The realization of a study on the current status and future trends of the cost of access to space for CubeSat missions.

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The realization of a study on the current status and future trends of the cost of access to space for CubeSat missions.

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Abstract

The increasing number of space-related applications and the development of miniaturized satellites (sometimes called CubeSats) recently became an exciting area in modern space science. Due to their diverse applications, smaller size, and low development cost. More sophisticated CubeSat missions have been recently introduced, signaling that CubeSats have started to progress from solely technical demonstration platforms to providing opportunities for low-cost actual research missions with a highly promising benefit in terms of commercial revenue. Despite major advancements in CubeSat technology, there is still a range of fundamental concerns regarding CubeSat barriers, pitfalls, and commercial effects. From both an academic and an industrial perspective, this report offers a thorough overview of various facets of CubeSat manufacturing and launch costs. The latest trends in CubeSat were discussed as well as an analysis of the launch cost and other variables that could influence the mission. An information-gathering approach was used from various proposed and launched missions, including journal articles, the official space mission webpages, and other publicly accessible satellite databases. Using data collected from various sources, we found that the latest launching price for future missions is influenced and modeled by various reasons. The Liquid propellant, miniaturized thrusters for small satellites, and modernized payload carriers could play a part in lowering the cost of potential launches. For instance, the RP-1 fuel used in Falcon 9 is expandable and reusable, increasing launch opportunities and low per-unit launch costs. Likewise, tiny satellites with miniaturized thrusters will significantly help change aerodynamics and launch processes. Whereas systemic payload structures can bear maximum weight, theoretically expanding the number of Nanosatellites deployed per launch. This paper attempts to facilitate various elements that make it practical in enabling a decision-making process related to technical aspects of the launch cost and future utilization of CubeSat technology.

Keywords: CubeSat, costs, current status, future trends.
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Chapter 1: Introduction

The purpose of the research on CubeSat was to find the reason behind the high launch cost for Nanosatellites. The design cost, development cost, and sustainability are never problems for any developer, but the cost of launching Nanosatellites is beyond private firms’ and universities’ reach. One must understand the critical factors playing a role in modeling launch costs. The first CubeSat was designed in 1999 by professor Jordi Puig-Suari, from California Polytechnic State University and Bob Twiggs from Stanford University (NASA’s CubeSat Launch Initiative, 2017, p. 1). Their purpose for developing a miniaturized satellite was to help University students to have practical access to the space environment with an instrument built and designed with similar functionality to Sputnik. Nanosatellites are a miniaturized version of the traditional satellite, built to perform operations in Lower Earth Orbit (LEO). They are designed to perform various scientific experiments and new scientific discoveries; multi Nanosatellites can form a constellation and perform bulky operations. In 2003, Russian Eurockot carried the first eight commercial CubeSat to orbit (Zak, 2020), and by now, hundreds of Nanosatellites have been placed. In the early days, only governmental projects were sent to Space. The price range varies from a few thousand to millions of dollars for sending a unit. The interesting would be to think about the high launch cost and find alternative technology to reduce the launch price.

The development of miniaturized satellites has initiated many space start-up companies, raising the challenge of frequent space travel. The increase in demand for space travel increases demand for launch vehicles which eventually calls for commercializing space flight. Fingertip availability of launch vehicles has made launch costs very expensive. Several organizations together send their mission to reduce launch costs; for example, QB50 mission 50 satellites were launched by teams from 15 Universities. In December 2020, India's Prime Minister Narendra Modi declared that the Indian space research organisation (ISRO) would open its doors to private sectors. It implies that India will launch governmental projects and commercial payloads. It will bring more projects and increase launch vehicle demand for space exploration.

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Information has been retrieved from the ISRO website: https://www.isro.gov.in/update/14-dec-2020/pm-interacts-with-space-industries-and-start-ups
The rationale of the study: Launch cost has become the most significant cost in a CubeSat-based satellite mission because it exceeds the Nanosatellite development cost. The satellite platform's cost, payload, hardware, and development are rapidly dropping due to the increased competition among suppliers—the introduction of the New Space approach by a growing number of start-up initiatives. Besides, the number of launches per year is relatively stable compared with the rapid growth in satellites. Overall, the upfront financial costs of a CubeSat mission are very high, hindering the realisation of promising business opportunities due to the reluctance of private capital to enter into investments of such characteristics. Identifying, promoting, and exploiting opportunities to access Space at minimum cost is the enabler for such businesses.

Aim: This paper aims to identify new and possible trends in launching Nanosatellites into Space. It analyses the different paths for launching a payload and discusses past, present, and future, along with futuristic ways of their development. It will also briefly analyse how different aspects of launch affect launch costs for the commercial space industry. The research also deals with giving some information about commercial/ start-up initiatives contributing to making spaceflight affordable. The end of the research draws a conclusion based on different observations of space market demand and spaceflight development. The motivation for this paper is to enlighten about various technologies under development. It will make space flight affordable for commercial companies and will bring more investors to the forthcoming missions.
Chapter 2 : Theory

For various purposes, artificial satellites are placed in an Earth’s orbit like mapping the planetary surface, broadband and communication services, or even observing a particular aspect of the planetary body. The application services of satellites are primarily categorized as civilian or military agendas like navigation or weather reports. Based on the functionality and development motive, the satellites occupy three prominent orbits: Lower Earth Orbit (LEO), Mid-Earth orbit (MEO), and Geostationary orbit (GEO). The world-first small artificial satellite was Sputnik-1, which was just 83.6Kg and was in the shape of a ball with antennas. It was a Russian satellite, which was carried by a launcher named Sputnik 8K71PS, and it cost a fortune at that time. The satellites have come a long way in terms of construction, dimension, design, and functionality. Small Satellites have very short operational periods, because of which we notice only a handful of the small satellite being operational at present; the rest either have fallen back into the Earth's atmosphere or have become space debris. The satellite industry has been revolutionizing and modernizing with new generation ideas, and at present space industry does not focus on big bulky satellites. Instead, they have put their prime focus on developing small satellites to take over the Earth's orbit.

In general, satellites are categorized based on their functionality, such as communication satellites and navigation satellites. Satellite weights ranging from 500 kg – 0.01kg are generally classified as small satellites. The CubeSat era goes back to 1999 when California Polytechnic State University (CalPoly) and Stanford University together proposed a small satellite concept (NASA’s CubeSat Launch Initiative, 2017, p. 1). This idea aimed to enable worldwide students and researchers to perform space exploration through affordable small satellites. Over the period, the CubeSat standard for design concepts became widely adopted, mainly at Universities.

There are five types of small satellites classified based on their wet mass, as shown in Table 1 (Joseph N. Pelton, 2020, pp. 87-101,Table 1). The satellites can be divided into two parts: payload and bus. The payload part contains the sensor used for a specific application like remote sensing or communication. However, the satellite bus is the carrier of the payload, including electrical, mechanical, or chemical propulsion systems.
**Table 1: Small Satellite classification.**

<table>
<thead>
<tr>
<th>Small Satellite</th>
<th>&lt;500Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini Satellite</td>
<td>100 - 500kg</td>
</tr>
<tr>
<td>Micro Satellite</td>
<td>10-100kg</td>
</tr>
<tr>
<td>Nano Satellite</td>
<td>1-10kg</td>
</tr>
<tr>
<td>Pico Satellite</td>
<td>0.1-1kg</td>
</tr>
<tr>
<td>Femto Satellite</td>
<td>&lt;0.01kg</td>
</tr>
</tbody>
</table>

1. **Mini Satellite**

   The satellite whose wet mass lies between 100-500kg is categorized as a mini-satellites. These satellites are fabricated using miniaturized electronic equipment. The satellites reduces their size and mass. Mini satellites are commonly used for Field-programmable Gate Array (FPGA) and Application Specific Integrated Circuits (ASIC). Some of the mini-satellites carry propulsion systems to perform orbit corrections.

   **Example:** MICROSAT, YOUTHSAT (IMS-1) (Government of India, n.d.)², SMART-1.

   **Launch Vehicle:** In their early development stage, mini satellites were carried as a secondary payload. After developing a Small Satellite Launch Vehicle (SSLV) (Gunter Krebs, 2022), they are taken in bulk as primary payload to orbit.

2. **Micro Satellite**

   The satellite whose wet mass lies between 10-100kg and has variation in size. These satellites are fabricated for a maximum of one or two years of operational application. They have essential redundancy for critical subsystems like bus management units. They are usually used in the constellation formation of the satellite over an area. Interestingly, two Mars Cube One (MarCo) MicroSat became the first satellite to leave Earth's orbit and be used in an interplanetary space mission.

   **Example:** Mars Cube One, Astrid – 1, (OHB Sweden, n.d.)Astrid – 2, UOSATs, Orbcomm.

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² For more information visit [https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/youthsat](https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/youthsat)
Launch vehicle: Kosmos 3M, a Russian space vehicle that carried Astrid – 1 and Astrid – 2. These two satellites were designed by Swedish Space Corporation but were launched from Plesetsk, Russia. The entire mission cost was $1.4 million (Sven Grahn). In July 1991, Northrop Grumman Pegasus partially failed while carrying seven Microsats into LEO orbit. Also, Swiss Space Systems (S3) had a clean space mission for which they had designed a 30 kg satellite that demonstrated the technology for removing space junk. A 6U CubeSat’s was built by NASA Jet Propulsion Laboratory for Mars insight lander and became the first microsatellite to be used on Mars. MarCo has two probes; one was named Wall E and Eva. Both the probes carried a propulsion system, and it was deployed by Atlas 5 launch vehicle and flew by itself to mars performing trajectory correction manoeuvres (Gunter D Krebs, “MarCO A, B (Wall-E, Eva)”, 2022).

3. Nano Satellite

The satellite whose wet mass is between 1-10kg belongs to Nano satellite category. These satellites are designed for a concise mission duration (like 1-6 months). These satellites are released without redundancy. These satellites mainly do not carry the propulsion system to have a lighter satellite. CubeSat is a kind of Nanosatellite, and this type has a different unit. The standard unit of a Nanosatellite is 1U, 2U, 3U, and 6U. The standardisation helps launchers have a standard satellite launcher interface and ejection system, creating fabricated subsystems from any vendors.

Example: Flock-3P, INS 1A/1B, SpaceCube (FR05), qbee (Kulu, 2022)

Launch vehicle: On June 22nd 2016, PSLV-C34 launched 14 Nanosatellites, out of which two were built by Indian universities and 12 were by the United States under the Flock-2P program. Subsequently on February 15th 2017, PSLV-C37 launched 103 Nanosatellites.

4. Pico Satellite

This term is given to the satellite whose wet mass is between 0.1-1kg. These satellites are the size of a soda can. They are designed for a concise duration of

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3 For more information visit [https://space.skyrocket.de/doc_sdat/astrid-1.htm](https://space.skyrocket.de/doc_sdat/astrid-1.htm), [https://space.skyrocket.de/doc_sdat/astrid-2.htm](https://space.skyrocket.de/doc_sdat/astrid-2.htm)
experimental purposes. They cannot operate for longer hours because of less power supply from a battery cell.

Example: StenSat, PICOSAT1.0, Artemis (ESA, OPAL (Orbiting Picosatellite Automatic Launcher), 2022), BeeSAT -5/-6/-7/-8 (Gunter D Krebs, “BeeSat 5, 6, 7, 8, 10, 11, 12, 13 (Tubsat 18, 19, 20, 21, 23, 24, 25, 26)”, 2022)

Launch Method: StenSat, PICOSAT1.0, and Artemis were the six picosatellites built by Santa Clara University students and DARPA organisation. These picosatellites were part of JAWSAT Project, in which secondary OPAL deployer were used for deploying these six picosatellites as a secondary payload. Minotaur launch vehicle carried this project to orbit and every satellite were deployed successfully. The launch part was partially managed by USA Air Force, Los Angeles (ESA, JAWSAT (Joint Airforce Academy / Weber State University Satellite), 2022).

5. Femto Satellite

These are primarily chip-based satellites whose mass is below 0.01kg (Joseph N. Pelton, 2020, pp. 87-101). They are a minimal number of systems, which can perform a particular task for a short time in a mission.

Example - Sprites

Launch vehicle: In April 2014, the Falcon 9 rocket carried 104 Femtosatellite under KickSat mission. The Femtosatellite were called chipsets, or "Sprites." Unfortunately, the mission was unsuccessful due to the failure of the on-board clock, and eventually, fall back into the earth atmosphere on May 14th 2014.

Attributes of Small Satellite

Before understanding the potentiality of the SmallSat market, it is essential to understand the attributes of SmallSat that have driven compelling cases for attracting the corporate industry. Alen space is one of the new pioneers in the NewSpace sector, and more companies are joining this sector. For over ten years, they have been developing CubeSat’s and helping many companies place their products in space (Alen Space, 2019). In their web source, they have discussed the benefits of small satellites.

1. Small satellites could open doors for multinational companies and other small countries to venture their business into the space application.
2. The cost of building one unit of CubeSat would be very low, which is a very affordable rate for any organisation. The current missions built by students indicated the affordability rate of small satellites.

3. The development period is very less compared to the development period for conventional satellites.

4. When it comes to launching costs, companies, prices are charged weighing each kilogram. Therefore having a small satellite of a few kilograms reduce the price for companies.

5. Small satellites mostly work in constellation systems; it provides more backup redundancy in case of any failure.

6. CubeSat’s are more flexible and adaptable to changes in mission. Changing one satellite in a constellation would change and update the functionality of the constellation.

7. The operational period for small satellites is less which indicates that the mission results will be quicker and faster.

2.1 Market Perspective of Nanosat and Development of Small Satellite

Markets and Markets website studies the global market for CubeSat’s and predict a small satellite market for the next five years. According to markets and markets’ recent predictions on the upcoming global market, CubeSat is expected to increase three times its current market size by 2025. During the forecast period, the Compound Annual Growth Rate (CAGR) is 21.3% (Markets and Markets, 2020). Low budgets and fast development has been the major driving factor for the growth of the small satellite market. Therefore, it provides an excellent opportunity for testing new technologies in space within a short timeframe and less amount.

Upon comparing traditional satellites to small satellites, the Markets and Markets website stated that small satellites are cheaper to operate and build, providing a platform for countries with low investment budgets for satellite manufacture and launch. Advancements in technology such as the miniaturization of electronics, and the usage of commercial off-shelves (COT) material, have accelerated the commercial applications, significantly affecting the small satellite launches in the next couple of years. At a surprisingly low budget plan, a small satellite collects real-time data for commercial companies. The constellation of the small satellite could provide faster access
to internet services across the world. In September 2020, Falcon 9 Starlink's mission carried the first satellite constellations to provide faster internet. According to the report published by the Satellite Industry Association (SIA) (SIA- Satellite Industry Report, , 2019, p. 2) in 2018, the Nanosatellites' manufacturing market had a 26% percent increase in their manufacturing revenue. On the other hand, the small satellite launch market had a 34% increase in their launch service revenue compared with the 2017 results (SIA- Satellite Industry Report, , 2019, p. 2). Therefore, it shows that revenue for launch service is higher than manufacturing expenditure.

An interesting observation noted in the collected information is that the cost of manufacturing small satellites has dropped. However, the cost of launch has not, representing today a significant cost element in the total mission cost. The previous missions for Nanosatellites carried as a secondary payload along with conventional satellites and have been costly and challenging from the market perspective. This problem has led to an increase in the demand for the development of small launch vehicles. Launching small satellites as an additional or secondary payload along with more extensive satellite, cause wastage of launch time and budget constraints for commercial companies. A small satellite payload must also wait for space on a launch vehicle which takes a long time and delay the mission by an extended period—all these points towards the need for developing launch vehicles dedicated to small satellite payloads. Low-cost and institutional interest is giving practical approach to university students attracting manufacturers worldwide to develop small launch vehicles.

Every year North America conducts and supports numerous small satellite projects, which include military and university. This makes North America the most prominent market for expanding the small satellite industry. The most significant space firms like NASA, SpaceX, and cooperates like space fab, Astro demand faster communication and speedy data transfer, which will drive the market exponentially. Compared to any other global region, North America has been where new technology or software takes the market very fast. National Aeronautics and Space Administration (NASA) initiated several small satellite missions to grow the small satellite industry, which other private space agencies followed. However, in the current scenario market seems to be swiftly moving to the Asia Pacific region. India and China are two strong countries spreading their wings in the small satellite fields with the help of private investors. The main reason could be that significant investors are routed in this part of the world. An article published by
Chinese news revealed that the China space mission program plan to launch more than 100 satellites by the end of 2025. Whereas in India start-up companies like Exseed Space launched a Nanosatellite for radio amateurs in 2015 (Mordor Intelligence, 2020, p. 3) and another start-up company Astrome Technology is planning to launch 200 Nanosatellites for high-speed internet by 2023 (Mordor Intelligence, 2020, p. 3).

In 1986, on one hand where the world saw the painful loss of seven astronauts on Challenger and Halley's Comet reaching perihelion. On the other hand, Russia launched 25 microsatellites as a secondary payload to LEO (Harvey, 2001, p. 126). Twenty-four of Twenty-five satellites weigh 61 kg mass, launched by Strela 1M built by the Soviet Union. Vietnam National Satellite Centre (VNNSC) did its first small satellite project in 2011. They launched the Pico Dragon mission with JAXA as their predecessor and launched three small satellites from the ISS J-SSOD deployer. This indicates that smaller countries like Vietnam are taking initiatives in this market. In 1991, the American Institute of Aeronautics and Astronautics (AIAA) and Defence Advanced Research Agency (DARPA) launched seven 22kg MICROsat under LIGHTSAT program (Janson, 2011). In the same year, under the TUBSAT program mission, various universities from Europe built CubeSat’s, and the first TUBESAT program CubeSat’s were carried by Ariane-4 (Gunter D Krebs, “Tubsat A”, 2022). Under the TUBSAT program, university CubeSat's are launched as secondary payloads using heavy launch vehicles. On January 27th 2000, the Orbital Science Minotaur rocket launched the OPAL mission, which was part of the primary mission of JAWSAT, and ejected three picosatellites that Santa Clara University students built (Miller, 2001). OPAL mission success eventually led to establishment of the CubeSat program challenge between Stanford and California Polytechnic State University (Janson, 2011).

There was a point in history when the small satellite industry became stagnant. During the first decade of small satellite exploration, nearly three Nanosatellites were launched in a year. During 1977 – 1987, a decline in the microsatellite and satellite industry named this period "small satellite doldrums." This period got over in 1990 when five-plus Nanosatellites were launched. However, the case is slightly different for picosatellite; the doldrum area lasts longer for the picosatellite industry (Janson, 2011). The picosatellite industry bounced back when the OPAL mission and launched six picosatellites in 2000. Most miniature satellites are carried by the Indian Space Research Organisation (ISRO) launcher PSLV, also took most Nanosatellites into orbit. In
2010, it also took StudSat-1, which was India’s first picosatellite built by Indian university students. After which, the industry is climbing new heights each year. It is evident from past missions that manufacturing Nanosatellite is never a cost concern because universities initiated most small satellite missions. If manufacturing is not a trouble, then probably the launch cost is very high, which could be why small satellites have not taken the commercial market till now.

All these are the essential steps in the development of any Nanosatellite. It takes approximately 12 -18 months the making a Nanosatellite. However, finding a launch vehicle and waiting for the payload vacancy to get rideshare could be very long. It is just a part of the bigger problem, which can be solved by developing small launch vehicles that frequently carry the Nanosatellite as primary payloads to space.

![LAUNCHES AND SATELLITES PLACED IN ORBIT PER YEAR](image)

*Figure 1: Launches and Satellite placed in an orbit per year (data provided by Oritare a.g)*

Figure 1 shows the difference in number of launches and the number of satellites placed in orbit per year. In the beginning, between 1955 – 1965 the survey shows that number of satellites and number of launches went hand in hand. In 1965, the number of satellites placed in orbit increased exponentially compared to the past. From 1965-2000, between these years development remained stagnant between launches and number of satellites. After this year we observe a slight dip in the graph, which indicates the development of nanosatellites, which started influencing conventional satellite development. After 2005, Nanosatellites’ development took major turns that
increased Nanosatellites’ growth. The gap between number of launches and number of satellites increased because more amount of satellites were developed in shorter period of time. After this year number of satellites kept increasing while launches remained stagnant.

Figure 2: Cumulated data on Spacecraft’s sent to space (data provided by Orbitare a.g)

Figure 3: Satellites placed in orbit yearly (data provided by Orbitare a.g)
Figure 2 graph shows the cumulated data on spacecraft’s sent to space, while the other graph in Figure 3 shows satellites placed in orbit yearly. Figure 3 has been divided in different phases. Beginning from first space race phase, between the years 1958 to 1965, we see many satellites were built by various manufacturers that we call the first space race. In this phase, every country’s space organisation was racing against each other to place their satellite in orbit. After this phase space maturity started where organizations worldwide were trying to understand space phenomena. Therefore, the graph is stagnant for long time. We observe dip in the graph from 1990-2005, which is first constellation phase. This was the phase when nanosatellites were introduced in the world and constellation application of small satellites were studied. Due to which conventional satellite development were on hold. After the big bird times phase, nanosatellites had their first commercial launch, which marked the beginning of nanosatellite era. Currently second space race is going on, which indicates that industrialists and governmental organizations are racing to place small satellite to orbit and even trying for space tourism.

The reason for launches being fewer than the number of satellites in orbit could be that it takes a considerable amount of time to develop a launch vehicle, whereas small satellite developments takes two years. Most rockets are just one-time use; once the launcher are used cannot be reused regardless of success or failure. The new launch vehicle of SpaceX; name Falcon 9 is a reusable launcher. It could allow us to have a faster availability of launch vehicles in the future.
Chapter 3: Methodology

3.1 Literature survey

Revolutionizing the space industry began in 1986 when the small satellite industry re-emerged after twenty years of stagnation. Since then, small satellites have been launched as rideshare, secondary or primary payloads or International Space Station (ISS) launches. To make the space market commercially available, it needs to be open for companies to operate and launch small satellites easily. To understand cost per launch and launch vehicle relations with its price, one has to look into the analogy of the past missions, past launch ideas and the reason for their failures or success. Very little research has been done in the past which provides cost analysis of current and future trends for CubeSat missions. Therefore the literature relevant to the research was selected from ten years old publications. The reason for their selection was their relevance and the first commercial small satellite was launched in 2009, after which many researchers initiated their interest in the small satellite future.

Science Direct published a report in 2010 (Kirk Woellert, 2010) that surfaced the importance of CubeSat missions and also focused on the economic influence of CubeSats. This paper gives detailed insight on the importance of CubeSat in various applications. It also surfaced the possible bright future for small satellite applications. Their methodology involved reviewing the evolution of CubeSat in technical aspects (manufacturing to deployment sector). Their results were conclusive with the realization of financial influence on small satellite missions and vast future possibilities. This report also agreed with my observation that manufacturing costs are lower for small satellites compared to conventional satellites. An interesting point noted by the author was that it acknowledged the different factors that can influence the reducing manufacturing cost of small satellites. The author also highlighted an issue about an increase in the frequency of secondary payload and incorporating secondary payload for launch providers. It also gave an idea about developing countries and their potential for small satellite missions soon. The missing point in this research would be that it did not give the technical/social factors influencing the price for small satellite launches. A report in 2013 by Michael Swartwout (Swartwout, 2013) in which he predicted that most of the missions launched in 2013 would have a failure rate higher than success. The author believed that the US ELaNa program plays a major role in launching the highest
number of university CubeSat’s. However, the program has a 50% failed launch record in history. According to this report, it was expected to have 80 CubeSat’s launches in 2013. Half of them were built for educational purposes, which implies that universities have been very active customers of the small satellite industry. This paper gave a historical database on driving nanosatellites and understanding which country produces/uses the maximum number of small satellites. His paper showcased that the highest developer of small satellites is the USA and addressed the number of failed missions. However, it did not identify the reasons for failed missions. Another similar paper was published in 2016 (Halis Can Polat, 2016), where the author demonstrated the usage of small satellites categorized by units. Both these papers talked about using off-the-shelf materials in launching payloads, which could affect the launch price. This technology has been used by many missions in present times, but it has not affected the cost of launch because the price at present for launching a unit can be up to $30,000.

A very interesting paper was published in 2017 (Timo Wekerle, 2017); the report addressed the trends in the small satellites industry. The author carried out the research by analyzing 863 CubeSat’s from 1995 – 2014. This paper dealt with challenges faced in developing of small satellites and identified future scenarios from a market perspective. This paper identifies that most of the satellites in the early years were carried by only heavy launch vehicles which were very high priced. It also identified various countries and their contributions to the small satellite market, their analysis matched the previous claims that the USA is a very prominent customer for nanosatellites followed by Russia. The report also briefed about the miniaturization of electronics and designing small satellite launch vehicles. Another paper in 2019 (Danton José Fortes Villas Bôas, 2020) dealt with the development of launchers; this surfaced the change in rocket technology and the development of small satellite launch vehicles specifically for carrying small satellite. This paper dealt with Brazilian VL range of rocket, but this approach surfaced that the advancement in rocket technology can influence the change in deployment method and can eventually affect the launch cost.

A paper in 2020 (Alina Orlova, 2020), made a market perspective development for the next 5-10 years for a small satellite. In this paper, the author analyzed and identified the advancement in the ecosystem of small satellites and launch vehicles for the next ten years. It claimed the development of constellations of small satellites, and the reuse of launch vehicles. This paper
focused on the development of the application of small satellites, which will increase the demand for nanosatellites. This report showcased the bright future for the small satellite industry in the near future. Two important papers related to this research were published in 2015 and 2020. This paper analyzed the trends in small satellites since 2009. Both papers were presented at AIAA conferences. In the 2015 paper (Greg Richardson, 2015), the methodology adopted was to identify various aspects of development time and mission delay sector for a small satellite. It concluded that decreasing launch prices would impact on small satellite designers. This paper focused on past missions to draw data and changed trends to reduce future launch costs. 2020 paper (Kara O’Donnell, 2020) re-evaluated the predicted data of 2015, it concluded that many predictions were held right by 2019 as well. Like the rise in the usage of 3U satellites and an increase in the number of satellites launched. Launch failure is claimed by 5%, out of which 4% failed in their initial years. The paper updated the data and information of past launched satellites.

U.S Government Accountability Office published a report in 2017 about sale price drives potential effects on the department of defense and commercial launch providers (GAO Government Accountability Office, 2017). In this report, they have examined the motor pricing for the current launch vehicle and future launch vehicle prices. This report concluded that motor pricing and changes in the law would affect the launch vehicles. It could benefit by increasing the competition and giving customers a wider range of choices. This report mainly focused on using surplus motors and their potential benefit in reducing the price. This report showcased different aspects affecting launch vehicle prices in the market. This can be considered when studying in depth the technical aspects that influence the launch price. In this report, I have covered other technical aspects affecting launch price.

The Federal Aviation Administration’s Office of Commercial Space Transportation (FAA AST) released an Annual Compendium of Commercial Space Transportation report in 2018 (FAA, 2018). This report highlights the difference in the amount of revenue generated by the satellite industry and the government space budget. It also mentioned the start-up space ventures and their contribution to the finances. According to the report, 2016 showed the highest investment in start-up firms almost an increase of 50%. FAA AST report mentioned the increase in launches and the failures of influential countries like the USA, China, India, and Russia which has also been talked in the markets trend chapter. This report has also identified similar upcoming launchers that have
been noted in my research and discussed in detail in the future launch vehicle chapter. The FAA report concluded that these new upcoming launchers are significantly impacting on launch costs and will provide more control over launch opportunities.

All the papers provided commercial industry and a promising future for the small satellite market. These papers surfaced the problem of expensive launch prices, limited launch vehicles, and various countries’ potentiality. The papers lack to identify the reasons for high launch costs and the solution to tackle high launch costs. These papers have made clear that demand for small satellites will increase exponentially in the near future, which will increase the competition in the market for the price. My research will fill the gaps of reasons for the launch price to be very high and identify the launch alternatives with advancements in current technology. Every year Satellite Industry Association publishes an analysis report for satellite industry performance. According to a 2018 (Satellite Industry Association, 2018) published report the revenue generated has increased ten times, making it a very profitable market for the commercial industry. The new market data has not been published since then. This report stated that 2017 revenue for satellite manufacturing increased by 10% making a record 345 satellites launched. Other reviewed literature where about rockets and their mission history, also the historical theoretical concepts for deployment and the reason for their rejection. Those journal data are summarised in the forthcoming chapters of this report.

3.2 Current Launchers

The literature survey highlighted the analysis studied by many researchers regarding the increase in demand for small satellites in the coming future, which indicates the need for dedicated launch vehicles. The barrier to commercializing the small satellite industry is the cost and availability of launch vehicles. These launch vehicles need to be dedicated to the small satellite category. Currently, the launch markets’ biggest clients have been Universities and the government sector. Universities built the maximum number of small satellites for academic or research purposes, which comes in handy in terms of cost budget for students and Universities. The launch price is a crucial part of academic projects. More than any commercial space firm, students have built numerous Nanosatellites for various missions. It raises a question - if the building of Nanosatellites is affordable, then why current market lacks in launching a constellation of small
satellites into space? Also, a question on why does launch vehicle market lags in providing launch vehicles? These questions can be answered by knowing the availability of current launchers and their background.

In 2003, a Russian space vehicle, "Rockot," shown in Figure 4, is a modified UR-100 liquid propellant intercontinental ballistic missile (ICBM) rocket that carried CubeSat’s of different nations and deployed successfully at LEO. In this mission, nanosatellite payloads were built by the Universities, which cost them a few thousands of dollars. However, the cost per launch for Rockot was about $41.8 million (GAO United States Government Accountability Office, 2017, p. 22) and can carry a payload of 1820 - 2150kg to LEO, whereas it can also carry up to 1000kg (Astronautix, n.d.) Of cargo to SSO. Therefore, sending one unit of CubeSat using Rockot launcher cost approximately $21,000 /unit. In 2006, another Russian modified R-36 liquid propellant launch vehicle that carried the American universities CubeSat into orbit but failed was "Dnepr". It was again tested in 2007 by carrying various 1U CubeSat's to SSO which was a success for the Soviet Union. In April 2015, Russia announced to the removal of these two vehicles from the market in 2019.

Indian launch vehicle PSLV –CA has a long history of successful missions, including the successful deployment of small satellites in orbit. In 2008, PSLV – CA successfully carried nanosatellites built by universities as a rideshare mission. PSLV is a three-stage solid-propellant rocket that took commercial flight in 2007. The cost per launch for PSLV is about $18 -$28 million, depending on the orbital destination. This launch vehicle can carry a payload of up to 3800kg. Therefore, sending one freight unit via this rocket would cost approximately $8,000 /unit

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4 One unit CubeSat weight is 1.33kg which is approximately 1 kg (Sarah Loff, 2018). However, when describing price for one kg of CubeSat payload it is written per unit. In industrial terms when it is talked about sending payload price it is said as per kg but when it is talked about small satellite payload, it is referred to as per unit i.e. 1U or 1.33 kg

5 Price is provided by PSLV manual given by ISRO (Indian Space Research Organization) member Mr. Sharma (retired ISRO member) (personal communication on 20th April). The prices is however little different from GAO report reference but it lies in the range of their data. This is because no one can give exact price and the prices don’t stuck same for every mission, there are other factors which also come into play like economic and political.
(GAO United States Government Accountability Office, 2017, p. 22), which is very low compared with other countries’ launch vehicles. PSLV took many flights in 2010 and 2013 carrying various CubeSat's to their orbital destinations and, at present timely available for launching a satellite at an affordable rate. In 2011, NASA initiated the Educational Launch of Nanosatellites (ELaNa) program to attract young minds into space science and technology (Heiney, 2017), which is active to date. This program is one of the most significant program operated by the United States because they are a prominent client for launching small satellites made by students. This program has been considered in other similar studies by Michael Swartwout report has also identified this program to be most important in launch analysis. Under this program, students develop nanosatellites, and only successful designs can orbit the Earth to collect data. US-originated Delta II launch vehicle carried the first successful ELaNa mission and ever since then they have used several heavy launch vehicles in the past like Atlas V, Flacon 9, Minotaur. They have started using some new dedicated launch vehicles like LauncherOne and Astra Space- Rocket 3.3. Heavy launch vehicles Delta II is also a solid propellant rocket and can carry 2600- 6100 kg of payloads to LEO, which means it is a heavy vehicle whose cost per launch is $137 million (FAA, 2018, p. 138), making the cost per launch per unit costly from a commercial point of view. For example, assuming payload weight to be a minimum of 2600kg, it makes the cost per launch to be approximately $52,600 / unit. Usually, every heavy launch vehicle carries Nanosatellites as a rideshare option, or they take them to ISS.

Along with India and USA, European Space Agency also joined the race in 2012, when their solid-propellant rocket “Vega” shown in Figure 5 carried Nanosatellites successfully. This mission carried seven Pico satellites from European Universities and two-science satellite (ESA, Vega qualification flight VV01, 2012), making a total payload of about 680kg. The Nanosatellites were carried as a secondary payload. Vega's cost per launch is about $37 million (GAO United States Government Accountability

Figure 5: ESA Vega Launcher (image from https://space.skyrocket.de/doc_lau_fam/vega.htm)

6 More information can be found on press kit Vega qualification flight VV01 (ESA, Vega qualification flight VV01, 2012)
Office, 2017, p. 22) (FAA, 2018) and can carry up to 1900 kg of payload to an orbit. Therefore, the cost per launch per unit is approximately $19,000/unit. Both USA and ESA have shown the history of a successful launch for Nanosatellites but the price is very high from a commercial market point of view. Interestingly on the other side, Japan also developed a rocket, “H-IIB,” which is a liquid propellant rocket. Its cost per launch is $112.5 million, carrying 16500kg to LEO (GAO United States Government Accountability Office, 2017) (Mitsubishi Heavy Industries, 2009) (FAA, 2018)). This rocket can cost $10,000 / unit, giving Japan many opportunities to launch its Universities' Nanosatellites. After which, every year, Japan launches Nanosatellites into space as secondary payloads. Their price range is nearly similar to the PSLV rocket, making it utilized maximum by University students. An interesting observation noticed here is that both PSLV and H-IIB hold approximately similar prices but their propellants used differs. This difference is shown in payload weight for both vehicles, H-IIB can carry six times more payload than the PSLV rocket. The propellant influence on rocket missions is discussed more in detail in the upcoming chapter.

These observations and information on various rockets highlight how the missions will be folding in the future. In 2015, NASA showed their interest in developing a new range of launch vehicles dedicated solely to satellites with a lesser weight range. NASA proposed the idea of Venture Class Launch Services (VCLS), providing a payload weight range between 30 kg to 60 kg per launcher. In 2015, NASA granted $17.1 million (Foust, NASA Awards Contracts for Dedicated Cubesat Launches, 2015) to three major start-up companies in this project. Rocket Lab (Electron Rocket) received the highest bid worth $6.9 million, Firefly Space Systems (Alpha rocket) received the second-highest offer of $5.5 million, and Virgin Galactic (LauncherOne rocket) got $4.7 million for each of their flight launches. Rocket Lab had a successful first mission launched in 2018 under ELaNa mission carrying ten CubeSat’s (Potter, 2020).

In the vision of developing small launch vehicles, some companies have already begun with design models and testing. The Electron rocket is a two-stage liquid propellant vehicle, which is developed in collaboration with the USA and New Zealand. Its estimated cost per launch is $8 million (Vance, 2020), carrying a 300kg to LEO (Rocket lab, 2020). The weight was increased to 300 kg in year 2020 but the price remains untouched. Initially an article in 2017 said the price was $5M (Boyle, 2017), but later, according to different articles and journals, the price increased. Despite its first test launch being a failure in 2017, the Electron rocket had 11 consecutive
successful tests afterwards. Its upcoming mission was to carry the ELaNa mission CubeSat in 2020, which has been postponed. On the other side, Virgin Galactic introduced its launcher model LauncherOne rocket, a liquid fuel two-stage rocket that can carry 300 - 500 kg of payload to SSO. According to the plan in 2017, its launch cost would be about $12 million (Foust, Virgin Orbit plans 2018 first launch, 2017). Same as the Electron rocket, even LauncherOne rocket had its first test failure but had a successful launch for ELaNa missions.

On the other hand, American aerospace company Firefly Aerospace developed the Firefly alpha rocket, a two-stage launch vehicle designed for the commercial launch market. These Firefly alphas can carry a payload of 1000kg to LEO at about $15 million7 (Firefly Alpha, n.d.). This rocket still requires to take its first test flight mission rescheduled for the first quarter of 2021. According to media reports that the company has been facing financial crises, which have led to the selling of all its assets and equipment, this has been mentioned in GAO report. Its first launch is expected to be in late 2022. Whereas ESA, has two major rocket: Ariane and Vega which are used for launching Nanosatellites. Their launch cost is similar to USA heavy launch vehicles and their maintenance costs $3 billion. Therefore a maximum number of University CubeSat’s are built by USA and EU Universities but the availability of launch vehicle at present are with India and Japan. This emphasizes one problem which is the availability of launch vehicles, due to which commercial markets are not investing in this field.

Rockets have come a long way in history, analyzing their upgrade in the propulsion system. For the Pentagon research agency (DARPA), Boeing built an airplane launcher named X.S- 1. This air launcher was missioned to carry 10 flights in 10 days costing of $5 million but planned the test flights for 2020 (Eshel, 2015) (FAA, 2018). According to a space.com article in 2020, this project has been scraped out because Boeing moved out from the experimental space plane phase (Wall, 2020). One of the SpaceX projects, Big Falcon Rocket or BFR which was later renamed Starship, can carry a payload thrice as much as a Falcon Heavy rocket. According to Elon Musk, it will cost less than its manufacturing cost for the clients to take payload (Cobb, 2019). An early version of BFG has been completed and a successful test flight in Texas in April 2019.

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7 The price in firefly website (Firefly Alpha, n.d.) and FAA report (FAA, 2018) are different this is due to 5 years gap in both the report.
Edward Cunningham, an undergraduate physics student at Cambridge University, said: “To launch a rocket from the ground requires lots of thrusts, quite a large rocket and lots of money. The challenge is not overcoming gravity but air resistance” (Hollingham, 2012). This is true for rocket launching or using other vehicles to gain acceleration. There have been many brainstorming sessions between many various possible concepts; one such idea is called “rockoon (rocket and balloon),” which is an ancient rockery concept and was first formulated by the U.S. military in the 1940s. The Cambridge student's idea is to fly parabolic rockoons to an altitude of 100 km in space at the cost of less than $1500 (Hollingham, 2012). The concept behind the idea is that a rocket will be suspended beneath a giant helium balloon before it burst, and the ground station sends a command to launch. It will penetrate through a helium balloon and will get into space. However, Cunningham emphasises that getting into orbit needs more than just power, a good idea, and a lot more money. This idea’s major problem lies in igniting the rocket in the air to be launched, which requires precision and thrust against air resistance. These two factors are yet to be solved for missions.

The miniaturized satellites are about 10cm cubes and usually "piggyback" on primary launch missions to keep costs down and fill the vacant weight. The question to be thought is, when the construction of a small satellite is so easy and handy that even school students can make it with proper guidance, why not space is filled with these small cases yet? CubeSat’s kits are increasingly very popular amongst student groups, and NASA started a program to launch some of the CubeSat’s free of cost. The list in table 1 shows that the approximately maximum price to launch a unit from the existing launchers would be $30,000/unit (including launch and other services), which is still well beyond most students’ budgets. If only $2,000 is manufacturing cost, which means $28,000 will be just for a unit to be sent in space. Fortunately, Zachary Robert Manchester, Cornell University New York 2015, came up with a design for budgeted people to get on board with affordable CubeSat missions. The idea is to launch an alternative, smaller spacecraft called "Sprite" (Manchester, 2015) shown in Figure 6. They are
bigger than a thumbnail, and consist of solar cells, a microprocessor, and a transmitter. Zac's mission is to have multiple sprites into a single CubeSat. It will orbit the craft and spring from the mothership to orbit around independently. In a few weeks, the orbit decay and it will fall back getting burned in the Earth's atmosphere. A significant part of the mission is its price which is $300 per Sprite. The Sprite project's funding has been done by donation and whoever has paid the total amount of $300 gets a Sprite of their name (Manchester, 2015). This mission was carried as a secondary payload in Falcon 9v to ISS on April 2014. After this Zac is now providing the KickSat kit for anyone interested in building a chip-based satellite.

After analysing the past Nanosatellite missions’ cost per launch listed in Table 2, we can approximate the value for launch would cost around $10,000 - $30,000 / unit. It was observed that propulsion could play a crucial role that may affect the launch cost. The cost per launch per unit for solid and liquid propellant is approximately the same, but the amount of payload that both rockets can carry differs significantly. Solid propellant rockets can take less payload under 5000 kg, but liquid propellants can carry double the amount. It was observed that companies focus more on developing small launch vehicles that could carry a small payload for future Nanosatellite missions. All of these are based on liquid propellants and in the coming chapters we will understand why companies are focusing on liquid propellants for small launch vehicles. PSLV, VEGA, and DNEPR have played very important in history for carrying small satellites. The problem with these rockets is that they are all heavy launch vehicles, which means they were not designed to carry less payload. Therefore small satellites are carried as secondary payloads. This takes time because payload weight availability in the rocket is a barrier. Also, the configuration of the payloads matters; some missions had ride share while others carried as a secondary payload. Further, the chapters will explore more aspects that affect the cost per launch and try to find some new trends and options to have a budget-friendly launch for Nanosatellites, bringing corporate space companies into the small satellite world.

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Mission Cost (in millions)</th>
<th>Cost per unit (as per 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSLV- CA</td>
<td>$18-28M</td>
<td>$8,000</td>
</tr>
<tr>
<td>H-IIB</td>
<td>$112.5M</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

8 The launch cost prices has been retrieved from Orbitare launcher directory and cross checked by the director Mr. Luis Mnoz and An email (Mr. Rakesh S., 2020, personal contact on 1st May) confirming the values are correct.
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<table>
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<tr>
<th></th>
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<tbody>
<tr>
<td>Vega</td>
<td>$37M</td>
<td>$19,000</td>
</tr>
<tr>
<td>Dnepr</td>
<td>$29M</td>
<td>$9,000</td>
</tr>
<tr>
<td>Athena Ic</td>
<td>$20M</td>
<td>$28,600</td>
</tr>
<tr>
<td>Athena IIc</td>
<td>$30M</td>
<td>$16,500</td>
</tr>
<tr>
<td>Delta II</td>
<td>$137M</td>
<td>$36,700</td>
</tr>
<tr>
<td>Falcon 9</td>
<td>$62M</td>
<td>$3,000</td>
</tr>
</tbody>
</table>

3.3 Rocket propellant

From the literature survey chapter, payload to fuel ratio affects overall launch cost. For any profitable business, it is ideal to have less investment and more implacable products. For many year’s engineers, scientists, and space entrepreneurs have been trying to find the best ways to access space at the lowest possible price. The most integral part of a launcher is the Propellants/Fuels. Common rocket fuels used are HTPB, N2O4/UDMH, and these are open-market restricted items, making them sporadic and pricy. New rockets use Kerosene and liquid oxygen, which is easier to get and is within a budget price.

Rocket propellants are of two major types: Solid and Liquid. Also, there are other ways to produce thrust like ion, electromagnetic and nuclear plasma. Most of the rockets developed in the 20th century used either solid form or powdered form of fuel. Hydroxyl-terminated polybutadiene (HTPB) is mostly preferred for Hybrid Rockets. They are non-hazardous and non-toxic to store, which lowers the manufacturing and launch costs (Dhruv Mehendiratta, 2018). Only a few launchers in the past used pure solid propellants like Vega and Athena II. These launchers use pure solid propellant for their first three-stage; their launch cost was nearly $30 - $37 million (ref. table1). Approximately it cost $16,000 - $19,000 per unit to send at SSO using Vega or Athena II spacecraft.

Most of the rockets built in the 21st century are hybrid rockets, which means alternating the use of solid-liquid propellant. Many heavy launch vehicles such as PSLV (Polar Synchronised launch vehicle), Ariane 5, Delta II, and Atlas V; are hybrid rockets that have placed many Nanosatellites into orbit. These are all heavy launch vehicles, which means they carry a substantial amount of payload and in which Nanosatellites have rideshare. PSLV has launched maximum Nanosatellite and recently QB50 mission launched eight Nanosatellites builds by different
Universities under European CubeSat Symposium program. According to one of the participating teams, it cost $22,500/team\(^9\) to launch with PSLV. Under the same mission, 28 CubeSat’s were carried to International Space Station by Atlas V rocket, which also cost the same amount, but it took more time to be placed in orbit.

Indian PSLV is a four-stage and expandable medium-lift vehicle. It has the biggest solid boosters in the world for the first stage carrying HTPB propellant. It provides a massive thrust to lift off the payload and its third stage contains HTPB fuel. On the other side, the second stage contains a liquid propellant, which is unsymmetrical dimethylhydrazine (UDMH), and nitrogen tetroxide (N2O4). Its final stage uses monomethylhydrazine (MMH) and mixed oxides of nitrogen (MON). All these fuels are restricted items in the open market; hence commercial companies cannot get their hands on these propellants, making it a super rare fuel to be found, so the price for such fuels is usually fixed, and buyers have to agree to the given price. However, getting the exact price of these restricted fuels is not possible. Instead, we can investigate why hybrid rockets are preferred over solid rockets, which will help us understand future trends in the launch vehicle.

ZARM Company (Eigenbrod, n.d.) has been working with hybrid engine development, and listed certain advantages on its website. This company is a part of the University of Bremen. The hybrid propellant advantage over solid and liquid propellants are summarized below:

1. Hybrid rockets require duel fuel, and they need to be stored in separate tanks, making them easy to transport separately to the launch area.
2. Compared with solid propellants, a launcher can use one stage as a solid propellant and another as a liquid propellant. It will help in a more controlled operation at each stage.
3. The mechanical design for a hybrid propulsion system is much less complex compared to monopropellant systems.
4. Hybrid rocketry does not require pumping a large amount of fuel, so a blowdown system or self-pressurized oxidisers is sufficient. It makes the designing process easy for hybrid rockets.

\(^9\) An Email (Vladimír Dániel, 2020, personal communication, 13th march) confirming the values are accurate.
From the list of hybrid rocket advantages, we understand why hybrid rockets are preferred over monopropellant rockets. The heavy launch vehicles are being developed using a hybrid propulsion system. Private companies do not have to wait for the heavy launch vehicle to be scheduled, it can have rideshare with the primary missions. Corporate companies are focusing on developing future launch vehicles for Nanosatellites, this group of launch vehicles will be called Small Satellite Launch Vehicle (SSLV). Most of the SSLV’s are already developed and are under testing. As mentioned earlier, rocket fuels are expensive and restricted items, so not every company can afford to manufacture their launch vehicle like airline companies. The private organisation is keen on developing SSLV’s such as Virgin Orbit, LauncherOne, and Vector R rocket. These rockets are not yet available in the market but have completed their initial testing stage. These are being developed for carrying a smaller payload, mainly a constellation of Nanosatellite. Every new range SSLV’s are using liquid propellants i.e. R.P. -1 as fuel. It is refined petroleum or, in other words, can be said as Kerosene (Mcdonald, 2017). According to the report published by the department of defence USA, the RP-1 price in the market is $3.03 per gallon (Department of Defense, 2022). Another fuel used along with RP-1 is liquid oxygen which is also very readily available in the market. The prices for these fuels are very affordable and can be stored easily without a luxurious storage area. SSLV rockets could take a payload of approximately 300 kg to Sun Synchronised Orbit (SSO), which is best suitable for sending small satellite constellations.

There are three categories of liquid propellants: Petroleum, Cryogenic, and Hypergols (Braeunig, 2008). Petroleum fuels are crude oil mixed with an organic compound of carbon and hydrogen (like hydrocarbons). The most commonly used petroleum propellant in the rocket industry is the highly refined Kerosene known as RP-1. Petroleum fuel costs are at an affordable rate and easy to be stored. Cryogenic fuels are liquefied gases stored at shallow temperatures, making them very difficult to store and process. It commonly uses liquid oxygen and liquid hydrogen as the fuel combination. Other options proposed to be used in cryogenic fuel are liquid methane and liquid fluorine. Many new researchers have proposed using liquid methane as a fuel for futuristic mars missions during the 21st Mars society conventions in 2019. Liquid fluorine has been abandoned as an option due to its high toxicity. One problem with cryogenic fuels is that they must be stored at a shallow temperature, which means they requires a particular storage.

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10 This price has been retrieved from the standard fuel price as of January 2022. This list get updated every year.
11 Personally attended the conference and presentation in 2019.
facility and cannot be stored for longer. This problem can be countered by using hypergolic fuels. They remain liquid at room temperature and can be stored for a longer time, but liquid fluorine is highly toxic, and the fuel ignition is very spontaneous. Therefore hypergolic fuel could be used in maneuvering spacecraft.

The upcoming new SSLV like LauncherOne and Vector R is built using liquid propellant. LauncherOne launched its satellite from orbit successfully on January 18th, 2021, and the launcher is fully working on petroleum fuel (Clark, 2021). However, Vector R is built on cryogenic fuel, its first launch test is yet to be launched. Its development has been put on hold when Vector R went bankrupt in 2019. In November 2020, it began its development under new ownership (Foust, Vector restarting operations under new ownership, 2020).

One common observation in SSLV’s is that they all use liquid propellants as fuel. One significant advantage of liquid fuel is that it is lighter in weight than solid, making extra room for payload. The payload ratio depends on three masses: structural mass, propellant mass, and payload mass. The payload mass and propellant mass are inversely related; the other needs to be increased to maintain a constant ratio if one is less. Analyzing the various aspects of propellants and comparing their pros and cons shows an excellent idea to develop a small launch vehicle for lesser-weight carriage. One reason could be that storage and transportation costs could be reduced, which will affect the overall cost of the launch. Another reason would be using liquid propellant will allow more payload, and at once, hundreds or thousands of Nanosat could be carried to orbit. It will help form the satellite constellation and eventually help in the various satellite applications.

Also, it gives more control over the ignition process. Propellants are kept in separate tanks, which are mixed in different chambers so that the valve operation can be controlled. It can be implemented on non-rocket launches as very little fuel will be required to reignite when spacecraft are losing altitude. The problem small satellite mission faces are time. It is not feasible for a small satellite to be carried as a rideshare because the missions need to wait for extra weight availability in the primary mission. The secondary mission’s payload is carried only when the primary mission is targeted at a similar destination. The small satellite missions need to wait for their turn. So it is always the secondary missions that are compromised in terms of space and priority. If we develop SSLV, the companies will not be required to wait for the primary mission to give a ride. It will save much time and will provide more frequent access to space.
Analyzing the pros and cons of solid and liquid propellants shows that solids are easy to store, but they are pretty heavy, whereas liquid fuels are light in weight. For instance, if a solid-propellant rocket can carry a 3000 kg payload to maintain fuel to payload ratio, the liquid propellant can carry 6000kg, double the amount at the same price. The rocket will have more fuel, which gives the mission a chance for the detour and additional research. SSLV’s are designed to carry smaller payloads (a few 100’s kg), which means that an entire constellation of Nanosatellite can be launched together. It will play a massive role in bringing more investors to space companies and boost the space industry. In a way, more space companies will be able to launch Nanosatellites in a shorter period, and that would increase orbital activity. One more advantage will be that the National defence department can protect its borders better, and GPS can provide more accurate navigation. It also will improve the communication system and will have better analyses of outer space. These advantages will attract many new space firms, increasing access to space directly linked with more fuel usage, so storage will not be a big problem.

3.4 Thrusters

Thrust is a force generated by the propulsion system based on Newton's third law of motion. Alternative to the traditional thrusters used in present spacecraft are ion thrusters, Hall Effect thrusters, Magnetoplasmadynamic thrusters, Electrodeless plasma thrusters, and Pulsed Plasma thrusters. This variety of thrusters is solely used for producing a small amount of thrust, just enough to maintain attitude control on orbital satellites. From the previous chapter, it was shown that propellant cost could be manipulated with alternative options for fuel. Another observed problem could be when taking Nanosatellites as a secondary payload, their destinations are compromised because of the primary mission. Thus, leading secondary missions compromises for primary agenda. Micro thrusters will be helpful to overcome this problem regarding orbital insertion.

Some electric propulsion systems worked on the principles of Lorentz force to generate thrust. One such propulsion system that works on these principles is Magnetoplasmadynamic (MPD) (Kenichi Kubota, 2011). The gaseous particles are ionized by accelerating quasi-neutral plasma in the chamber. These particles are propelled using Lorentz force, which uses the magnetic
and electric fields as a power source. No fuel combustion occurs in this process; instead, an interaction between the magnetic field and plasma current occurs. Edgar Choueiri's observation on Magnetoplasmadynamic thrusters stated power input supply was 100 – 500 kilowatts and output velocity of 15–60 km/s, producing a thrust of about 2.5–25 N (Choueiri, 2009). MPD thrusters have theoretically shown a high exhaust velocity of 110000 m/s, which is more than the xenon-based ion thrusters. However, the commercial interest in utilizing MPD thrusters in Nanosatellites is low due to several issues. A significant problem is the power requirement, it requires the system optimum performance to produce such a high value of kilowatts. Currently, spacecraft are incapable of producing that high-power supply.

Another kind of MPD is Electrodeless Plasma Thrusters; it uses an electron gun to ionise the propellant. A model was first created by Mr Gregory Emsellem and is currently under development by The Elwing Company (Gregory D. Emsellem, 2007). Another electric spacecraft propulsion system that also works on similar MPD principles is Pulsed Plasma Thruster (PPT). It was the first electric propulsion flown in space along with two Soviet probes in 1964. PPTs are flown on spacecraft with a surplus supply of electricity, providing abundant availability of solar energy. In November 2000, NASA (Glenn Research Center, 2004) flew PPT, an inflight experiment on the Earth Observing-1 spacecraft that demonstrated the ability to perform roll control. These have been an option but could not attract commercial investors to develop them on a large scale. All-electric propulsion systems are tested for small-scale applications like orbital plane change or docking the satellite. Research on their application in launch vehicles is still in process. An electric propulsion system has yet to practically achieve the power required to produce enough thrust for lift-off.

These big thrusters can be used for propelling rockets, but if these thrusters could be scaled down, they can be used for Nanosatellites. The miniaturization of these thrusters is under research by many institutes and labs. Austrian university students have theoretically designed and experimented with miniaturized PPT (M. Tajmar, 2011). The inventors mentioned several problems, and one such problem is related to the structural material. Students have difficulty in the carbonisation of Teflon surface. Therefore the results of this research are still on hold with problems to be solved. On the other hand, the same Austrian University student also designed their experiment for Field Emission Electric Propulsion Thruster (FEEP). The propellant decided to use
was indium, because of its higher melting point. The basic principle is that it ionizes the liquid metal and accelerates the ions using a strong electric field. The thrust obtained by a single FEEP is between 0.1 - 15 µN, and multiple FEEP can produce up to 350 µN thrusts (M. Tajmar, 2011, pp. 3, table 3). These students also experimented with designing chemical micro thrusters (M. Tajmar, 2011). They designed mono and bipropellant thrusters that produce 5N and 1500 mN, respectively. They used standard liquid propellants like MMH and UDMH.

An exciting development that probably will attract the private space industry to invest in Nanosatellites' development is Micro Thrusters for small satellites. One major problem in carrying Nanosatellites as a secondary payload is that it has to wait till the dispatching of the primary mission, and only then are secondary payloads dispatched. In this process, secondary payload missions are compromised. Therefore, sometimes Nanosatellites are unable to reach their destination. Nano thrusters will play a significant role in overcoming the problem. As a secondary payload, the Nanosatellites can be launched in any orbit, and the ground station can easily perform orientation of the satellite or even maneuvre the orbit. These small thrusters can also be used for immediate change in the mission and be utilised in another mission. Another application could be to make orbital insertion or altitude change.

A group from the aerospace corporation has developed micro thrusters on Nanosatellites, which they have called MicroElectroMechanical System (MEMS). In their experiment, they fabricated two chemical micro thrusters whose impulse produced was 0.1 mN-s each (Siegfried W. Janson, 1999). Nanosatellites require micro thrusters with micro-to-mill newton thrust levels for performing orbital operations or small control operations. For accurate altitude change or orbital insertion, the thrusters need to provide several µN up to 100 µN throughout the missions’ period. It requires very little power to be consumed to produce a few micro Newton of thrust. Purdue University made the first working model of micro thrusters in 2017 (Katherine Fowee), shown in Figure 7. Their model uses liquid water vaporization as a propellant and produces
230 \( \mu \text{N/W} \) as thrust to power ratio. The amount of thrust produced by the FEMTA micro thruster is enough to perform small applications with Nanosatellites. In Purdue University’s design, four Nano thrusters were placed in four corners of the CubeSat - 1. The CubeSat made here was of 1U and rotated along one axis. The micro thrusters were attached diagonally so that nozzle A and B were attached to thrusters one and nozzles C and D were attached to thruster 2. When FEMTA A/C is used, the module turns clockwise, and when FEMTA B/D is used, it turns anti-clockwise rotation. Their experiment was successful, with three nozzles working perfectly for the rotation, but FEMTA C was not contributing to the satellite's rotation. The cube made an entire rotation in 1 min 13 sec. Their promising results were very appealing for exploring micro thrusters for Nanosatellites.

Ariane group also designed a miniaturized propulsion system, which uses bipropellant and produces 10N thrusts. They have managed to produce thrust using MMH and N\(_2\)O\(_4\) as fuel. The design produces a specific impulse of 292 s with a thrust range between 6 – 12 N. They have two designs: a single valve and a dual valve system (Borgmeyer). It allows maximum thruster performance at operational temperatures up to 1500°C (2700°F). The thrusters are designed for both steady-state long-term and pulse mode operations; they can operate at regulated inlet pressure conditions. Also, they have designed 200 N bipropellant thrusters shown in Figure 8, whose design is also capable of operating at both the operation mode, the same as 10 N thrusters. Also, it has a broad regime of inlet pressure regulation conditions, even exhibiting extreme conditions.
The D orbit company also has designed micro thrusters named FENIX for Nanosatellite (Lopes). Their design is influenced by a solid rocket motor, as shown in Figure 9. It consists of four independent motors that provide a highly directional oriented thrust-to-volume ratio. It can increase the satellite's lifetime efficiency up to 65% and requires only a 6% volume of a 3U CubeSat. The four motors can be used independently or simultaneously depending on the desired maneuvers. Fenix can be installed in any CubeSat configuration, starting from 1U satellite. It can provide CubeSat with an average thrust of 77 N (Lopes), which is enough for altitude change or orbital insertions. Along with that, another development in micro thrusters uses electrical or chemical propellant.

There are several other ways to ignite a thrust for microsatellites. Ion thrusters, electrical propulsion systems, chemical propulsion systems and nuclear thermal systems are now being developed, and much theoretical research has been done over the years. The fuel used can either be monopropellant or bipropellant or even can be an electrical field. An Electric propulsion system uses electricity to accelerate ions and produce thrust shown in Figure 10. It first extracts ions and electrons, then ionizes the particles, which creates positive ions/electrons. Electrical thrusters rely on electrostatic force because ions/electrons are accelerated using Coulomb forces. Whereas electromagnetic thrusters use Lorenz force to accelerate ions, and they are also called plasma propulsion engines. In these thrusters, the
electric field and acceleration are not in the same direction. The technology has been used in orbital orientation/positioning of the satellite, and along with that, it has been used for low-mass robotic vehicles. This technology was first used in 1998 for Deep Space-1 spacecraft (Choueiri, 2009). The spacecraft changed the velocity by 4.3 km/s, and it consumed less than 74 kg of xenon.

The most widely used technology in spacecraft is the Electric propulsion system. Russian satellites have used these for decades. NASA predicted in 2000 that in 19 years, over 500 spacecraft could start using electric propulsion for various orbital operations. In the coming future, electric thrusters' advancements will be capable of imparting 100 km/s Delta-v, making travelling to the outer solar system possible but not enough to have a deep space mission (Choueiri, 2009).

Another exciting innovation in this aspect is nuclear thermal propulsion systems, which use nuclear reactor heat from nuclear fission to provide thrust. This technology is still only in theory and has not been developed in practical use. Electric and nuclear propulsion systems are very much in the experimental stage. Their commercial use is still not known, the output power required to lift off against gravitational pull is very high, and theoretically, this has matched the numbers, but in practice, this requires quite an amount of energy that is not yet in practice. However, the thrust required by Nanosatellites can be met using an electric propulsion system. Nuclear thermal is still very much in the theoretical stage, and it is quiet in the future. Some micro thrusters are theoretically designed to use solid propellant or liquid propellant, an excellent Nanosatellite option. Miniaturizing the propulsion system could help not just for Nanosat but for traditional satellites as well in the future.

### 3.5 Payload Configuration

Nanosatellites are carried as a secondary payload or when weights are available on the launch vehicle in a rideshare mission. Moog Space and Defence Group is a company in the business of developing payload carrier designs since the 1950s. They have developed very affordable and feasible structures that could carry and deploy maximum Nanosatellite together. They have developed three different payload adapter designs, namely: Evolved Expendable Launch Vehicle (EELV), Secondary Payload Adapter (ESPA), Flat Plate Adapter (FPA), and
Composite Adapter for Shared Payload Ride (CASPAR). These Adapters were developed to utilise excess launch capacity by mounting additional payloads in a different configuration.

In 2007, Atlas V became the first spacecraft that carried the **ESPA ring** voyage in STP-1 mission. Many missions like Lunar Crater Observation and Sensing Satellite (LCROSS), OG2 mission, and Eagle missions are a few names that utilised ESPA ring technology for caring and deploying payloads. ESPA ring is one of the trendiest ways used by launch companies to deploy more payloads to orbit (Moong Space And Defence Group, 2020). Shown in Figure 12, it is a ring-shaped device that can be mounted on a vehicle and has six satellite mounting port over the ESPA ring. In these ports, the payloads are attached to the launch vehicle in circular form. The multiple rings can be mounted on each other, allowing more small satellites to be carried at once. As illustrated in Figure 11, multiple ESPA rings can be stacked above each other. It enables dozens of auxiliary payload satellites to be launched at once for rapid constellation formation. It provides a significant cost saving for individual satellites by sharing a ride with numerous others.

![Figure 11: ESPA ring stacked one above another (image provided from ESPA user guide manual).](image)

![Figure 12: ESPA ring structure (image provided from https://www.moog.com/markets/space/structures.html).](image)
According to Moong Space and defence group (Moong Space And Defence Group, 2020), "The objective behind developing Adapters to carry payloads was to decrease launch costs for the primary mission and to enable secondary or tertiary payloads to have a minimal impact to the primary payloads." The ESPA ring is a modular platform for mission designers to optimise launch configurations for constellations and multi-manifest missions, as shown in Figure 13. Building an ESPA ring is less than $0.5 million per satellite, but the cost of using each port of the ESPA ring during secondary payload is approximately $50,000 (Capt Scott A. Haskett). The estimated price for the ESPA ring is worth $1M in Evolved Expendable Launch Vehicle (EELV). Using ESPA ring for launching payload reduced cost exponentially to $0.5M. ESPA ring can provide access to space for a small satellite that is less than 5% of the traditional launch vehicle.

The Moog space and defence group also designed flat plat adapters (Moog space and defence group, n.d.)\(^\text{12}\). It is a disc-like structure with two payload attachment ports. Two primary satellites can be attached to the disk and deployed simultaneously to the desired location. It enables multiple primary payloads to be deployed consecutively. This type of configuration can affect weight distribution and occupancy management for the overall payload. It will maximise the use of extra weightage for secondary/tertiary payloads. Influenced by a flat plate adapter, CASPAR is to be tested in Minotaur I mission. It deployed two satellites to lower earth orbit and cost $10 million each (Joseph R. Maly). Another option could be FANTM- RiDE, which has not been practically used in any missions. FANTOM- RiDE is a cubical container, which can be attached to the ESPA ring ports. It works by manipulating the mass and centre of gravity of the dispenser. It allows a single load for a dozen of small satellite rideshare (fantm-ride, 2015).

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\(^\text{12}\) For more information upon flat plate adapters can be found on moog space and defense website (Moog space and defence group, n.d.).
On the other side, NASA developed Nanosatellite launch adapter system (NLAS) shown in Figure 14, which can deploy 24U CubeSat’s. The system is designed to accommodate satellites measurement ranging from 1U- 6U sizes. It consists of an Adapter, which is mounted to the upper surface of the launch vehicle. It has dispensers that are attached to the lower deck of the primary mission spacecraft. The CubeSat’s are kept in fully enclosed dispensers, and each can carry up to 14 Kg weight. NLS can be expandable by attaching one above the other for multiple payloads. The last part of NLAS is a Sequencer, which works as a deployment mechanism. In 2013, NLAS flew to space, successfully deploying 26 CubeSat’s (Ames Research Center, 2017).

An Italian company name D - orbit developed another design for carrying a payload name ION CubeSat carrier, a free-flying CubeSat deployer launched in 2019 using a Vega launcher. This carrier is a complete spacecraft in itself; it has its propulsion module, software for handling information, and altitude control unit, as shown in Figure 15. It can modify its attitude to deploy the specific requirement of each CubeSat throughout the mission (D-Orbit, n.d.). According to D - orbit, “The carrier features triple-fault tolerant release commanding subsystems, guaranteeing the release of all CubeSat’s even in case of failure of the main system.” This system can launch a combination of CubeSat’s of any unit ranging from 1U to 12U+, forming a satellite constellation at a faster rate. Also, with its directional manoeuvre, it can manage to deploy satellites in multiple required locations.

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13 More information can be found https://spaceflightnow.com/2020/06/27/cluster-of-international-satellites-ready-for-ride-into-orbit-on-vega-rocket/
Advantages of using ION CubeSat carrier (D-orbit, n.d.)\textsuperscript{14}:

1. A soft launch environment guarantees a launch environment with reduced vibration and shock levels.
2. It guarantees an accessible access port during launch integration.
3. Each CubeSat is deployed independently given a command from the ground, with a personalised attitude, pointing, and impulse. Hence it makes the deployment of each satellite very precise.
4. It gives up to an 85\% faster CubeSat constellation, a stable collision-free formation.

The above options showed innovative development of equipment’s for payload accommodation or deployment payloads technique. Every design was developed, keeping in mind to utilise as much space in the launcher as possible. Also, they were designed with a focus on launching small satellites/constellations. Currently, the ESPA ring is highly used in every mission for secondary payload. However, the other technologies are under the experimental phase and can be in commercial use soon. The reason for the ESPA ring to be popular in use is that it can be reused. The ring remained attached to the launcher and brought back to the ground, making them available for another primary mission. The small satellite being carried as a secondary payload

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\textsuperscript{14} This is power point presentation prepared by d-orbit, which is accessible from the link and also from company website.
requires sufficient space and arrangement in the payload configuration. The previous payload arrangement, which is one above the other, takes much space and leaves much-unused space in the payload section. The new ways of development showed possible ways to arrange or deploy small satellites. The ring-like structures carrying a cluster of satellites together is the most efficient ways to make satellite reach orbit.

On the other hand, the ION CubeSat carrier is a very innovative idea that can be used solely for sending a cluster of small satellites. This carrier can be used as a small spacecraft to deploy small satellites at various altitudes/orbits. It can also be programmed so that it can be returned to the central station and brought back to the Earth after it deploys satellites. Using this equipment, many organizations can send together their satellites and share the launch price. It will, in return, reduce the launch cost for the individual group making the space accessible for even budget constraints firms.
Chapter 4: The trend in launching the satellite

A significant concern in the growing space sector is the low availability of launches for small satellites, which has been observed in the current launch vehicle chapter. The cost of small satellites has been driven down by miniaturizing equipment, using COTS products, and simplifying manufacturing processes. Any propellant rocket are having a high launch cost because the fuels are expensive materials, and propellant pumps are complicated designs. The choices for launching small satellites to LEO are narrow and distributed among air-launch platforms, rideshare, piggyback, or International Space Station. In every option, customers are required to compromise between launch costs, availability of launch window, or access to the desired orbit. The present options for launching a satellite carrier are significantly fewer which builds competition in the space market. Some of these options are strictly only used by countries' defence forces. For the commercial market, only few rockets are available but for particular missions.

4.1 Air launch

The aircraft carry satellites on top/bottom/towed or internally and launch them from a height. Ground lift-off takes a tremendous amount of fuel to overcome gravitational pull and atmospheric drag. The carrier is deployed around 20 km above sea level providing the initial velocity for the launch vehicle, it reduces the Δv required to reach the orbit. The best location to launch the carrier is from the equator in the east direction, as the Earth's rotation will accelerate the speed. Launching from a height reduces the atmospheric drag loss and the fuel could be saved for different operations in the mission (Alireza Forouzandeh Tabrizi, 2015). The carrier reaches orbit in a shorter time and will have enough fuel to perform orbital manoeuvres. The aircraft can be reused for another launch carrier.

The payload attachment can vary based on the design and requirement. It can either be on top of the aircraft like the design proposed by MBB Company and the German government (N Sarigul-Klijn, 2006). Many ideas were proposed throughout history for the air-launch method, but all the theories require advanced technologies. Those cannot be made using present technology. Three air launch vehicles in history were considered the most significant (Mitchell, 2012). In 1990,
Orbital Sciences Corporation developed the Pegasus launch vehicle which was carried on Lockheed L-1011 aircraft. It remains active to date and is capable of carrying a payload to LEO or Sun-synchronous orbit. It was the first air launcher which has placed the satellite in an orbit and completed 45 successful missions until September 2020 (Northrop Grumman, 2020, p. Appendix D). The second air launcher was an air-launch target built by Coleman Aerospace which showed a demonstration in 2004. The last was SpaceShipOne (SS1) (Harwood, 2004) developed by Mojave Aerospace Ventures and Scaled Composites, it was built for competition. It was carried under White-Knight aircraft, which is a jet aircraft. Other designs were in the conceptual phase and are not yet physically available\textsuperscript{15}. This concept also has some noticeable disadvantages:

- The launch vehicle and weight size will be a tight constraint because it depends on an aircraft carrier.
- Depending on the launch carrier's location, i.e., top/bottom/towed, it will influence launch cost.

The air launch can provide an immediate launch window or can even have a demand launch. Some other projects are in process, and some projects are abandoned.

4.2 Rideshare and cluster launch

Since the beginning, space launch vehicles have been deploying multiple payloads through ride-sharing method. A rideshare launch can be either be secondary or manifested ride. Commonly rideshare missions are multi-manifested launches, where a single launch vehicle carries several similar-sized payloads with the similar destinations. The missions are offered by launch service providers or are arranged by launch brokers who can reduce the launch cost for individual payload customers. The most commonly used launch vehicle for cluster or rideshare missions are Falcon 9 and PSLV, which could cost approximately $10k/kg (Nicholas Crisp, 2013). In comparison, Athena II c advertised their Ride Share cost to be $12.5 million per 110kg, which is approximately $110k/kg (Gregory Kehrl, 2012).

\textsuperscript{15} For more information on air launchers vehicle’s A Conceptual Analysis of Spacecraft Air Launch Methods by Rebecca A. Mitchell (Mitchell, 2012)
United Launch Alliance is one of the biggest private space firms that arrange launches for commercial payloads (Karuntzos, 2015). This company has a reputed history of providing launch services for various purposes. They have been providing successful launch services through Atlas and Delta family launch vehicles. Most of their services had been a secondary payload and a few of them as multi/dual manifest payload. All ELaNa programme missions are carried by Delta family spacecraft and whereas some commercial Nanosatellites missions are carried by Atlas family launch vehicles (ref. chapter 2 current launchers). Rideshare vehicles utilise maximum total payload capacity by distributing the total launch cost to various companies sharing the ride. For multiple payloads, the launch date is agreed upon the schedule for the primary payloads, which could cause delays for the secondary missions. The primary payload determined the orbital destination, which could result in a non-optimal altitude for the secondary payloads.

Rideshare is the best option for reducing the launch cost for commercial customers, instead of dedicating a single launcher for a single type of payload, which will be a hefty cost for commercial companies. Customers can choose to have a secondary or manifested ride to orbit, which will divide the total launch price. The dual manifestation of payload could influence significant savings. Satellite constellations are primarily launched using rideshare methods; the multiple satellites with similar purposes are transported and deployed at the designed orbit. Orbcomm on Pegasus XL, and RapidEye on Dnepr are some of the missions.

4.3 Piggyback launch

It is another kind of rideshare launch that utilises extra space and weight on a launch vehicle, and satellites are carried as a secondary payload. The primary mission influences the destination and launch date for the secondary payload. This influences payload such that it is either designed for the same particular orbit can have alternative features to operate at different orbital locations or can wait for other piggyback rides. However, it can provide small payloads to achieve orbit at notably lower expenses compared to a dedicated launch.

For Piggyback missions, primary payload deployment is never compromised over the secondary payloads requirements. There is a high risk for secondary payload as they may or may not get deployed as planned in an anomaly launch. (Nicholas Crisp, 2013) For example, Nicholas
Crisp reported in his research that on October 7th 2012, SpaceX launched a mission to the ISS in CRS-1 spacecraft. The perfect delivery of the primary payload by the Dragon capsule and the issue in the first stage engine were the reasons Secondary payload Orbcomm was not inserted into the designed orbit. Subsequently, Orbcomm satellites were destroyed upon re-entry. In the case of primary payloads being damaged by secondary payloads, the secondary payloads insurance needs to cover the damage caused to the primary payload. The insurance cost is prohibited only when the primary payload is of higher value than the secondary payload. This additional cost can be mitigated if a certified launch adapter is used for the primary and secondary payload.

As also mentioned in Nicholas Crisp report, the cost could range from $200k to $7M (Nicholas Crisp, 2013) for a piggyback ride of a 3U Nanosatellite shown in Table 3. The cost could go from thousands to as high as a million dollars for a Nanosatellite for some launch providers or brokers. The advertised costs are higher than the cost of the launch vehicles themselves.

Table 3: Launch price for rideshare and piggybacks ride.¹⁶¹⁷

<table>
<thead>
<tr>
<th>Launch Vehicles</th>
<th>Cost Per Kg (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athena 2c</td>
<td>$16,500</td>
</tr>
<tr>
<td>Delta II</td>
<td>$36,700</td>
</tr>
<tr>
<td>Dnepr</td>
<td>$9,000</td>
</tr>
<tr>
<td>H-2B</td>
<td>$10,000</td>
</tr>
<tr>
<td>Kosmos</td>
<td>$8,000</td>
</tr>
<tr>
<td>Pegasus XL</td>
<td>$45,100</td>
</tr>
<tr>
<td>Rockot</td>
<td>$21,000</td>
</tr>
<tr>
<td>Vega</td>
<td>$19,000</td>
</tr>
<tr>
<td>Falcon 9</td>
<td>$3,000</td>
</tr>
<tr>
<td>PSLV</td>
<td>$8,000</td>
</tr>
<tr>
<td>Lockheed Martin</td>
<td>$113,600</td>
</tr>
</tbody>
</table>

¹⁶ The launch cost prices has been retrieved from Orbitare launcher directory and cross checked by the director Mr. Luis Mnoz and an email (Mr. Rakesh S., 2020, personal contact on 1st May) confirming values are correct.

¹⁷ Some values refer to table 1 in current launcher chapter.
4.4 International Space Station

International Space Station uses a deployer-like device that sends out Nanosatellites. At present, ISS has two deployers: The Japanese Experiment Module (JEM) Small Satellite Orbital Deployer (J-SSOD) (Keith, 2012), and the NanoRacks CubeSat Deployer (NRCSD) (Messier, 2014). The very first kind of deployer ever built was J-SSOD, whereas NRCSD became the very first commercially operated deployer for small satellites. One method that will take NanoSats to orbit is by transporting payloads as cargo to the space stations. The NanoRacks CubeSat Deployer arranges Sat’s into such a position that it is grabbed by the ISS's robotic arms, as shown in Figure 16. They are then held into the NanoSats deployer and deployed into the correct position by externally mounting them onto the ISS. This enables the deployer arms to release satellites to the proper orbit.

![ISS robotic arm placing Nanosatellite in orbit. (Image provided from https://www.nasa.gov/mission_pages/station/research/benefits/cubesat/).](Image)

Payloads on their way to the orbit are simulated to a high vibration level, which is first tested on the ground level\(^\text{18}\). The test verifies if payload equipment can survive the vibrational phase of the launch. This test is crucial for the piggy ride launch of a small satellite because they are loaded in the same place as a primary satellite. When deploying satellites from the space station, they are first delivered to ISS by cargo spacecraft, where they are stored in a soft bag and buffered with packing material. The vibration experienced by primary cargo is less compared to piggyback satellites. The electrical components are quite expensive for students to be custom-built, so this test could be a help for not being extravagant budget.

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\(^{18}\) For more information’s : https://www.nasa.gov/mission_pages/station/research/benefits/cubesat
To ensure that the small satellites are in operational conditions before deploying into space, ISS astronauts aboard give a quick performance and quality check on the hardware systems. The disadvantage of small free-flying satellites is that they can be destroyed by flying space debris. The uncertain duration of the flight to ISS that has the electronic equipment survived or is in perfect working condition. There is uncertainty about whether the small satellite will be in working conditions after enduring the launch vibration. With this deployment method, there is still an opportunity to check out satellite systems and intervene before deploying. In 2009, USA commercial company Nano Racks provided ISS deployment services to Universities and commercial firms. The price was $30,000 - $60,000 to provide the full experimental logistics to the deployment (NASA, updated). The success of this mission made ISS launch very popular and demanding but at a heavy cost price. Ever since then, Nano Racks have provided many successful rides to many small satellite payloads. They have been using NRCS deployers and have launched thousands of governmental experiment missions. The experiment usually lasts for 30 days in space and then can be brought back to the ground. They also have another new deployer name KEBER Small Satellite Deployer, which can deploy 100Kg of payload (NanoRacks ISS Workshop, 2015). In 2017, Nano Racks successfully deployed NovaWurks SIMPL satellites with Keber Deployer from ISS\textsuperscript{19}.

\textsuperscript{19} For more information: https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/iss-simpl
Chapter 5: Non-rocket launch concepts

Historically many ideas were proposed about alternative launch methods. Some ideas required building gigantic structures and some uses partial aircraft. These ideas were all theoretically successful but were practically lacking the technology to transform into reality. One such concept that engineers came up with was the Spin launch, which proposes that momentum can be transferred between objects using the tethering concept in space. The research on different historical launch trends stumbles upon another innovative idea: to have a "Non-Rocket space launch." The concept behind this type of launch is that one needs speed and altitude which can be provided by something more powerful other than a rocket propulsion system. Such technologies do not yet exist in which launching a payload does not need any engine for thrust; the speed and altitude can be provided by other means. Some of such theories are skyhook, space elevator, loop launch, or air-launch system.

Space tether is a unique concept presented by a Russian scientist named Konstantin Tsiolkovsky around 1895, a science fiction writer who described space tethering theory in his novel (Yi Chen, 2012). The visualised concept was to build a sizeable pole-like structure, connecting with one end to the Earth's surface, and the other end will be at GEO orbit height. The momentum exchange concept is being used in this method, it uses two types of trade-in motion one is by rotating and another by non-rotating. Turning works on centrifugal acceleration, the acceleration motion is passed on to the object, and it experiences continuous acceleration motion. The released item then experiences loss of energy along with velocity and altitude. The system can re-boost itself, consuming very little fuel. (Yi Chen, 2012) NASA has used this method in past in some of its mission. Most of the missions were aborted at the last minute because of equipment malfunction.

![Figure 17: SpaceHook concept (image provided from https://medium.com/predict/skyhook-the-technology-that-could-challenge-spacex-3ed5fa84696f).](image)

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20 Regarding these mission more information can be read in Yi Chen report (Yi Chen, 2012)
Based on the space tether theory, a space hook, another type of tethering, is available to launch the spacecraft (Lockett, 2020). This theoretical concept has been explained, and many people have researched this theory. Most researchers and articles have proclaimed that this concept for launching payload would be very cheap and potentially can replace expensive rockets. This concept is based on tether momentum exchange, where a long cable is connected to an orbiting station. The payload is attached to the other end of the rope, which will be very light compared to the counterweight of the orbiting station, as shown in Figure 17, the payload is flung in the desired direction using the cable's rotation motion, obtaining the momentum into speed. A Russian team presented two types of skyhook method: rotating and non-rotating (Manzano, 2020). The cable attached to the orbiting station will be just as long as it reaches the upper atmosphere. This old concept had many problems, and the concept could be used for launching payload outside Earth. But when it comes to bringing it back to the ground, the cable's motion has to be reversed, for which first hypersonic speed needs to be reduced. Another difficulty is that the thread will rotate at the hypersonic, and the payload needs to match the exact rate to be attached. Also, continuous rotating and momentum exchange will lead to the loss of all the momentum at one point.

Another concept generated from the space tethering concept is the space elevator (Pearson, 1997). The conceptual design for this theory is much like an elevator. A long pole-like structure whose one end will be on Earth's surface, and another end would be beyond geostationary orbit. The earth’s end will be anchored at the equator. The pole is held between the counterbalance of gravity and centrifugal force; as shown in Figure 18, climbers on the cable/pole will be taking/bringing the payload to orbit. Elon Musk in his interview with BBC news denied this concept, and he thought having a long tube will be very impractical (Fleming, 2015). This concept has its pro and cons, and it will make use of less fuel while the structure in itself could be cumbersome. Also, the cable will be a problem with space debris, and any disaster to the cord could harm the surface. The structure maintenance cost would be very high and challenging for any person. One researcher has come up with the material plane for the cable as carbon nanotubes. In 2004, another researcher based on the space elevator's
primary concept came up with a lunar space elevator (Jerome Pearson, 2005)\textsuperscript{21}, the same as a space elevator. Still, the elevator cable is between the moon and Earth using Lagrangian points for the launch.

In 1982, Paul Birch proposed another Non-Rocket Payload launch concept, named the orbital ring (Birch, Orbital Ring Systems and Jacob's Ladders - III., 1983)\textsuperscript{22}. As shown in Figure 20 opposite ends on Earth, an elevator (fixed rope) is built on an equator in his theoretical model. The connected elevators form a big orbital rotating ring around the Earth's surface. A train-like structure moves using an electromagnet on these elevators, and attached to these elevators are stations. These stations can bring down or take the payload to the ring. The model is similar to the space elevator and launch loop model. According to Birch's cost estimation, building a space structure during the '80s was around $13 billion (Birch, Orbital ring system and Jacob ladder - II, 1983)\textsuperscript{23}. This was the price for just building a ladder of the orbital ring system. This system would take a payload to orbit in just $0.05, which is an unbelievable number. Many other theories were proposed based on the orbital ring concept, like space fountains and launch loops.

An American engineer named Keith Lofstrom discussed the launch loop model (Lofstrom, 2009)\textsuperscript{24}, along an elevated bridge-like structure is made, which will work as an acceleration track

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image1.png}
\caption{Launch Loop Model design (image provided from http://www.ngltnews.com/lofstrom-launch-loop/).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image2.png}
\caption{Paul Birch model for Orbital Ring concept.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image3.png}
\caption{Launch Track Model design (image provided from http://www.ngltnews.com/lofstrom-launch-loop/).}
\end{figure}

\textsuperscript{21} Space elevator has been discussed deeply in the reference (Jerome Pearson, 2005).
\textsuperscript{22} More information can be read in the journal published by British Interplanetary society (Birch, Orbital Ring Systems and Jacob's Ladders - III., 1983)
\textsuperscript{23} More information on cost estimation and breakdown of cost can be found on Paul Birch journal report series Orbital ring system and Jacob ladder –II (Birch, Orbital ring system and Jacob ladder - II, 1983)
\textsuperscript{24} More information can be read on the report by Keith Lofstrom (Lofstrom, 2009).
for the payload. As shown in Figure 19, the payload will apply a magnetic field to generate an eddy current and move the payload at a very high speed. Shooting the payload at the end into space and just before losing momentum with very little fuel consumption can ignite the propulsion system. Also, another concept name cable space accelerator uses minor modifications on the rail track. It creates a high elevated Planck, with high-speed spacecraft running on it gives a push. The spacecraft can leave the atmosphere with very little fuel consumption. Lofstrom points out many difficulties; one of the problems with the launch loop model is that the infrastructure will be pretty high. Failure of any part would cause a significant catastrophe to the human race in the area. Hence the launch loop rail needs to be built on the water so that no land will be harmed, which will be a challenge. Lofstrom addressed other difficulties in his paper, which pointed out that manufacturing and maintenance would be complicated for these structures.

Interestingly many papers in the past have proposed several new innovative ideas regarding Non-Rocket launches. The most discussed approach in history was tethering and orbital ring. In every proposal, a common observation is noticed that every model required a gigantic infrastructure. To launch a payload without fuel consumption, one needs to build a very high structure and achieve a hypersonic speed to escape the Earth's gravitational pull. These structures are pretty complicated and will involve a considerable amount of challenge to be built. Several other concepts and theories were described before, like space guns, space fountains, and ramjet accelerators. Still, all these concepts use the same view of either space tethering or launch loop. As mentioned earlier in the chapter, all these theories were just concepts and were not practically approached. A structure of 2000 km long and 80 km in height would make it impossible to build using present technologies. These ideas in practice require building structure, massive investment and technologies that are not yet developed. Every concept has proven to minimise the launch cost almost to zero, but having such a gigantic structure reaching across the atmospheric levels would be an impractical concept.
Chapter 6: Future launch vehicle

The problem emphasised in the previous chapters was the gap between launching a spacecraft and the availability of the launchers. This problem has deviated many investors in the past from their investments, so future investments will require addressing the gap between the payload launch opportunity and the existence of the launch vehicle for small satellites. The factors determining the profit in the launch vehicle market are efficiency, durability, and easy accessibility. A system's reliability is primarily a factor in all launch vehicles, especially throughout the early operation. Due to this factor, payloads are subjected to additional risk or have a high insurance cost associated with the launch. Every new launch vehicle needs to clear the test flights with a good analysis report. The test flight analysis reports are critical from a marketing perspective because these reports could fetch more investments and demand for the launch vehicle's manufacturing.

Launch vehicles made using the old technologies like PSLV and H-IIB gained popularity very fast, but the new launchers like Vector-R and Virgin Galactic even find it difficult to find a constant investor. Due to this reason, their manufacturing and testing have been delayed for quite some time in past\(^{25}\). From chapter 3.1, analysing the durability and affordability of the small launch vehicles, it should have been easy to fetch any investors but that has not been the case. The reason is that they all failed their first test flight, which revoked questions about their success. The problem with currently available launchers is that they are not available around the clock for the launch. All the launchers are nation oriented, which means that their priority missions are government-oriented. These launchers are very pricy for commercial usage and are not available around the clock for commercial missions. The lifespan of the existing launchers is significantly less, and their maintenance costs billions of dollars. It showcased that the availability of the vehicle for launch can significantly impact commercializing the space industry.

Another challenge for future launch vehicle manufacturers is the readiness or efficiency of the launch vehicle. Compromising in designing the launch vehicle will have a severe impact on its

\(^{25}\) More information about launch vehicle company, financial crises and stock market effect can be read in the following link from news article: https://spacenews.com/vector-replaces-ceo-amid-reports-of-financial-problems/ https://www.cnbc.com/2021/07/12/virgin-galactic-shares-rise-after-successful-branson-flight-paves-wave-for-space-tourism-industry.html
performance and price. However, the current trend of developing and manufacturing in a shorter period, specifically for small satellites, could bring better responses for launch capability and frequency for each launch. Developing in weeks rather than years would be a great asset for small satellite launchers. The manufacturing process will require flexibility, which will increase the demand in the launch market flexibility in the manufacturing process will also be required. The small satellite launch market and its predictive analysis are still very young and unknown from the market perspective.

Big companies like Boeing, Garvey Space, and Swiss Space Systems have announced their interest and investment in the small satellite launch market (Bennett, 2009)\textsuperscript{26}. There is no proper availability of information, and it is a very early stage of development that is not yet hatched into the practical world. The list in Table 4 shows new launchers and their estimated cost per Unit Launch, which shows pretty affordable numbers when sending a satellite constellation. The list in Table 3 shows the new launchers price but some information’s not available because of confidentiality or because the launcher has not completed its test phase. Their domestic commercialisation is still uncertain, so it is highly impossible to scale their globalisation. Many other launchers like Long March 6 and VLM-1 there information’s are currently unknown.

<table>
<thead>
<tr>
<th>Launch vehicle</th>
<th>Cost per kg [USD/kg]</th>
<th>Status(updated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DARPA ALASA Program</td>
<td>$1million/100pound\textsuperscript{27(1)}</td>
<td>Airborne Launch Assist Space Access. Development under halt.</td>
</tr>
<tr>
<td>Epsilon (Japan)</td>
<td>$32,500\textsuperscript{27(2)}</td>
<td>Successfully entered for commercial use.</td>
</tr>
<tr>
<td>Vector R</td>
<td>$25,000\textsuperscript{27(2)}</td>
<td>First launch in 2017 successful. Its future missions are to be announced.</td>
</tr>
</tbody>
</table>

\textsuperscript{26} There have been more articles published regarding interest in small satellite industry, can be found on https://www.globenewswire.com/news-release/2022/06/23/2467737/0/en/With-12-55-CAGR-Small-Satellite-Market-to-Reach-10-75-Billion-by-2028-Fortune-Business-Insights.html
\textsuperscript{27} 1. Retrieved from https://www.darpa.mil/program/airborne-launch-assist-space-access
3. An email (Mr. Rakesh s., 2020, personal contact on 1\textsuperscript{st} May) confirming the values.
4. Retrieved from space fund database (SpaceFund, 2022)
<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Cost</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSLC</td>
<td>$8,400&lt;sup&gt;27(3)&lt;/sup&gt;</td>
<td>India solid propellant planned. First test flight was partially failed.</td>
</tr>
<tr>
<td>VLM-1 (Brazil)</td>
<td>---</td>
<td>Solid propellant. Vertical launch. The first launch is planned for 2022.</td>
</tr>
<tr>
<td>Virgin Galactic LauncherOne</td>
<td>$4,032&lt;sup&gt;27(4)&lt;/sup&gt;</td>
<td>Air launch. The first launch planned for 2020, failed. Second launch was planned for 2020 October, delayed.</td>
</tr>
<tr>
<td>Falcon 9 (Chow, 2022)</td>
<td>$1,200/pound&lt;sup&gt;28&lt;/sup&gt;</td>
<td>Had a successful launch of Starlink satellite in 2020.</td>
</tr>
<tr>
<td>Long March 6 (China)</td>
<td>---</td>
<td>Kerosene/LOX propellant. Successful First launch in 2015. Commercially not Available. April 2021, launched nine small satellite</td>
</tr>
</tbody>
</table>

The most critical requirement in developing a launch vehicle is the deployment method and aerodynamic stability during ignition level. These two factors decide the final verification of the launch vehicle to be practically used in the market. Virgin Galactic launcher shows an excellent design because it is based on traditional technology and systems. Other minor contributors to the total launch cost are launch brokers’ fees, range and ground operation arrangements. This cost plays a vital role in ground lift-off, but air launching methods are still uncertain, and it uses young technologies'. So their cost is difficult to model from the existing launchers. The only known successful air launcher was Pegasus, but it showed a cost model opposite to the predicted theory. The cost model for Pegasus was much higher than the traditional launching method.

Elon Musk’s idea for developing a reusable launch vehicles has revolutionised the space market. The Falcon 9 rocket uses a two-stage LOX/RP-1 propellant capable of lifting over 13,000 kg to LEO. Its recent success in sending the crew to the ISS and cargo service has proven that Falcon 9 has long durability in the future. Of all the 19 launches to date, 17 have been entirely successful. However, falcon 9 has not been very active in carrying secondary payloads to orbit. During its second mission in 2010, it lifted eight CubeSat's and its primary Dragon payload. The mission successfully deployed the payload but the booster landing was a failure. The small satellites were taken to ISS for the deployment, but Falcon 9 has not deployed any small satellites directly into orbit. The government organisation, NASA’s Goddard space flight centre, developed a new design for the satellite, which is called a capsulation satellite (Joe Burt, 04-11 March 2017). It is a low-cost; three axes stabilised, and standardised spacecraft, based on a pressurised volume.

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<sup>28</sup> One pound = 0.45 kilogram
with active thermal control allowing ruggedized COTS commercial off the shelves hardware to be flown reliably in space. It takes new launch vehicle mass to orbit capabilities; is specifically designed for an ESPA Grande Ring. Capacity goes unused in large parts, which affects the cost. Typically from previous tables and chapters, the launch CubeSat's will still be near $1M/kg. With new technologies and alternative methods of launching a single CubeSat with over 300kg of mass might cost 20 times lesser, which means approximately $50K/kg.

This analysis for future spacecraft predicts how new ideas will affect and bring change to small satellite businesses. The price in the beginning is expected to be high because the new launch vehicles are single models in the market, which makes them little pricy and demanding in cost perspective. However, if such dedicated launch vehicles are produced in bulk, it will have impact on the launch cost. Two of the future launch vehicle Electron launcher by Rocket Lab and Firefly launcher has successfully entered into the commercial market. Even with their present advertised price, we cannot predict the future launch price because of fast changing economy and technology. Moreover, some are at testing phase and some have just entered the market. Therefore, it is too early to draw a conclusion on the impact these launchers will mark in the future.

Chapter 7: Launch service provider companies

Table 5 provides some companies and start-ups list that could help sending payload to space. It will give insight into companies and their price to get payload to the orbit.

<table>
<thead>
<tr>
<th>Company</th>
<th>Payload (kg)</th>
<th>Launch Price ($M)</th>
<th>Price/kg ($/kg)</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arianespace/Avio</td>
<td>20,000</td>
<td>170</td>
<td>8,500</td>
<td>Italy</td>
</tr>
<tr>
<td>Mitsubishi Heavy Industries</td>
<td>19,000</td>
<td>112.5</td>
<td>5,921</td>
<td>Japan</td>
</tr>
<tr>
<td>Northrop Grumman</td>
<td>8,000</td>
<td>80</td>
<td>10,000</td>
<td>USA</td>
</tr>
<tr>
<td>Rocket Lab</td>
<td>300</td>
<td>7</td>
<td>23,333</td>
<td>USA</td>
</tr>
<tr>
<td>SpaceX</td>
<td>63,800</td>
<td>90</td>
<td>1,411</td>
<td>USA</td>
</tr>
<tr>
<td>United Launch Alliance</td>
<td>17,800</td>
<td>99</td>
<td>5,562</td>
<td>USA</td>
</tr>
<tr>
<td>iSpace</td>
<td>300</td>
<td>5</td>
<td>16,667</td>
<td>China</td>
</tr>
<tr>
<td>Virgin Galactic/The Spaceship Company</td>
<td>372</td>
<td>1.5</td>
<td>4,032</td>
<td>USA</td>
</tr>
<tr>
<td>Virgin Orbit/VOX Space</td>
<td>500</td>
<td>12</td>
<td>24,000</td>
<td>USA</td>
</tr>
<tr>
<td>Firefly Aerospace</td>
<td>1300</td>
<td>15</td>
<td>11,000</td>
<td>USA</td>
</tr>
<tr>
<td>Relativity Space</td>
<td>1,250</td>
<td>10</td>
<td>8,000</td>
<td>USA</td>
</tr>
<tr>
<td>ABL Space Systems</td>
<td>1,350</td>
<td>12</td>
<td>8,889</td>
<td>USA</td>
</tr>
<tr>
<td>Astra Space</td>
<td>204</td>
<td>2.5</td>
<td>12,255</td>
<td>USA</td>
</tr>
<tr>
<td>One Space</td>
<td>200</td>
<td>3.2</td>
<td>16,000</td>
<td>China</td>
</tr>
<tr>
<td>Interstellar Technologies</td>
<td>100</td>
<td>0.440</td>
<td>4,400</td>
<td>Japan</td>
</tr>
<tr>
<td>Maritime Launch Services</td>
<td>5,000</td>
<td>45</td>
<td>9,000</td>
<td>Canada</td>
</tr>
<tr>
<td>Sykora</td>
<td>500</td>
<td>12.6</td>
<td>25,200</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Equatorial Space Systems</td>
<td>220</td>
<td>4.5</td>
<td>20,455</td>
<td>Singapore</td>
</tr>
<tr>
<td>Bellatrix Aerospace</td>
<td>150</td>
<td>2</td>
<td>13,333</td>
<td>India</td>
</tr>
</tbody>
</table>

30 It’s a live website which contains launch database for companies and has been last updated on 10th Feb 2022.
32 Updated information - https://www.cnbc.com/2022/10/03/firefly-aerospace-reaches-orbit-joining-spacex-rocket-lab-and-others.html#:~:text=Standing%20at%2095%20feet%20tall,of%20%2415%20million%20per%20launch.
Chapter 8: Conclusion and discussion

In recent years CubeSat's gained popularity, and this has happened because of small competitions organized for University students. Every year colleges around the world organize CubeSat challenges, and thousands of students participate with their ideas and models. Many small satellites are built across the world, but not every small satellite gets an opportunity to orbit in space. The biggest investors for CubeSat's are the commercial industry for various purposes, but even they hesitate to invest in this field. The hesitation is because of the significant risk involved like cost, lack of launch opportunity etc.

Most of the risks involved has been addressed in this research with a plausible solution. The risk and prices could be minimized by knowing the requirements for frequent launches. The use of solid propellant has significant risks of storage and weightage. This risk could be minimized by using Refined Petroleum and liquid oxygen. The impact of using refined petroleum and liquid oxygen as rocket fuel has been discussed in the chapter propellant. The chapter showcased new age launchers which are based on these new fuels. These new propellants are used in their upcoming missions by Vector R and Falcon 9 rockets. Using these alternative propellants will have a huge influence on the launch price factor. Predicting or concluding the future cost for new launch vehicles is very difficult at this early stage of their development and service. However, near future foresee the rise in competition for launching small satellites. The competition will demand more dedicated launch vehicles in near future for small satellites, which will reduce the launch price for companies. Cost analysis over current launchers have shown that sending one unit of a CubeSat in current available launchers would cost approximately $25,000 or even more.

The most common launch trends are sending satellite's to ISS and launching them. It takes double the time or can have rideshare with the primary mission. Various current methods for launching satellites were analyzed and observed in the chapter on trends in launch vehicles. Building a small launch vehicles dedicated to small satellite-range payloads will give more access to space. The price of upcoming small satellite launch vehicles is lower compared to the existing heavy spacecraft which has been discussed and shown in the chapter on future launch vehicle. The chapters in this report surfaced the difference between the current spacecraft and newly designed spacecraft. It also answered how the difference in design could influence the price for launch in
the near future. In past usage of ESPA rings for payload configuration have been proven very efficient in weight management. The ring gave more access to constellational satellites. Along with that using miniaturized thrusters on the small satellites will be a great feature. Using miniaturized thrusters on nanosatellites will easily alter the deployed orbit and bring the satellite to desired location.

Rockets like Vector – R and Virgin Galactic LauncherOne are designed to utilise new concepts of deployment and propellants. The most attractive development was Falcon 9, with its reusable and expandable technology. Its successful launch history makes it the centre of attraction for many commercial firms, but the USA has not opened its borders to outside Nation technology to be launched from its soil. This notion has been followed by Russia, China, Europe and other Nations as well. For the further study of this research, it would be a different perspective to observe how political and economic aspects affect the commercial launch cost.\(^{33}\) When commercializing space, there are other factors that comes into play like insurance, launch facilities and transportation of the launchers. These open ends are still to be covered, but this report will provide a different perspective for making space available for commercial companies, manufacturers and launch service consumers. The new technologies and theories have surfaced in this report, which will guide the companies for investments and give a market analysis for small satellites. It will also contribute to developing modernised versions of small satellites with its mini-thrusters and updated deployment technics.

This report also discussed non-rocket launch theories, which require big gigantic structures. The technology has not been developed to support such ideas, but there could be some expectations with the advancement of Artificial Intelligence. Tethering and elevator concepts require huge investments and new technologies, and analysing the future is difficult. However, as someone once said, "every great invention was first a small idea".

\(^{33}\) For more information on how economy affecting launch cost can be read from these sites:
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