model-predicted values of the dependent variable.[13] A statistical analysis was performed using IBM SPSS Statistics software - the world’s leading statistical software used to solve business and research problems.[1] The results are presented in “results and discussions” section.

Launch vehicle’s price-effectiveness has been evaluated as price per Kg into orbit. This metric is calculated based on several assumptions, including the specified orbit whether Low Earth Orbit (LEO), Geostationary Earth Orbit (GTO), or both. The metric assumes the payload utilizes the full capacity of a launch vehicle, which is rarely true even with secondary payloads. Though, there is a trend of decreasing wastage capacity due to multiple payloads, the average wastage still represents around 20% of a total capacity (Boone and Miller 2016).

The launch costs were not considered in the current research. The cost analysis was not possible due to the data restrictions on manufacturing and operation costs. The reusability factor

[13] https://www.ibm.com/support/knowledgecenter/en/SSLVMB_24.0.0/spss/tutorials/curveest_coeff.html last access November 2018

wasn't considered due to the lack of publicly opened information. More launch data should be collected to establish an empirically based RLV-operations model to define generalize patterns.

IV - LITERATURE REVIEW

Space economy

The Organisation for Economic Cooperation and Development (OECD) Space Forum members established that the space economy should not be limited to the industry's core activities in launch and spacecraft systems manufacturing and satellite operations. Instead, a broad definition of the space economy should encompass the full range of activities that create value and benefits for people in the course of exploring, researching and utilizing space.

"The space economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilizing space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications and the scientific knowledge generated by such activities. It follows that the space economy goes well beyond the space sector itself, since it also comprises the increasingly pervasive and continually changing impacts of space-derived products, services and knowledge on economy and society" (Source: OECD 2011)

This broad definition of the space economy helps capture space actors, space activities, space-enabled applications, scientific knowledge arisen from space exploration and derived spin-offs that benefit other industries and the public. Despite space systems and applications originated more than 60 years ago, there is no internationally agreed terminology for space activities (OECD 2011). The current edition of the United Nations International Standard Industrial Classification (ISIC Rev. 4 released in August 2008) includes constituents of the space sector under different aggregate categories. Thus, the differentiation of the space sector from the larger aerospace&defence sector remains an open issue in most countries. In this dissertation, the terms "space/space-based /space-enabled/space-related activities, applications, products or services" are being used interchangeably.

The space sector separates "upstream" and "downstream" segments. Upstream segment includes activities that focus on design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of launch and spacecraft systems. Downstream segment refers to activities that employ signals or data derived from the space technologies (Strada 2018). The boundary between the upstream and the downstream segments is a moving frontier as many companies are vertically integrated and involved in several different space activities (Euroconsult 2015). Nevertheless, this division remains essential in order to understand the structure of the space sector and a wide range of its actors at different levels:

> Government agencies, investors, insurance companies and regulatory institutions that develop, fund and provide legal framework for space activities;

> Public and private companies that design and manufacture launch vehicles, spacecrafts, satellites and/or provide launch services and ground infrastructure;

> Satellite operators that own and operate satellite systems and market their capacities to the service providers;

> Satellite service providers and terminal suppliers who deliver communications, navigation and geographic information services to end users by integrating the satellite signal into packaged solutions;

> The end users, whether governmental or commercial, who buy integrated solutions for communication, navigation or geographic information services tailored from satellite technology.

Over the past decade, the number of actors involved in space activities worldwide and commercial revenue generated by space-enabled products and services have increased. In 2013 commercial revenue generated by the space economy amounted to some $256.2 BN globally (OECD 2014). The breakdown was as follows:

- Space systems manufacturing represents conservatively $85 BN;
- Services from satellite operators represent $21.6 BN;
- Consumer services that based on satellite capacity estimated at roughly $149.6 BN

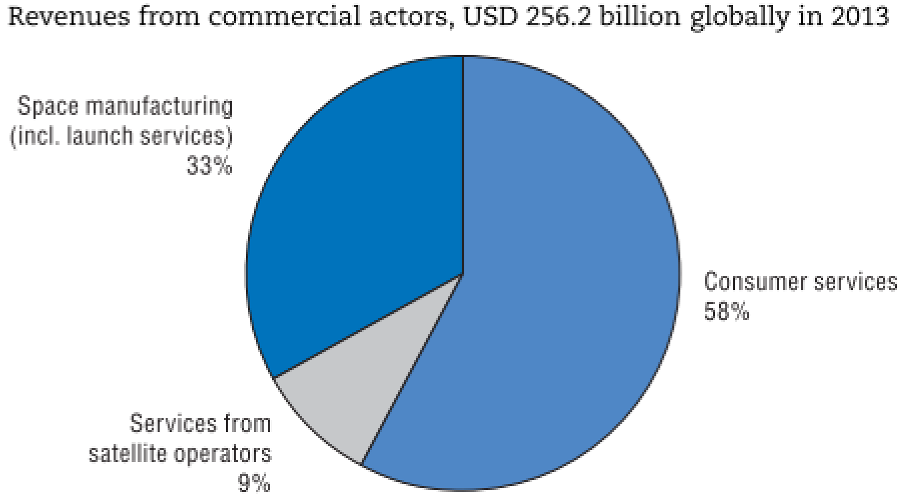


Figure 2. Main segments of the space economy. Revenues from commercial actors. Source: OECD 2014

Despite its growth, the space industry has not become a key driver of the global economy and generates relatively modest revenues in comparison to other markets. The large-scale exploration and exploitation of space keep being restrained by high launch costs, hence prices. Although, rockets have improved greatly in their capability - the payload mass to Geostationary orbit increased from 68 Kg (Syncom-3) to more than 10,000 Kg, producing a considerable reduction in the price per Kg, average prices from US$15,000 to US$20,000 per Kg deter space industry development (Bhavana, Mani Shankar, and Prathana 2013; Coopersmith 2011).

Present space launch costs are the result of decades of societal, technological, and political influences (Kaplan 2002). Corresponding high launch prices imply no elasticity in the supply-demand curve (Kaplan 2002). Handberg (2014) and Kaplan (2002) agree that it will take reduction by at least a factor of ten below current launch prices, before appreciable increases in market demand can be realized.

To enable affordable access into space, humanity needs launch vehicles which cost-effectiveness greatly exceeds that of those in the past (Boone and Miller 2016). Many field experts agree that revolutionary changes in how cargo and people are transported into space are needed. Without these advances, any significant development in space exploration cannot occur (Kaplan 2002); Koelle 2003; (Mankins 2002).

Space technology

The core technology behind any space-related activities is the space rocket or space launch vehicle. Since the beginning of space travel, the primary Earth-to-Orbit launch capability has been a multistage expendable launch vehicle (ELV) (Reddy 2017). This kind of rocket uses two or more stages, each of which contains its own engines, propellant and oxydant that are fired in succession and jettisoned when the fuel is exhausted. By dropping the stages which are no longer useful, future stages achieve the increasing acceleration, thanks to the reduced mass. To reach an Earth orbit a rocket needs to develop the velocity of 6.4 Km/s (28 300 Km/h) or nearly 24 times the speed of sound (Mach 24). The reason multistage rockets are required is the limitation the laws of physics place on the maximum velocity achievable by a rocket of given fueled-to-dry mass ratio.[14]

In the traditional scenario, a space launch vehicle is expendable. “The core stage and accompanying boosters are discarded in the ocean or land, whereas the upper stage is left orbiting the Earth” (Reddy 2017, p.1). The drawback of expendability is the high cost of a launch (hence price) that has limited civilian and commercial efforts in space (Ragab et al. 2015).

Reuse of complex, high-performance, high-cost rocket stages and engines can be attractive, both from economic and ecological perspective (Sippel et al. 2017). A reusable launch vehicle

[14] http://web-solutionz.blogspot.com/2008/10/what-is-multistage-rocket-and-its.html last access September 2018

(RLV) refers to a vehicle which can be used for several missions (Bhavana, Mani Shankar, and Prathana 2013). The idea behind reusability is both to achieve launch cost reduction, hence price, and subsequent increase in launch rates (Ragab et al. 2015). Potentially, RLV offers a substantial cost advantage compared to ELV (Sippel et al. 2017).

However, the inherent performance loss by bringing used stages at high speed back to Earth as well as additional refurbishment and infrastructure expenses are questioning this advantage (Sippel et al. 2017). Suffice to say, that a "typical modern expendable launch vehicle lifts off with between 84% and 89% of its total mass being propellants for orbit injection. This leaves only between 11% and 16% for dry mass" (Kaplan 2002). The added requirement of reusability means added structure, propellants, thermal protection, etc. Thus, the inherent drawback of reusability is the reduction of rocket`s dry mass while adding the required elements for reusability. This reduction is known as the performance penalty. The engineering challenge is to adopt reusability with minimum reduction of the rocket payload capacity. Another challenge is to optimize the refurbishment and recurring procedures both in costs and time.

On the course of space history, there had been several attempts to design and develop a cost-effective reusable launch vehicle. In the 1970s, the United States consolidated its efforts on the STS/Space Shuttle program, a partially reusable Vertical Take-off, Horizontal Landing (VTHL) orbital launch vehicle. The system consisted of a rocket launcher, orbital spacecraft and re-entry spaceplane (Reddy 2017). The Space Shuttle had been operational from 1982 to 2011 and accomplished 131 flights, 2 of them ended in tragedy with the loss of Challenger in 1986 and Columbia in 2003. The U.S. Congress and NASA spent more than US$192 BN (in 2010 dollars) on the Shuttle program from 1971 to 2010 ('A costly enterprise'). During the operational years from 1982 to 2010, the average cost per launch was about US$1.2 BN. Over the life of the program, it increased to about US$1.5 BN per launch (Pielke R, Byerly R. 2011). Not only Space Shuttle didn't prove itself more cost-effective than an expendable rocket, it ultimately became the costliest spaceflight program ever undertaken (Pielke Jr and Byerly 2011). The main reasons behind the program failure were design flaws, extremely high recurring costs and low flight rate (Pielke Jr and Byerly 2011).

Soviet Union had been also developing a partially reusable space launch system. Its space program Energia/Buran was created after Space Shuttle with a break of around 5 years. The Energia rocket was only launched twice, with Buran shuttle only launched once, in November 15, 1988.[15] Due to the USSR's economic and political collapse, the program was terminated in 1993.

[15] https://forum.nasaspaceflight.com/index.php?topic=31376.0 last access September 2018

These early attempts in partially reusable launch systems served as an impetus for serious review of possible concepts and designs (Kaplan 2002). In 1980s and 1990s, NASA was given a lead role in conducting studies on a new generation of space launch systems (Mankins 2002). The agency initiated a wide range of projects grounded in very different strategic visions of how Earth-to-Orbit capabilities should be advanced. Some of the NASA-conducted projects were: Advanced Manned Launch System (AMLS) studies; National Aerospace Plane (NASP) Program; Reusable Launch Vehicle Program (RLV); Highly Reusable Space Transportation program (HRST); Space Transportation Architecture Study (STAS); Commercial Space Transportation Study (CSTS) (Mankins 2002). Despite all efforts, by the end of 1990s, it became crystal clear that there would be no near-term, new generation of reusable launch vehicles (Kaplan 2002).

By the end of 2017, the space launch market numbered nearly 90 different space launch vehicles operating around the world (Federal Aviation Administration 2018). This figure includes all variants of a family of vehicles. Not all of these vehicles are available for commercial use, some are restricted to the government orders only. There are currently 25 orbital class launch vehicle types available for commercial use worldwide: Delta IV, Atlas V, Falcon 9, Falcon Heavy, Minotaur, Antares, Electron, Angara, Ariane 5, GSLV, LVM3, H-II A/B, Kuaizhou 1/1A and 11, LandSpace 1, Long March 2D, Long March 3A, Long March 3B, Long March 5, Long March 6, Long March 11, Proton M, PSLV, Rockot, Soyuz 2, and Vega. The commercial status of the Dnepr and Zenit vehicles is unclear (Federal Aviation Administration 2018).

Space launchers have different performance and capacity capabilities and are designed to deliver payloads into targeted orbits. Among the most commonly used orbits for satellites are Low Earth Orbit (LEO) and Geostationary orbit (GEO). GEO have a period that matches Earth's rotation on its axis and locates at around 36,000 Km altitude directly above the equator. A satellite in a Geostationary orbit appears stationary, always at the same point in the sky, to observers on the surface. The satellite can provide continuous operation in the area of its visibility. Weather, communication and global positioning satellites are often located on a Geostationary orbit. However, due to its distance from Earth, GEO satellites have a signal delay of around 0.24 seconds for the complete send and receive path. This can be a problem with mobile communication or data transmission.[16]

Low Earth Orbit (LEO) are close to the Earth, normally at an altitude of less than 1,000 Km. Satellites in this circular orbit travel at a speed of around 7.8 Km per second, taking approximately 90 minutes to circle the Earth.[17] In general, LEO orbits are used for remote sensing, weather forecasting, military purposes and for human spaceflight as they offer close proximity to

[16] http://www.suparco.gov.pk/pages/orbit-type.asp last access September 2018
[17] https://www.esa.int/Our_Activities/Space_Transportation/Types_of_orbits last access September 2018

the Earth's surface for detailed imaging and the short orbital periods allow for rapid revisits.[18] The transmission delay is very small.[19] LEO systems can provide continuous operations by means of satellites` constellations.

Special types of LEO orbits are Polar and Sun Synchronous (SSO). Polar orbit has high inclination angle (close to 90 degrees), which means a satellite travels over the poles. On Sun Synchronous orbit, satellite passes over any given point on Earth's surface at the same local solar time. Because of the consistent lighting on Sun Synchronous orbit (Earth surface is always illuminated by the Sun at the same angle when viewed from the satellite), it is mainly used for remote sensing applications. A Sun Synchronous orbit can place a satellite in constant sunlight, which allows the solar panels to work continually. Graphic images of some common types of Earth orbits are presented below:

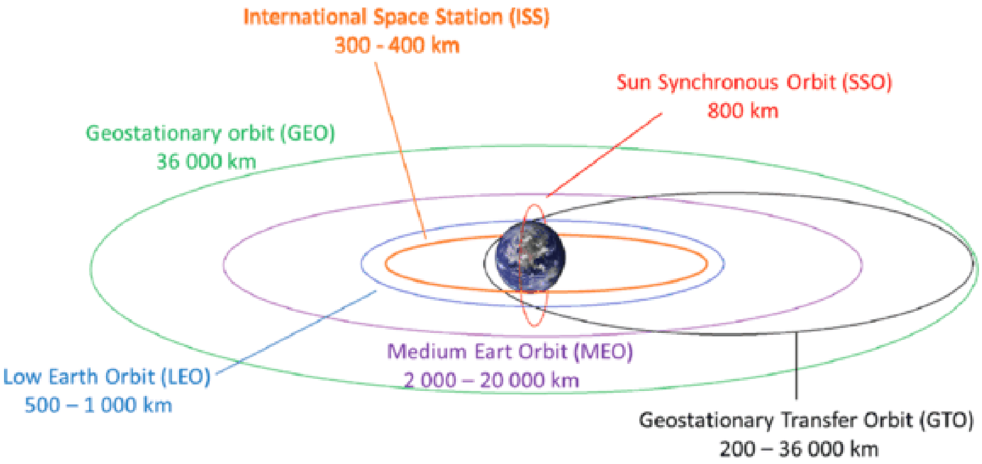


Figure 3. Principal orbits for artificial satellites around the Earth. Source: Cottin et al. 2017

Space Ecosystem actors

While space capabilities were once concentrated among two superpowers, increasing number of governments began to develop their own space programs and technologies. According to Paikowsky (2016), the rationale of governments to engage in development of national space programs fell into three main categories: national security and military considerations, economic growth and benefits for society; and the aspiration to sustain and upgrade its international status. As of 2007, 58 countries possessed dedicated civil space programs, 44 countries have placed nationally owned satellites into orbit, and 8 countries and one regional organization, European Space Agency (ESA), have achieved domestic space launch capabilities (Early 2014). These are Russia, the United States, China, Japan, India, Israel, Iran and North Korea. Only three nations,

[18] https://www.esa.int/Our_Activities/Space_Transportation/Types_of_orbits last access September 2018
[19] http://www.suparco.gov.pk/pages/orbit-type.asp last access September 2018

Russia, the United States and China have launched their own manned spacecrafts. During 2018, only Russia provides space rides to other nations' astronauts.

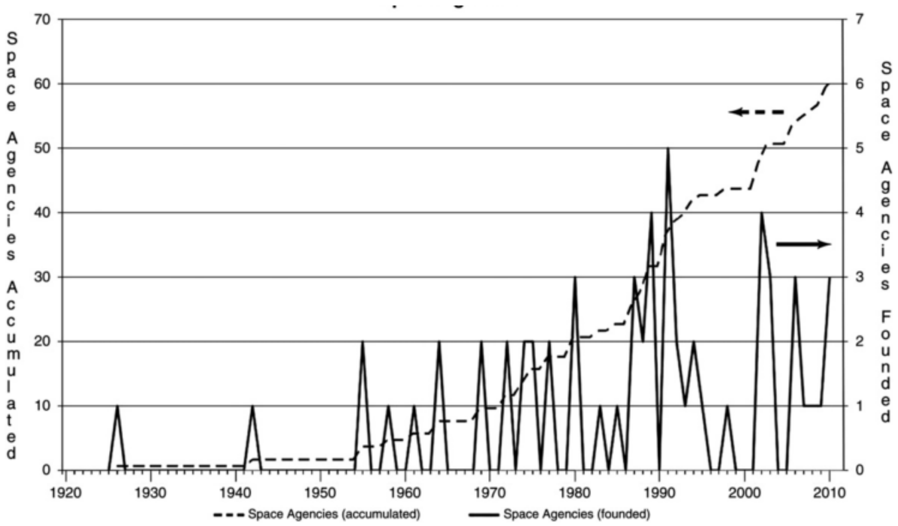
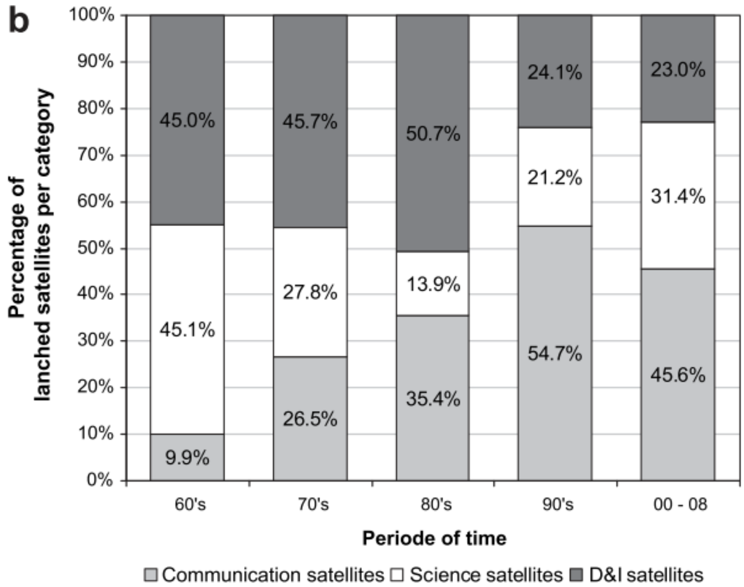


Figure 4. Yearly and accumulated number of space agencies worldwide. Source: Devezas et al. 2012

Started from 1980s, political and legal frameworks to enable private sector participation in space activities were put into place (Frischauf et al. 2017). In the mid-90s, military missions were substituted by a growing number of civilian missions, evidencing an important transition in the space sector (Devezas et al. 2012). The broadcasting monopoly of the intergovernmental organization Intelsat was broken by several private satellite telecommunication companies to meet the growing demand for Direct-Broadcast Satellite (DBS), specifically the digital satellite television (Launius et al. 2012). As a next step, Earth observation was opened to the private sector after legislation change from a state ownership of Earth observation satellites by the Land Remote Sensing Commercialisation Act (Denis and Pasco 2015).

Increasing number of commercial satellite operators had been founded to provide satellite telecommunications services or earth observation and geospatial data to third parties. The telecommunication became the primary driver of the space economy. For the past two decades communication satellites accounted for roughly half of all launches worldwide (Hiriart and Saleh 2010). By revenue, satellite television accounts for 78% of the satellite services, satellite radio 3.2%, and satellite broadband 1.4% (Hanson 2015).

Figure 5. Satellites launched by applications. Substitution process of military missions by growing number of civil missions since mid 90s. Source: Devezas et al. 2012



** Defense and intelligence (D&I) satellites*

Figure 6. Launched satellites per category from 1960 to 2008. Source: Hiriart and Saleh 2010

Satellite industry

Today, there are 8 major companies that build large commercial Geosynchronous satellite platforms: Airbus Defence and Space, OHB SE, Boeing Defense, Space & Security, INVAP, JSC Information Satellite Systems, Lockheed Martin, Orbital ATK, Space Systems/Loral Thales Alenia Space. Companies that manufacture landers, rovers and probes are: Brown Engineering Company, China National Space Administration, Deep Space Industries, Lavochkin, NASA JPL, ISRO, Planetary Resources.

Many companies have developed capabilities to design and build smaller less sophisticated satellite platforms. Increasing number of start-ups are emerging to construct CubeSats and

NanoSats that are being used more frequently as a cost-effective way to conduct various forms of research. The standard 1U CubeSat is 10cm x 10cm x 10cm in size. Since its inception in 1999, new cube satellite companies have developed more variations in size. A 1.5U, 2U, 3U, 6U, 8U, 12U etc. are now offered to meet customer's growing specifications. Some examples of CubeSat and NanoSat companies are Pumpkin Space Systems, AAC Microtec, Adcole Maryland Aerospace, Blue Canyon Technologies, Compagnia Generale per lo Spazio, Harris Corporation, Clyde Space, Endurosat, GomSpace, GAUSS Srl, Innovative Solutions In Space (ISIS), Millennium Space Systems, NanoAvionics.

Nowadays, there are more than 50 satellite telecommunications operators established around the world. The World Teleport Association publishes the list of the world's largest satellite operators in terms of revenues from all customized communications sources and includes operators of teleports and satellite fleets. Major satellite operators in 2016 were Intelsat S.A. (Luxembourg/USA); SES (Luxembourg); Eutelsat (France); EchoStar (USA); Telesat (Canada); Telespazio (Italy); SingTel (Singapore); Thaicom (Thailand); Hispasat (Spain); Optus (Australia); AsiaSat (China); MEASAT (Malaysia); Telenor (Norway). Earth observation operators with satellite constellations include: Planet Labs (USA), Airbus's Spot Image (France), DMC International Imaging (UK), DigitalGlobe (USA), ImageSat (Israel).

Satellite services providers are companies offering commercial space-related services and products to the final consumers. They are generally don't refer to the traditional space industry, and are only using space signals and data in their own products. Typically, their services concern communications, satellite television (e.g. BskyB, Dish and DirectTV), geospatial products and location-based services (e.g. Trimble, Garmin). Only a small part of their revenues and employment are derived directly from their space-related activity. They are included in the space economy as far as a share of their activity directly depends on the provision of satellite signals or data.

Space launch industry

Historically, spaceflight capabilities have been developed and managed by state space agencies. Below is a list of incumbent organizations of the space launch industry, incl. space agencies, their public and private prime contractors and launch service providers.

Table 1. State agencies and their contractors. Space launch industry

Company	Foundation year	Revenue	Parent company	Launch Vehicle	Information
ArianeGroup (EUR)	2015	$3.44 bln (2016)	Airbus Defence and Space	Ariane; Vega	ArianeGroup formerly Airbus Safran Launchers is a joint venture of the European aerospace company Airbus and the French group Safran. Subsidiaries: ArianeSpace, Aerospace Propulsion Products, CILAS, Eurockot Launch Services, NUCLETUDES, Pyroalliance, Sodern.
ArianeSpace (EUR)	1980	$1.64 bln (2015)	ArianeGroup	Ariane; Soyuz-ST; Vega	ArianeSpace is a multinational company founded in 1980 as the world's first commercial launch service provider. The company offers a number of different launch vehicles: the heavy-lift Ariane 5 for dual launches to geostationary transfer orbit, the Soyuz-2 as a medium-lift alternative, and the solid-fueled Vega for lighter payloads. As of May 2017, ArianeSpace had launched more than 550 satellites in 254 launches over 34 years (236 Ariane missions minus the first 8 flights handled by CNES, 17 Soyuz-2 missions and 9 Vega missions).
Eurockot Launch Services (EUR; RUS)	1995		ArianeGroup, Khrunichev	Rockot	Eurockot Launch Services is a commercial spacecraft launch provider founded in 1995. Eurockot uses an expendable launch vehicle called the Rockot to place satellites into Low-Earth orbit (LEO). Eurockot is jointly owned by ArianeGroup, which holds 51 percent, and by Khrunichev State Research and Production Space Center (RUS), which holds 49 percent. Eurockot launches from dedicated launch facilities at the Plesetsk Cosmodrome in northern Russia.

Starsem (EUR; RUS)	1996		Roscosmos (25%); "TsSKB-Progress" Samara Space Center (25%); Astrium (35%); ArianeSpace (15%)	Soyuz	Starsem is a European-Russian company that was created in 1996 to commercialize the Soyuz launcher. Starsem is headquartered in Évry, France (near Paris). The exclusive rights of the European "Starsem" for Soyuz-2 launches expired in 2016.
Sea Launch (RUS)	1995		S7 Group	Zenit	Sea Launch was established in 1995 as a consortium of four companies from Norway, Russia, Ukraine and the United States, managed by Boeing with participation from the other shareholders. Sea Launch uses a mobile maritime launch platform for equatorial launches of commercial payloads on specialized Zenit rockets. Zenit rocket family is manufactured by Ukrainian PA Yuzhmash (1st and 2nd stages) and Russian RSC Energia (3rd stage). Due to increasing political tensions between Russia and Ukraine starting in 2014, and the resulting international sanctions, the future of Zenit is uncertain. In September 2016, S7 Group, owner of S7 Airlines Russia announced they were purchasing Sea Launch.
Lockheed Martin Space Systems / Lockheed Martin Commercial Launch Services (USA)	1953		Lockheed Martin	Atlas; Titan	Lockheed Martin Space is one of the four major business divisions of Lockheed Martin. The division currently employs about 16,000 people. The Atlas V family is a product of the U.S. Air Force's Evolved Expendable Launch Vehicle Program (EELV), begun in 1995. Lockheed Martin originally developed the Atlas V, but manufacturing and operations are now conducted by United Launch Alliance (ULA), a joint company between Lockheed Martin and Boeing. ULA markets the vehicle to the U.S. Government and Lockheed Martin Commercial Launch Services markets to commercial clients worldwide. The Atlas V family debuted in 2002 with the successful launch of an Atlas V 401 from Cape Canaveral. It will be replaced with ULA's Vulcan family by expected mid-2020s.

Boeing Defense, Space & Security (USA)		$21.057 bln (2017)	Boeing	Delta; SLS	Boeing Defense, Space & Security is a consolidated group which brought together major names in aerospace: Boeing Military Airplane Company; Hughes Satellite Systems; Hughes Helicopters minus the civilian helicopters products; Piasecki Helicopter, subsequently known as Boeing Vertol and then Boeing Helicopters; the St. Louis-based McDonnell division of the former McDonnell Douglas Company; and the former North American Aviation division of Rockwell International. McDonnell Douglas (now The Boeing Company) introduced the Delta II series in 1989. The Delta IV family successfully debuted in 2002. Currently United Launch Alliance (ULA) manufacture and launch Delta rockets.
United Launch Alliance (ULA) (USA)	2006			Atlas; Delta; Vulcan; SLS	United Launch Alliance (ULA) was formed as a joint venture between Lockheed Martin Space Systems and Boeing Defense, Space & Security in December 2006 by combining the teams of the two companies. ULA is a provider of spacecraft launch services to the United States government, incl. the Department of Defense and NASA. With ULA, Lockheed and Boeing held a monopoly on military launches for more than a decade until the U.S. Air Force awarded a GPS satellite contract to SpaceX in 2016. ULA has historically only served U.S. government customers but has indicated plans to open its Atlas V and future Vulcan vehicles for international competition. The Vulcan family of launch vehicles was introduced in 2015 as an eventual replacement for the company's Atlas V and Delta IV.
Northrop Grumman Innovation Systems (USA), former Orbital ATK Inc.	2015 as Orbital ATK; 2018 as Northrop Grumman Innovation Systems	$4.455 bln (2016)	Northrop Grumman	Antares; Minotaur; Pegasus; Omega; NGL; SLS	Northrop Grumman Innovation Systems is an American aerospace manufacturer and defense industry company. It specializes in the design, manufacture and launch of light- and medium- class space and rocket systems for commercial, military and other government customers. It was formed as Orbital ATK Inc. in 2015 from the merger of Orbital Sciences Corporation and parts of Alliant Techsystems, and was purchased by Northrop Grumman in 2018. Innovation Systems designs, builds, and delivers space, defense, and aviation-related systems to customers around the world both as a prime contractor and as a merchant supplier.

NASA (USA)	1958	Budget: $20.7 bln (2018)		Space Shuttle; SLS	The National Aeronautics and Space Administration (NASA) is an independent agency of the United States Federal Government responsible for the civilian space program, as well as aeronautics and aerospace research. Since its establishment, most U.S. space exploration efforts have been led by NASA, including the Apollo missions, the Skylab space station, and later the Space Shuttle. NASA is supporting the International Space Station and is overseeing the development of the Orion Multi-Purpose Crew Vehicle, the Space Launch System and Commercial Crew vehicles. The Space Launch System (SLS) is a launch vehicle system being developed by NASA for the next era of human exploration beyond Earth's orbit. The vehicle will be used to send crews of up to four astronauts in an Orion spacecraft, cargo, or large robotic scientific missions to Mars, Saturn and Jupiter.
Roscosmos State Corporation for Space Activities (RUS)	25 February 1992 (formerly the Soviet space program)	Budget: $2.78 bln (2015)		Soyuz; Proton; Angara Kosmos; Rockot	The Roscosmos State Corporation for Space Activities is a state corporation responsible for the space flight and cosmonautics program for the Russian Federation. Originally established as the Federal Space Agency, the agency evolved and consolidated itself from an independent state enterprise to the national megacorporation on 28 December 2015 through a presidential decree. In 2015 the Russian government merged Roscosmos with the United Rocket and Space Corporation, the re-nationalized Russian space industry, to create the Roscosmos State Corporation that took over 1 January 2016. The Prime manufactures of Russian orbital space launchers are: 1. Korolev Rocket and Space Corporation Energia - the prime developer and contractor of the Russian manned spaceflight program; the lead developer of Soyuz and Progress spacecrafts; the lead developer of the Russian part of the International Space Station. 2. Khrunichev State Research and Production Space Center – the manufacturer of spacecraft and space-launch systems, including Proton, Angara and Rockot rockets; the company designed and produced all Soviet space stations, including the Soviet Union's Almaz (Salyut) and Mir space stations, and two modules of the International Space Station (ISS).

					As of 2017, Roscosmos had more than 60 subsidiaries, incl.: United Rocket and Space Corporation; Information Satellite Systems Reshetnev; JSC SRC Progress; NPO Lavochkin; GK Launch Services, Glavkosmos, etc.
Yuzhmash/ Yuzhnoye Design Office (UKR)				Tsyklon; Dnepr; Antares; Zenit	The Production Association Yuzhny Machine-Building Plant named after A.M. Makarov, or Yuzhmash is a Ukrainian state-owned aerospace manufacturer. The company is headquartered in Dnipro, and reports to the State Space Agency of Ukraine. The company is in close co-operation with the Yuzhnoye Design Office also situated in Dnipro. It works with international aerospace partners in 23 countries. The launch service provider for its Dnepr rocket is a GK Launch Services, a subsidiary of Roscosmos State Corporation. The launch service provider for Zenit rocket is See Launch.
International Launch Services (ILS)	1995		Khrunichev State Research and Production Space Center	Proton; Angara	International Launch Services (ILS) is a joint venture with exclusive rights to the worldwide commercial sale of Angara and Proton launch systems` services. ILS was formed in 1995 as a private spaceflight partnership between Lockheed Martin, Khrunichev and Energia. ILS initially co-marketed non-military launches on both the U.S. Atlas and the Russian Proton launch vehicles. In 2006, Lockheed Martin sold its ownership interests in to Space Transport Inc. The company has retained all rights related to marketing the commercial Atlas vehicles. In May 2008, Khrunichev State Research and Production Space Center acquired all of Space Transport's interest and is now the majority shareholder in ILS. ILS remains a U.S. company and headquarters are currently in Reston, Virginia, near Washington, D.C.
GK Launch Services	2017		Glavkosmos (75%); Kosmotras (25)	Dnepr; Soyuz	GK Launch Services is a joint stock company that was established because of expiration of exclusive rights for Soyuz-2 launchers by Starsem. In order to keep up with growing international demand for satellite launchers and to increase the workload of the Russian space industry and launch sites. GK Launch Services is an operator of Dnepr and Soyuz-2 commercial launchers from the Russian spaceports (Vostochny, Plesetsk) and the Republic of Kazakhstan (Baikonur).

China National Space Administration (CNSA)	1993	Budget: $11 bln (2017)		Long March; Kaitouzhe; Kuaizhou	The China National Space Administration (CNSA) is the national space agency of China. It is responsible for the national space program and for planning and development of space activities. CNSA and China Aerospace Corporation (CASC) assumed the authority over space development efforts previously held by the Ministry of Aerospace Industry. It is a subordinate agency of the State Administration for Science, Technology and Industry for National Defence (SASTIND), itself a subordinate agency of the Ministry of Industry and Information Technology (MIIT).
China Aerospace Science and Technology Corporation (CASC)	1999			Long March; Kaitouzhe; Kuaizhou	The China Aerospace Science and Technology Corporation (CASC) is the main contractor for the Chinese space program. It is state-owned and has a number of subordinate entities which design, develop and manufacture spacecrafts, launch vehicles, strategic and tactical missile systems, and ground equipment. It was officially established in July 1999 as part of a Chinese government reform drive, having previously been one part of the former China Aerospace Corporation. Its main subordinate entities are China Academy of Launch Vehicle Technology (CALT); China Academy of Space Technology (CAST); Shanghai Academy of Spaceflight Technology (SAST); Sanjiang Space Group, etc.
The Japan Aerospace Exploration Agency (JAXA)	2003			Epsilon; H-IIA / H-IIB; H3	JAXA is the Japanese national aerospace and space agency. Through the merger of three previously independent organizations, JAXA is responsible for research, technology development and launch of satellites into orbit, and is involved in many more advanced missions such as asteroid exploration and possible manned exploration of the Moon. The main contractor for the design and manufacture of Epsilon rocket is IHI Aerospace Corporation.
Mitsubishi Heavy Industries (MHI) / MHI Launch Services (JPN)				H-IIA / H-IIB; H3	Mitsubishi Heavy Industries, Ltd. is a Japanese multinational engineering, electrical equipment and electronics company headquartered in Tokyo, Japan. Together with Nissan and IHI Aerospace, MHI is the manufacturer of the H-IIA/H-IIB and H3 launch vehicles, Japan's main rockets, and provider of launch services through MHI Launch Services.

The Indian Space Research Organisation (ISRO)	1969	Budget: $1.5 bln (2018–19)	Department of Space	SLV, ASLV, PSLV, GSLV Mk.III (LVM3)	The Indian Space Research Organisation (ISRO) is the space agency of the Government of India headquartered in the city of Bangalore. Its vision is to "harness space technology for national development while pursuing space science research and planetary exploration."
Antrix Corporation (IND)	1992	$260 mln (2014–15)	Department of Space	SLV, ASLV, PSLV; GSLV	Antrix Corporation is the commercial arm of the Indian Space Research Organisation (ISRO). Its objective is to promote the ISRO's products, services and technologies. It was incorporated as a private limited company owned by the Indian government on 28 September 1992. The company is a Public Sector Undertaking (PSU), wholly owned by the Government of India. It is administered by the Department of Space.
Israel Space Agency (ISA)	1983 (successor agency to National Committee for Space Research 1960–1983)	Budget: $48 mln	Israel's Ministry of Science and Technology	Shavit	The Israel Space Agency (ISA) is a governmental body, a part of Israel's Ministry of Science and Technology, that coordinates all Israeli space research programs with scientific and commercial goals. The Shavit is manufactured by Israel Aerospace Industries (IAI) and the Shavit program is managed by the Israel Space Agency (ISA). Today, Israel is the smallest country with indigenous launch capabilities.

Orbital launch capabilities have been also developed by North Korea and Iran governments. The Unha family of vehicles represents North Korea's launch capability introduced by its first launch in 2009. The first confirmed launch of Safir, the Iran orbital launch vehicle, occurred in 2008. Both launchers have a capacity of less than 100 Kg to LEO. It is believed that the third stage of North Korea's Unha vehicle uses Safir`s third stage. Both Iran and North Korea have cooperated on missile and launch vehicle development since at least the 90s.

Started in the early 2000s, an increase participation of private companies in the space sector, both under public–private partnerships (PPP) and through private initiatives, became known as a New Space movement (Brady 2016); Denis and Pasco 2015; Frischauf et al. 2017; Paikowsky 2016). Saverio Calderoni, specialist in European New Space activity, defines it in the New Space Global's monthly market analysis report: "When we say New Space, we are not talking merely of the general commercialization of space, as there has been a commercial element in space activities for decades, but rather the cultural and philosophical shift toward greater private entity participation" (Anderson 2013). While satellite broadcasting, Earth observation, meteorology, operational oceanography, and global navigation systems fell into the civilian and commercial domain back to the 1990s, the New Space currently comprehends private companies attempting to build space launch systems (Handberg 2014).

New Space focuses on space as a resource and venue for a profitable business. In order to make space a commercially attractive market place, new companies are working to develop low-cost access to space and affordable space technologies (Paikowsky 2016). Handberg (2014) argues that without reducing the price of getting to space by at least a factor of ten, humans will accomplish very little in space. The ultimate goal of New Space companies is to give customers of all types the opportunity to access space at a much lower cost and with greater flexibility thus increasing the demand for space-related activities (Najam 2014).

Originated and currently progressing mainly in California, USA, the commercial launch industry began to see a considerable inflow of start-up space ventures and private capital (Frischauf et al. 2017). From 3 companies, Orbital Sciences Corporation, Lockheed Corporation, and The Boeing Company, the Federal Aviation Administration (FAA) projects 12 companies capable of providing orbital launch services by 2020 (Kim 2018). Entrepreneurs from the personal computer and Internet industry have demonstrated a particular enthusiasm for establishing new private space ventures (Autry and Huang 2014). The most notable astropreneurs are Elon Musk, cofounder of PayPal and Tesla, Jeff Bezos, founder of Amazon, Paul Allen, cofounder of Microsoft (recently deceased), Eric Schmidt and Larry Page, from Google. These days we can also observe the growing number of private spaceflight companies in China. These new born Chinese companies have entered the race for the space, with inaugurated first launches of their developing rockets scheduled for the following years. General information on some most notable new spaceflight companies (Handberg 2014) and their flagship rockets is provided below:

Table 2. New Space companies. Space launch industry.

Company	Foundation year	Launch Vehicle	Information
Space Exploration Technologies Corp., SpaceX (USA)	2002	Falcon	SpaceX is a private American aerospace manufacturer and space transportation services company headquartered in Hawthorne, California. It was founded in 2002 by entrepreneur Elon Musk with the goal of reducing space transportation costs and enabling the colonization of Mars. SpaceX has since developed Falcon launch vehicle family and the Dragon spacecraft, which both currently deliver payloads into Earth orbit. The company`s flagship Falcon 9 and Falcon Heavy are partly reusable orbital launchers. SpaceX's achievements include the first privately funded liquid-propellant rocket to reach orbit (Falcon 1 in 2008), the first private company to successfully launch, orbit, and recover a spacecraft (Dragon in 2010), the first private company to send a spacecraft to the International Space Station (Dragon in 2012), the first propulsive landing for an orbital rocket (Falcon 9 in 2015), the first reuse of an orbital rocket (Falcon 9 in 2017), and the first private company to launch an object into orbit around the sun (Falcon Heavy's payload of a Tesla Roadster in 2018). NASA also awarded SpaceX a further development contract in 2011 to develop and demonstrate a human-rated Dragon, which would be used to transport astronauts to the ISS and return them back to Earth.
BlueOrigin (USA)	2000	New Glenn	Blue Origin, LLC is an American privately funded aerospace manufacturer and spaceflight services company headquartered in Kent, Washington. Founded in 2000 by Jeff Bezos, the company is developing technologies to enable private human access to space with the goal to lower costs and increase reliability. Blue Origin is employing an incremental approach from suborbital to orbital flights, with each developmental step building on its prior work. The New Glenn family will feature a reusable first stage with six landing struts. The BE-4 engine will run on liquid oxygen and liquid methane (CH_4), making it the first engine to use such propellants. Year of planned first launch is 2020.

Virgin Orbit (USA)	2017	LauncherOne	Virgin Orbit is a company within the Virgin Group which plans to provide launch services for small satellites. The company was formed in 2017 to develop the air-launched LauncherOne rocket, which had previously been a project of Virgin Galactic. LauncherOne is a two stage orbital launch vehicle under development by Virgin Orbit since the 2010s. It is an air launch to orbit rocket, designed to launch payloads up to 500 kg into LEO, following air launch from a carrier aircraft at high altitude.
Stratolaunch Systems (USA)	2011	Stratolaunch	Stratolaunch Systems Corporation is an American space transportation venture developing an air launch to orbit system, with its corporate headquarters located in Seattle, Washington. The project was officially announced in December 2011 by Microsoft co-founder Paul G. Allen and Scaled Composites founder Burt Rutan, who had previously designed the first private suborbital manned spacecraft. SpaceShipOne. The project is a mobile launch system with three primary components; a carrier aircraft being built by Scaled Composites, a multi-stage payload launch vehicle, which would be launched at high altitude into space from under the carrier aircraft, plus a mating and integration system by Dynetics. The system will employ the largest airplane ever built to be a carrier vehicle for an orbital rocket. The first test flights are planned to begin in 2019, with a goal of a commercial launch by 2020.
Rocket Lab (USA/New Zealand)	2006	Electron	Founded in New Zealand by entrepreneur Peter Beck, Rocket Lab is now headquartered in the United States with a subsidiary in New Zealand. The company develops lightweight, cost-effective commercial rocket launch services. The Electron Program was founded on the premise that small payloads such as CubeSats require dedicated small launch vehicles with flexibility not currently offered by traditional rocket systems. The lightweight Electron rocket is explicitly designed to service the small-satellite market with dedicated, high-frequency launch opportunities. Electron is designed to deliver payloads of 225 kg to LEO.

Relativity Space (USA)	2015	Terran	Relativity Space is a private American aerospace manufacturer company headquartered in Los Angeles, California. It was founded in 2015 by Tim Ellis and Jordan Noone. Relativity Space business model is based on the idea of 3D printing in rocket manufacturing. Relativity plans to 3D print an entire launch vehicle. The extensive use of 3D printing supposedly allows the company to iterate designs quickly, use less tooling and human labor. In order to 3D print large objects, Relativity has created a system named Stargate which it claims is the world's largest 3D printer of metals. The Terran 1 launch vehicle will consist of two stages. The first stage will contain 9 Aeon 1 engines powered by liquid methane and liquid oxygen. The second stage will contain a single Aeon 1 engine. The maximum payload will be 1,250 kg to LEO.
Vector Launch Inc (USA)	2016	Vector	Vector Launch Inc is an American space technology company which aims to launch small satellites into orbit with its eponymous family of small launch vehicles. The company plans to provide launch services with two rockets, the smaller Vector-R, and the larger Vector-H. Both rockets use a single engine for their second stage and a cluster of engines, three in the Vector-R and six in the Vector-H, for their first stage, all of which will run on propylene and liquid oxygen. Like other private launch companies such as SpaceX and Blue Origin, Vector plans to recover the first stages of its rockets for reuse. Their strategy for doing so differs from autonomous landings, but rather using a unique aerial recovery system. Other notable design features include a carbon fiber structure, some 3D printed engine parts, minimal infrastructure launch pads, and a fast launch cadence, which the company hopes will eventually reach 100 launches per year.
Firefly Aerospace (USA)	2017	Alpha	Firefly Aerospace is a private aerospace firm based in Austin, Texas, that is developing small and medium-sized launch vehicles for commercial launches to orbit. The Alpha vehicle developed by Firefly Aerospace is an expendable launch vehicle with 1,000 kg payload capability to LEO.

Rocket Crafters, Inc. (USA)	2010	Intrepid	The company was founded in 2010 and is based in Titusville, Florida. Rocket Crafters, Inc. designs, develops, and tests hybrid rocket engines and launchers. The company's products include D-DART, a hybrid rocket engine, and Intrepid launch vehicles. The vehicles will be powered by hybrid liquid-solid engines produced through additive manufacturing and using a proprietary propellant mixture.
SpaceFlight Industries (USA)	2010		Spaceflight Industries, Inc. is an American private aerospace company based out of Seattle, Washington that specializes in organizing rideshare space launches of secondary payloads and geospatial intelligence services. Spaceflight Industries has two primary business services: Spaceflight, their launch rideshare service, and BlackSky, their geospatial intelligence service. Spaceflight buys excess capacity from commercial launch vehicles, sells the capacity to a number of "rideshare" secondary payloads, and integrates all of the secondary satellites as one discrete unit to the launch vehicle, providing a significant price discount to reach orbit compared to buying an entire launch vehicle.
ExPace Technology Corporation (CHN)	2016	Kuaizhou	ExPace also called CASIC Rocket Technology Company is a private Chinese space rocket company based in Wuhan, China. ExPace Technology Corporation offers commercial space launch services on small satellite launchers to Low Earth orbit. ExPace Technology Corporation operates as a subsidiary of China Aerospace Science and Industry Corporation.
Landspace Technology Corporation (CHN)	2015	Zhuque	LandSpace or Landspace Technology Corporation is a Chinese private space launch company based in Beijing. It was founded by Tsinghua University, in 2015. The company conducted its first launch of the Zhuque-1 rocket on 27 October 2018, however the payload failed to reach orbit due to an issue with the third stage.
One Space Technology (CHN)	2015	OS-M	OneSpace or One Space Technology is a Chinese private space launch company based in Beijing. OneSpace was founded in 2015, with support from the National Defense Science and Industry Bureau. OneSpace is targeting the small launchers market for micro and nanosatellites. The company plans to unveil its family of rockets early in 2019.

LinkSpace (CHN)	2014	New Line	LinkSpace or Link Space Aerospace Technology Inc. is a Chinese private space launch company based in Beijing. The New Line 1 is a two-stage small orbital rocket under development to launch microsats and nanosats, with a reusable first stage. As of the end of 2017, the main rocket engine has been tested over 200 times, and first launch is planned for 2020.
i-Space (CHN)	2016	Hyperbola	i-Space is a Chinese private space launch company based in Beijing. As of August 2018, i-Space has successfully launched the Hyperbola-1S rocket into space twice on a suborbital flight. The Hyperbola-3 rocket is a two-stage, liquid-fueled, reusable rocket that aims to lift 2,000 kg into LEO by 2021. In May 2018, i-Space indicated they hoped to eventually develop a reusable sub-orbital spaceplane for space tourism.

“Space launch is a classic case of the “chicken-and-egg” problem, and one which has proven to be extremely hard to overcome” (Mankins 2002, p. 733). The challenge is to design a space launch vehicle with low enough launch cost, even at moderate launch rates, to engender subsequently the significant market growth that would progressively lead to even lower launch costs, hence prices.

In 2011, Space Exploration Technologies announced that it was beginning a reusable launch system technology development program, using Vertical take-off, Vertical landing (VTVL) rocket configuration. In December 2015, the Falcon 9 successfully accomplished a propulsive vertical landing. The first time in history of an orbital rocket. In March 2017, SpaceX demonstrated its reusable vehicle technology by relaunching the first stage (booster) of a Falcon 9 rocket initially flown a year before (Reddy 2017). “Following stage separation, Falcon 9’s first stage successfully performed a landing on the “Of Course I Still Love You” drone ship stationed downrange in the Atlantic Ocean” (Sippel et al. 2017). As of August 2018, SpaceX has recovered 21 first-stage boosters from previous missions, 6 of which were recovered twice, yielding a total 27 landings. In 2017, SpaceX flew a total of 5 missions out of 20 with re-used boosters. In total, 14 boosters have been re-flown as of August 2018.

Previously, Blue Origin has already achieved successful recoveries and re-flights of the first stage of a New Shepard rocket. These missions, however, were suborbital with a maximum apogee slightly above 100 Km (Sippel et al. 2017).

The technical approach of SpaceX and Blue Origin are similar with Vertical Take-off, Vertical Landing (VTVL) configuration. However, until 2017 the attained launch records were insufficient to establish an empirically based RLV-operations cost model (Sippel et al. 2017). According to those authors, nobody in the world is capable of giving any reliable quantified prognosis on the actual cost structure for the reusable launch vehicle (Sippel et al. 2017). It would be premature to conclude that VTVL reusable launch vehicle is an optimal design and will lead to significant cost reduction by a factor of 5 or 10.

SpaceX intends to succeed where NASA had failed (Reddy 2017). Incumbents put doubts on the viability of VTVL approach as well as on the overall economic feasibility of reusability concept in rocketry. United Launch Alliance (ULA) stated that retrieving and refurbishing the entire core stage could offer utmost 10% cost savings (Waters 2017). The French space agency estimated that a completely reusable core stage booster would have to fly at least 50 times a year to lower the cost by 10%–20%, whereas ArianeSpace chief executive Stephane Israel put the number between 35 and 40 launches (Wood 2017). This figure represents half of all annual launches worldwide, but estimations were provided by incumbent companies.

Despite existing concerns, some state and private space launch companies do not rule out utilizing reusable systems, and reconsider reusability for their space transportation systems. Indian Space Research Organisation (ISRO) has launched RLV-TD open architecture program to evaluate various technological options to retrieve and reuse launch vehicles or components. China also has been working on preliminary experiments on controlled vertical landing system and parachute–airbag system before deciding to proceed further with the latter option (Reddy 2017). United Launch Alliance also plans to make some parts of their future Vulcan rocket reusable starting in 2024. Instead of recovering the entire core stage, ULA is planning to recover and reuse only Vulcan's engines. Those would be desegregated from the stage, decelerated and recovered in midair using helicopters. ULA has assessed that it makes economic sense to recover the engines that weigh only a quarter of the core stage's overall weight but constitute 65% of the stage's entire cost.

Many field experts agree reusability will become a commonplace in the industry. It would be just a matter of time. Blue Origin`s CEO Bob Smith summed it up as: "I think for many years the cost advantage was with expendable launch vehicles. But it seems like with the breakthroughs that SpaceX and Blue Origin are having, that equation is starting to shift."[20] Results of the spaceflight astropreneurs renewed interest in reusability for space launch vehicles (Sippel et al. 2017), and also unleashed price competition as SpaceX started to offer comparably lower launch prices, forcing competitors to take a beat and reconsider the way they approach space launch as a business.

Using the presented literature and technical data, we applied the described research method and produced our results - those will be shown in the following section.

V - RESULTS AND DISCUSSIONS

Research Objective (1): To identify, chart and analyze the Space Ecosystem

Applying the Methodology of Business Ecosystem Network Analysis (MOBENA), we produced the Space Ecosystem chart. A table with all actors and connections among them is reported in Appendix-A. The ecosystem consists of nodes and links, where nodes represent actors, and links represent existing connections among them. For nodes, color and dimension codes are

[20] http://interactive.satellitetoday.com/via/may-2018/calculating-the-economics-of-reusable-launch-vehicles/ last access September 2018

used to represent the weight of each actor, being the number of connections. The logic is: the more established relationships has an actor, the more power it possesses in the ecosystem.

On the chart, actors that have more weight have larger size and more saturated blue color.

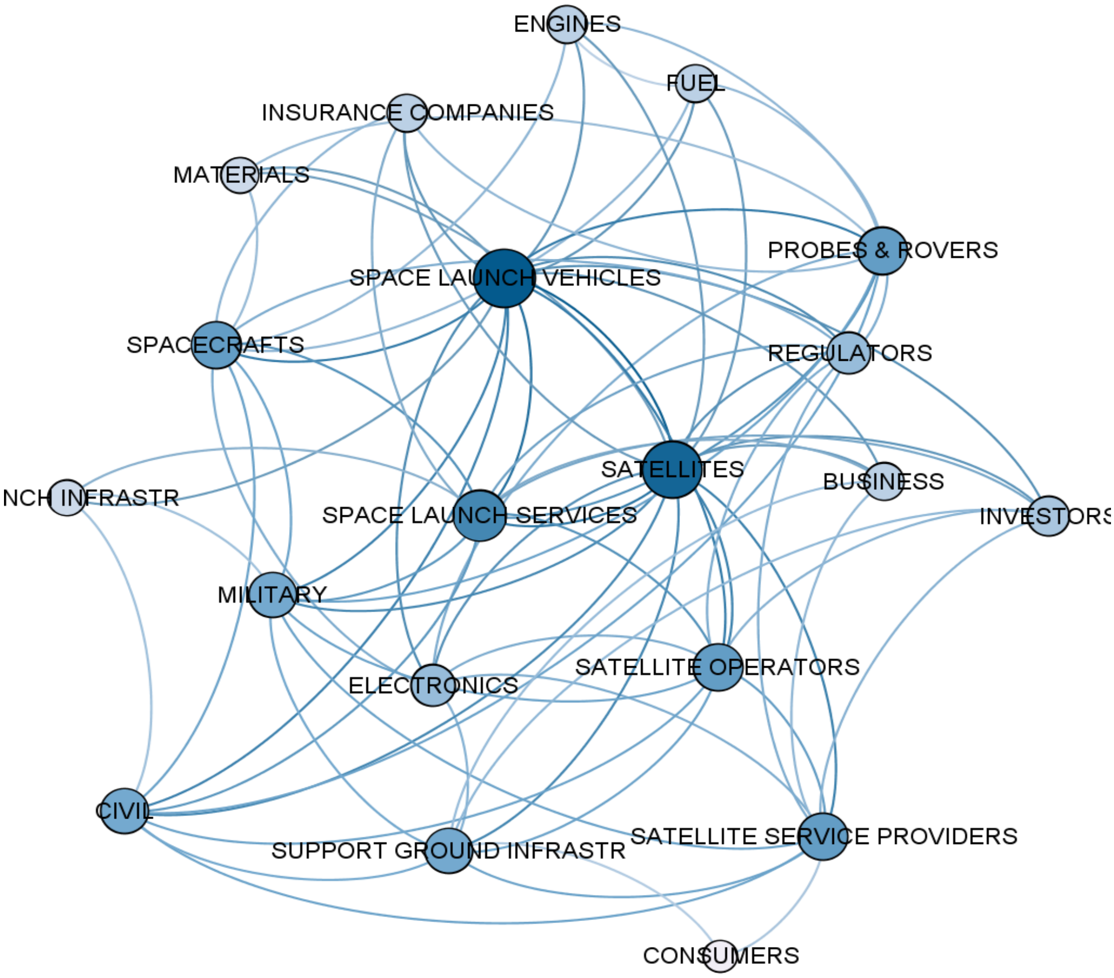


Figure 7. Space Ecosystem.

The ecosystem analysis confirmed our initial assumption that Space Ecosystem's hub consists of companies that design and manufacture space launch vehicles. Below is the graph presenting each actor's link counts, meaning the number of actors with whom it has an established relationship. We will focus our market and performance analysis on the hub.

"Space launch vehicles" node has the largest number of connections, being related to 16 out of 20 actors, or 80% of the ecosystem. "Satellites" node follows, being related to 15 actors.

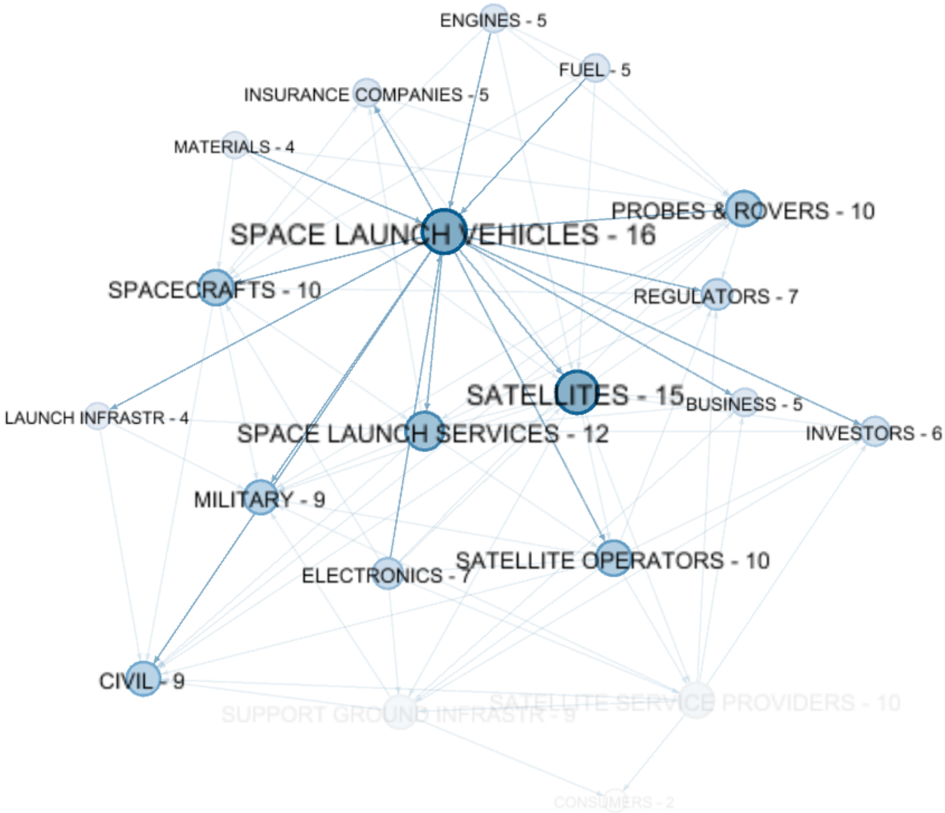


Figure 8. Connections of "space launch vehicles" node with other actors of the Space Ecosystem.

Research Objective (2): To identify key elements of space launch industry and to analyze its evolution

From the literature review we could compare the space launch industry's key strategic, technological, operational and financial characteristics in the course of its history. Three clearly different periods emerged: Space Race, started in the middle of 20th century; Stagnation, in 80s-90s; and the New Space in the 21st century.

Table 3. Key characteristics of the space launch industry in different time periods.

Category	Key Element	Time Period		
		Space Race	**80s – 90s**	**New Space**
Strategic	**Mission**	Military	Civilian	Commercial
	Actors	Government/ Military	Government/ State contractors	Public–private partnerships/ Private
	Business model	Defense contractors	Outsourcing	In-house production

Technological	**Launch vehicle**	Expendable	Expendable/Partly reusable	Partly reusable/Fully reusable
	Basic design	Modified ballistic missile	Modified ballistic missile	Clean-sheet design
	Propulsion system	Kerosene	Kerosene	Methane/ Propylene
	Electronics / Systems	Hydraulic/ Analog flight control	Hydraulic/ Digital flight control	Electromechanical actuation/ Digital flight control/ GPS
Operational	**Manufacturing**	To-order production/ Customization	To-order production	Scalability/ Economy of scale
	Launch rate	Low-frequency	Low-frequency	High-frequency
	Capacity	Small	Medium	Large
	Payload	Single	Secondary payloads	Multiple payloads
Financial	**Investment**	Government	Government/ Private	Private/ Venture capital
	Financial model	Cost plus	Cost plus	Fixed price
	R&D model	100% success	100% success	‘‘Good enough’’

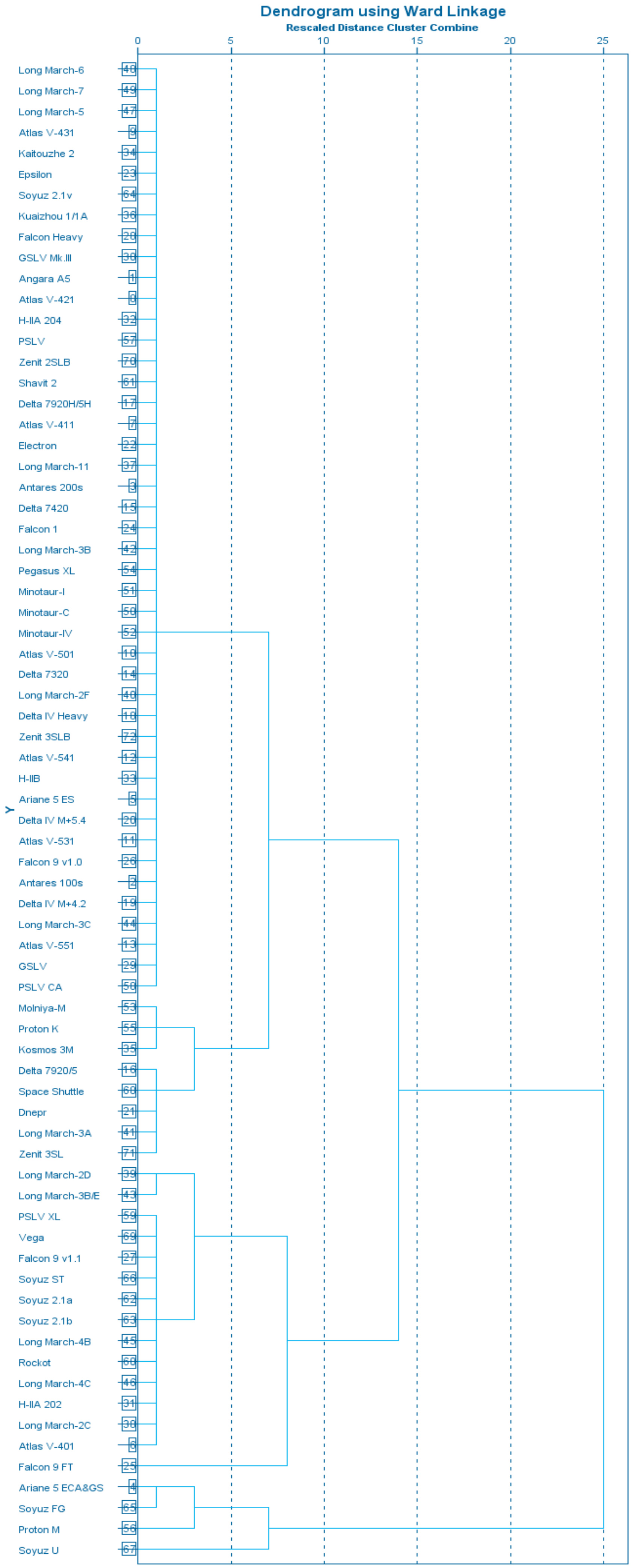
New Space launch companies drives the development of new rocket technologies and also business models. The fact that clients and investors are private actors triggers a shift in the spaceflight sector financial model from cost-plus to fixed price (Paikowsky 2016). This change requires different management methods and demands shorter research and development cycles. As a result, project management is inclined to take higher risks. It is tuned toward a “good enough” R&D model, performing technological tests in service, instead of aiming for 100% success in orbit, as was the case for rocketry in the 20th century (Paikowsky 2016). To ensure timely delivery and keep production costs low, new spaceflight companies switch from outsourcing to in-house manufacturing of critical components. “Preference is given to producing critical elements in-house while remaining open to sharing ideas according to the “open source” principle if there is a strategic benefit” (Frischauf et al. 2017). Technical solutions are sought for scalable business models. Instead of customized and therefore expensive individual products, commercially available components are utilized wherever possible (Frischauf et al. 2017).

Research Objective (3): To describe, compare and analyze operational space launch vehicles

The results of the comparison and analysis of the space launch vehicles are presented as follows: (1) Market analysis by clusters; (2) Performance analysis by clusters; (3) Regression analysis for each cluster.

The clustering process is represented on the dendrogram (Figure 9). The horizontal axis shows the distance or dissimilarity between clusters. The vertical axis represents the launch vehicles.[21]

[21] https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Hierarchical_Clustering-Dendrograms.pdf last access November 2018



Dendrogram using Ward Linkage
Rescaled Distance Cluster Combine
0
5
10
15
20
25
Y
Long March-6
Long March-7
Long March-5
Atlas V-431
Kaitouzhe 2
Epsilon
Soyuz 2.1v
Kuaizhou 1/1A
Falcon Heavy
GSLV Mk.III
Angara A5
Atlas V-421
H-IIA 204
PSLV
Zenit 2SLB
Shavit 2
Delta 7920H/5H
Atlas V-411
Electron
Long March-11
Antares 200s
Delta 7420
Falcon 1
Long March-3B
Pegasus XL
Minotaur-I
Minotaur-C
Minotaur-IV
Atlas V-501
Delta 7320
Long March-2F
Delta IV Heavy
Zenit 3SLB
Atlas V-541
H-IIB
Ariane 5 ES
Delta IV M+5.4
Atlas V-531
Falcon 9 v1.0
Antares 100s
Delta IV M+4.2
Long March-3C
Atlas V-551
GSLV
PSLV CA
Molniya-M
Proton K
Kosmos 3M
Delta 7920/5
Space Shuttle
Dnepr
Long March-3A
Zenit 3SL
Long March-2D
Long March-3B/E
PSLV XL
Vega
Falcon 9 v1.1
Soyuz ST
Soyuz 2.1a
Soyuz 2.1b
Long March-4B
Rockot
Long March-4C
H-IIA 202
Long March-2C
Atlas V-401
Falcon 9 FT
Ariane 5 ECA&GS
Soyuz FG
Proton M
Soyuz U

Figure 9. Dendogram.

(1) Market analysis

Four clearly different rocket groups were produced. One strands out by its recent launch rate – consisted of a sole rocket, Falcon 9 FT, that has been developed by private spaceflight company SpaceX. Based on launch rate patterns, we assigned names to the rocket groups. The other cluster descriptions follows:

Cluster 1 includes 53 launch vehicles, which is 74% of all rockets. This is the most numerous group. Despite number of rockets have been gradually increasing, its market share has halved since 2006. The average annual number of launches is appallingly small 1 launch. We named it as “Failures”.

Cluster 2 consists of four rockets (6% of all), Ariane 5, Proton M, Soyuz FG and the legendary Soyuz U. Soyuz U held the world record of the highest launch rate with 47 flights in 1979. Another world record for a total of 793 missions over its operational lifetime since the first launch in May, 1973. Soyuz U has also been one of the most reliable launchers, with a success rate of 97%. We entitled those as “WorkHorses” for being leaders of the launch industry for several decades. However, over the last 5 years they were struggling, with a significantly reduced launch rate.

Cluster 3 consists of 14 rockets (19% of all) that have been gradually “stealing” market share from the “Failures”. Currently holding half of the launch market. The assigned name is “Sluggish”.

As previously said, Cluster 4 consists of a single rocket (1% of all), Falcon 9 FT "Full Thrust upgrade" model. Started operations in 2015, it got 20% of the market in just in 2 years, which makes it one of the most successful rockets in the history of space exploration.

Table 4. Rocket groups.

Failures	WorkHorses	Sluggish	BigHit
Angara A5	Ariane 5 ECA&GS	Atlas V-401	Falcon 9 FT
Antares 100s	Proton M	Falcon 9 v1.1	
Antares 200s	Soyuz FG	H-IIA 202	
Ariane 5 ES	Soyuz U	Long March-2C	
Atlas V-411		Long March-2D	
Atlas V-421		Long March-3B/E	
Atlas V-431		Long March-4B	
Atlas V-501		Long March-4C	
Atlas V-531		PSLV XL	
Atlas V-541		Rockot	

Atlas V-551 Delta 7320 Delta 7420 Delta 7920/5 Delta 7920H/5H Delta IV Heavy Delta IV M+4.2 Delta IV M+5.4 Dnepr Electron Epsilon Falcon 1 Falcon 9 v1.0 Falcon Heavy GSLV GSLV Mk.III H-IIA 204 H-IIB Kaitouzhe 2 Kosmos 3M Kuaizhou 1/1A Long March-11 Long March-2F Long March-3A Long March-3B Long March-3C Long March-5 Long March-6 Long March-7 Minotaur-C Minotaur-I Minotaur-IV Molniya-M Pegasus XL Proton K PSLV PSLV CA Shavit 2 Soyuz 2.1v Space Shuttle Zenit 2SLB Zenit 3SL Zenit 3SLB		Soyuz 2.1a Soyuz 2.1b Soyuz ST Vega	

Table 5. Market analysis by clusters.

	Cluster															
	Failures				**WorkHorses**				**Sluggish**				**BigHit**			
	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights
Before 2006	1336	62%	21	64	770	36%	4	193	57	3%	7	8	.	.	0	.
2006	33	54%	25	1	17	28%	4	4	11	18%	9	1	.	.	0	.
2007	36	53%	29	1	22	32%	4	6	10	15%	10	1	.	.	0	.
2008	37	54%	32	1	20	29%	4	5	11	16%	11	1	.	.	0	.
2009	33	45%	34	1	27	37%	4	7	13	18%	11	1	.	.	0	.
2010	30	41%	37	1	28	38%	4	7	15	21%	11	1	.	.	0	.
2011	33	39%	36	1	23	27%	4	6	28	33%	12	2	.	.	0	.
2012	24	33%	35	1	26	36%	4	7	23	32%	13	2	.	.	0	.
2013	22	27%	37	1	25	30%	4	6	35	43%	14	3	.	.	0	.
2014	21	23%	37	1	21	23%	4	5	49	54%	14	4	.	.	0	.
2015	18	22%	38	0	18	22%	4	5	44	54%	14	3	1	1%	1	1
2016	26	31%	40	1	15	18%	4	4	36	43%	14	3	7	8%	1	7
2017	20	22%	42	0	14	16%	4	4	37	42%	13	3	18	20%	1	18
2018	29	26%	43	1	12	11%	3	4	51	46%	13	4	20	18%	1	20

(2) Performance analysis

Cluster 4 beats all others in performance characteristics and offers the lowest price per Kg into both orbits. Falcon 9 FT main upgrade in comparison to its earlier versions, Falcon 9 v1.0 and Falcon 9 v1.1, is the cryogenic cooling of propellant to increase density, that allows a 17% increase in thrust. In 2017, SpaceX started incremental changes, mainly in engine trust calling them the "Block 4" version and the most recent "Block 5”.[22]

It is important to mention, that during data collection, we had a discussion on the relevant performance and price for the Falcon family rockets and decided to be conservative and use the capacity related to the stated launch price of $62M as published on SpaceX website. The maximum nominal vehicle’s capacity is higher and so would be the rocket`s performance characteristics. There is also information on discounts provided to clients for launches with higher risks connected to the booster landings or exploitation of used boosters. However, the price for nominal capacity and data on launch price discounts were not confirmed and were not used.

As inferred by results of the analysis, SpaceX is on the right track with its iconic Falcon 9 launch vehicle. However, other representatives of New Space launch companies were clustered as “Failures”, including Falcon Heavy and Electron rockets. To the present day, these rockets were launched only 1 and 3 times respectively (all launches were successful). With more launch history, cluster analysis should be updated.

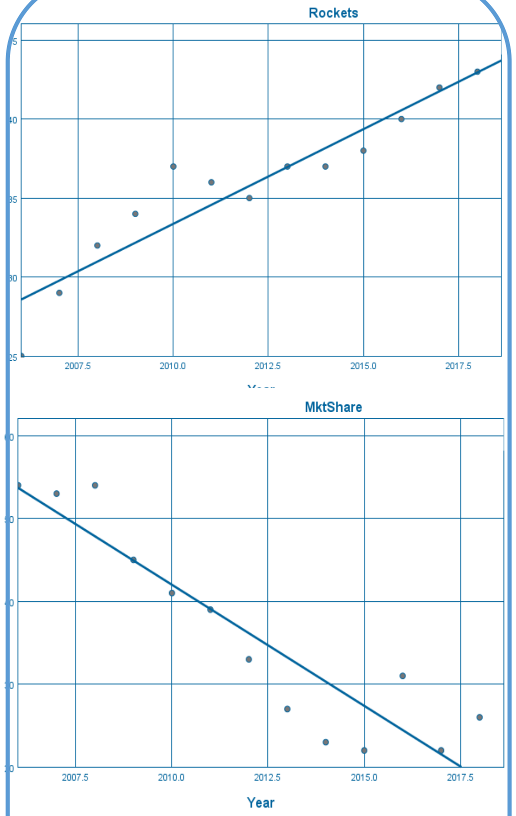
Table 6. Performance analysis by clusters.

	Cluster			
	Failures	**Workhorses**	**Sluggish**	**Big Hit**
Reliability (%)	93	95	95	100
Price per launch ($M)	113	86	53	62
LEO Capacity (KG)	9205	14238	6363	15100
Payload Ratio LEO (%)	2.2	2.6	2.1	2.8
Price per kg to LEO ($K)	17239	6388	10160	4106
GTO Capacity (KG)	5995	8400	2855	6100
Payload Ratio GTO (%)	1.2	1.1	0.8	1.1
Price per kg to GTO ($K)	24481	13635	21803	10164

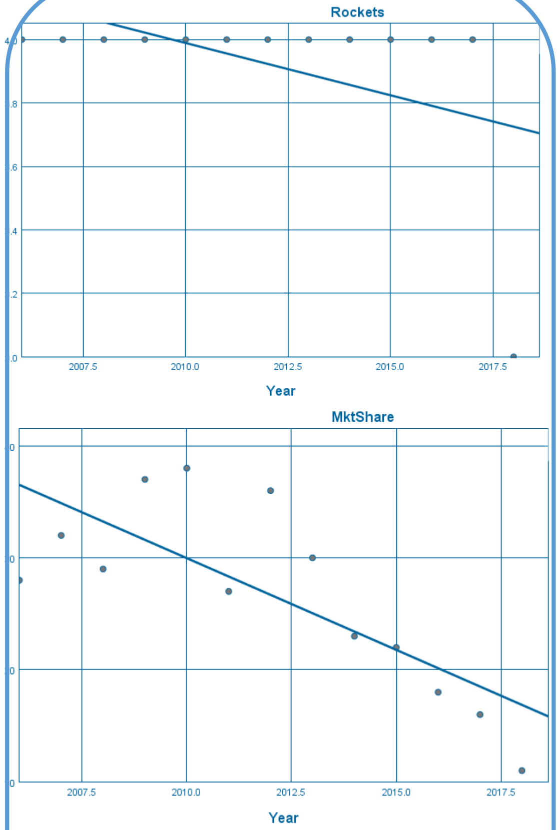
(3) Regression analysis

[22] https://www.space.com/37343-spacex-final-falcon-9-design.html last access November 2018

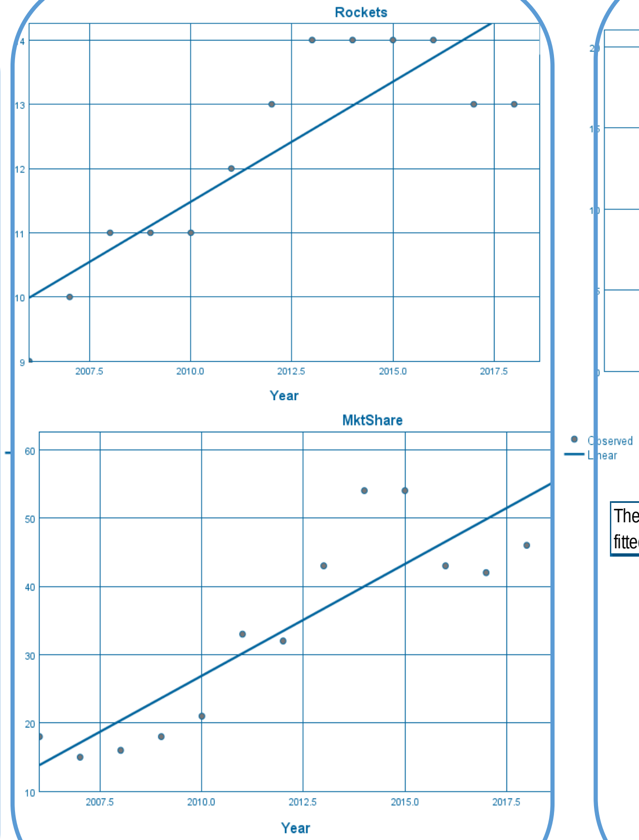
Failures



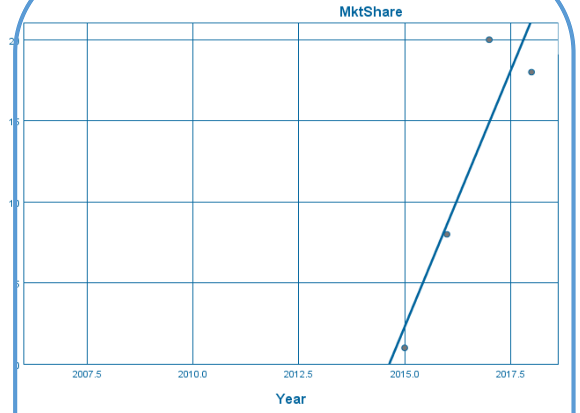
WorkHorses



Sluggish



BigHit



The dependent variable (Rockets) is a constant (1). No equations will be fitted for this variable.

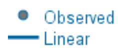


Figure 10. Regression analysis by clusters.

"Failures" is a paradoxical cluster. Despite the annual decrease of 1.2 flights per year (B1 is the annual growth rate), there is a new rocket being added to the cluster (B1 = 1.2). That means that each year one launcher becomes obsolete, while at the same time a new rocket emerges without an existing demand for its services.

Both "Sluggish" and "BigHit" clusters presented a significant increase in both launches and market share. Falcon 9 FT presents almost twice the annual growth rate, compared to the "Sluggish" cluster. The model doesn't take into consideration the level of market saturation. In practice, the growth of launch rate is limited by the existing demand in space launches. The R^2 value indicates the high percent of variance explained by the model for all clusters except "WorkHorses".

Table 7. Models Summary and Parameter Estimates.

Cluster	Dependent Variable	Parameter Estimates		Model Summary		
		Constant	B1	R^2	F	Sig.
Failures	Launches	2482.04	-1.22	0.55	13.36	0.004
	Rockets	-2374.21	1.20	0.88	77.24	0.000
	Market Share	5917.39	-2.92	0.85	62.75	0.000
WorkHorses	Launches	1446.70	-0.71	0.29	4.38	0.060
	Rockets	70.25	-0.03	0.21	3.00	0.111
	Market Share	3321.07	-1.64	0.58	15.30	0.002
Sluggish	Launches	-7080.41	3.53	0.83	53.26	0.000
	Rockets	-739.51	0.37	0.74	31.40	0.000
	Market Share	-6544.23	3.27	0.77	36.14	0.000
BigHit	Launches	-13700.70	6.80	0.94	33.51	0.029
	Rockets	-	-	-	-	-
	Market Share	-12692.20	6.30	0.84	10.36	0.084

VI - CONCLUSION AND FUTURE RESEARCH

This research presents a comprehensive analysis of the space sector, by identifying, describing and analyzing the relevant actors and their connections in the Space Ecosystem. From that, we could identify the space launch industry as the current hub and we could, based upon the reviewed literature, identify three clearly distinct historical phases, comparing the strategic, technological, operational and financial aspects.

Through the ecosystem lens, we affirmed that the most important element of the Space Ecosystem nowadays is space launch vehicles. We could list and compare launch history, performance characteristics and price of all operational orbital rockets. By conducting classification analysis, rockets were grouped based on launch history similarities. In that way, 4 clearly different rocket groups were produced. One group stands out by its recent launch record – of a sole rocket, Falcon 9 FT, developed by private spaceflight company SpaceX. From the performance analysis, we could also see that it excels in all the chosen variables. In a nutshell, it's currently the best and cheapest option to launch a payload into orbit.

The results of this study can be useful for researchers and practitioners in space sector. This study can inspire management to invest in emerging technologies in order to enhance their relevance in the space arena.

In fact, both the results of conducted literature review and comparative analysis of space launchers indicate the shift in the Space Ecosystem. It may be the early warning for the incumbents that should reconsider their strategy for the Space Ecosystem. Due to the novelty of the reusability (started in 2017), there is currently no cost data available for analysis. If reusability proves itself a cost-effective and efficient solution, significant reduction in launch costs, hence prices, might follow. Mastering refurbishment procedures will decrease the turnaround time between launches. These could dramatically increase the capacity and accessibility of orbital launches.

A robust commercial spaceflight industry would require not only a solid level of supply, but an equally strong demand. Currently, the downstream actors of the charted ecosystem don't seem prepared to take advantage of that. This would open doors for multi-industry reconfigurations, such as the one announced by Elon Musk, extending his footprint into satellites and communication services to final consumers. In addition, the increasing relevance of the so-called Internet of Things could boost the demand in low-latency, real-time, two-way communications such as the ones required for the support of autonomous terrestrial and flying vehicles. Among other promising commercial space applications are satellite servicing, debris mitigation, energy and resource gathering, and human spaceflights to name but a few.

Last year, China has beaten the U.S. and other spacefaring nations, for the first time, in the number of performed launches. This could be an early warning for a major power shift in the space domain. Based on the launchers data organized by country of origin (Table 8), several questions arose: Do country and finance/governance structure impact space company performance?

We also suggest that the extension of this study now emphasizing the satellite industry - the second hub in importance, according to this analysis (Figure 11). The produced ecosystem indicates the leading role of satellites on the par with space launch vehicles.

The Space Ecosystem appears to have quite important externalities that would impact key industries in the whole world, such as defense, telecom, healthcare, mobility. Depending upon the evolution in the following years we could witness quite different futures for humanity. One opportunity for research is to develop a full scenario planning exercise for this ecosystem, and subsequent analysis from the perspectives of New Space companies, Incumbents, Nation-States and also Citizens.

Table 8. Market analysis by countries.

	Russia				USA				China				Europe			
	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights	Sum of flights	Market share	Rockets	Mean flights
2006	20	33%	9	2	17	28%	15	1	7	11%	7	1	5	8%	1	5
2007	22	32%	9	2	19	28%	16	1	10	15%	8	1	6	9%	1	6
2008	24	35%	9	3	15	22%	16	1	11	16%	9	1	6	9%	2	3
2009	26	36%	9	3	24	33%	17	1	6	8%	9	1	7	10%	2	4
2010	28	38%	9	3	15	21%	20	1	15	21%	9	2	6	8%	2	3
2011	29	35%	8	4	18	21%	21	1	20	24%	9	2	5	6%	2	3
2012	26	36%	8	3	13	18%	20	1	19	26%	9	2	8	11%	3	3
2013	34	41%	8	4	18	22%	22	1	15	18%	9	2	5	6%	3	2
2014	33	36%	9	4	23	25%	21	1	16	18%	9	2	7	8%	3	2
2015	24	30%	9	3	19	23%	21	1	19	23%	11	2	8	10%	3	3
2016	19	23%	9	2	22	26%	22	1	22	26%	13	2	9	11%	3	3
2017	20	22%	9	2	30	34%	22	1	18	20%	14	1	9	10%	3	3
2018	20	18%	8	3	34	30%	23	1	38	**34%**	14	3	8	7%	3	3

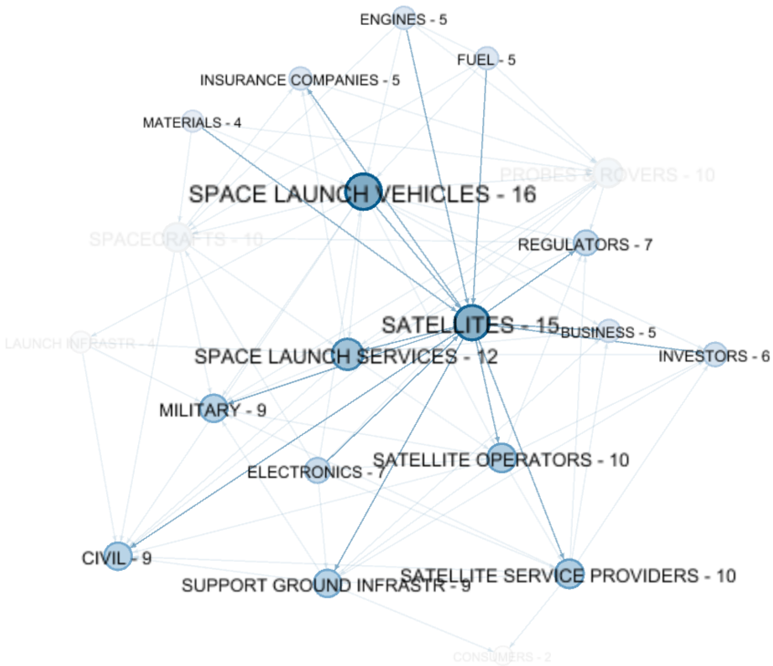


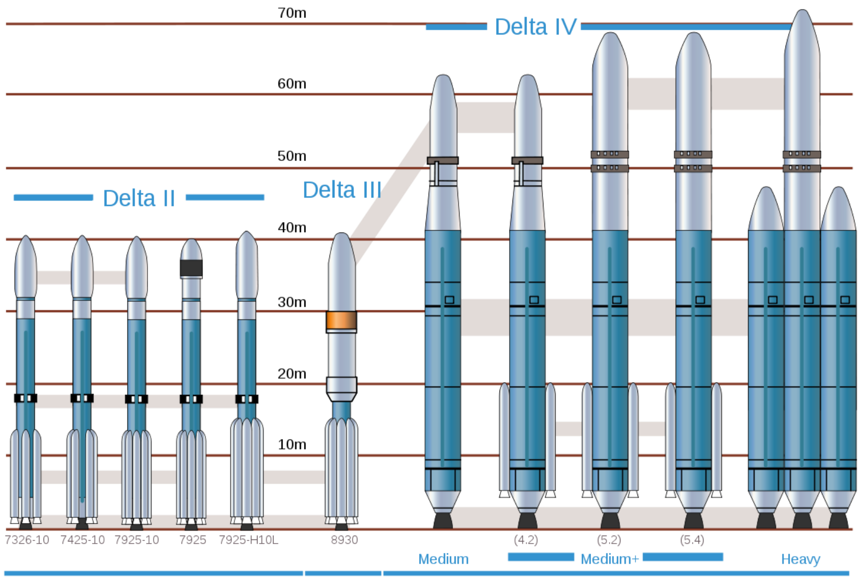
Figure 11. Connections of "satellites" node with other actors of the Space Ecosystem.

Appendix-A

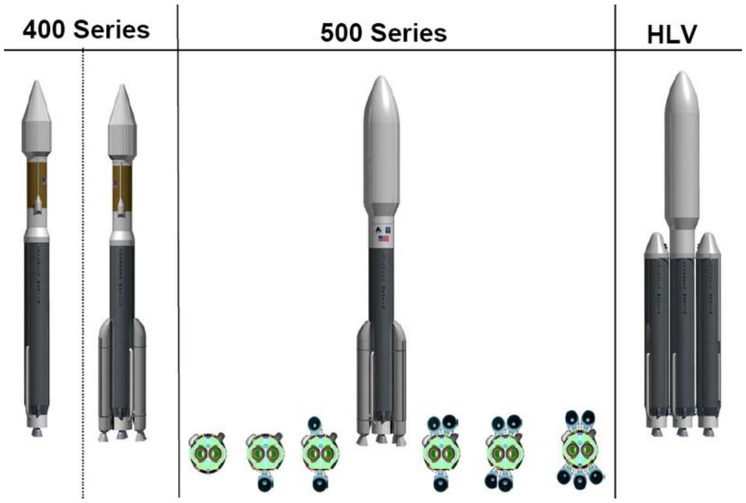
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1,FUEL				X	X	X	X	X												
2,ELECTRONICS					X	X	X	X			X	X	X							
3,MATERIALS					X	X	X	X												
4,ENGINES					X	X	X	X												
5,SPACE LAUNCH VEHICLES						X	X	X	X	X	X				X	X	X	X	X	X
6,SATELLITES										X	X	X	X		X	X	X	X	X	X
7,SPACECRAFTS										X						X	X	X	X	
8,PROBES & ROVERS										X						X	X	X	X	
9,LAUNCH INFRASTRUCTURE/CONTROL CENTER										X						X	X			
10,SPACE LAUNCH SERVICES											X				X	X	X	X	X	X
11,SATELLITE OPERATORS												X	X			X	X	X		X
12,SATELLITE SERVICE PROVIDERS													X	X	X	X	X	X		X
13,SUPPORTING GROUND INFRASTRUCTURE														X	X	X	X			X
14,CONSUMERS																				
15,BUSINESS																				
16,CIVIL																				
17,MILITARY																				
18,REGULATORS																				
19,INSURANCE COMPANIES																				
20,INVESTORS																				

Appendix-B

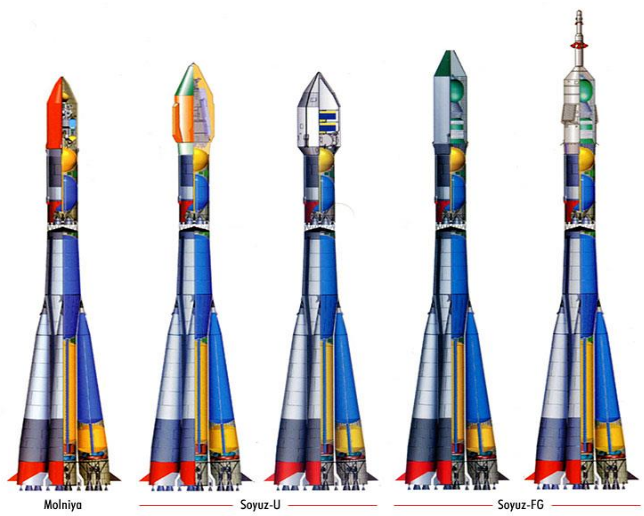
Delta family



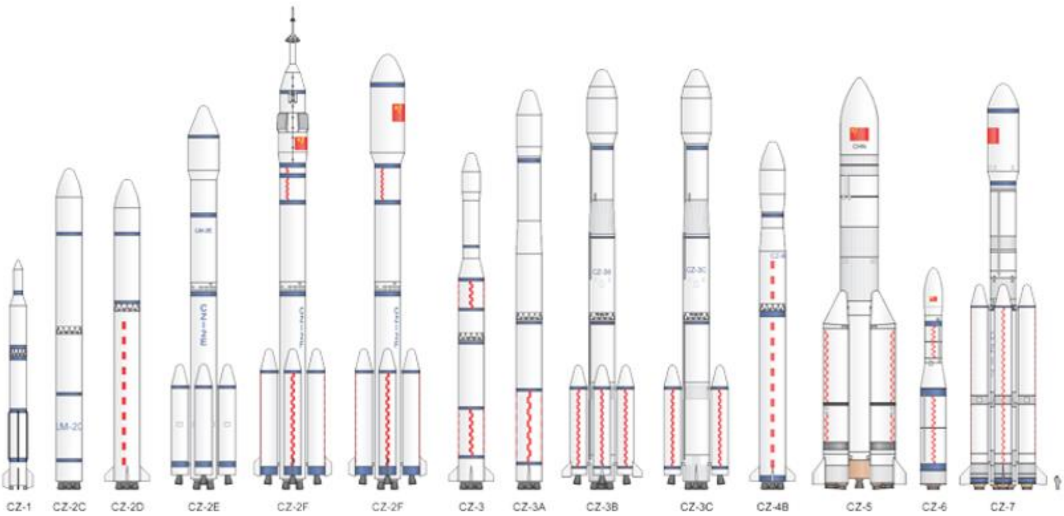
Atlas family



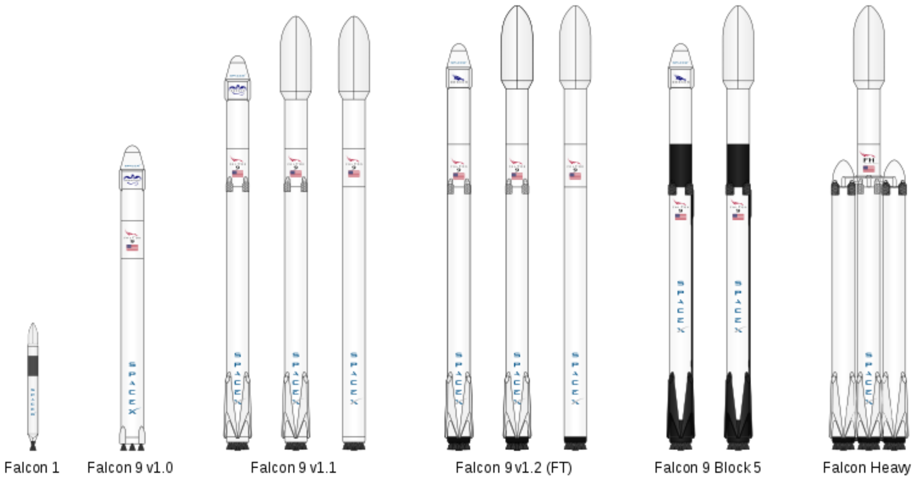
Soyuz family



Long March family



Falcon family



Appendix-C

The Delta II 7000 series used a four-digit system to generate its technical names. It specified (1) the tank and main engine type, (2) number of solid rocket boosters, (3) second stage, and (4) third stage. An “H” following the four digits indicates the vehicle`s Heavy variant.

Three other configurations of Delta IV Medium vehicles are designated as Medium+ (4,2); Medium+ (5,2); and Medium+ (5,4). The first numbers indicate the diameter of the second stage and payload fairing, and the second numbers designate the number of graphite-epoxy motor strap-ons. The fifth vehicle is called Delta IV Heavy. The configuration uses three of the common 5-meter diameter first stages in parallel. The second stage uses the same 5-meter diameter, longer tank that is used on the Medium + (5,2) and (5,4) vehicles.

Atlas V 400 and 500 series use a three-digit system to identify its configuration. The first digit shows the diameter in meters of the payload fairing and always has a value of "4" or "5". The second digit indicates the number of solid rocket boosters attached to the base of the rocket and can range from "0" through "3" with the 4-meter fairing, and "0" through "5" with the 5-meter fairing. The third digit represents the number of engines on the Centaur stage, either "1" or "2". As of October 2018, only the single-engine Centaur (SEC) has been used.

Appendix-D

Country	Provider	Family	Rocket	Firstflight	Status	Category	MissionType	LiftoffMass	LEOCapacity	GTOCapacity	Upto2005	Flightsin2006	Flightsin2007	Flightsin2008	Flightsin2009	Flightsin2010	Flightsin2011	Flightsin2012	Flightsin2013	Flightsin2014	Flightsin2015	Flightsin2016	Flightsin2017	Flightsin2018	Flights	Reliability	Priceperlaunch$mln	PriceperkgtoLEO$	PriceperkgtoGTO$	PayloadRatioLEO	PayloadRatioGTO
Russia	Roscosmos/ILS	Angara	Angara A5	2014	2	3	ALL	773 000	24 000	7 500	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	100%	100	4167	13333	3,1	1,0
USA	Northrop Grumman	Antares	Antares 100s	2013	1	2	LEO	296 000	5 700	#NULL!	0	0	0	0	0	0	0	0	2	3	0	0	0	0	5	80%	80	14035	#NULL!	1,9	#NULL!
USA	Northrop Grumman	Antares	Antares 200s	2016	2	2	LEO	298 000	7 900	#NULL!	0	0	0	0	0	0	0	0	0	0	0	1	1	2	4	100%	80	10127	#NULL!	2,7	#NULL!
Europe	Arianespace	Ariane	Ariane 5 ECA&GS	2002	2	3	ALL	780 000	20 000	10 500	6	5	6	5	7	6	4	6	3	5	6	6	5	5	75	97%	178	8900	16952	2,6	1,3
Europe	Arianespace	Ariane	Ariane 5 ES	2008	1	3	ALL	760 000	21 000	3 400	0	0	0	1	0	0	1	1	1	1	0	1	1	1	8	100%	178	8476	52353	2,8	0,4
USA	ULA/LMCLS	Atlas	Atlas V-401	2002	2	2	ALL	333 731	9 797	4 750	3	0	3	0	3	1	1	3	5	7	4	3	4	1	38	97%	109	11126	22947	2,9	1,4
USA	ULA/LMCLS	Atlas	Atlas V-411	2006	2	2	ALL	380 760	12 150	5 950	0	1	0	1	0	0	1	0	0	0	0	1	0	1	5	100%	115	9465	19328	3,2	1,6
USA	ULA/LMCLS	Atlas	Atlas V-421	2007	2	2	ALL	427 790	14 067	6 890	0	0	1	1	1	0	0	0	0	0	2	1	1	0	7	100%	123	8744	17852	3,3	1,6
USA	ULA/LMCLS	Atlas	Atlas V-431	2005	2	2	ALL	474 819	15 718	7 700	1	0	0	0	1	0	0	0	0	0	0	1	0	0	3	100%	130	8271	16883	3,3	1,6
USA	ULA/LMCLS	Atlas	Atlas V-501	2010	2	2	ALL	380 760	8 123	3 775	0	0	0	0	0	2	1	1	1	0	1	0	0	0	6	100%	120	14773	31788	2,1	1,0
USA	ULA/LMCLS	Atlas	Atlas V-531	2010	2	2	ALL	474 819	15 575	7 475	0	0	0	0	0	1	0	1	1	0	0	0	0	0	3	100%	140	8989	18729	3,3	1,6
USA	ULA/LMCLS	Atlas	Atlas V-541	2011	2	2	ALL	521 849	17 443	8 290	0	0	0	0	0	0	1	0	0	2	0	1	1	1	6	100%	145	8313	17491	3,3	1,6
USA	ULA/LMCLS	Atlas	Atlas V-551	2006	2	2	ALL	568 878	18 814	8 900	0	1	0	0	0	0	1	1	1	0	2	1	0	2	9	100%	153	8132	17191	3,3	1,6
USA	ULA	Delta	Delta II 7320	1999	1	1	LEO	152 000	2 809	#NULL!	6	0	0	1	2	0	1	0	0	1	1	0	0	0	12	100%	137	48879	#NULL!	1,8	#NULL!
USA	ULA	Delta	Delta II 7420	1998	1	1	LEO	162 000	3 185	#NULL!	7	1	2	2	0	1	0	0	0	0	0	0	0	1	14	100%	137	43108	#NULL!	2,0	#NULL!
USA	ULA	Delta	Delta II 7920/7925	1990	1	2	ALL	230 000	5 030	1 819	77	5	5	1	6	0	1	0	0	0	0	0	1	0	96	98%	137	27237	75316	2,2	0,8
USA	ULA	Delta	Delta II 7920H/7925H	2003	1	2	ALL	283 000	6 097	2 171	3	0	1	1	0	0	1	0	0	0	0	0	0	0	6	100%	137	22470	63105	2,2	0,8
USA	ULA	Delta	Delta IV Heavy	2004	2	3	ALL	733 000	28 790	14 220	1	0	1	0	1	1	1	1	1	1	0	1	0	1	10	90%	350	12157	24613	3,9	1,9
USA	ULA	Delta	Delta IV M+4.2	2002	2	2	ALL	316 776	13 140	6 390	1	2	0	0	1	2	2	2	0	3	1	2	0	1	17	100%	200	15221	31299	4,1	2,0
USA	ULA	Delta	Delta IV M+5.4	2009	2	2	ALL	384 052	14 140	7 300	0	0	0	0	1	0	0	1	2	0	1	1	1	0	7	100%	250	17680	34247	3,7	1,9
Ukraine	GK Launch Services	Dnepr	Dnepr	1999	1	1	LEO	211 000	3 700	#NULL!	5	2	3	2	1	3	1	0	2	2	1	0	0	0	22	96%	29	7838	#NULL!	1,8	#NULL!
USA	Rocket Lab	Electron	Electron	2017	2	1	LEO	10 500	225	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	50%	5	21778	#NULL!	2,1	#NULL!
Japan	JAXA	Epsilon	Epsilon	2013	2	1	LEO	90 800	1 200	#NULL!	0	0	0	0	0	0	0	0	1	0	0	1	0	1	3	100%	39	32500	#NULL!	1,3	#NULL!
USA	SpaceX	Falcon	Falcon 1	2006	1	1	LEO	27 670	454	#NULL!	0	1	1	2	1	0	0	0	0	0	0	0	0	0	5	40%	8	16520	#NULL!	1,6	#NULL!
USA	SpaceX	Falcon	Falcon 9 FT	2015	2	2	ALL	549 054	15 100	6 100	0	0	0	0	0	0	0	0	0	0	1	7	18	20	46	100%	62	4106	10164	2,8	1,1
USA	SpaceX	Falcon	Falcon 9 v1.0	2010	1	2	ALL	333 400	10 450	4 680	0	0	0	0	0	2	0	2	1	0	0	0	0	0	5	80%	55	5263	11752	3,1	1,4
USA	SpaceX	Falcon	Falcon 9 v1.1	2013	1	2	ALL	505 846	13 150	4 850	0	0	0	0	0	0	0	0	2	6	6	1	0	0	15	93%	61	4654	12619	2,6	1,0
USA	SpaceX	Falcon	Falcon Heavy	2018	2	3	ALL	1 420 788	25 800	8 800	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	100%	90	3488	10227	1,8	0,6
India	ISRO/Antrix	GSLV	GSLV	2001	2	2	ALL	414 750	5 000	2 500	3	1	1	0	0	2	0	0	0	1	1	1	1	2	13	58%	47	9400	18800	1,2	0,6
India	ISRO/Antrix	GSLV	GSLV Mk.III	2017	2	2	ALL	640 000	8 000	4 000	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	100%	60	7500	15000	1,3	0,6
Japan	MHI Launch Services	H-II	H-IIA 202	2001	2	2	ALL	289 000	10 000	4 000	7	3	2	1	2	2	2	1	1	4	2	2	4	3	36	94%	90	9000	22500	3,5	1,4
Japan	MHI Launch Services	H-II	H-IIA 204	2006	2	2	ALL	443 000	15 000	6 000	0	1	0	0	0	0	0	0	0	0	1	0	2	0	4	100%	113	7533	18833	3,4	1,4
Japan	MHI Launch Services	H-II	H-IIB	2009	2	2	ALL	531 000	16 500	8 000	0	0	0	0	1	0	1	1	1	0	1	1	0	1	7	100%	113	6818	14063	3,1	1,5
China	EXPACE/PLA	Kaitouzhe	Kaitouzhe 2	2017	2	1	LEO	40 000	350	#NULL!	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	100%	Undisclos	#NULL!	#NULL!	0,9	#NULL!
Russia	Roscosmos/ILS	Kosmos	Kosmos 3M	1967	1	1	LEO	109 000	1 500	#NULL!	435	1	3	3	1	1	0	0	0	0	0	0	0	0	444	96%	15	10000	#NULL!	1,4	#NULL!
China	EXPACE/PLA	Kuaizhou	Kuaizhou 1/1A	2013	2	1	LEO	30 000	300	#NULL!	0	0	0	0	0	0	0	0	1	1	0	0	1	1	4	100%	3	10000	#NULL!	1,0	#NULL!
China	PLA/LandSpace	Long March	Long March-11	2015	2	1	LEO	58 000	530	#NULL!	0	0	0	0	0	0	0	0	0	0	1	1	0	3	5	100%	5	10000	#NULL!	0,9	#NULL!
China	PLA/CGWIC	Long March	Long March-2C	1982	2	2	ALL	233 000	3 850	1 250	24	1	1	1	2	0	4	2	2	4	0	0	3	6	50	98%	30	7792	24000	1,7	0,5
China	PLA/CGWIC	Long March	Long March-2D	1992	2	2	LEO	232 250	3 500	#NULL!	6	0	1	2	1	3	2	3	2	2	4	6	3	8	43	98%	30	8571	#NULL!	1,5	#NULL!
China	PLA/CNSA	Long March	Long March-2F	1999	2	2	LEO	464 000	8 400	#NULL!	6	0	0	1	0	0	2	1	1	0	0	2	0	0	13	100%	Undisclos	#NULL!	#NULL!	1,8	#NULL!
China	PLA/CGWIC/ CNSA	Long March	Long March-3A	1994	2	2	ALL	241 000	8 500	2 600	9	2	4	1	0	3	3	1	0	1	0	1	0	2	27	100%	70	8235	26923	3,5	1,1
China	PLA/CGWIC/ CNSA	Long March	Long March-3B	1996	1	2	ALL	425 800	12 000	5 100	6	1	1	1	1	0	0	2	0	0	0	0	0	0	12	83%	70	5833	13725	2,8	1,2
China	PLA/CGWIC/ CNSA	Long March	Long March-3B/E	2007	2	2	ALL	458 970	12 000	5 500	0	0	1	1	0	1	5	3	3	0	8	3	5	11	41	97%	70	5833	12727	2,6	1,2
China	PLA/CGWIC/ CNSA	Long March	Long March-3C	2008	2	2	ALL	345 000	9 100	3 800	0	0	0	1	1	4	1	3	0	1	1	3	0	1	16	100%	70	7692	18421	2,6	1,1
China	PLA/CGWIC	Long March	Long March-4B	1999	2	2	ALL	249 200	4 200	1 500	7	2	1	2	0	1	3	2	2	4	2	2	1	2	31	97%	30	7143	20000	1,7	0,6
China	PLA/CGWIC	Long March	Long March-4C	2006	2	2	ALL	250 000	4 200	1 500	0	1	1	1	1	3	0	2	4	3	2	2	1	4	25	96%	30	7143	20000	1,7	0,6
China	PLA/CGWIC/ CNSA	Long March	Long March-5	2016	2	3	ALL	867 000	25 000	14 000	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	50%	Undisclos	#NULL!	#NULL!	2,9	1,6
China	PLA/CGWIC	Long March	Long March-6	2015	2	1	LEO	103 217	1 500	#NULL!	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	100%	Undisclos	#NULL!	#NULL!	1,5	#NULL!
China	PLA/CGWIC	Long March	Long March-7	2016	2	2	ALL	597 000	13 500	7 100	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	100%	Undisclos	#NULL!	#NULL!	2,3	1,2
USA	Northrop Grumman	Minotaur	Minotaur-C	1994	2	1	LEO	77 000	1 458	#NULL!	7	0	0	0	1	0	1	0	0	0	0	0	1	0	10	70%	50	34294	#NULL!	1,9	#NULL!
USA	Northrop Grumman	Minotaur	Minotaur-I	2000	2	1	LEO	36 200	580	#NULL!	4	2	1	0	1	0	2	0	1	0	0	0	0	0	11	100%	40	68966	#NULL!	1,6	#NULL!
USA	Northrop Grumman	Minotaur	Minotaur-IV	2010	2	1	LEO	86 300	1 600	#NULL!	0	0	0	0	0	2	1	0	0	0	0	0	1	0	4	100%	46	28750	#NULL!	1,9	#NULL!
Russia	Roscosmos/ILS	Soyuz	Molniya-M	1964	1	2	LEO	305 000	2 000	#NULL!	293	1	1	1	0	1	0	0	0	0	0	0	0	0	297	93%	40	20000	#NULL!	0,7	#NULL!
USA	Northrop Grumman	Pegasus	Pegasus XL	1994	2	1	LEO	23 130	450	#NULL!	26	1	1	2	0	0	0	1	1	0	0	1	0	0	33	91%	40	88889	#NULL!	1,9	#NULL!
Russia	Roscosmos/ILS	Proton	Proton K	1967	1	3	ALL	700 000	19 760	4 430	302	2	2	3	1	0	0	1	0	0	0	0	0	0	311	88%	65	3289	14673	2,8	0,6
Russia	Roscosmos/ILS	Proton	Proton M	2001	2	3	ALL	705 000	22 400	6 300	12	4	5	7	9	12	9	10	10	8	8	3	4	2	103	89%	65	2902	10317	3,2	0,9
India	ISRO/Antrix	PSLV	PSLV	1993	1	2	ALL	295 000	3 200	1 150	12	0	1	0	0	0	1	0	0	0	0	1	0	0	15	87%	31	9688	26957	1,1	0,4
India	ISRO/Antrix	PSLV	PSLV CA	2007	2	2	LEO	230 000	2 100	#NULL!	0	0	1	2	2	1	1	1	1	1	1	0	0	2	13	100%	21	10000	#NULL!	0,9	#NULL!
India	ISRO/Antrix	PSLV	PSLV XL	2008	2	2	ALL	320 000	3 800	1 300	0	0	0	1	0	0	1	1	2	2	3	5	3	2	20	95%	31	8158	23846	1,2	0,4
Russia	Eurockot	Rockot	Rockot	1994	2	1	LEO	107 500	2 140	#NULL!	9	1	0	1	2	2	1	1	4	2	2	2	1	2	30	90%	42	19533	#NULL!	2,0	#NULL!
Israel	Israel Space Agency/I	Shavit	Shavit 2	2007	2	1	LEO	70 000	800	#NULL!	0	0	1	0	0	1	0	0	0	1	0	1	0	0	4	100%	Undisclos	#NULL!	#NULL!	1,1	#NULL!
Russia	GK Launch Services	Soyuz	Soyuz 2.1a	2004	2	2	ALL	310 000	7 400	1 500	1	2	0	0	1	2	3	2	2	4	4	3	3	4	31	90%	49	6554	32333	2,4	0,5
Russia	GK Launch Services	Soyuz	Soyuz 2.1b	2006	2	2	ALL	313 000	8 700	2 000	0	1	0	1	1	0	4	0	3	6	2	3	4	3	28	93%	49	5575	24250	2,8	0,6
Russia	GK Launch Services	Soyuz	Soyuz 2.1v	2013	2	1	LEO	160 000	3 300	#NULL!	0	0	0	0	0	0	0	0	1	0	1	0	1	1	4	75%	15	4394	#NULL!	2,1	#NULL!
Russia	Glavkosmos	Soyuz	Soyuz FG	2001	2	2	LEO	313 000	7 400	#NULL!	15	2	5	3	4	4	4	5	4	4	4	4	4	5	67	99%	50	6757	#NULL!	2,4	#NULL!
Russia	Arianespace	Soyuz	Soyuz ST	2011	2	2	ALL	308 000	4 850	3 250	0	0	0	0	0	0	2	2	2	4	3	2	2	3	20	94%	80	16495	24615	1,6	1,1
Russia	Glavkosmos	Soyuz	Soyuz U	1973	1	2	LEO	313 000	7 150	#NULL!	737	6	6	5	7	6	6	5	8	4	0	2	1	0	793	97%	50	6993	#NULL!	2,3	#NULL!
USA	NASA	Space Shuttle	Space Shuttle	1981	1	3	LEO	2 041 166	28 803	#NULL!	114	3	3	4	5	3	3	0	0	0	0	0	0	0	135	99%	1200	41662	#NULL!	1,4	#NULL!
Europe	Arianespace	Vega	Vega	2012	2	1	LEO	137 000	1 500	#NULL!	0	0	0	0	0	0	0	1	1	1	2	2	3	2	12	100%	37	24667	#NULL!	1,1	#NULL!
Ukraine	Sea Launch AG	Zenit	Zenit 2SLB	2007	2	2	LEO	458 900	12 030	#NULL!	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2	100%	85	7066	#NULL!	2,6	#NULL!
Ukraine	Sea Launch AG	Zenit	Zenit 3SL	1999	2	2	ALL	472 000	6 100	6 160	18	5	1	5	1	0	1	3	1	1	0	0	0	0	36	89%	95	15574	15422	1,3	1,3
Ukraine	Sea Launch AG	Zenit	Zenit 3SLB	2008	2	2	ALL	466 200	5 000	3 750	0	0	0	1	3	0	3	0	1	0	1	0	1	0	10	100%	85	17000	22667	1,1	0,8

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