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REUSABLE LAUNCH SYSTEM: THE GATEWAY TO THE FUTURE OF SPACE TRAVEL

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Abstract—*In the past, nearly every part of a rocket used to propel shuttles and satellites into orbit has been designed for one time usage. Generally, after the first stage rocket (which amounts to 70% of the total cost of a rocket) is used, the rocket falls back to the Earth's surface, burning up in the atmosphere and being destroyed. The reusable rocket is an attempt to resolve this dilemma. SpaceX, the leading company pursuing the technology of reusable rockets, has successfully developed rockets capable of multiple launches. Being able to reuse a rocket is a daunting task that requires multiple processes. The following processes have been used by SpaceX to land its relaunched rockets: stage separation, boost-back burn, supersonic retropropulsion burn, landing burn, touchdown and recovery. After landing, the rockets undergo an inspection and then are ready for relaunch. While this is still a relatively new technology and process, the benefits of reusable rockets are apparent: time, money, and materials are dramatically conserved. By conserving these valuable resources, reusable rockets prove to be a sustainable option for space exploration. This sustainable technology will facilitate greater space access, allowing a deeper understanding of the universe. There is much to be gained from increased space exploration including the obtainment of materials, the development of new technologies and possible colonization of other celestial bodies such as Mars*

Key Words—Elon Musk, Falcon 9, Falcon Heavy, Reusable Rockets, SpaceX

THE NEED FOR REUSABLE ROCKETS

With good reason, the human race has always been fascinated by space [1]. We long to seek out what space has to offer and what can be gained from traversing the universe. Space exploration leads to the development and use of new ideas, materials, and future possibilities. The knowledge gained through space exploration and research can be integrated into many industries and areas of study, leaving many experts agreeing that it is worth both the money and the risk [1].

In order to benefit from all space has to offer, one idea is key: we must first be able to get to space. Furthermore, we need to minimize the cost of entering and exiting the atmosphere while increasing the frequency at which launches can take place. Elon Musk's space transportation company, SpaceX, aims to satisfy both of these issues so that space exploration can be done more efficiently and quickly with the innovation of reusable rockets, specifically, the Falcon 9 rocket.

Figure 1 [2]
Space X's Falcon 9 Rocket

The key to this reusable launch system is the ability for the first stage rockets to land themselves at a target location. SpaceX's Falcon 9 rocket, pictured above in Figure 1 has been tested with a multitude of successful launch and landing attempts after engineers at Space X learned and developed new ideas through past failures. The successful landing process for Falcon 9 is achieved by following a series of intricate processes that allow the vessel to properly land itself on target. The chronological order of descent processes is: stage separation, boost-back burn, supersonic retropropulsion burn, landing burn, touchdown, and recovery. By following these steps, the Falcon 9 is able to be recovered and reused for future missions.

This new mode of space transport takes advantage of technology that enables the recovery and relaunch of the first stage rocket boosters. With only the costs of inspection and refueling, these rockets can save up to 70% of the total launch cost as compared to traditional, one-time-use rockets [3]. The benefits to using these rockets allow for a higher launch frequency and a dramatically reduced cost of money, resources, and energy This will allow the rate at which we can access and discover space to be dramatically accelerated.

A key aspect to this innovation is its sustainable nature. Sustainability can be thought of as a multi-pillar ideology that considers environmental, economic, and social concerns. "Creating and nurturing innovations that benefit the environment, positively impact the community and improve quality of life" is crucial for sustainable technological advancement [4]. The Falcon 9 rocket aims to satisfy all three pillars of this definition of sustainability. Environmentally, the Falcon 9 saves crucial materials for the construction of first stage rockets [3]. Economically, the Falcon 9 save millions of dollars in just a single rocket launch compared to traditional rockets [3]. When looking at the societal impact, this technology allows for increased space access. This will result in having a better understanding of our universe and for a more secure and prosperous future for the human race [5].

There are many benefits to be gained through increased space exploration. One of these benefits includes the multitude of resources waiting to be discovered and utilized. For example, the moon is rich in helium-3 which is a rare isotope found on Earth but can be used for nuclear fusion research [1]. In addition to materials, increased access to space can provide us with a better understanding of the workings of the universe. With that, we will have a better chance for solving currently unknown questions regarding how the universe and its components function. Given that the universe is infinite, it means that there can literally no end to space exploration.

Perhaps the most significant reason for space exploration is to rescue life on Earth from extinction. Many scientists, including Stephen Hawking [5], agree that at some point the Earth will not be able to support human life. Even if there are no asteroid collisions or life-ending nuclear wars, it is only a matter of time before Earth becomes uninhabitable due to our expanding sun and limited natural resources. We have a very limited future as a species if we do not become multi-planetary. It truly is a race against time to develop the technologies that will allow for the colonization of other celestial bodies.

All of the benefits of more space travel and exploration can be achieved through the use of reusable rockets which allow for cheaper, more frequent, and more sustainable access to space.

HOW TRADITIONAL ROCKETS ARE USED

Since the dawn of space travel with the launch of the Soviet satellite, Sputnik 1 in 1954, payloads have only been able to overcome gravity and break away from the Earth's atmosphere through the use of multi-stage rockets. "Multi-staged" means that a rocket is separated into sections (usually a primary and secondary stage and the payload), that detach after using up their fuel. The first stage, for instance, is the largest stage and provides the initial and largest thrust to get the rocket moving skyward from launch. As P. Timm, in the article "Stages of a Rocket Launch" explains, once the rocket has reached a specific height, generally somewhere between 40 and 80 miles above the surface, the first stage runs out of fuel and is jettisoned from the rest of the rocket which continues soaring upward under the power of the second stage engines. After separation, the first stage falls back down to Earth [6]. The concept of multistage rockets was separately worked on simultaneously in the early 20th century by three scientists, American Robert Goddard, German Hermann Oberth, and Russian Konstantin Tsoilkovski [7]. Engineers designed rockets with multiple stages so that when the fuel on one stage is depleted, that rocket can detach itself to prevent the rest of the rocket from having to waste energy carrying unnecessary weight [6]. This process is very efficient as it greatly conserves fuel, which saves both resources and money.

Despite the success and practicality of using multistage rockets, there is one very critical issue to this practice regarding what happens to the first stage after it separates. Traditionally, first stage rockets are designed to either burn up upon entry to the Earth's atmosphere or plummet into the ocean at thousands of miles an hour [8]. Either way, the rocket is rendered useless, never to fly again. This creates a serious problem because, as reported by distinguished international business magazine, *Fortune*, "the first stage of any space rocket is far and away the most expensive piece of the space launch enterprise, containing the bulk of the rocket's engines" [9]. On average, of the estimated $100 to $150 million required to build a rocket and launch it, around $60 million (if not, more) of that price goes to building the first stage as reported by Loren Grush of the technology news site, *The Verge* [3]. Having to continually rebuild first stages accounts for anywhere between 40%-70% of the entire launch process alone [3]. Additionally, having to rebuild these rockets means a huge cost to time and resource. According to NASA, a first stage rocket requires hundreds of thousands of pounds of aluminum and titanium and potentially several years to build [10].

These setbacks illustrate the non-sustainable economic and environmental issues that traditional rockets have by constantly needing to be rebuilt. Due to the costs of money, time, and resources, launching rockets has become a very limited practice leading to repressed space exploration which proves them to also not be socially beneficial. This is a very unfortunate case because there's still so much to learn about and gain from space exploration. However, due to recent innovations from space travel companies such as SpaceX, rocket travel will become much more practical. This is thanks to the development of reusable rockets.

THE PROCESS OF LANDING FALCON 9 ROCKETS

Although several companies have made advances in the development of relaunchable rockets, SpaceX, under the leadership of CEO Elon Musk, is regarded as the most successful company in perfecting this technology [9]. On December 22, 2015, the SpaceX rocket Falcon 9 became the first rocket to recover its first stage after launching a payload into space. On April 8, 2016, SpaceX launched another Falcon 9 rocket which successfully landed its first stage on a drone ship located off the coast of Florida. That same rocket was again launched and landed on March 30, 2017, marking it the first launch of a reused first stage rocket [11].

Through years of testing and continuous development, SpaceX has been able to perfect the technique of landing their Falcon 9 rockets. However, it isn't just a simple matter of slowing the rocket down before it hits the surface in order to salvage the first stage. All Falcon 9 rockets go through a complex procedure in order to properly land. This intricate procedure is made up of the following individual processes: stage separation, boost-back burn, supersonic retropropulsion burn, landing burn, touchdown, and recovery.

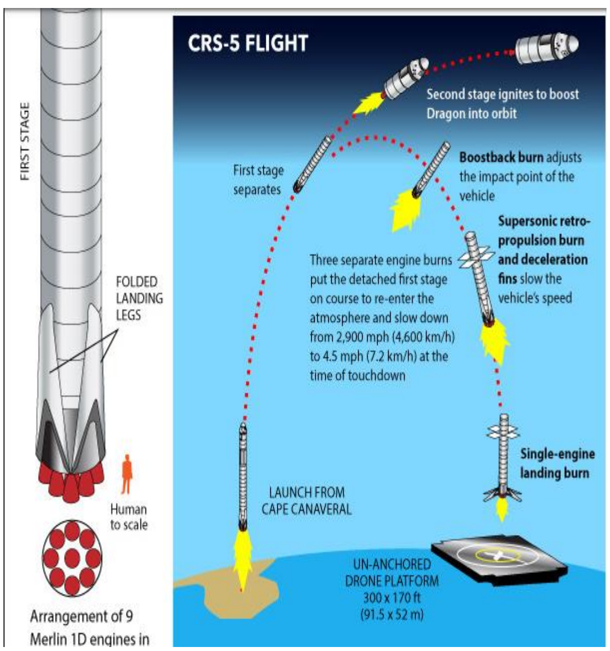

Figure 2 [12]
The Falcon 9's Controlled Landing

The above infographic shows the path and steps the Falcon 9 rocket takes in its flight which details the controlled landing of the first stage [12]. The listed processes are implemented in order to slow the rocket's descent to a near halt before landing,

position it above its landing pad, orient it vertically and secure a soft yet secure landing to allow the rocket to be recovered and use again later. Each step is its own intricate process that requires its own special equipment and technology.

Launch and Stage Separation

From launch until the first stage separation, Falcon 9 rockets launch the same as any other rocket would. SpaceX reports that it launches its rockets from one of its three launch pads in Cape Canaveral, Vandenberg or at the Kennedy Space Center [13]. The Falcon 9 rocket measures 230 feet tall and weighs 1.2 million pounds before fuel is added. At launch, nine Merlin engines arranged around the base of the vessel in an octaweb formation, ignite to provide 1.7 million pounds of thrust upon lift-off at sea level. These rockets burn for 162 seconds, getting the rocket an altitude of about 50 miles reaching a velocity of up to 5,369 mph. At this point, the engines are gradually throttled to limit the launch vehicle's acceleration as the rocket's mass decreases with the burning of fuel [11]. Finally, once it has used up a certain amount of fuel, the first stage separates, leaving the payload to continue its journey under the power of the second stage.

The first stage, according to *Popular Mechanics'* author, Joe Pappalardo, then continues to coast upward for several miles before beginning to descend [14]. At this point, the first stage of a traditional rocket would just free fall to the ocean getting destroyed or rendered unusable again in the process. However, for the Falcon 9, at this point the boost-back burn stage commences, beginning the first step of the landing process.

Boost-Back Burn

As the Falcon 9 begins its first stage of descent, three of the nine Merlin engines at the base of the rocket reignite. These engines, shown below in figure 3, are developed and manufactured in-house by SpaceX and are designed for high reliability and low cost.

Figure 3 [15]
Merlin Engines Used on a Falcon 9 Rocket

The propellant is fed from the fuel tanks to the engine through a dual impeller turbopump. This pump is also responsible for carrying kerosene to the hydraulic thrust vector control steering system. The kerosene acts as the hydraulic fluid and is used to affect the pitch and yaw (terms used to describe the orientation) of the first stage. Additionally, the kerosene propellant is used as coolant as it flows through hundreds of channels and tubes to, as described by SpaceX's Space Exploration Technologies head Brian Bjelde, "provide cooling to the hot wall before being injected into the thruster chamber for combustion" [15]. This system provides increased performance and efficiency. The fuel is stored in tanks made of an aluminum-lithium alloy; these tanks are both lighter and stiffer than traditional aluminum tanks and are pressurized to withstand the maximum flight loads. The collective power these engines can provide for the rocket is so great that any two of the engines could shut down, and the rocket would still be able to complete its mission.

During the first stage of descent, as the three engines reignite, a guidance control software inside the rocket gimbals (orients) the engines to aim the rocket towards its landing destination (either an onshore landing pad or an offshore drone ship). SpaceX's Falcon 9 user guide states that the orientation of the engines can rotate the rocket between 120 and 180 degrees in order to position the vessel above its landing target [14] [16]. At this point, the rocket is travelling downward over its target at 3,000 miles per hour and is gaining speed. Next, the supersonic retropropulsion burn begins.

Supersonic Retropropulsion Burn

As the first stage of the rocket begins to fall downwards towards its landing pad, it commences its next stage known as the supersonic retropropulsion burn. The main goal of this stage is to get the rocket oriented into a vertical position and to slow down its descent dramatically. Joe Pappalardo describes that during this process, the center Merlin engines reignite, delivering 205,500 pounds of thrust to slow the falling vessel from 3,000 miles per hour downward to about 560 miles per hour [14]. This engine also works with cold-gas thrusters located at the top of the stage to gimbal the rocket into a vertical position [10]. The rocket needs to be oriented in exactly the right position to have a soft touchdown on its landing pad so that it can be used again.

As an additional measure to help decelerate and stabilize the rocket, the Falcon 9 first stage is equipped with four hypersonic grid fins located near the top of the cylinder. These four foot by five foot titanium (as opposed to traditional aluminum which is less durable and flimsier than titanium) fins are placed in an X-wing formation to allow the fins to withstand the extreme heat experienced during the descent [17]. Despite the small size of these fins, they are able to independently move, allowing them to roll, pitch, and yaw the 14-story stage up to 20 degrees in order to achieve a precision landing according to SpaceX's webpage dedicated to the specifications of the grid fins used on Falcon 9 rockets [17]. Now that the rocket is successfully positioned over the landing pad and is oriented vertically, it is able to continue slowing itself down to a near halt as it enters the last stage before making a triumphant landing.

Landing Burn

A few moments away from touchdown, the last stage of the Falcon 9 descent, known as the landing burn, is underway. In this stage, the engines reignite for one last burn to bring to rocket to a near halt at five miles per hour. At this time, no more than 20 seconds before touchdown, the rocket's landing legs deploy to secure and stabilize the landing [14]. Each rocket is equipped with four of these legs placed symmetrically around the base of the stage that are stowed along the side of the vessel and extend when it is time for landing. The legs, made of state-of-the-art carbon fiber with aluminum honeycomb, unfold by using compressed helium as described by SpaceX's webpage about the Falcon 9 landing legs [18]. Now that the rocket has achieved the amazing feat of positioning itself precisely over its landing pad and has slowed itself down from over 3,000 miles per hours to a near stop within about five and a half minutes, the Falcon 9 rocket is ready to land.

Landing and Recovery

The rocket stage lands on its landing legs on either an onshore landing pad or on a pad located on a drone ship located a few hundred miles off the coast of Florida. For a rocket landing on the drone ship, technicians arrive from a different ship that was located several miles away. They board the drone and secure the rocket with metal shoes to make sure the rocket is stabilized as it is carried back to shore. After landing, any leftover gases are vented from the rocket, which is then taken away to be processed, cleaned, and reused [14]. The entire process of launching and landing the rocket takes only about nine minutes total. The picture below shows the first stage rocket on its drone immediately after securing a successful landing [14].

Figure 4 [14]
Falcon 9 Rocket on Its Landing Pad After a Successful Landing

Ideally, the rocket will have such a secure and stable landing that it will be ready for another launch immediately after being refueled. However, according to *MIT Technology Review* author Will Knight, during the rocket's flight, it is exposed to extreme temperature fluctuations, pressure changes, and vibrations [19] which can cause damage to the aluminum-lithium alloy walls of the rocket, the engines, tanks or grid fins. The damage caused is usually enough to call for the rockets to be refurbished before they're able to be reused later on. Once the rocket is repaired, vigorously inspected, and has met the standards needed for another launch, SpaceX is able to send the first stage on another mission. The hope is that, according to SpaceX CEO Elon Musk, nearly every part of the Falcon 9 rocket should be able to be reused up to one hundred times with certain parts such as heat shields needing to be replaced after about ten uses [9]. Because the Space X engineers follow these intricate procedures in order to attain a successful landing, the Falcon 9 rockets will be able to be reused time and time again, dramatically cutting costs. This is a revolutionary practice for space travel that proves to be economically and environmentally sustainable and will forever change the world's exploration of the universe.

THE FALCON HEAVY LAUNCH

The most recent launch of a SpaceX reusable rocket occurred on February 6, 2018 with the debut of the Falcon Heavy rocket. This rocket, as calculated by SpaceX on the company's webpage, is "the most powerful operational rocket in the world," [20]. This rocket is more than two times as powerful as the second most powerful rocket in use (the Space Shuttle).

This rocket has a first stage consisting of three Falcon 9 rockets connected in a row as depicted in Figure 5 below [20]. With its collective 27 engines, it provides over five million pounds of thrust at liftoff. At a cost of $90 million, this massive vessel stands at 230 feet tall and 40 feet wide, weighs 3.1 million pounds and can carry a payload of over 140,000 pounds to low Earth orbit [20]. Because the first stage is just made of three Falcon 9 rockets, it features all the properties of ordinary Falcon 9 rockets including the ability to withstand up to six total engine failures, an octaweb engine layout for each of the three bases and, of course, the ability to land in order to be reused [20].

Figure 5 [19]
SpaceX's Falcon Heavy Rocket

For the historic maiden voyage of the Falcon Heavy, SpaceX decided to send Elon Musk's very own Tesla Roadster into space as the payload to orbit the sun with a dummy aptly named "Starman" behind the wheel. This voyage was accomplished through the technology of Falcon 9 rockets providing the thrust for the first stage. At liftoff, all three Falcon 9 rockets that make up the first stage ignited and boosted the rocket at full thrust. Shortly after liftoff, the center core engine throttled down, allowing the two other side rockets to carry the vessel upwards. Once the rocket reached an altitude of about 40 miles, the side cores throttled down and separated to land themselves back to the surface. The center core continued to an altitude of nearly sixty miles before it separated from the second stage that continued to carry the payload, the Tesla, into space [20]. For the maiden voyage, in addition to successfully launching the payload into space, both side rockets achieved successful, simultaneous landings on their respective landing pads at Cape Canaveral, Florida making reusability a reality for the world's most powerful rocket.

FAILURES AND SETBACKS

When working with technology as expensive as rockets, failures are obviously something to try to avoid at all costs. However, when they happen, it's important to use them as learning opportunities, taking measures to avoid the cause of failure in a next attempt. Luckily for SpaceX, the technology of launching rockets has been continuously worked on and improved upon through numerous launches by several companies since the 1960s. That is why, as of March of this year, the company has had a 96% success rate for its 49 Falcon 9 launches as reported by its launch manifest [13]. There have only been two failed SpaceX launches, as reported by the technology news website Recode. One occurred in June 2015 when the second stage disintegrated from a helium tank failure. The other occurred in September 2017 when the rocket exploded on the launchpad while fueling [21]. SpaceX has since learned from these failures and has enforced precautions in fueling and reinsuring the tanks to keep these outcomes from happening again.

However, for Falcon 9 rockets, their ability to land is what sets them apart from all other rockets. Since this practice is still new, SpaceX is pioneering the technology needed for successful landings. That being said, SpaceX has unfortunately seen a fair share of failures when it comes to rocket landings. It took six failed attempts for a Falcon 9 to successfully land on its landing pad in December 2015. However, since then, there have been only three landing failures and one partial failure (the center core of the Falcon Heavy crashed while the two side cores landed successfully) as opposed to 20 successes [22] according to *Popular Mechanics* author, Jay Bennett. The center core of the Falcon Heavy was unable to land due to engine failure causing the rocket to miss its drone by about 328 feet, hitting the water at 300 miles per hour. According to Elon Musk, the problem was that there was “not enough ignition fluid to light the outer two engines after several three engine relights... [the] fix is pretty obvious” [23]. So even though there were some failures in landing rockets at first, SpaceX was able to learn from these mistakes and improve upon the technology and coordination of the Falcon 9 rockets to achieve a much higher success rate which is particularly good considering that SpaceX has nearly 50 future missions already in the works.

BENEFITS OF REUSABLE ROCKETS

The goal of the reusable rocket is to make space more accessible by drastically lowering monetary costs while also saving time, resources, and increasing launch frequency, making the technology sustainable. The average traditional rocket costs upwards of $150 million for the entire production and launch process. Anywhere between 40%-70% of this cost is used directly to produce the first stage rocket booster [3]. After the Falcon 9’s first stage rocket successfully lands, it will require inspection and refurbishment before another launch. These costs could reach as much as $500,000. However, this price is miniscule when compared with the cost of rebuilding a new first stage engine from scratch which can easily amount to $60 million [3]. With this dramatic cost reduction, the Falcon 9’s cost of launch is only a mere $6 to 8 million which proves that this is an economically sustainable technology [8].

In addition to reusable rockets saving time from not having to be rebuilt, they also save material resources. Building a first stage rocket, according to NASA, requires hundreds of thousands of pounds of aluminum and titanium [10]. These resources are limited and costly and often not found freely in nature. For instance, titanium, used for its high strength to weight ratio, costs about $3000 dollars per pound [24] which adds up quickly when building an entire 14-story tall rocket. The benefit of reusable rocket technology is that these nonrenewable resources aren’t required for each successive launch; the rocket can just be used again with minor adjustments. Since Elon Musk predicts that these rockets will be reusable up to 100 times [10], reusable rockets can save billions in a relatively short time span. By conserving natural resources, reusable rockets attest to being environmentally sustainable.

The benefits of the reusable rockets are abundant and can be seen in aspects beyond just monetary costs. By eliminating the need to continuously rebuild first stages, this allows SpaceX to cut back on the costs of time, energy, and resources as well. Simple rockets that only fly to suborbital levels, as reported by the Smithsonian Museum of Air and Space, can take up to 18 months to build, while more complex rockets, like the space shuttle, require up to five whole years to produce [25]. The time intensive act of producing traditional rockets has been one of the outstanding restrictions on space access. SpaceX provides the solution to this problem through the Falcon 9 as the time taken to refurbish a landed first stage rocket, according to the company, is only a matter of one to two weeks [11].

With monetary, material, and time costs of space travel substantially reduced due to the implementation of reusable rockets, the frequency of launches will increase. An increased rate of space travel at a significant cost reduction means more possibilities for exploration, discovery, and multiplanetary human colonization in the future which makes reusable rockets socially sustainable.

WHAT REUSABLE ROCKETS MEAN FOR THE FUTURE

Taking advantage of reusable rocket technology will lead to great opportunities in the very near future for space exploration. With the ability to increase launch frequency, more can be done in space on a larger scale. The progress that will be made from increased space travel shows that reusable rockets are socially sustainable. This sustainability is shown in the form of increasing knowledge about the universe, improving the quality of life using new technology and allowing for eventually multi-planetary colonization.

One such advancement that is made possible due to this increased launch frequency is the increased placement of satellites. These satellites, both around Earth and those traversing deeper space, are major components in the communication and broadcasting fields. They provide signals for televisions, beaming for phone calls around the world and navigation through GPS. They can also be used in surveillance, as well as for detecting potential Earth-asteroid collisions. Satellites, according to NASA can receive, interpret, and send out information nearly instantaneously and are an essential part of present-day life [26]. The ability to place many satellites cheaply into orbit allows for the implementation of new technologies that weren't possible prior to the reusable rocket. For example, SpaceX has revealed that the company is currently taking on the project of sending over 10,000 tiny satellites into orbit that will provide "broadband services directly to [people] anywhere in the United States or around the world" at speeds similar to the quickest ground-based internet connections [27]. This benefits the billions of people in the world who are still without the internet. More information and the ability to communicate without bounds will be provided to everyone by allowing internet usage across the world using these satellites [27]. This is an example of the societal benefit made possible by this sustainability of this technology.

Another impact reusable rockets can have on the future is the ability to obtain materials from other celestial bodies. For example, helium-3 which is a rare isotope found on Earth used for nuclear fusion research, is found in high quantities on the moon [1]. By utilizing materials like helium-3, the possibilities of producing long-term, efficient energy by way of nuclear power become more realistic. This paves the way for more environmentally safe and sustainable sources of power.

Looking into the future of reusable rocket technology, SpaceX is pursuing a mass transport rocket called the BFR that can hold 240 passengers. This vehicle aims to facilitate ultra-fast travel between major international cities. According to SpaceX's webpage dedicated to the capabilities of the BFR, the flight time to any point on Earth will take approximately 30 minutes. For example, the flight time from New York to LA is 25 minutes using the BFR [28]. While this is still a developing idea, this technology could connect the world like never before all while being able to efficiently reuse the rocket's major components. This idea is a great display of the reusable rockets' sustainable economic, environment, and social qualities.

Arguably, the most important reason for developing the technology that facilitates increased space travel frequency is to prevent the extinction of the human race. World renowned physicist Stephen Hawking makes the claim that eventually the Earth will no longer be able to support the ever-growing human race. Sooner or later, there will no longer be enough resources or space on Earth to meet the demands of human life. Unless humans become multiplanetary, there is most certainly a finite amount of time before we face the threat of extinction [5]. With this limited time line in mind, Elon Musk and his company SpaceX already have a plan in mind. By using the BFR rocket, which can carry a load of 100 passengers for long space voyages, Musk plans that by the 2020s, humans will be able to walk on Mars [29]. From that, it's only a matter of time, Musk reports, before human colonization of the Red Planet commences through the use of reusable rockets, effectively sustaining human life.

SPACE TRAVEL WILL BE FOREVER CHANGED

Advances in space travel have been pursued ever since the launch of Sputnik 1 in 1945. Over the course of the 20th and 21st century, we have been able to launch satellites that have granted us a deeper understanding of the universe around us. As time and our knowledge of physics and space technology advanced, we then sent people into space and eventually to the moon. Even though tremendous progress has been made in space travel, the same restrictions of high cost and low launch frequency due to the non-reusability nature of traditional rockets remained. Within the past decade, SpaceX has been the leading space travel company attempting to overcome these restrictions by developing reusable first stage rocket boosters with the development of the Falcon 9 rocket. This is all made possible through the use of the rockets' intricate landing procedure, allowing the first stage to be refueled and reused readily. This cutting-edge technology dramatically saves money, materials and time when it comes to launching rockets. Due to these reduced costs, reusable rockets attest to the definition of sustainability by benefitting the environment, the economy and, society. These reduced costs facilitate the increase of launch frequencies which leads to opportunities not possible with traditional rockets.

The opportunities presented through this technology include: the discovery and obtainment of useful materials, the ability to launch satellites into space cheaply and quickly, and the eventual colonization of other celestial bodies, specifically Mars. Given what they have to offer and what possibilities they hold, reusable rockets will play a crucial role not only in the future of space travel but also the future of humanity.

"You want to wake up in the morning and think the future is going to be great - and that's what being a spacefaring civilization is all about. It's about believing in the future and thinking that the future will be better than the past. And I can't think of anything more exciting than going out there and being among the stars."

— Elon Musk, CEO and Lead Designer, SpaceX [28].

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