Space and Society

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The Space and Society series explores a broad range of topics in astronomy and the space sciences from the perspectives of the social sciences, humanities, and the arts. As humankind gains an increasingly sophisticated understanding of the structure and evolution of the universe, critical issues arise about the societal implications of this new knowledge. Similarly, as we conduct ever more ambitious missions into space, questions arise about the meaning and significance of our exploration of the solar system and beyond. These and related issues are addressed in books published in this series. Our authors and contributors include scholars from disciplines including but not limited to anthropology, architecture, art, environmental studies, ethics, history, law, literature, philosophy, psychology, religious studies, and sociology. To foster a constructive dialogue between these researchers and the scientists and engineers who seek to understand and explore humankind’s cosmic context, the Space and Society series publishes work that is relevant to those engaged in astronomy and the space sciences, while also being of interest to scholars from the author’s primary discipline. For example, a book on the anthropology of space exploration in this series benefits individuals and organizations responsible for space missions, while also providing insights of interest to anthropologists. The monographs and edited volumes in the series are academic works that target interdisciplinary professional or scholarly audiences. Space enthusiasts with basic background knowledge will also find works accessible to them.

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Scott Madry
University of North Carolina
Chapel Hill, NC, USA
Only if what I tell you appears absolutely unbelievable, have we any chance of visualizing the future as it will really happen.

—Arthur C. Clarke
This book is dedicated to the first person to walk on the surface of Mars, who is most certainly alive today. Whoever and wherever you are, you have no idea today what amazing things the future will bring to you. But remember when you look back at Earth on that singular day that you stand on the shoulders of giants.
The world of space is abuzz these days with phrases such as “Space 2.0” and “NewSpace.” The hot topic of the day is how this type of innovative thinking and the disruptive technologies that come out of Silicon Valley are transforming the world of commercial aerospace. Undoubtedly, change is in the air, and disruptive innovations are driving this transformation at an ever-faster rate.

Professor Scott Madry has finally produced a landmark book that sets the change that is now occurring into a much broader historical, economic, cultural, technological, and political context. His first mission is to explain how the change and innovation that come in a dynamic society such as ours seem to almost explode with new ways of doing things. There is a constant drive to do everything more efficiently and more economically and with heightened productivity. Unfortunately, there is much less care about doing things more sustainably and more environmentally friendly.

For hundreds of thousands of years, humanity lived as hunter-gatherers, but then, seeds that could produce plants with a profusion of seeds allowed the invention of agriculture, farming, towns, and settlements and the specialization of skills, talents, and processes that led to ever more invention. This led to the Industrial Revolution, the postindustrial society, and the unfettered information networking. Technical, social, legal, political, and military innovation abounded. Urbanization and innovation changed our world forever.

On the one hand, our prosperity, health, technology, physical stature, legal and civic systems, and systematic settlement of the world grew and grew. This expansion, however, led to new problems such as mechanized wars, pollution, and overpopulation of the regions of the world. These have led to new inventions to cope with these issues, such as peace treaties, nuclear disarmament pacts, environmental protection agencies, birth control systems, and more.

In fact, innovation, new technology, and new and more systematic ways to cope with societal and economic productivity have been with us for several thousands of years. Professor Madry has cataloged for us some of the ways that innovations have transformed society and modern ways of living. He has especially highlighted totally new ways to think about space, satellites, launch vehicles, space applications, and services and how commercial space technologies can transform our world.
Perhaps, his most important message is to not think about what has been happen-
ing in the world of commercial space in too narrow of a context. He suggests to us
that the changing world of commercial space is not just about highly efficient
CubeSats, new types of ground systems with electronic tracking, or reusable launch
vehicles. He explains that these important innovations are simply a means to an end
and how space has been democratized so that many more people, especially in
developing countries, can now use space systems, at much lower costs, to provide
amazing new services in communications, networking, governmental services, agri-
culture, forestry, fishing, mining, education, health care, transportation, law enforce-
ment, and so on across all sectors of the economy and across the broad reach of the
planet. Developed and developing economies can benefit from small satellites and
reusable launch vehicles. Remote-sensing CubeSats can be used to prevent crimes
against humanity and drug smuggling, illegal fishing, or acts of pollution.

This book explains the process of innovation and the meaning of disruptive tech-
nologies and the “NewSpace” revolution in a rich historical and cultural sense. It
also explains how technological innovation leads to new services and applications
and new social and political issues and problems and the need for new legal and
regulatory reform. Some believe that you cannot have too much of a good thing. But
in most contexts, an excess of almost anything can lead to serious problems. The
rush to exploit low-cost space systems with small satellites is indeed giving rise to
concerns about orbital space debris and equitable access to space by those who have
just entered the world of commercial space.

The clear exposition and broad social, political, regulatory, and economic narra-
tive that Professor Madry provides in this book is impressive. He has provided us
with a very clear explanation of the important subject of disruptive technologies and
how this has changed industry after industry over time. He has explained how
“Space 2.0” systems, including new launch vehicles and user terminals on the
ground, are changing our world. “NewSpace,” via a plethora of disruptive new tech-
nologies, systems, and services, is offering new opportunities.

This book is a very useful read for anyone interested in space and the rapid
changes that are happening in this amazingly innovative field. Currently, the United
Nations has agreed on 17 difficult and demanding “Sustainable Development
Goals” for our small six sextillion ton planets. These goals seek to take on issues
such as hunger, pollution, improved standards of living, social equity, and fairness
to all people of types, genders, and cultures. The many innovations that have come
from the current revolution in space technologies to make them less costly, more
affordable, more widely available, and easier to use can help accomplish these
demanding goals. Dr. Madry’s list of the top ten things to know about the changes
that NewSpace systems are bringing to the world is well worth knowing. His very
personal narrative is a true delight. Read on.

Dean Emeritus, International Space University
April 3, 2019
Preface

“Any sufficiently advanced technology is indistinguishable from magic.”
–Clarke’s Third Law

This book grew out of a series of academic research, public lectures, and discussions that I took part in over the years from 2010 to 2018 at various places around the world. These included several programs at the Singularity University, at the NASA Ames Research Center, and at the International Space University while I was managing their summer programs in Adelaide, Australia, and teaching in various academic programs around the world, including the University of South Africa’s Space Lab in beautiful Cape Town and several Space Generation Forums and International Astronautical Congresses around the planet.

Like all works, it has many different beginnings and influences but was mostly driven by the amazing changes that I have observed and played a very small part in, which can be called “NewSpace,” and the extraordinary changes in the space world from that of large, government agencies and international aerospace corporations to the wild new Silicon Valley private sector revolution. It is a very interesting time to be involved in the space sector.

I became fascinated with the idea that a single person or small group of people or a single idea or technological development could have such tremendous impacts on markets, societies, and individuals. I wondered how this occurs, and also wondered how many times it has happened, and what motivates, enables, or inhibits this amazing process of radical technological innovation. Why does it occur in one place and time and not another? Can it be fostered and managed, planted, and watered like a garden seed on demand? Or does it simply “happen” unannounced and, like the wind, disappear in its own time? I also began to think of the larger, societal effects and social consequences of disruptive innovation. Does anyone care who gets disrupted? And who gets to decide what happens to those who are negatively impacted? How can these negative impacts on so many people be mitigated? How can this powerful force of renewal be harnessed for the benefit of the millions on the planet who have so very little? Is that even possible? I had a lot of questions but very few, if any, real answers. This was the journey I decided to take. The book was written
primarily at my home institution, the University of North Carolina at Chapel Hill and also in Cape Town, South Africa; Mountain View, California; and Adelaide, Australia, with bits and pieces added in all too many hotels and airports around the world. Wi-Fi is a good thing.

This book must cover a very wide range of topics, by virtue of the enormous range of subjects that we must consider to tell this complex and fascinating story. In Chapter 1, we will present the basic definitions and basic concepts of disruptive innovation and technologies. This will focus on the traditional business school and economics perspectives of how this movement has been studied. In Chapter 2, we present three traditional and non-space-related case studies of how disruptive technologies have reshaped existing markets and the larger world. These three case studies demonstrate the power of disruption and the broad impacts that they can have on markets, companies, nations, and even cultures. The power of individuals as drivers of change is also clearly evident.

Following this, in Chapter 3, we will consider the space arena: what is it, how did we get there, what do we do once we are in space, why do we want to do this, and more. We look at the various orbits, commercial businesses, markets, and governmental programs and agencies that are involved in space activities. Finally, we shall look at the revolutionary idea of NewSpace and how the space world is on the brink of a revolution. Chapter 4 will present case studies of disruptive space innovations, similar to Chapter 2. We will look at new concepts in space launchers, reusable space rockets and vehicles, space tourism, inflatable orbiting space hotels, as well as new concepts in practical space applications, such as telecommunications, satellite navigation, and remote sensing of our home planet Earth. In Chapter 5, we will present what might be the top disruptive space technologies and innovations that are on the horizon and what their impacts may be. And we will consider a few honorable mentions as well.

Chapter 6 will discuss how this revolution in space will impact the developing world, specifically on how disruptive space technologies can support the UN’s Sustainable Development Goals and become a positive force for the three billion people who share our planet Earth who have so very little. Chapter 7 will look at the complex international regulatory and treaty efforts and the relationships between these legal frameworks and the NewSpace revolution. Our existing international policy and regulatory framework are woefully antiquated and need to be significantly reworked in order to remain relevant to the future that is right around the corner.

Chapter 8 will consider the downsides of disruption. Everyone wants to be disruptive these days, but nobody wants to be disrupted, and the NewSpace revolution is upending many established and powerful players who are not at all happy about this change. How do these very large changes impact not only the powerful and wealthy aerospace corporations but also the lower end workers and society in general? How does it provide some recompense to those who lose their jobs and livelihoods? What are the cultural and personal prices of massive economic and cultural disruption? There are many important issues to consider, and these are not often addressed in the tech world.
Chapter 9 will present the top twelve things that you need to know about disruptive technological innovations and space, and our final chapter, Chapter 10, will present the final conclusions of all of this and will present a few predictions for the future as well. A glossary of terms and TLAs (three-letter acronyms), which are so prevalent in the space and tech worlds, is provided at the end. Citations appear at the end of each chapter.

Like any book about quickly changing events, as soon as this goes to the press, it begins to age, and there will surely be many events that will occur just after this project is completed, but that is the way it always happens. I have used metric units throughout but have added imperial units (feet and pounds) for our American friends who have not yet taken the plunge. American dollars ($) have been used throughout as well. There are many facts and much technical data presented here and also my own opinions. Any errors of fact are clearly my responsibility and are unintentional. My apologies if I got some things wrong. My own opinions are just that, and I am sure you can tell the difference between the data presented and my own views.

There are so many people who have influenced my ideas and thinking on these issues and who have helped make this book become real. There are many people that would deserve a mention here. First of all is my longtime friend, colleague, editor, and fellow Okie, Dr. Joseph Pelton, who has the most knowledgeable and prolific space mind that I know. My Springer Press editor Maury Solomon has always been a wonderful source of publishing knowledge and sound advice. She knows her business and has helped me to learn much about it. Finally, my everlasting thanks go to my family; my wife, Sarah; and my daughter, Adrienne, who have always been there waiting when I come home from my global ramblings to greet me, help me recover, and listen while I recount my tales of people and places far, far away. Thanks to you all.

Chapel Hill, NC, USA

Scott Madry
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Chapter 1
Fasten Your Seat Belt, It’s Going to Be a Bumpy Ride!

When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.
—Arthur C. Clarke

Why Write a Book on Disruptive Technologies and Space?

This is a book about disruptive innovations and space, and the current revolution in space activities around the world that is reshaping our space endeavors. There have been many books about space that tell how we get there, what we can do there, and what this all means for the people here on Earth. There have also been many business books about innovation and disruptive technologies. This work is focused on how disruptive innovation has developed and evolved over time, and how it has, at last, come to the domain of space, how it has transformed how we ‘do’ space, what that means, and where this is all going in the future.

This chapter will introduce the concept of disruptive technologies from the now rather well established traditional academic, business, and economics perspectives on the subject. It will include the history and theory of disruptive technologies and will provide definitions and basic concepts. We will cover the disruptive innovation model, again as it is generally understood from the traditional business perspective. This chapter sets the stage for the later presentation of space disruptive technologies, and how they are both similar and very different.

What Exactly Are Disruptive Space Innovations and Technologies?

Ultimately, we need to try to see how this process works, and also how it all fits together – in space, on the ground, in our lives, and in our future. Ultimately, we hope you, the reader, will consider what all of this has to do with you and your life, and the future of our planet.
Humans as Innovators

We are living in an era of unprecedented technological and social change. For over 99.9% of the time that we, Homo sapiens, have existed on this planet, and that is at least 200,000 years, or over 6,600 generations, we lived in small groups of hunter-gatherers, in roving bands of 10 to 50 people or so [1]. We lived in an intimate relationship with the local environment, and lived for generation after generation with basically the same technologies: stone tools and spears, woven baskets and animal skin pouches, clay pots, and simple implements of hunting and daily living. Nothing more than you could carry. We lived the life that our parents and their parents lived, and we passed on our material possessions and skills, our cultural toolkit, to our children, and they on to theirs.

However, eventually humans began to change into ‘Man, the Wise’ as we call ourselves (Homo sapiens), in ever-faster waves. First, there was the domestication of animals and the development of agriculture, and the mastery of tools and metals such as bronze and then iron, which led to permanent towns and then cities, the creation of food surpluses, wealth and, stratified societies with nobles and elites, and we became a species with a very different way of living in our world [2].

We lived in ever more complex and larger societies, with more specialization and ever-newer ways of making a living. Innovations and inventions were continually introduced and shared, and we became more and more settled in how we lived. Up until the late 1700’s or even later around the world, people pretty much lived their lives in a single and relatively constant cocoon of society, of social organization, and of understanding the relationship between human society and the world we live in. But this all began to change, and the world started to spin ever faster, if you will, and technological change became an ever-increasing and disorienting whirl.

The industrial age of steel and steam brought us enormous changes and innovations: steamships, locomotives, and rail networks, great bridges and industrial production and trade on a vast, global scale. We had new capabilities and new tools, and these brought us new ways to make our lives better, longer, and more fulfilled. But we also started to lose the connections that linked us to our history and our place in the world. We no longer could rely upon the technology and tools of our parents, and we could no longer be certain that what we knew would be enough to sustain our children. The future became more uncertain and less known.

And then came the silicon age, the age of the computer, of invisible zeros and ones, of email and the Internet, of digital data, and the spinning became a whirlwind. Wave after wave of new technologies, new computing capabilities, and new digital realities were washing over our lives. New businesses were rapidly replacing old ones and themselves being abandoned in flash.

Today, a person in the developed world may no longer rely upon the training and education they received in college to last them more than a few years before they require a ‘reboot’ in order to maintain enough knowledge to be productive in the ever-changing workspace. Wave after wave of new digital technologies are crashing upon us, and the question quickly becomes “Will we surf the next tech wave, or will
we be swamped?” Parents live in a completely different digital world than their children, and the grandparents are left back in a previous version of the world that is deeply separated from that of their grandchildren. Grandpa does not do WhatsApp. The cloud, social computing, artificial intelligence, data analytics, machine learning, big data, edge computing, constant observation of our planet and of our lives… all of these and more are washing over our social, political, and economic realities. It is all very unsettling, and we seem somehow less connected, even though we are constantly online with 24-hour cable news and social media.

And we are poorly equipped, by our evolution and our culture, to respond and react, let alone create a purposeful version of this that is actually beneficial and desirable for us. Humans have evolved to survive in the world in a way that is unique among the animals. Others come into the world already equipped to survive. Beavers know how to build lodges and robins know how to build their nests, but we survive through a complex web of ties that we call culture. Each of us is born into a culture, invisible yet enveloping, that we absorb from our parents and families, and that equips us with the language and social tools to be able to survive in almost any climate, from the high Arctic to the remotest of the Pacific islands. Our ability to learn, to adapt and adopt this web of culture has served us well, and yet we find ourselves in a new situation where the tools of our parents are irrelevant when we become adults. How do we give our children the tools they need to survive when we do not yet know what they are?

Several important questions are raised by all of this. They include: Has the world of technology accelerated to the point where it is now becoming counterproductive to humanity? When does the disruptive outweigh the innovation? How can societies plan for and make effective use of such rapid change? What do we do when we can no longer control or adapt to the ever-faster rate of technological change? There are many more questions and, interestingly enough, there is a tremendous amount of thought and development in creating these new technologies, but there are very few considerations of how these are impacting our world and what we can, or should, do about it. If we can develop it, we do it! However this all unfolds, there is no question that these things are going to have powerful impacts on all of our lives, and the lives of our children.

Space, and our access to space and the benefits that this provides to us, has become an integral part of our lives, as we shall explore later. Some aspects of this we can clearly see, but more often than not, space is integrated into our world in ways that we are not really aware of, such as the effect that the Global Positioning System (GPS) has had on so many aspects of our lives. And space is undergoing its own radical change before our eyes. The entire space domain is undergoing a pervasive and rapid disruptive transformation, and that is what this book is about. What the financial, social, and personal effects of this will be remains uncertain, but we can begin to consider all this.

But what exactly is disruptive innovation? It is a term we hear a great deal today, but what does it mean? Who first considered it? How does it actually work?
The Initial Concept of Disruptive Innovation

The initial concept of disruptive technologies, or disruptive innovation, was originally presented by Prof. Clayton Christensen of the Harvard Business School in Cambridge, Massachusetts, in the United States in his book The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail, published by the Harvard Business Review Press in 1997. In this seminal and game-changing book, he presents the case that the introduction of new technologies can disrupt, and even destroy, major existing businesses, even if they are doing everything correct from a standard business planning and management perspective. This book, and several others by him (i.e., The Innovator’s Solution) and by other authors who have followed him, have very much altered how businesses, academics, and the tech sector think about, and try to plan for, cycles of disruption that are introduced by new technologies and new and innovative products and services. This is also very much the story of the disrupters themselves, the people who drive this process by their ideas and will.

There is now a rather well developed theory of disruptive innovation and technologies in the business school and economics literature, although there is also much discussion and argument among academics and others about what all this actually means, and how well the concept actually fits within different business sectors and cultures. This is normal, as that is what academics do, argue and debate new ideas and what they mean, while seeking to expand and develop the concepts. These discussions take on a life of their own, and grow and meander. Additional books, journal articles, and conferences continue to debate and expand these new ideas, in this case, examining how new and disruptive developments disturb the prevalent status quo of existing markets and dominate players in a market. Much of this business literature is focused on mass consumer markets, and space has always been a very different type of commercial activity, as we shall consider later. One geostationary satellite launch can cost over US$250 million, not including the satellite that can cost much more than that. But the theory of disruptive technologies allows us to view space and the current revolution(s) in the space domain from a very different and useful perspective.

There are many different views about all this, but a good working definition of our topic is: “a disruptive technology is one that fundamentally alters the status quo of both the competitive market space, as well as altering the market position of the dominant technology and who controls that market.” A new, disruptive technology can simply replace the existing major players in a market segment, but more often, it can bring about totally new markets, applications, and industries that never existed, and it can also redefine the mix of dominant players in these markets in rapid fashion.

There are many, well known examples of this over the past 100 years or more. The development of the telegraph and then Marconi’s (actually Nicola Tesla’s) radio are two good, early examples of totally new disruptive technologies that did not previously exist. These both created completely different ways for people to
communicate across vast distances, and both created entirely new businesses, such as Western Union and commercial radio stations, as well as affecting existing markets and dominant businesses like the national post offices of the world. Existing players were affected, often negatively, and a new mix of technologies, businesses, and markets emerged that were fundamentally different from what had existed before. Email and its impact on Western Union and the traditional post office and postal mail is another, similar example. Another wave had arrived.

The list of well-documented cases is long: steam replaced sailing ships, and in their turn, jet commercial aircraft replaced transatlantic passenger steam liners in only a few years; the personal computer, FedEx and overnight package delivery, digital cameras replacing film (does anyone remember Kodachrome and 35 mm SLR cameras?) and there are many, many more examples of this process.

Space has significant differences from most of these examples, which tend to reflect consumer mass market products, and space has not, so far, been seen as a consumer product, at least not quite yet. But there is much that we can learn from these business school studies of this phenomenon that are relevant and important for our understanding of space and the extraordinary changes we are seeing [6].

Often, the new, disruptive innovation that damages established market leaders and that upsets the status quo is not radically new, in and of itself, nor is it necessarily extremely complex or difficult from a purely technological view. This is not always the case. Radio was a totally new and different technology, but FedEx and Uber had no new technological aspects at all; it was rather how the various existing pieces of technology were put together in a new and innovative way to create a new product or service and a new commercial market that competed with existing businesses such as the government-operated post offices and traditional taxi and limo companies.

However, according to the available business school literature, nearly all of these disruptive innovations that have been studied share two important characteristics. First of all, they almost always present a new and different package of performance characteristics. Often, and very interestingly, the new mix is initially less useful or interesting at first, at least to the majority of users. It is fascinating that, more often than not, these new mixes of capabilities are not really recognized or valued at the outset by the general consumer, and, even more importantly, they are not seen by the dominant players in the field to be a significant threat to their market position, and thus they do not initially respond to the threat, often until it is too late. This was Christiansen’s breakthrough concept.

The second common characteristic of disruptive innovations in the marketplace is that this new mix of capabilities and attributes improves at a very rapid rate. In fact, it is at such a rapid rate that the new technology can quickly gain new customers, overwhelm the dominant players, and can take over existing markets, while also creating entirely new markets that had not existed before. These new innovators can also quickly grow minor, niche markets into major, new mass markets that the dominant players did not consider worth their time when their existing offerings, and expertise, were providing such a good return.
Once a new technology that could revolutionize an existing market or industry emerges, it is a very common thread in these studies that the established major players in the affected market typically see it as not very interesting, and the technology is not initially perceived as a threat to their dominant situation. They are the market leaders and know their market and customers, and ‘own’ their markets. And their traditional analysis will usually show, convincingly, that this is not really something that their existing customer base really wants or needs, and that it is not something that the dominant players need to be concerned about. Part of this is that, initially, the projected mix of benefits is not that good or is quite different from the existing paradigm, the market and profit margins will be small relative to their existing activities, and that this would not cover the costs of going after this new opportunity.

Part of this is also hubris, and being ‘fat and happy’ market leaders. The view often looks really good from on top. It is also common that, being a new approach, the dominant players do not want to incur the costs associated with what are, at this point, not worth the price, and it will also require new production, marketing, distribution, manufacturing, and management resources in a new area that is considered to be ‘not our core mission’ and that brings with it new additional risk and uncertainty. After all, customers are not screaming for this new thing (at least not yet). And this is also a new technology or application that we really do not completely understand, we do not have the right people for, and we didn’t think it up anyway. It is probably just a fad and not really as good as what we offer. We know what we are doing. Ignore it and it will go away.

So as a result of these very understandable, very human, and totally predictable reasons, the new, soon to be disruptive innovation and technology tends to be dismissed, ignored, or actively rejected in favor of continuing to do what the market leaders know best, what that they have been very successful in doing all along.

However, rather quickly, another company; a smaller, more agile one, less invested in the existing paradigm, comes along and sees the potential that the new idea has, or perhaps they brought the concept into existence themselves. And they bring the new technology to the market, or sometimes to a slightly different version of the existing market, or even try to create new and different versions of the market, a small niche that they can occupy and exploit with the limited resources a startup can bring. Slowly, the new business becomes successful, and other, new players catch a whiff of what is going on, and they add their own ideas and different innovations onto the new idea, and much more quickly than the existing market leaders had assumed, the new players keep enhancing and improving the idea, its capabilities, markets, and value to existing customers and start bringing in new ones as well. Customers start to become interested, and money begins to flow into the small start-ups, and this draws the attention of others, including investors and money looking for the next big thing. What this does is to raise the benefits and performance in ways that mainstream customers begin to recognize and value. New users are added, and in a rapidly spinning cycle, the disruptive technology rises past the perceived benefits of the existing paradigm and becomes a serious challenge to the status quo.

By the time this has happened, it is often too late for the existing paradigm and market leaders to respond effectively. There are multiple, interlocking, and complex
reasons for this, but it is a mix of business philosophy and perceptions, psychology, personal skills and knowledge bases, economic realities, risk strategies, market changes, and much more. Another very common feature of this process is that, in the end, it is most common that the existing market leaders fight back rather than adopt the new ideas and approaches. They fight back with advertising, with minor improvements to ‘refresh’ their existing offerings, and more.

At first their responses are minor and without great investment, but as the cycle turns, and they realize the risk, they invest more resources to maintain their position and the old paradigm. They may try to buy out or otherwise kill off their new upstart competition, or they may file lawsuits and patent infringement suits and try to lawyer the threat away, or even seek political pressure to address the threat. They do this through new regulations or legislation limiting the new idea, trade tariffs or other, less ‘soft’ means. Sometimes it gets nasty. They do not give up easily, but they tend to fight rather than adopt. If they do try to adopt, often their efforts are grounded in the existing paradigm, and these often are not successful.

Ultimately, the paradigm shifts, consumer desires change, and the existing companies are overtaken. Jobs are lost, businesses and factories are closed, and the world moves on. People can’t imagine how they lived before without the new whatever it is. The fascinating thing is that this pattern has occurred over and over again, and people make the same mistakes in the same general patterns again and again. This raises fascinating questions about how people think and how organizations react, how they perceive threats, and how they make decisions in response to rapidly evolving threats and changes. But it is the broad patterns that interest us the most in this context, and how this is relevant to the current situation in the space domain.

**The S-Curve**

Christensen also introduced the concept of the S-curve as a way to graphically describe this disruptive process, and this has become a commonly used way to represent the process of disruptive innovation in the marketplace. It appears now in many books and articles and is a simple but effective way of representing this recurring pattern. Figure 1.1 shows an example of this S-curve. You can see that it represents a series of continuous, overlapping and intersecting S-shaped curves that each represents an iteration of a market or technology and its natural lifespan. The line in red shows the initial introduction of a new technology or product, which initially is less effective or widely adopted than the existing market leader, represented by the gray line. There is, at first, an initial performance gap and lack of interest. The red line then takes off and replaces the previous paradigm, and enjoys its period of ascendancy. But then, at the top of the diagram, you see the initial introduction of the next, new disruptive innovation, in blue, into this market segment. You can see that there is, again, an initial performance gap between the two just as there was at the bottom, but at some point the new future system begins to overtake the existing.
red paradigm, and the cycle repeats itself again. The small insert in green shows the pattern repeating over and over again.

Although this is, clearly, a simplified representation of very complex realities, the recurring patterns of S-curves provides a useful model for the process of recurring introduction and replacement of existing solutions and technologies that we are concerned with here. Each curve, each new technology, has its own natural cycle of birth, growth, maturity, and decline. Floppy drives, anyone? Text me on your BlackBerry if you can’t find one.

The Gartner Hype Cycle, the Valley of Death, and Resurrection on the Other Side

Another related way to visualize new and innovative technologies and their process of introduction and potential for the future is represented by the Gartner Hype cycle, with its variation on this S-curve theme. The Gartner Hype cycle is a trademarked, proprietary concept and represents a slightly more complex way of representing the various phases of how technologies are introduced [8]. You can see at left that the Y axis represents expectations, and below, on the X axis, time is represented. We see five different ‘zones’ in time, representing the stages through which a new technology becomes established in a marketplace.

The cycle begins with a technological trigger and a period of rising, perhaps unrealistic, expectations, followed by a peak of inflated expectations and unrealistic hype. This is inevitably followed by a descent into a trough of disillusionment, also referred to as the ‘valley of death,’ where there is a major shake out and consolidation.
At this point, only a small number of users have adopted the new tools, and the situation is very unstable for those who are trying to keep their businesses alive. Then we see a slow climb out, where second and third generation products become established and, finally, enter into a plateau of productivity where the innovation and its products and companies become established in the marketplace and the businesses that survived gain maturity and stable markets (Fig. 1.2).

Gartner produces tailored versions of this curve for numerous technologies and market segments, including the space sector; all are available for a commercial fee. There have been criticisms of this approach, and some critics have suggested that several recent examples of disruptive innovations have not followed this type of a process at all, and that the curve is not applicable in all cases. But it is a useful concept in general, and in relation to the current space industry changes that we are seeing today.

**Conclusion**

So in conclusion, we can see that there has developed over the past decades an academic framework for the analysis of disruptive technologies and innovations. This approach has initially focused on mass consumer markets, but it has significant benefits in our consideration of how these are going to impact the space sector.

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**Fig. 1.2** Gartner’s Hype curve. The Trough of Disillusionment is also called the Valley of Death [9]. (Graphic from https://en.wikipedia.org/wiki/Creative_Commons.)
We can also see that this pattern has occurred many times in the past, at least since the Industrial Revolution, and that there are multiple recurring patterns. Many market leaders react as if this has never happened before, and many do all the right things, from a traditional business perspective, and yet they are swamped by the new wave.

In the next chapter, we will review in detail some case studies of traditional disruptive innovations, to better understand this process and how it has worked in the past.

References

Chapter 2
Case Studies of Traditional Disruptive Technologies

If we have learned one thing from the history of invention and discovery, it is that, in the long run and often in the short one, the most daring prophecies seem laughably conservative.

– Arthur C. Clarke

This chapter will present several well-known business case studies of traditional disruptive technologies and their origins, process, and impact.

The first will be the automobiles and mass industrial production techniques introduced by Henry Ford. The second case study will be the introduction of the shipping container and intermodal transportation in the maritime shipping industry. The final one will be more familiar to you all, the development of the smartphone by Apple and Steve Jobs. There are many, many others, but these three will serve our purpose of setting the stage for the space era’s own versions of disruptive innovations.

Case Study #1: The Creation of the Mechanized Transportation Revolution

For many thousands of years of human history, nothing relating to people could move faster than a horse could run. Since the most ancient days, people had an intimate working relationship with domesticated horses and relied on them for transport, the movement of goods, war and conquest, working the fields, and more. The first good evidence of horse domestication comes from chariot burials dating back to some 4,000 years ago on the vast Asian steppes. Civilizations as disparate as the ancient Persian and Roman empires created dedicated systems of roads and messengers. Herodotus, the 5th century B.C. Greek historian, wrote that “There is nothing in the world that travels faster than these Persian Couriers,” who were called the Pirradazis back in the 5th century B.C. The Angareion (Ἀγγαρίειον in ancient Greek) was the system of Persian royal mounted couriers that operated over a series of over 100 post stations across over 2,700 km of roads, stretching all the way from the Ionian sea of what is now western Turkey to the Persian Gulf, between the ancient
cities of Susa to Sardis. A series of riders could cover this vast distance in only 7 days, an astonishing feat [1]. It was also Herodotus who wrote about them that “Neither snow nor rain nor heat nor gloom of night stays these couriers from the swift completion of their appointed rounds,” the very same famous phrase that was much later attributed to the U. S. Post Office.

The ancient Romans later adopted and improved on the Persian messenger concept and created the ancient world’s most complete system of paved roads in antiquity that spanned the entire Roman empire, from the Middle East to the Scottish border in Britain. The major roads all had stage relay houses about 30 km apart, located at regular intervals with fresh horses, beds and food for the official couriers of Rome. All others had to pay to stay at commercial inns, but all could use the roads without cost. This system was called the *cursus publicus*, or ‘the public way,’ and could speed a message a distance of up to 80 km in a single day between the various stage houses, which were called mansions [2]. The system remained in place in the Eastern (Byzantine) empire of Constantinople all the way up to the late 6th century A.D. But no human or message could move faster than a fast horse and rider for another 1,200 years.

Up to the early 1900’s, around the time of the First World War, a horse and buggy or light two or four-wheeled carriage was the most common means of travel in much of Western Europe, North America, and around the world. A single horse could pull a simple buggy costing only US$25 or $30, and it was easily set up and driven by anyone, including the elderly and older children. These simple buggies, also known as carriages in Europe, were made and sold locally by thousands of local carriage-builders; they lasted for decades and required nothing but a single horse or pony for

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**Fig. 2.1** A ‘Chase’ buggy built by the Oxford Buggy Company in Oxford, North Carolina, USA, now on display in the Oxford Town Hall. There were three buggy makers in Oxford, NC, alone in the late 1800’s, and thousands across the United States. (Photo by the author.)
These simple machines provided cheap, reliable, and efficient transportation for people and light goods around the world, requiring only the most basic of roadways and a horse, pony or mule. But this was all about to change (Fig. 2.1).

Today, we cannot imagine life without our gasoline-powered automobiles and trucks, and the vast, paved road networks that exist to support them. In the very same way, our ancestors lived in a close and personal relationship with horses and mules that we simply cannot understand today. Our entire economic and cultural infrastructure today is intertwined with our cars, trucks, and highways. The ancient Romans would surely be very impressed! Modern society is, at least in good part, built upon the car and its network of paved roads and gasoline fuel stations, along with the massive and invisible global petroleum exploration and processing infrastructure that makes it all possible. In only 100 years, just a blink of an eye in geological terms, since the ancient Persians, the world has been transformed into an auto-centric one, and horses are some distant memory of the past.

The invention of the ‘horseless carriage’ had been an idea since the ancient Greek and Roman days, and Leonardo da Vinci himself created a wind-up carriage powered by two springs as a marvel to display at galas and parties in 1478, just one of many precursors to our modern world from his fertile mind. It was the first self-propelled, wheeled vehicle that we know of. It was also one of the very first programmable machines, as it could be made to turn left or right at certain times by putting small pegs into holes in various configurations. It can also be considered to be the first programmable and mobile robot. What if he had lived in our time, talk about disruptive! (Fig. 2.2)
However, the creation of a practical self-powered carriage was not developed until the early 1800s, and there were many different attempted methods of power, including steam, electricity, and the newly developed internal combustion gasoline engines. These first automobiles were experimental, temperamental, and even dangerous and disruptive in a different sense from this book’s meaning, at least to the horses and drivers they encountered, who were terrified by them. One early local law in the United States required a man to run in front of every horseless carriage waving a red flag, to warn the public of its approach. Not very practical today.

One of the first real automobiles as we know it was the Benz Velo. It was created in 1894 by Karl Benz, founder of the famous Mercedes Benz cars of today. He created a vehicle that used the new internal combustion engine that provided an efficient and reliable source of power, compared to the steam boilers or electric motors that were also being tried at the time (Fig. 2.3).

These, and the many internal combustion automobiles that followed initially, however, were not for everyone. They were hand-crafted, very expensive, and were often the plaything or status symbol of the very wealthy upper class. Each was a unique vehicle, and most parts could not be replaced with any standard parts if replacements were needed. One man was going to change that.

Henry Ford created the Ford Motor Company in 1903 with a loan of $28,000 (in the neighborhood of $800,000 today), and he set up shop in a small, old, converted factory in Detroit, Michigan. It was actually his second attempt to create an automobile company, with his first attempt later becoming the well-known Cadillac Company, after he left it in a dispute with his original partners over the direction of the company. Ford started out like all the other ‘horseless carriage’ producers, in

Fig. 2.3 The Benz Velo, one of the first practical autos, with over 1,200 produced. (Image from Wikipedia. https://commons.wikimedia.org/wiki/File:Benz-velo.jpg.)
creating hand-crafted machines that were assembled by a small team of craftsmen, each working in place, building a single vehicle at a time from start to finish; this could produce in total only a few vehicles per day at most. But Ford had much, much bigger ideas, and even though he had produced a wide range of Models A through S from 1903 through 1908, he was determined to create a new scale of production for his new Model T in an enormous new factory that was designed from the start for mass production at a scale never before attempted [3] (Fig. 2.4).

Henry Ford forever changed the nature of our world through his mass production of inexpensive automobiles. Clearly, Ford was not the first to conceive of or implement assembly line manufacturing, even in the automobile industry. Ransom Olds was the first to use an assembly line, with his Curved Dash Oldsmobile starting in 1901, but it was on a relatively small scale and was a fixed assembly line, where the workers moved down the line and not the vehicles. But this was a major step in the right direction.

Henry Ford was thinking on a much grander and far more ambitious level [4]. He broke down the process of assembling his new Model T Ford into 84 discrete processes or steps on his new, moving assembly line, and he trained workers to do only one part of this work. Ford had designed and then built the first moving assembly line in the world for automobiles in Highland Park, Michigan, just outside of Detroit. It was a massive complex, with offices, power plants, glass works, workshops, warehouses, and an automated assembly line at its core. It was not Ford’s first factory, but was on a scale never seen before, a massive and integrated plant.

Once his assembly line started to move on October 7, 1913, he could assemble a complete, working auto from the original 6 ½ hours down to an amazing 93 minutes,
from individual subcomponents assembled in 84 individual steps into a finished auto driving off the end of the assembly line, ready for sale. What this extraordinary efficiency of scale did was to change the price to the consumer of a new Model T from over $700 in 1910 before the assembly line to only $350 after the new system was in production. This made it something that could be purchased by a far larger number of people than before. And all parts were standardized. Any engine worked with any car, as any axel worked with any wheel. Spare parts were assured to work with any vehicle, as opposed to the old, hand-crafted unique carriages and autos produced before. Only five years later, in 1918, over half of the cars in the United States were Ford Model T’s, all produced on the single, massive assembly line in Highland Park, Michigan (Fig. 2.5).

A key aspect of his breakthrough innovation was that Ford wanted to control all aspects of production, as far as he possibly could. He insisted on a vertical integration that gave him complete control of production from raw materials to finished vehicles. He had raw sand delivered and melted it into windshields and other components in his own glass works on site. His famous statement that customers could have a car in any color they wanted as long as it was black was driven by the fact that he found a black paint that would dry much faster than existing color paints (which he had used in previous models) and thus could speed up the assembly line. He wanted an integrated, vertical production structure that fed the continual improvement in production, and sale, of the Model T.

Ford was interested in more than industrial production and efficiency, though. He offered three times the standard wage paid for similar industrial work in the Detroit area, and he decreased the standard work shift from 9 to 8 hours per day. Ford wanted his workers to be able to afford to purchase the very cars that they made, and to have a reasonable standard of living. This was called “Fordism,” and while it was indeed beneficial to his workers, it was at least partly self serving, as it provided a much more stable and higher skilled workforce. His worker turnover dropped to 1% or less, a drastic reduction, which kept skilled workers on the job, thus improving throughput and the overall quality of the work [5].

Fig. 2.5 Henry Ford’s huge automobile factory in Highland Park, Michigan. (Image from Wikipedia: https://en.wikipedia.org/wiki/Highland_Park_Ford_Plant#/media/File:Farm_Mechanics_1922_Ford_Highland_Park_cropped.png)
Ford continually refined and improved his assembly process, and on May 26, 1927, Henry Ford himself drove the final, fifteen-millionth Model T off the line in Highland Park, an amazing feat of innovation, organization, and business acumen. Fifteen million cars produced from the same moving line in just fifteen years. He then moved into a new, even more advanced factory, to produce his next model, the Model A.

It was not until around 1920 that automobiles actually outnumbered horse carriages in the United States, and these horse-drawn carriages carried on long after, in American rural areas and in remote places around the world, even to today. But in our current world, the automobile and truck are integral parts of our lives and economies. We have created massive networks of roads, gas stations and garages at the cost of billions of dollars that have altered the landscape and created our car-centered modern world. Not to mention the global petroleum exploration and refining business that spends and makes billions each year to keep it all fueled and operating. As always happens, this has brought its own set of massive problems, including air pollution, environmental degradation, and a crippling reliance on fossil fuels and all that this entails. Not to mention over 50,000 deaths and many more serious injuries in automobile accidents each year in the United States alone.

Henry Ford forever changed our world, and his model of mass production and assembly line structure has been adopted across the world in everything from cans of beans to Boeing Airliners to GPS satellites. The Ford Motor Company remains one of the largest and most successful corporations in the world today. It produces millions of cars and trucks each year in over 80 factories located around the world, each with a moving assembly line. It also remains largely under the control of the Ford family. One man changed the world.

Case Study #2: Amphorae, Barrels, and the Shipping Container Revolution

Since ancient times, shipping goods at sea has been a slow, dangerous, and expensive process. General, mixed cargo, also called break bulk cargo, has been the traditional means of organizing, loading, and distributing goods since the ancient Phoenicians and Egyptians shipped large amounts of goods around the Mediterranean Sea thousands of years ago.

In the ancient world, the amphora was the standard means of shipping grains and olives and liquids such as oil, wine, and vinegar. There was a standardized size of these large, clay vessels, which could be carried by two people using the large handles on the sides; they held about 50 kg of goods each. In fact, this was an official unit of measurement throughout the Roman Empire, with 1 amphora equaling 1 cubic foot of contents, or about 26 liters in today’s units [6]. They had a pointed end at the bottom, which may sound strange, but that was actually very practical. This allowed them to be stacked into a wooden framework on the ship or a wooden
structure or sand inside a building. Amphorae by the many hundreds of thousands have been discovered by archaeologists around the world, and in many ancient shipwrecks found on the floor of the Mediterranean Sea. They often made one-way trips, and massive piles of amphora fragments have been found in archaeological excavations of inland cities throughout the ancient world (Fig. 2.6).

Things remained the same for a very long time, until the introduction of the wooden barrel. This was the next major revolution in the long distance shipping of grains, liquids, and small goods. The wooden barrel is a wonderful design – light, strong, watertight, a full barrel can be stacked several deep on its side or on its end, and a full or empty barrel can be easily rolled and moved by a single person up and down a gang plank or raised by a simple block and tackle, as shown in Fig. 2.7. Barrel makers around the world, called coopers, produced barrels of many sizes, but various goods such as beer and wine came to be shipped in standardized barrels of the same size and volume.

Although this provided an excellent way to store and ship both liquids, grains, and small goods, it still required large amounts of manual labor to move thousands and thousands of individual barrels around the world.

In these days, cargo was shipped in sacks, or stacked as individual items, each being catalogued, loaded, unloaded at a port, stored in a nearby warehouse at the port, reloaded, and safely lashed into ships and unloaded by manual laborers called stevedores or longshoremen who did this dangerous and difficult work at each port. Each individual item also had to be tracked and accounted for. The cost and inefficiency of the system is obvious. Another major problem was pilferage, or theft, of some amount of the cargo at each step along the way, as the individual items were so readily accessible to the workers. This was a constant aspect of global trade, and highly valued goods such as whiskey or fresh fruit always had a large portion of...
missing goods upon arrival. Damage was also a constant concern, with so many steps in the process and so many individual movements of each item.

The inefficiency, slow speed, large amount of manual labor, and damage and theft all led to a very high cost of break bulk cargo shipping, and this was a significant limiting factor in international trade, slowing the process and increasing the cost of goods beyond what most markets would normally bear. Most of the cost of shipping, and even much of the total time involved in shipping an item, was taken moving things the few hundred meters between the ship, the dock, and the warehouse and back. Ships would be weeks in port at each stop, and would make numerous calls on their way. It simply took too much time and cost too much to justify international shipping of any but the most highly valued goods.

However, there were positive aspects to this system as well. One obvious advantage is that break bulk cargo could be managed without any shore infrastructure and using local, unskilled labor. Around the world in the 19th century, one ethnic group often dominated the work in individual ports, providing an important economic benefit to what were often the lowest paid workers on the economic ladder. In the Pacific Northwest of the United States this work was controlled by the native American communities; in New York City it was the Irish and Italian immigrants, and black workers provided the labor throughout the American South and beyond, usually having their own separate unions from those for the white workers. The unions were powerful entities, and they could stop trade with a strike when needed. The work was dangerous and difficult, and there was never a regular schedule. There might be work one day and nothing the next. International trade at sea was little changed over the centuries, except for larger and larger sailing ships. The
introduction of steam-powered vessels was a slow change, leading to the eventual replacement of sail powered vessels. But the means of handling cargo changed very little from ancient days up to the 1950’s (Fig. 2.8).

This image of break bulk cargo being loaded in Adelaide, Australia, in the 1920’s clearly illustrates the problem. We can see two steamships in the foreground (from two different shipping lines, as shown by the different looks of their funnels), and on the dock the various groups of individual break bulk goods, including barrels of different sizes, bags of what could be grain or coffee, various wooden crates and boxes, piles of stone, and other goods sitting in the open air between the ships and the warehouses lining the docks at left. Horses or mules and wagons stand by, and we can see rail tracks next to the warehouses. A group of workers can be seen doing the hard, heavy, and hot work of loading and unloading the ship. They are standing under one of the many davits, or shipboard cranes that used steam or manpower to lift the goods into and out of the cargo holds deep in the ship.

Each ship had to have its own self-contained cargo handling and hoisting capability, as the docks were simply open areas between the warehouses and the ships. You can see all of the shipboard davits from the two steamships, reaching over the docks. Each ship, and you can see a large number of sail vessels in the background, had to be individually loaded or unloaded with the correct goods. Deep in the holds, another group of workers placed the cargo around the hold under the direction of a ship’s officer. The unions required a set number of workers at each hold, set working hours, and the work pace, all agreed to in contracts with the shipping lines.

Packing the ship was an art form, and usually the third mate or another junior officer was responsible for the correct and safe loading of the cargo; this was a very
important job. Not only did the right goods need to be brought aboard, but the ship had to be safely loaded by weight distribution, and all cargo had to be lashed down securely. A shifting cargo in a storm at sea could be a disaster. At the next port of call, the correct goods, now located all around the vessel, had to be identified, unpacked and unloaded one at a time, lifted or carried up out of the hold, counted again, and then moved into the warehouses for further shipment.

Customs officers inspected each shipment, and new cargo could then be brought aboard or sent on to the final destination. This process was repeated thousands of times in ports around the world every day. The movement of cargo in port was a slow and complex process, and weeks could pass before a ship could again leave the dock for the open sea and its next destination. Ships only made money while at sea, so the long waits in port were a financial drain, and a main cause of the inefficiency and high cost of the system.

The system worked, but the slow speed, danger, amount of manual labor, loss of cargo due to damage or theft, and overall high total cost made international shipping more the exception rather than the rule. Many manufacturers who routinely shipped abroad would cluster around the major ports, to reduce the time and cost of getting their goods onto the ships, or to receive raw materials shipped to them.

A disruptive innovation changed all this, however – the standardized shipping container. This completely revolutionized international trade and shipping, and is our second case study of a massive disruptive innovation.

There were several early attempts to use containers in shipping over the years, going back as far as the early 1800’s with standardized shipping boxes in some British railroads for coal and other ideas. Other ideas were presented, but none of these ever really became a major success or was widely adopted until the 1950’s and a man named Malcom Purcell McLean. Marc Levinson, in his fascinating 2006 book The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger, published by the Princeton University Press [8], tells the fascinating tale of ‘the box,’ the modern shipping container and its impact upon our modern world; this is also very much the story of Malcom McLean.

Malcom Purcell McLean was born in Maxton, North Carolina, in the United States. Maxton (originally named Shoe Heel, NC) is a very small farming town in Robeson County, near the South Carolina border, with a railroad running right through the middle of it. Malcolm grew up in the Great Depression and graduated from high school, but his parents did not have the money to send him to college. So his father bought him a used truck and set him up, with his brother and sister, in a trucking business. He started out hauling dirt for local, government-funded work projects, and then shipping North Carolina tobacco locally around the state. Later, McLean Trucking Co. also shipped tobacco and textiles, then a major North Carolina product, to New York for distribution throughout the Northeast and abroad. McLean knew how to grow a business, and by the 1960’s his McLean trucking company was one of the largest trucking business in the United States, with over 5,000 trucks and over 60 trucking terminals across the eastern United States, including the largest single truck terminal in the United States, located in Winston-Salem, NC, where he
had moved his headquarters. He was a self-made man, intelligent, bold, and confident in his abilities.

According to several sources, very early in his career, McLean was watching longshoremen in the port of New York slowly unload one of his trucks and then equally slowly load the textiles onto a waiting ship. He was frustrated by the inefficiency of the process and wondered why the entire truck containing the goods could not simply be loaded onto the ship and delivered to its destination, unloaded, and then driven to its final destination. This would eliminate almost all of the problems in the existing shipping approach, it seemed.

This story may be true or not, but clearly the idea formed in him that he could marry the convenience of loaded trucks with ships to improve the speed and cost efficiency of the transportation system. McLean had a very successful business, but he believed that he could revolutionize international trade by shipping entire truck boxes or containers, and not individual lots of goods. In the years after the Second World War, surplus ships could be acquired for very little money, so McLean decided to take the leap and sold his McLean Trucking Company in 1955 for US$6 million (a good sum in those days). Then he purchased two small, war surplus tanker ships and a small fuel tanker company named the Pan Atlantic Shipping Co., which he later renamed as the Sea-Land Co., to signify the marriage of shipping and trucking. This company held the governmentally regulated rights to sail between New York harbor and Houston, Texas, so McLean could now begin offering shipping services between these two ports using his new idea.

McLean had to sell his trucking firm and buy existing rights to ship goods between New York and Houston because, at that time, U. S. federal antitrust laws prohibited the simultaneous owning of a trucking and shipping company, and the U. S. Interstate Commerce Commission (ICC) controlled who could transport goods by ship between which ports in the United States.

The role of governmental policies and regulations cannot be underestimated in the story of disruptive innovation, and the ICC tightly regulated all aspects of interstate and international trucking, shipping, and railroads. It maintained a firm grip on rates, routes, and regulations and was a major preventer of anything that would disrupt the existing structure. This is a common feature in the disruptive innovation process. Those in control intend to do what is required to remain in control, and controlling the legal and regulatory process is a key component of this.

McLean had faith in his idea, though, and so he took the leap and gave up his very successful business, one that he had created with a single, used truck in the Depression, because he believed that he could change how goods were moved around the world. He had a better idea and was willing to put it all on the line to find out if he was right. He could have easily failed, but, to jump ahead in our story a bit, in 1969 McLean sold his ownership share of Sea-Land shipping for a total of US$160 million, and he revolutionized global shipping in the process.

By purchasing the Pan Atlantic Shipping Company, he now held the rights to sail between Houston, Texas, and New York City. This purchase also gave him their two military surplus tanker ships, but he was not interested in hauling oil in tankers. He quickly had one ship rechristened the SS *Ideal-X*, and had it custom refitted to try
his new concept of container shipping. His original concept was to sail from Houston, Texas, with a load of oil for New York Harbor, and then return with the tanker holds empty, but with a load of truck boxes, pre-filled with goods, that were to be quickly loaded onto a special deck he had installed that would hold a single layer of pre-packaged truck trailers. These containers were pre-loaded with goods and were then hoisted aboard and chained down on the new deck above the pipes and valves of the tanker’s original deck. Then he would fill the tanker with oil and again make the return run to New York Harbor. He originally thought of simply driving the trucks right onto the ship and then just driving them off at the destination, what is called ro-ro (roll on-roll off) today, but that quickly proved impractical, as the weight and difficulty of dealing with the truck cabs, engines, and fuel made him decide to only load the truck boxes instead. As previously pointed out, others had tried various shipping container concepts before, a few with limited success, but McLean was determined to make it work, no matter what it took.

On April 26, 1956, the Ideal-X left the port of Newark, NJ, and sailed for Houston, Texas, with a total load of 58 containers on the new container deck, and the international shipping container industry was born, even though the world little knew about it on that day. There were a few reporters present, and as soon as the ship sailed, McLean flew to Houston to be there when it arrived. Later, at the dock in Houston, he watched 58 trucks that were waiting on the dock, quickly haul off the boxes to their final destinations. He assumed he would return only oil to New York, but was surprised to find that there were quickly customers who wanted to ship truck containers back to New York as well, and his business was very clearly a successful concept.

The cost of unloading a traditional ship by hand using union longshoremen was almost US$6 per ton in those days, but with containers only, the cost dropped hugely to only $0.16 per ton, a massive cost decrease. The time needed to load and unload was also very significantly reduced, from a week or more in port to only a day or

![Fig. 2.9 A container being loaded on the Ideal X’s first voyage in 1956 from Newark to Houston. Each container was pre-filled, and loading and unloading were done quickly and with only a few people. (Image courtesy of https://www.aseanlines.com/Show.aspx?id=2907.)](image-url)
two. Today’s massive container ships spend less than 24 hours in a port to load and unload thousands of sealed containers, all controlled by computers in an integrated system. Again, ships only make money when they are at sea, so reducing the time in port was a key innovation (Figs. 2.9 and 2.10).

McLean had to load his ship from an out-of-the-way part of the greater New York Harbor, at the port of Newark, New Jersey. Newark was on the far side of the outer New York Harbor from Manhattan Island, which was then the primary site of the city’s huge port complex, along with Brooklyn. Manhattan Island was lined with historic wooden wharves and warehouses, dating back many years, but all the rail lines ended on the New Jersey side, and almost all cargo had to be carried by barge across the Hudson River, unloaded again aboard the ship, and then finally shipped. The labor union, the International Longshoremen, were a powerful political force, and union contracts required a set number of longshoremen at each hatch, both on the dock and down in the hold, and the process was slow and expensive, something the unions and their members did not mind at all.

However, McLean could not find the space for the large number of trucks and containers that his approach required in dense, urban Manhattan, as there was simply no room on the crowded Manhattan docks that were designed for break bulk cargo. His was a different type of operation. He also did not need the usual port infrastructure of warehouses, large gangs of expensive longshoremen, and all the traditional forms of the shipping industry. So he chose a rather out of the way part of the harbor with large, open spaces and easy access to the highways for his trucks.

Today, the port of Newark, New Jersey, is one of the world’s great intermodal container ports, and the old, wooden docks and rows of warehouses that once lined the sides of Manhattan are long gone, along with the thousands of jobs of the longshoremen. A new paradigm had arrived and another world was quickly vanishing. Interestingly, the same pattern occurred on the other side of the continent, where San Francisco had been the traditional shipping center of the West Coast, and it lost
almost completely out to Oakland on the other side of the bay. San Francisco was isolated from the rest of the county by rail, except from the South, and rail goods had to be shuttled by barge across the bay, just like in New York Harbor. The docks were old and rotten, and there was a perception of entitlement and a lack of concern about potential competition and no vision for the future. Things would simply continue to go on as it had. With the arrival of new container ships and new government approvals to sail between coasts through the Panama Canal, McLean agreed to site his new container terminal in Oakland, where there was plenty of empty space and direct access to rail and highways, very similar to Newark on the East Coast. In a decade, San Francisco had lost its preeminent port status, and Oakland is now the massive container hub of northern California, shipping millions of containers each year (Fig. 2.11).

It was not a quick or simple transition, but this is a common aspect of disruptive innovation. It never is. There was a significant effort by many powerful groups, including the powerful unions that loaded and unloaded the ships, the existing leaders of the shipping companies who did not want to spend the money to adjust their existing business models and purchase new ships and containers, the owners of the existing port facilities, and even the railroads, to stop this dangerous new idea before it could succeed. Each of these had its own reasons for doing so and its own interests to protect, and many strikes, lawsuits, political interventions, and other, less than legal means were used to try to scuttle the concept and McLean’s business. Powerful political pressure was brought to bear, as large economic interests are always intertwined with political power, and existing major players never give in easily when their economic interests are threatened.

Fig. 2.11 Malcom McLean, shown standing above the container port of Newark, New Jersey, showing rows of shipping containers, massive cranes, and container ships. None of this existed only a few years before. (Image from https://upload.wikimedia.org/wikipedia/commons/3/3f/Malcolm_McLean_at_railing%2C_Port_Newark%2C_1957_%287312751706%29.jpg.)
The unions fought a desperate and unflinching rear-guard battle, demanding such things as new items in their contracts saying they must unload and then reload each container on the dock (which was ridiculous make-work), and that unloading gangs could not be reduced in size even though there would be nothing for them to do, but it was all to no avail. And in the end, it did not take long for the global shipping industry and producers of shipped goods to realize the tremendous advantages of scale and economy that containerization provided.

In fact, there was an initial period of about a decade, where many competing ideas were proposed, as each player wanted the others to adopt its own approach with different types and sizes of containers and means of securing them. But in the end, the industry finally settled, via a long and difficult process, through international standards committees and meetings, on a system of common 20- and 40-foot standard containers, 8 feet high and wide, all secured and stacked with twistlocks that would stack easily on a ship as well as be usable on trucks or by rail. The box had arrived.

The benefit of this twistlock system was that it would allow any standardized locked container to be moved directly by a producer via truck, rail car, or ship, using the same reliable and sturdy locking system and cranes. Interestingly, the adopted standard container was not the size containers that McLean had used at first, as he had sized his boxes to best fit the dimensions of his first ships, at 33 feet long. But he took the loss of purchasing all new containers, in order to have the benefit on interlining with others, and the standard system of containers and locks was established.

McLean also understood the vital importance of standardization in this field, going beyond his own business interests in order to make interlining possible. He took the very forward step of making his several container-related patents available on a royalty-free basis to the industry, in order to foster the adoption of his system across the international shipping business.

The adoption of the twistlock was another pivotal invention leading to the success of this system. When McLean first loaded the Ideal X he lashed the truck boxes down onto the deck with shackles and chains. But this was, in itself, not an efficient solution. But another invention was to become an inherent part of the container system, one that allowed the containers to be quickly loaded and unloaded, and to be stacked high safely. The twistlock and corner casting form the worldwide standard means for attaching and holding containers aboard ships, trucks, and railcars. It was invented by a transportation engineer named Keith Tantlinger in the 1950’s. It consists of a simple and reliable rotating device that fits into a matching fitting that is capable of quickly and securely holding or releasing a loaded container. McLean hired Tantlinger and had him design and patent several key parts of the system. Automated twistlocks today allow a crane to place a filled container onto a ship, train, or truck and it have it be locked down automatically. And it can do the same operation in reverse (Fig. 2.12).

That first shipping run to Houston with 58 containers is now dwarfed by the size and scale of the modern shipping world that McLean conceptualized and put into motion. The long-established Danish Maersk Line bought out Sea-Land in 1969 and
has become the largest, but not the only, global player in this field, with over 500 container ships, 50 container terminals, and some 2 million individual containers constantly moving around the globe. The Danish A. P. Moller-Maersk Group today has over 89,000 employees worldwide and had a gross revenue of some US$35.5 billion in 2017. Their annual fuel bill alone is an astounding US$7 billion per year.

In 2014, the world’s fleet of container ships included over 5,000 dedicated container vessels of many sizes, able to carry 17.3 million 20-foot equivalent containers simultaneously, known in the industry as TEUs, or Twenty-Foot Equivalent Units, the standard unit of measurement in the global shipping industry today. These huge ships are constantly circulating between the world’s major ports in an integrated dance of millions of boxes, all tracked by computers and constantly in motion. They are moving while you read this right now, and much of what you buy the next time you go to the shopping mall will have made part of its journey in one, or several, of these containers.

And the ships continue to get bigger and bigger, all driven by increasing the scale of efficiency and reduction of cost. Maersk has recently ordered, and had delivered, 20 new vessels, costing US$190 million each. These massive ships are over 400 meters long, and are able to hold an amazing 20,000 individual TEU containers; they can be operated with an amazingly small minimum crew of only 15 to 20 people. The ships were so large that no ports in the United States could handle them, because they had such a deep draft, but the major ports all had to accept the cost to be dredged to accept them, because no port wanted to be passed by and left out. These massive ships are powered by the largest diesel engines in the world and a single, massive screw propeller. The ultimate size of these ships continues to be

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**Fig. 2.12** Twistlocks on board a container ship. The bottom right twistlock is in the open position, and the one at the rear is holding a container fast to the deck. (Photo by Hervé Cozanet [http://creativecommons.org/licenses/by-sa/3.0/].)
pushed, and some of the newest ones, called PanaMax, cannot even fit within the recently expanded Panama Canal locks. And these ships will continue to get larger in the constant drive for improved efficiency and lower cost (Figs. 2.13 and 2.14).

The system consists not only of these massive ships but also a totally new generation of container port facilities around the world. Today, the world’s largest container port, the Yangshan Deep Water Port off of Shanghai, China, moves over 800 million tons of freight each year. The massive port of Rotterdam, the largest container port in Europe, handles over 350 million tons of cargo each year, and the largest U. S. ports, such as Los Angeles and Newark, each handle over 2 million individual containers each year and growing.

The efficiency of this integrated global system is astounding. It now costs only a few thousand dollars to ship a fully loaded, 20,000-kg container from Shanghai, China, to Los Angeles in just over two weeks, all managed and tracked by computers. With the new and largest ships able to carry 20,000 containers per trip, and each
ship having a single massive diesel engine and a crew of only about 15, the efficiency of the system is obvious. This adds an incredibly small shipping cost of only a few cents to the cost of a sweater or pair of pants to the price paid at Walmart or Costco in the United States of goods manufactured in China or Vietnam.

Manufacturers now produce their goods in lots of TEUs by destination, and they can locate their factories anywhere on the planet, always seeking the lowest wages and least regulation. The scale is staggering, and the scale of automation, in the never-ending drive for efficiency and reduced cost, continues. Computers decide the ship schedules, the arrival dates of the trucks and trains, loading and unloading process and order, and even how the now fully automated container movers shuttle the containers around the massive yards. The mini trucks in Rotterdam and Shanghai are now completely automated, moving without a driver, using GPS and computers to move the containers from the ships to the right storage area and back.

Imagine an integrated computer system, merging the container database, GPS, AI and computers, all without a single person on the dock-side of the operation, except for the small group in a control room some distance away. Even the massive cranes that load and unload the containers in Shanghai and Rotterdam are computer controlled, without a human operator, while many around the world still use an operator sitting high above the wharf. These container ports require an enormous investment in infrastructure, worth many millions of dollars, with the massive cranes lining the docks towering high above the ships, but these costs are more than balanced by the extraordinary efficiency of the total global system. And there are also fewer and fewer major ports, as it is more efficient to serve only a few mega-ports and then distribute containers via rail and trucks in a vast, intermodal integrated transportation system.
Intermodal reaches far beyond the ocean, and the real benefit of containers goes far beyond only the ships and their massive ports. McLean’s original idea was the marriage of truck and ship, and this is the true value of the efficiency of the global intermodal system, which seamlessly links ships, rail, trucks, and air. The modern intermodal port of Newark New Jersey, mirrored by others around the world, contains a nexus of a vast container port, multiple rail lines, a network of interstate highways, and a major international airport. The ability of containers to seamlessly move by the tens of thousands across these connections is what creates the modern transportation and distribution system, a marvel of efficiency and economic power.

It is interesting to note that the railroads in the United States were originally strongly opposed to the concept of containerization, fearing the loss of freight loading and unloading charges and the cost of new equipment and processes. But today, rail systems around the world operate as a seamless aspect of the intermodal system, hauling double stacks of containers deep inland from the mega-ports, and at a very sizeable profit. Containerization has revitalized the rail systems as well (Fig. 2.15).

It is the global, point-to-point aspect that is so compelling. As stated before, manufacturers can now be located anywhere, not directly adjacent to the ports as they once were, and they manufacture their goods in lots of full containers to be shipped to a single destination. The same container can be packed with goods and locked, then picked up at its origin by a truck, driven to an international port, shipped across the vast ocean, loaded onto a train, taken half way across a continent, loaded onto a truck, and delivered to the final destination’s door without ever being opened and tracked each step of the way. And this can be done in a matter of only a few weeks, and at an amazingly low cost. Shippers can do full door-to-door logistics from anywhere to anywhere on the planet at a cost that makes shipping anything possible. It also makes modern, just-in-time delivery of goods and parts possible on

Fig. 2.15 Just before landing at the intermodal complex at Newark Liberty Airport. Note the I-95 interstate highway, the multiple rail lines, and the massive container port of Newark with ships, cranes, and containers, all in one, integrated, and connected system. (Photo by the author.)
a scale unheard of just a few decades ago, and pushes almost all manufacturing jobs down to the lowest bidder (and wages) around the world, located where there is the least regulation.

Many thousands of manufacturing jobs in the developed world are now permanently lost, and are unlikely to ever be recovered. This is because it is less expensive to ship goods half way around the world, from the manufacturer of least cost using the global, intermodal shipping container infrastructure. The positive social transformation of developing economies around the world is offset by the loss of massive numbers of manufacturing and longshoremen jobs in the developed world.

And so today, 90% of world trade is by shipped by sea, packed into 700 million individual container movements around the globe per year. This is an extraordinarily powerful engine for international commerce and social change, and it has interconnected the world’s producers and buyers in a way never conceived of before Malcom McLean took the gamble to put his idea to the test. Millions of tons of goods pass among the world’s great ports each week on a largely automated schedule, putting inexpensive goods into stores across the planet and creating a single, massive integrated international system of commerce.

There are, though, also real challenges in the intermodal freight world today. These challenges include expensive port delays aggravated by the mismatch of ship sizes with port capacity, and the inability of ocean carriers to achieve consistent profitability as they continually compete with lower and lower costs. However, containerization has helped change the world by providing the means for a phenomenal increase in global trade, and for making global sourcing profitable by reducing transportation costs that previously had been a de facto trade barrier. The days of the busy dockside and port, with stevedores and longshoremen loading break bulk cargo, are now a thing of the past, except in the smallest and most out-of-the-way ports of the world. The mind of Malcom McLean and his courage to take a chance and try something new and revolutionary altered our world. His box came along and changed it all [9].

The third and final case study in disruptive innovation will be the introduction of the smart iPhone by Steve Jobs and Apple Computers, and the death of the traditional cell phone.

Today most of us all have a smartphone, constantly with us, an integral part of our daily lives. How long has it been since you checked your email and text on your smartphone? Does reading this make you want to do this right now?

Of course, this was not always the case. Cell phones had been around for a while but not that long. The first ones were huge and heavy brick-phones with limited range and battery power, but they quickly got smaller and smaller. But they were just telephones without cords.

How did smartphones come to be such an indispensable part of our lives? Apple has now sold over 1 billion iPhones so far, and still counting. The iPhone has become over 50% of Apple’s total revenue. Apple computers and its charismatic founder, Steve Jobs, changed the world we live in, and it is a fascinating and complex story of disruptive innovation, moving information and data instead of containers full of goods, or people in automobiles [10].
Nokia is a major Finnish company, involved in many technology businesses, ranging from televisions to auto tires to computers to even toilet paper in its early days. Founded in the 1860’s, it was involved in a wide variety of technology activities. In 1981 they purchased Mobira, a Finnish mobile telephone company, and launched the first national cell phone system in Finland, which was very successful and showed the built-up desire for such a system. It also developed the first commercial car phone and became the leader in mobile telephones worldwide.

Fascinatingly, initially there was little interest in the cell phone market from the Nokia upper management. It was seen as a niche market and not their core market (sound familiar?). This changed with a management restructuring, and the new leadership became focused on mobile communications, selling off their other, wide-ranging, businesses. They were very successful, and by 1998 Nokia overtook Microsoft as the largest seller of cell phones worldwide; they built their 100 millionth cell phone by the end of that year [11].

Apple was not the first to consider doing a smartphone. Earlier PDAs (personal digital assistant – a term coined by Apple) were developed by Blackberry and others, and Apple themselves failed rather badly with their early Newton PDA, first developed in 1987 and marketed from 1993-1997. The Blackberry, Palm Pilot, and others had a good measure of success, but these early examples all relied upon a stylus or tiny keys and scroll wheels. Many did not even have cell phones at all at

Figs. 2.16  a & b Ever-shrinking Nokia cell phone designs from 1987 to 2000, and Apple Founder Steve Jobs introducing the iPhone to the world on iDay in 2007. (Images courtesy Wikimedia Commons.  https://en.wikipedia.org/wiki/Mobile_phone#/media/File:Mobile_phone_evolution.jpg and https://commons.wikimedia.org/w/index.php?search=iPhone+Jobs&title=Special%3ASearch&go=Go&ns0=1&ns6=1&ns12=1&ns14=1&ns100=1&ns106=1#/media/File:Steve_Jobs_and_iPhone.jpeg.)
first, and it was definitely a niche market for business professionals and not a mass consumer market by any stretch.

By 1998 Nokia was the king of cell phones, producing a stream of ever smaller hand-held cell phones, as shown in Fig. 2.16a below. The company was valued in 2007 at some US$250 billion, and it was the clear global market leader.

Nokia, in the context of our earlier discussion of disruptive technologies, was a classic dominant player in their market. They were fat and happy and were the king of the cell phone market, with the largest market share and profits in the world. But it was all on the verge of ruin.

In 2007, Apple introduced the first version of its iPhone, though not to universal acclaim. But only seven years later, Apple was the new king of the roost, and Nokia sold their now failing cell phone division to Microsoft for only 3% of their peak market value. The costs of this acquisition, by rival Microsoft, were written off in 2014 as a total business loss. A massive and rapid change of fortunes, all brought on by a disruptive innovation and an equally disruptive innovator.

The Apple iPhone project started in 2004, with the project codename of ‘Purple.’ At that time computers, cell phones, and music players were each separate business domains, separate devices, and sold in separate markets with separate business management teams. The original iPod music player was released in October of 2001 and it was a very quick hit and was a major profit center, as production costs were very low. The separation of computers, phones, and music players was similar to the fact that not that long ago, copy machines, printers, scanners, and fax machines were all separate business areas, and you had to have three separate devices to do these tasks.

Today, we all enjoy integrated, small combined printer/scanners (there are not too many people faxing any more) that do all of these, but this was not always the case. It was the same with computers, cell phones and music players. Steve Jobs was initially very cool to the idea of Apple making a cell phone, concerned that it would be a limited market and one that might not be appropriate for Apple’s innovative and elegant design paradigm. He also did not like the fact that the phone carriers had too much power over how products would look and work, as he liked vertical integration and complete control of his markets. In addition, he was also worried about Apple’s launching into new product areas after he had recently cut several other programs. He simply did not see cell phones as a key part of Apple’s future, which was focused on desktop computing, music through the iPod, and new and innovative computer interfaces [12].

Apple had launched an iPod music capability on the latest Motorola phone, in an unusual pairing with their long-term competitor, and it was not viewed well by Jobs. He thought it was a terrible product, and if Apple was going to do a smartphone, then they were going do it right, and do it the Apple way, with an innovative and elegant Apple user interface. But he, and most senior Apple managers, all thought that the current generation of cell phones were terrible in design and user interface. They were convinced that the current state of cell phones was simply awful. Apple added iPod music to the then market-leader Motorola Rockr, but Jobs thought that the finished product was, again, awful, and unworthy of Apple’s focus on elegant design and market innovation. So he started two secret and competing teams to
work on an Apple cell phone, one to just add a cell phone onto an iPad, using the iPad’s existing click wheel, and one to do a completely new approach. This team was using a very innovative and completely new touchscreen-based mini computer that was also a phone. Yes, it would be a cell phone, but it was really a tiny computer with a revolutionary new and elegant touch user interface. It was cell phone, but much, much more. It was a cell phone that was also an iPod for music and a calendar and a web browser, and much more. And it would have apps, and a marketplace where users could purchase inexpensive, small programs from Apple to customize their systems.

The multi-touch screen revolution had begun.

The key aspect of the iPhone, as it was to be developed, was the reliance on and further development of the multi-touch screen interface. This was not even an Apple technology, and was originally conceived of in the 1960’s by a variety of researchers around the world. But Apple popularized the new computer user interface in its iPhone and iPad product lines.

The interface in these uses a touch screen that can discriminate multiple touches at the same time, thus allowing for a user interface without a keyboard or stylus. The user simply touches, swipes, or pinches the screen. No knobs, no dials, no buttons, the ultimately clean and elegant user interface, just what Steve Jobs loved. This allowed Apple to create a small but powerful pocket computer that could be interacted with by simple swiping or touching the screen, and, by the way, it was a cell phone. And it was just cool and clean and elegant and totally new. The idea was a radical departure from the existing cell phones of the day, even though Nokia and others like BlackBerry had put small text screens and buttons for texting, and some higher end phones also had cameras.

And Steve Jobs was a master disrupter, as well as a master publicity-generator [13]. The iPhone was marketed brilliantly, and that was an important aspect of this story. Leading up to the product launch, Apple kept secret what the new product would be, and even on the stage at the much publicized launch, Jobs announced they were launching three new products that day: an improved iPod, an Apple phone, and a new Internet device, which were, of course, all the iPhone. It was brilliant marketing, and the world wanted one… now. The hype was tremendous. Suddenly, every other device looked several generations behind, and Apple sold over 700,000 in the first week after they became available on ‘iDay.’ An innovative product was launched by the world’s best pitch man, and everything else looked like a Model T.

Initially, the new iPhone was expensive, very expensive, compared with the existing cell phone options available. Steve Ballmer, then the CEO of Microsoft, was quoted in a recorded interview in 2007 saying “You can get a Motorola Q for $99. Apple will have the most expensive phone, by far, in the marketplace. There’s no chance that the iPhone is going to get any significant market share. No chance.” Alas for Mr. Ballmer, his words were recorded and are available on YouTube for all to hear. It is hard to be wrong, and worse to be recorded being wrong for all the world to hear.

Nokia was not the only victim of the iPhone. Research in Motion, a Canadian start-up, had great success with their BlackBerry device. In 2007 RIM’s BlackBerry
was very popular, but its tiny button interface was now instantly seen as outdated, inelegant, and not the leading edge. In fact, even though RIM had an established market and very loyal users, Apple passed it in sales by the end of 2007. RIM’s stock fell 87% between 2010 and 2013 due to the iPhone (and its many instant Asian clones). By the beginning of 2016, only 1 ½ million out of almost 200 million total smartphone users in the United States used a BlackBerry, with iPhones approaching 50% of all smartphone users. Nokia and BlackBerry, and new entrant Google with its Android OS all had adopted a touch-screen cell phone design by the end of 2008 in response to the iPhone, but for the most part, the change had come. The iPhone simply exploded on the global market. It was transformative, and, while the competition were loath to admit it, they all started creating their own versions, with minor differences that they hoped would make them stand out in the new market. Microsoft still thought it was really stupid, but had no choice. Innovation in technology became the driving force in global business. The world was not the same.

By 2013 there were more smartphones in service around the world than traditional landlines, and by 2017 there were over 2.5 billion smartphones sold worldwide, and over a third of the people on the planet now have some version of a modern smartphone. Apple sells some 75 million iPhones per quarter, and the market continues to grow. Google and their Android OS remains the market leader. A recent study by IHS Markit showed that the current smartphone market worldwide was some US$335 billion, with an estimated 6 billion devices sold. The fact that smartphones can have apps provides another US$70 billion market on top of that. Fully entrenched in the developed world, smartphones are now finding their most rapid growth in Latin America, the Middle East and also Africa, where so many old Nokias continue to survive in the SMS markets there [14].

This is a new and massive worldwide market of over US$400 billion, one that simply never existed before. The Apple app store opened in 2008 with 500 offerings, and it now offers over 2 million apps, many for free, the rest for just a few dollars each. There have been over 130 billion downloads from the Apple app store so far, and developers have received over US$50 million in revenue. The Google Android operating system allowed other manufacturers such as Samsung, Google, Huawei, and even the new Nokia to join Apple in this massive new market. A new generation of developers are creating another entirely new landscape. It is all about the app.

One interesting note is that many hundreds of thousands of older Nokia and Motorola cell phones found new life in Africa, where simple SMS cell service continues to be the norm. This spawned an entire set of new SMS business applications in Africa, but that will have to wait for the next edition.

So let us look at the iPhone from the perspective of our initial discussion of traditional disruptive innovation. Nokia (and others like Microsoft and Research in Motion) had huge and profitable cell phone businesses worth billions of dollars. The existing paradigm was a small, portable phone, constantly getting smaller, but it really was a phone, maybe with some text or a small resolution camera.

Apple could have simply added a phone to its wildly popular iPod, the path of least resistance, and it looked into this idea. But Steve Jobs decided to take a
revolutionary approach and presented its new iPhone that was just slightly larger, was more expensive, and which had a variety of additional features that were outside the range of existing cell phones.

Apple presented a totally new paradigm, and the existing market leaders all were convinced that it was not viable. It was more expensive, had lots of extraneous features that most cell phone users had never thought important, and the mix of new features and added cost convinced Nokia and the others that this was not something worth competing against. Instead, they doubled down on their primary market that had worked so well, making ever-smaller versions of the same overall design, with a small screen and tiny buttons, and with maybe a camera and color screen added as well. They put money into marketing and were convinced that their approach was right and that the iPhones would be a failure, or at best, a tiny, high-end niche market. They were very wrong.

The advantages of Apple’s new approach quickly became evident, and new uses, markets and new ideas quickly took off. One curious aspect of this was that, originally, Steve Jobs was totally against the idea of an ‘open’ market for iPhone apps, and he was adamant that only Apple-developed apps would be available to purchase and add to the iPhone. Once this decision was reversed, and Apple opened up the App Store to outside developers, the product really took off and never looked back. You could now download a vast and growing array of free or $1 to $5 apps to do a huge range of things, everything from a guitar tuner to a pocket planetarium. The iPhone, and all the other smartphone clones that quickly followed, are really pocket computers that are also cell phones, and not cell phones that also do a few other things. This was the revolutionary paradigm shift that destroyed Nokia, BlackBerry and the other traditional cell phone manufacturers.

One of the most extraordinary aspects of the smartphone revolution is that today, we simply cannot imagine not having a smartphone that does all these amazing things with us all the time. It has become an indispensible part of our daily lives, maybe too much so. There are several images on the Internet of all the traditional office and other tools on a desk that have been replaced by the small glass object we constantly carry around with us. There are over 50 items, and our smartphones are now a phone, text, Internet, music player, scanner, calendar and planner, notepad, GPS navigation tool, alarm clock, flashlight, camera, and on and on. And you can also make a phone call. This is a classic example of disruptive innovation.

We cannot separate the story of the iPhone from the story of the famed and controversial co-founder of Apple, Steve Jobs. Many books have been written about him, his life, and his impact on computing. Steve Jobs was a driven and charismatic individual, who was notoriously difficult to work for, and who was driven to produce elegant and enveloping computing designs. There is a much repeated story, perhaps apocryphal, regarding when Jobs presented the iPhone to the Apple board of directors for final approval for production. After his presentation and demo of the iPhone prototype with its extraordinary touch-screen interface, one of the board members said something like, “But this will put our iPod out of business. It is one of our most profitable and popular products. You are going to kill it with that.” Jobs, in one of his famous fits of anger with those who could not share his vision, replied
with something like: “Yes, we are going to kill our most profitable product! If we don’t do it, someone else will, Motorola, or Microsoft, or some 15-year-old kid in his garage in Palo Alto! We are going to kill every one of our products, and replace them with new and better Apple products, before someone else does. That is our job!” He got their approval, and the rest, as they say, is history. But it is a fascinating and instructive story, if true. Jobs saw that it was his job to put their best products out of business before someone else did. He realized that constant and driven innovation was the very fabric of the high-tech computer industry with its rapid development cycle and evolving technologies. And he realized that this was fundamentally different from how things were done in the past. The wheel had sped up, and he understood what that meant.

To be fair, Nokia and RIM have recovered, and both remain very successful companies, employing a large and international workforce; they are major players in many tech markets, but not in cell phones. Once again, they did all the right things in protecting their existing markets and businesses and were washed away by a disruptive innovation, driven by a very disruptive innovator, that presented a danger that they could not perceive and did not react to in time. The story repeats itself once again.

So what do these three examples tell us? They show us, as Prof. Christiansen identified, the process whereby good companies and market leaders can do all the right things and still be overtaken by revolutionary new innovations that fundamentally disrupt the status quo. It reaches back far before computers and hi tech. There are many other examples – the telegraph, Nicola Tesla and the alternating current motor, and his (and Marconi’s) wireless radio, the conversion from sail to steamships, the development of jet commercial aviation and the demise of trans-Atlantic ocean liners, FedEx and concept of overnight shipping, digital cameras and the replacement of chemical films, and the list goes on and on. You can certainly think of others yourself as well. It is interesting and useful to look back and see these patterns, and it is fascinating to see the same process play out again and again.

It is far more fun, and important, however, to try to look forward and see where the next tsunami might come from. What will be the next big disruption in our lives and in the arena of space? How can today’s market leaders learn to see these in time to react? Is this even possible? Can there be a workable strategy of identifying and defeating disruptive innovations by the market leaders? Does all this just happen? We will consider this further towards the end of this book, but this is a very complex and central question to disruptive innovation and NewSpace.

Let us consider what these examples (and the many others) have in common and what lessons can be learned from these before we focus on the space industry.

There are several common threads here that can be very informative. Mass production, efficiency, and economies of scale are a common feature in each of these. The reduction in cost through new processes and standardization expand existing markets and create new markets. Mass production and the resulting reduced cost and efficiencies drive new markets and new applications, thus providing a real benefit to the end users through increased access, lower cost, and standardization.
However, this is much more than a story of things; it really is, at its heart, a story about people. Daring and dynamic people, people with personal courage and visionary leadership, who dared to take on the status quo and create a new reality. People with determination, willing to take great risks, to go up against long odds and powerful political and economic forces to create a new vision of how things are done, with the side benefit of creating great personal wealth. It is a story of driven personalities, self-confidence, willingness to think out of the box, willingness to go against the grain and to take chances, willingness to take on powerful interests, and also people who have the money to do what they want.

The mirror image of this is the predictable reaction of the market leaders and their inability to see and respond to the threat. All of this takes money, and timing is hugely important. Some ideas come back again and again until the technology and markets are ready. We often see ideas fail because the technologies were simply not there yet, like the Apple Newton and other early PDAs. Some are simply not at a state where the technology has developed to where an innovation can occur. The policy and regulatory environment must be conducive, or at least not be so restrictive as to prohibit new markets.

It is also a story of failure and resilience, and each of these three disruptive innovators also failed in many ways. Malcom McLean drove Sea-Land into bankruptcy later on, when he bet that oil prices would remain low and they rose to new heights. Steve Jobs was fired from Apple before his return to create the iPhone, and his Next computer venture was a massive financial failure between his two terms at Apple. These failures laid the foundation for later successes. All of these people had the courage to risk it all and to seek help when they had lost everything to start all over again. Disruptive innovation is not for the faint of heart, or for those who will not get back up and try again after getting kicked down hard. Most of us would not be able to do that. How many great ideas and inventers never succeeded because they gave up after they had an early failure? We will never know.

In conclusion, there is a long and fascinating history of disruptive innovation, and the examples we have considered in this chapter now set the stage for our next chapter, which will look at space, what and where it is, what the traditional space business domain looks like, and how space fits into the larger picture of disruptive innovation.

References


7. https://commons.wikimedia.org/wiki/File:Amphorae_stacking.jpg Ad Meskens [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]


Chapter 3
Space, an Arena Ripe for Disruptive Innovation

2001 was written in an age which now lies beyond one of the great divides in human history; we are sundered from it forever by the moment when Neil Armstrong and Buzz Aldrin stepped out on to the Sea of Tranquility. Now history and fiction have become inexorably intertwined.

– Arthur C. Clarke

We are now a full 50 years since that momentous Moon landing in June of 1969. This chapter will turn our attention to the arena of space, space technologies, and space businesses, which are very different from cars, shipping containers, and smartphones.

What actually is space, how do we get there, and what can we do once we arrive? The space business environment is similar in some ways, and yet very different from, traditional businesses and business models. We will present information about the different regulatory, policy, economic, and national security issues, and other factors that are particular to the current and future space business arena. We will discuss the concepts of “NewSpace” or “Space 2.0,” and how innovations in this environment are rapidly changing the space world. We will also consider the current status and likely directions of space business vs. the traditional government and large corporation approach to space activities. It is a very exciting time to be involved in the space arena.

The Space Domain

Space is big – really, really big – and difficult to get to and operate in. It is a very expensive and rather risky place to do business [1]. This is true for the space devices we call satellites, and even much more so for human beings getting to and working in space. Space is a very foreign and dangerous environment, one very different from our familiar world here on planet Earth. We all know that doing space technology projects are difficult, and that space is an unforgiving environment. “Space Is Hard” is a common phrase used in press conferences after a rocket has exploded or a satellite has failed. And while space is really big, some parts of space are not actually that far away. The ‘official’ edge of space is called the Karman line,
and is only 100 km up, or 60 statute miles above your head. International astronauts win their wings by crossing this line for the first time, but NASA and the FAA in the United States recognize 50 miles (about 80 km) as the magic limit. And this is not that far if you measure on a map a town that is 100 km from where you are reading this book.

There is no sharp break between our atmosphere and outer space; it is a slow and gradual change with the loss of the atmosphere, but we set the ‘edge’ of space to arbitrarily be 100 km. Below this altitude, satellites cannot remain in orbit due to the large amount of atmospheric drag, and aircraft do not have enough air to provide sufficient lift, so 100 km is recognized by the FAI, the Fédération Aéronautique Internationale, as the official edge of space.

The specific definition of where space begins is not simply a matter of where you get your astronaut wings; there is a very important international regulatory meaning to this. Below the official beginning of outer space, the airspace, and all things that fly within it, are under the regulatory control of that Nation-State. Above the line, satellites can, and do, fly unrestricted by national airspace control. We will discuss the regulatory issues of space later, in Chapter 7, but where exactly space begins is a very important matter, and there is no real, physical ‘edge’ of space. It is actually more accurate to think of this as where Earth’s atmosphere ends (or begins), given the vast size of space, and the tiny area covered by our planet’s thin, gassy covering.

Being able to get people and satellites above this line and into a stable orbit around Earth provides us with very many important benefits. In fact, our modern digital world is deeply interconnected with space, and a day without our assets in space would be a very bad day indeed here on Earth. Our space satellites have become intricately interwoven with our world, though mostly hidden in the background, and we need to protect and enhance this vital relationship.

We have many beneficial activities that our satellites can perform in orbit around our Earth; these orbits are generally broken up into three general ranges of low Earth orbits (LEO), middle Earth orbits (MEO), and geostationary Earth orbits (GEO). There are others, such as the highly elliptical orbits (HEO) that cross several of these zones, but these are the main three that are in common use today.

The region of low Earth orbit (LEO), where many of our new, small satellites live and work, is only a few hundred kilometers above our heads. None of us would win any prizes or become national heroes for getting in our cars and driving 400 km to go on a vacation or to visit friends, but getting to the International Space Station in its orbit of some 400 km (or about 250 miles) above Earth is an expensive and dangerous undertaking, costing millions of dollars and years of planning and training. Those lucky few who get to go there become lifetime heroes, but it really is not very far away ‘as the crow flies’; it is just going straight up rather than around the planet’s surface (Fig. 3.1).

Fig. 3.2 shows the relative position of the three primary orbital zones for our satellites, LEO, MEO, and GEO. It also shows the orbital speed needed to remain in orbit, the height above sea level, the radius of the orbit (measured from the center of Earth’s mass), and the orbital period, measured in hours. Also shown are the
Fig. 3.1  The edge of space, with the Moon above the clouds. (Image courtesy of NASA.)

Fig. 3.2  Satellite orbits, their orbital speeds, and their altitudes and orbital periods. (Graphic courtesy of Wikimedia Commons: https://upload.wikimedia.org/wikipedia/commons/b/b4/Comparison_satellite-navigation_orbits.svg.)
locations of the inner and outer Van Allen radiation belts. It is clear that LEO is actually very close to Earth, and lies just below the inner Van Allen radiation belt, which sets its upper limits. LEO ranges from just above the Karman line to perhaps about 2,000 km. It is the domain of many polar orbiting remote sensing satellites, the Iridium communications constellation, and is also the area where almost all human spaceflight (except for the twelve Moon missions those 50 years ago) is conducted, including the international Space Station, which is about 400 km altitude. This is also the place where very small, microsats are launched, and it is quickly becoming a very crowded place.

Well above this, and above the inner Van Allen radiation belt, is the MEO zone, which is the domain of the navigation satellites such as the U. S. GPS, Russian Glonass, European Galileo, and others. These are at about 20,000 km (12,500 miles) altitude, and this orbital range is used relatively little at this point. But the GPS navigation and timing satellites in this zone play a vital role in our modern world. As mentioned before, a day without GPS would be a very bad day indeed, given its role in everything from ground and commercial air navigation to timing the Internet and timing stock market transactions.

Finally, much farther out, nearly a tenth of the way to the Moon, lies the very important GEO, which is a very special place. At an altitude of precisely 35,786 km (22,236 miles), the period of rotation of a satellite in this orbit at the equator exactly equals the period of rotation of the planet on its axis. This makes the satellites appear to hang stationary in the sky, and three telecommunications satellites, equally separated around the world, can broadcast to nearly the entire world. A small dish on the ground can be pointed to a fixed location in the sky at a geostationary satellite, to receive a constant stream of TV, movies, and Internet or other data services.

At any other orbital altitude, a satellite’s receiving antenna will have to be able to track the motion. A telecommunications satellite in GEO provides easily scalable broadcast over vast areas of the globe, and can bypass rugged terrain such as mountains or provide coverage to hundreds of islands without cables. It also has an important national prestige factor, and many countries have wanted to launch their own satellites for commercial as well as national pride reasons.

The concept of a GEO telecom satellite is not really all that new. Herman Oberth, the visionary space pioneer, first proposed in 1929 a satellite system using mirrors to do Morse code using the Sun, but it was the exceptional mind of Arthur C. Clarke who first published, in 1945, a short paper called “Extraterrestrial Relays” in an obscure British journal Wireless World [2]. In this paper, he proposes that a group of three artificial satellites, equally spaced around Earth’s equator in this unique GEO orbit, could broadcast a radio message to almost the entire planet (not quite to the North and South poles). Interestingly, his satellites were to be manned, as they would have to rely upon vacuum tubes that would have to be constantly replaced by astronauts (Fig. 3.3).

Not much later, he said: “Comsats will end ages of isolation, making us all members of a single family, teaching us to read and speak, however imperfectly, a single language.” Our global GEO satellites, constantly broadcasting TV, data, and music,
have largely made this prediction come true, and have fundamentally changed our world.

Of course, we all know that the first artificial satellite, Sputnik 1, was launched in October of 1957 by the Soviet Union, and the potential for satellite telecommunications was immediately apparent. The first voice broadcast via satellite was only one year later, when U. S. President Dwight Eisenhower broadcast a Christmas greeting to the world in December of 1958 using the SCORE satellite, which was an Atlas booster with a radio transmitter that relayed his recorded message. Telstar made the first commercial trans-Atlantic broadcast in July of 1962, and the Tokyo Olympic Games were broadcast using the Syncom 3 satellite in GEO, just as Arthur C. Clarke had envisioned, in August of 1964.

It did not take long to realize the potential of GEO telecom satellites. The INTELSAT organization was created in 1964, to foster international satellite telecommunications using GEO, and today we have hundreds of very large and very expensive telecom satellites in GEO, providing a wide range of data, video, telephone, and more. It is the only real space business, and makes many, many millions of dollars in revenue and supports the launcher, ground infrastructure, insurance, and other major space commercial markets. Without the commercial telecom GEO satellites, there would be no space businesses.

However, there are disadvantages to satellite telecommunications that must be taken into account as well. There is a delay of about ½ second for the signal to go up and down, as well as issues of noise or a bit error rate in the data transmission.
across this distance, limited bandwidth, and limits to the power that is available. Another negative is the total cost of buying, launching, and operating a satellite in GEO, which is very high, and the potential loss in a launch failure can be a US$700 million hit to the bottom line. Finally, there have also been several recent cases of intentional jamming of satellite broadcasts by nations who want to control the flow of information into their countries. But the advantages of space for telecommunications, navigation and timing and remote sensing of our Earth are without question.

Beyond Earth orbit is the vast expanse of space. We can travel to the Moon, some 385,000 km (239,000 miles), in about three days with today’s chemical rockets, as it is about nine times the distance of GEO, or nearly 30 Earth diameters away. But beyond our Moon, the distances quickly become difficult to comprehend. Discussions of going to or settling on Mars are complicated by the vast distance to Mars, and it is one of our nearest neighboring planets. Both Earth and Mars orbits are elliptical, and the distance varies throughout the year, but Mars is an average of some 225 million km (130 million miles) from Earth. Sending vehicles, or people, to Mars can only be realistically done using our current chemical rockets during a recurring 26-month launch window, with a transit time of between some 150 and 250 Earth days, depending on the distance and speed. Except for a few planetary probes, going anywhere in person beyond this, at least at present, is simply beyond our capability. Saturn and its moons are over 850 million miles away from Earth. Space is big, and it was a difficult achievement to have a space station just 400 km above the planet. We have a very long way to go, and there has been much discussion about exactly how far we have come in these 50 years since the Apollo landings.

The Three Segments of Every Space System

Every space system consists of three, interconnected segments that vary significantly in cost and complexity according to the goals of the system. These are the space segment, the ground segment, and the user segment. The space segment consists of the actual satellites in orbit, each with their own electrical power, communications, guidance, and navigation sub-systems, as well as the vital payload that is the purpose of the satellite. The ground segment consists of the infrastructure that is required to build, test, launch, and operate the satellites in the space segment. This includes the launch facilities and ranges, the mission control centers, the testing and operations capabilities, the Earth stations and telecommunications networks that both send and receive data from the space segment; all of the data processing, distribution and archiving facilities; training facilities; business offices; and more. Finally, the user segment consists of the data or useful information that is derived from the space segment. This could be a direct broadcast television program on a home TV, a remote sensing satellite image, or a derived product such as fire mapping, a GPS location or moving map display in a car – even a scientific dataset that is used for basic or applied research (Fig. 3.4).
The Space Segment: Satellites

Earth-orbiting satellites are the only, real commercial aspect of space. New areas such as space tourism and extraterrestrial resource extraction may be coming, but at least for now, satellites and the services that they provide are the real business of space. Interestingly enough, the term satellite comes from the ancient Latin *satellus*, which was a servant, often a slave, of a powerful master or lord in ancient Rome. A satellite went running before his master in the streets to clear the way and would do his master’s bidding. The term was used to describe the moons of Jupiter when they were discovered by Galileo in 1610. The planets were named for the ancient Roman gods, and the moons seemed to scurry around them, so servant seemed an appropriate name.

*Sputnik 1*, launched by the Soviet Union on October 4, 1957, soon came to be known as an ‘artificial satellite,’ a very appropriate name. Satellites are the servants of humanity, placed in space orbits to provide us with a range of various capabilities, services, and data. They truly are our servants in space.

Since *Sputnik 1* was launched, we have placed an enormous number of satellites (and a great deal of junk) into Earth orbit and outer space. A total of over 33,000 individual items have been launched into Earth orbit, but the vast majority of these have naturally had their orbits decay over time, and have harmlessly reentered the atmosphere. Today, we have about 13,000 individual satellites in orbit, but just over 1,400 are both functioning and are actually in their correct orbit. Just over 400 of these are commercial telecommunications, with most of these satellites way up in
GEO, the most expensive real estate off the planet, making a pile of money for their owners. Many of the remaining are for defense communications.

Fig. 3.5 shows the distribution of satellites by orbit and function as of 2012. The number of satellites is higher today, but the relative distribution and application remain generally the same. Nearly half of all satellites are in LEO, and 40% are in the magic GEO telecom orbit. Current plans for launching thousands of small satellites in LEO constellations will change the distribution and raise concerns about orbital collisions. There are actually very few navigation satellites in MEO, but this is growing with all the new, national GPS systems being developed. And finally, there are a few scientific or other satellites in unusual elliptical orbits, but very few compared with the rest.

In Fig. 3.5 on the left is shown the purpose of these, with almost half being commercial, military, and civil government communications satellites, as that is where the real utility of space and also where all the money is. Then there are a few civil and military remote sensing (19%), navigation (9%), weather satellites (4%), and a few others. At this point there is only one, permanent human-occupied space station, the International Space Station, with a total of 6 humans onboard most of the time.

Earth-orbiting satellites provide us with the only real commercial space industry today, but this may be changing, as we will soon see. Satellites provide the jobs and applications that make our access to outer space both profitable and beneficial to all the peoples of Earth. In the years since the launch of Sputnik 1 we have mastered Earth orbit, and we have also mastered the building and operation of various satellites and applications that we place there. We have also made a mess of the place, leaving vast amounts of trash and junk up there.
Fig. 3.6 shows a representation of all the satellites and orbital debris currently surrounding Earth. Currently, over 75% of all the satellites in orbit are non-functioning junk, and there are thousands and thousands of additional bits of old launchers, panels, and bits of other debris that are rapidly being recognized as a serious problem. You can clearly see the GEO orbit ring at the outside, and the dense cloud of dots just above Earth show the mass of debris that now litters LEO. The satellites that form a halo extending above and below are primarily MEO navigation satellites such as the U. S. GPS system.

Space debris has emerged as a very serious problem that must be addressed. There are over 600,000 objects in space between 1 and 10 cm in size that are currently being tracked, and we have had five known collisions with satellites and debris or between satellites. The International Space Station regularly has to make small maneuvers to avoid space debris. Major space nations such as the United States, China, and Russia are also developing and testing anti-satellite capabilities, to destroy military satellites in times of conflict. We are rapidly polluting our near space environment, and this is a very serious problem that must be addressed, or perhaps it is a new commercial business opportunity?

The Kessler syndrome is a recent concept that represents a runaway process of space collisions creating more space debris that creates more collisions that could make near Earth orbits unsafe for any human use. This would be a catastrophe, because we have become so dependent upon space telecommunications and GPS
navigation and timing systems for daily life. Once considered an unrealistic concept, this has now gained credence in the scientific community, and it would have terrible consequences if it ever occurs.

Due to the orbital dynamics required to keep a satellite such as the ISS in orbit, it must also be going some 27,000 km per hour (17,500 mph) or about 8 km per second, relative to the surface of Earth. It was Sir Isaac Newton who conceptualized this, long ago. Getting out of Earth’s gravity well and going to the Moon, an asteroid, or Mars will take far more energy than Earth orbit. The escape velocity from Earth is just over 40,000 km per hour; or 23,000 mph.

One of the fundamental challenges for doing anything in space is that it takes a tremendous amount of energy to get a payload, a satellite or a person from sitting still at sea level on a launch pad into an orbital altitude and moving at a velocity of about 8 km per second so it will stay there, let alone to set off for Mars. The only reliable way we know how to do this today is with chemical rockets, and these are complex, dangerous, and expensive devices. If something goes wrong, and there are many things that can go wrong, you will be “having a bad day,” according to space experts. Space is hard. This is why many of the current generation of space entrepreneurs are working hard to develop new, more reliable, and radically less expensive ways to get satellites and people into Earth orbit and beyond.

The Ground Segment: Space Launchers and Launch and Tracking Facilities

All modern space rockets are the descendants of early work by several of the great pioneers of space technology. Key among these was the German Werner von Braun, who, using his 2-ton, liquid fueled A-4 (A for Agregat) rocket, was the first human to place something into what we now consider outer space. This was on an early launch from the German Peenemunde Island test facility on the German Baltic coast, when, on June 20, 1944, a rocket rose some 170+ km above Earth, beyond what we consider to be the boundary of space. For the first time in human history, a manmade object was sent into outer space [3] (Fig. 3.7).

The A-4 had all the basics of a modern liquid-fueled space launcher rocket. It was powered by liquid oxygen and alcohol, had four control fins, and had a gyroscopic guidance system, not to mention a very powerful explosive warhead. Over 3,000 of these were built and launched as weapons in the Second World War.

After the war von Braun and most of his team were brought to the United States and became the core of the American post-war rocket research program. Von Braun’s team had drawings and plans for a piloted version of a winged A-4, and a much larger A-10 design that would have been capable of delivering a warhead to the United States, a true intercontinental ballistic missile. The Soviet Union took the German production facilities and the remaining engineers who could not get to the western areas.
Immediately after the end of the war, both superpowers began their space rocket research in earnest using this highly successful template. In the intense and dangerous era of the Cold War, both the United States and the U.S.S.R. devoted huge resources to develop ever larger and more powerful rockets for intercontinental ballistic missiles, capable of delivering nuclear warheads anywhere around the world. These missiles became the first generation of launchers of satellites and humans into orbit during the U.S.-Soviet space race, which was only one aspect of the much larger battle for post-war dominance that we call the Cold War.

Today, we have a large number of very successful rocket launchers, but they are virtually all variations on this same theme – long tubes full of chemical propellants with a liquid fuel and an oxidizer, powered by rocket engines, controlled with control fins and electronics, and capable of placing payloads into orbit.

A rocket launch into orbit follows the general pattern shown in Fig. 3.8.

In Fig. 3.8 we see a typical orbital launch profile. In this case it is a Delta 2 rocket launching a satellite from the NASA Cape Canaveral facility in Florida. At liftoff,
the rocket launches vertically but quickly steers into its correct launch orientation, out over the ocean and heading into its intended Earth orbital inclination. If it is using solid rocket strap-on boosters, as in this case, they quickly burn out and are jettisoned and fall back into the safety zone off the launch site. These assist in getting the heavy rocket, which at launch is mostly propellant, off the ground and on its way. The main engine(s) then burn out when their fuel is exhausted, and the first stage is also jettisoned. This process of jettisoning stages is to reduce the mass of the vehicle to make the launch as efficient as possible in terms of the energy produced by the engines versus the remaining mass of the vehicle.

The second stage rocket, optimized for the space environment, is ignited, and continues to push the system ever higher and faster. As soon as the rocket is out of the atmosphere, the payload fairing protecting the satellite is dropped, again to reduce weight, and the payload is pushed into the correct altitude and speed required, where the payload is separated from the launcher. The launch is now considered complete. It only takes from 8-15 minutes to take a large, multi-ton payload from the launch pad at sea level to orbital altitude. This is the power of chemical rocket engines. This process can traditionally cost about US$200 million or more, and each launcher was always a use-once-and-throw-away expendable item. The space launch industry today is a US$4.5 billion industry, and it currently costs on the order of US$20,000 to place 1 kilo of mass into orbit, and many of the large, GEO telecom satellites today weigh several tons. Of course, many things can go wrong, so you are betting a massive US$350 million on it all working perfectly. But this is changing rapidly, as we shall soon see.

Fig. 3.8 The Delta 2 launch profile of the Jason 2 satellite. (Image courtesy of NASA.)
The high cost to orbit is one of the great limiting factors in the space business today, and it is the focus of many space entrepreneurial efforts, as we shall see. There is a very high cost of development for space vehicles, with very low production rates. Costs are also raised by the abundant use of very advanced materials, such as titanium and carbon composites, the need for high levels of redundancy and extensive quality control requirements, very complex designs, and very costly components such as throwaway rocket engines, electronics, etc. Many different versions of each vehicle are developed for specific uses such as launch to GEO or for smaller payloads to LEO. The actual cost of propellants for a SpaceX Falcon 9, liquid oxygen and rocket grade kerosene, is only about US$200,000 per launch, so making launch vehicles reusable is having major impacts on the cost of getting into space.

The rocket is not the only part of launching things into orbit. Each rocket is only the most visible part of a much larger system that includes the launch facility and an even bigger launch range. The launch facility provides the infrastructure that is required for the assembly, preparation, testing, and launch of the vehicle and its payload. It requires fuel tank farms, offices, industrial zones, tracking stations, hazardous chemical and explosives storage areas, and the infrastructure required to operate a launch site. Rail lines and airports are usually needed. Security is clearly an important requirement, along with special police and fire/rescue requirements that include special hazardous materials management and disaster response capabilities. The threat of political protests or terrorist attack is a more modern concern that has increased the security net at major launch facilities around the world.

The launch range extends from the launch site all the way down the launch path in the direction of the orbit, and provides a safe environment for the tracking of the rocket ‘down range.’ It requires all the communications, tracking, and telemetry to control the rocket and track it all the way into its intended orbit. There are many safety features required for the range, including facility security, range safety and launch limits to prevent launches over populated areas and launch debris hazards. Weather is another vital aspect, including the measurement of high level winds that can rip a rocket apart miles above Earth. Each rocket must also have self-destruct explosive capabilities, so that a range safety officer can destroy the vehicle if it veers towards occupied areas or becomes a threat to life or property. All of this is very expensive, and a launch range can only accommodate a certain number of launches per year. There are frequent delays caused by weather, equipment problems, or ships or aircraft wandering into the launch zone, and launches can quickly stack up due to these delays (Fig. 3.9).

The original launch facilities were enormous, Cape Canaveral in Florida and Russia’s massive Baikonur facility in Kazakhstan, the granddaddy of them all, were massive. The cost and requirements of these facilities were a major factor in the huge cost of launching into space. Thousands of people were required, and one of the radical innovations of today is the reduction in size and cost of these required launch facilities and ranges.

The launch pad is the heart of the launch facility. This is where the rocket and payload are placed for launch, and it includes the launch table, a flame duct to redirect the hot exhaust, lightning protection, computers and power, testing equipment,
Fig. 3.9  ICBM row at the Cape Canaveral launch facility in the 1960’s, the heyday of testing intercontinental ballistic missiles for the United States as well as NASA launches at the site. (Image courtesy of NASA.)

Fig. 3.10  Pad 39-A at the Kennedy Space Center in the 1970’s preparing for a space shuttle launch. This is the pad where the Apollo 11 crew departed for the Moon and is now the home of SpaceX and its Falcon 9 and Falcon Heavy rockets. (Image courtesy of NASA.)
service towers for the final loading of propellant, and the infrastructure to support what will take place. Each pad has to be customized for a specific type of launch vehicle, again increasing the overall cost. One pad can only be used for one class of vehicle without major alterations, and it can take weeks of refurbishment between launches (Fig. 3.10).

This is the current, Space 1.0, launch paradigm. All of these together, the very expensive and expendable launch vehicle, large and costly satellites and launch facilities and ranges, the control centers, many tons of expensive and dangerous volatile cryogenic fuels, a large and highly trained staff, these all come together to make launching items into space in our current paradigm a hugely expensive, dangerous, and complex activity. Current launch prices are in the range of US$2,000 per pound to LEO, and only a few rockets can be launched per year from each pad. The lead time required to order a launch stretches into years, and one problem or accident, and the entire stack and payload can erupt in a massive fireball, delaying that launcher type for potentially several years as the cause is determined and fixed. This is the key bottleneck that must be broken through to make space affordable and accessible. Doing space in the traditional manner is not anything like the traditional business cases for disruptive technological innovation we discussed before… but could it be in the near future? We will soon see that the answer is yes.

The ground segment also includes the telecommunications capabilities that both control and receive data from the satellites in orbit, along with the integration and testing facilities, mission control centers and operational capabilities. It also includes all of the data processing, distribution and (very importantly) data archiving facilities. These will be covered later, in addition to the various user segment capabilities, where end users actually put the data received to some practical purpose. This could be a national security purpose, scientific exploration, or a commercial or public good purpose such as environmental monitoring.

The Space Environment

Once you get yourself or your satellite into space, taking that short but very exciting 8 to 12 minute ride up, you have many other very unique problems to deal with. The space environment is very hostile for people and machines accustomed to Earth’s gravity and protective atmosphere. Space is a hard vacuum, with a very tiny number of atomic particles and plasmas present in Earth orbit and beyond.

The baseline temperature of space is −270°C (−454°F), but a satellite can quickly heat to over +116°C (+240°F) if a structure is exposed to the direct radiation of the Sun. This large variation between the temperature of a satellite in the Sun and in the shade portions of an orbit, which is usually about 90 minutes long in LEO, creates difficult design constraints. Alternating 45 minutes in the heat of the Sun and 45 minutes in the cold shade is a difficult environment to work in for years, and satellites must be designed to withstand this very radical and unusual environment. You also lose the power generation from your solar panels as well each time
you are in Earth’s shadow, for half of each 90-minute orbit. The radiation levels in space are dangerously high, especially in orbits that enter or are near the inner and outer Van Allen radiation belts, and random cosmic rays can easily disable a vital computer hard drive, so radiation hardening is often required, again increasing the cost.

Space debris, both natural and human-made, are constant threats, as even a grain of sand or fleck of paint can be deadly at orbital velocities. And there is more. Electrostatic charging of materials can easily destroy electronics and computers. Due to small amounts of molecular oxygen and hydrogen in these regions, your orbit will eventually degrade due to friction and Earth’s gravitational pull, so you will require additional energy to periodically boost your satellite back into its intended orbit. Electrical power is generally derived from solar panels, and communications back to Earth requires antennas and radios. You require sensors to determine, and correct, the orientation of the satellite, and, in the end, you need a payload like a remote sensing camera or telecommunications system, to do the useful work.

Space satellites have therefore been very complex and expensive devices, built by hand from the finest quality ‘space qualified’ components. They required large amounts of redundancies built in, as there are no repair shops in space, and if a major component fails the mission may well be ended and a great deal of money lost. Putting humans into this environment is another level of difficulty, with requirements for a pressurized, heated cabin with the appropriate atmosphere and liquid, solid, and gas waste removal, food and water, sleeping and toilet facilities, work areas, and more. Putting humans into space is very difficult and expensive, and, at least so far, only the United States, Russia, and China have developed and flown human-rated rockets and spacecraft. Human space really is hard.

**Dual Use and the Military Paradox**

Many space activities were, and still are, very much related to military and national security activities and requirements. Space provides a unique vantage point for satellite telecommunications, remote sensing, and satellite navigation, and these activities were very much funded and driven by their military potential. Dual use is the term that is used for technologies that have both military or national security applications as well as commercial or ‘peaceful’ uses. Virtually all aspects of space activities, from launchers to the various telecommunications, remote sensing, and navigation applications, are dual use technologies, and this greatly complicates the international policy, legal, and commercial uses of space. Each nation wants to create, maintain, and enhance its national security capabilities, and each also seeks to establish the technical fundamentals for both defense and international commercial competitiveness.

The original bi-polar space race between the United States and the Soviet Union has evolved over the decades into a much broader domain of international space
involvement, but the dual use nature of space remains. Today, many nations have space agencies, and launch and operate a wide variety of satellites and space-related businesses, but the dual use and military nature of space activities colors all space activities, especially in the cooperation and competition between nations. Nations are very concerned about sharing space technologies for both national security and international commercial competitiveness reasons. There is much international espionage within the space domain, and nations (and private corporations) actively seek to acquire classified space technologies developed by others.

The Traditional Space Context: Space 1.0

The traditional paradigm of conducting space has been done in more or less the same way since the launch of Sputnik in 1956. Let us take a look at the current space paradigm.

According to the U. S. Federal Aviation Administration’s Office of Commercial Space Transportation’s 2018 Annual Compendium of Commercial Space Transportation [4], the current global space commercial business is around US$345 billion per year, and growing at about 5 to 7% per year.

Satellite telecommunications is, by far, the largest space business segment. Satellite telecom is the original, and still the largest, space business, and always has

![Image of GEO orbit and telecommunications satellites](image-url)

**Fig. 3.11** The GEO orbit and the location of telecommunications satellites of different frequencies. The large blank area at lower left is over the empty Pacific Ocean, and the areas with many satellites stacked together are over eastern North America, western Europe, and eastern Asia. (Image courtesy of Smithsonian Air and Space Museum.)
been. Within this, direct broadcast satellite television is the largest commercial space sector, at around $100 billion of commercial revenue per year. This is direct broadcast of TV, music, and Internet services using satellites as the broadcast location far up in the GEO orbital ring, as shown below (Fig. 3.11).

The next largest market is GNSS-related services at about $85 billion, or 25% of the total space business. This number includes not only GNSS services such as car, boat, air, and rail devices, but also traffic systems, maritime tracking systems, and the fast growing autonomous vehicle market. If we include all of the millions of GPS chipsets in smartphones, this market could be considered to be over US$100 billion. The GNSS market is also the newest and fastest growing space market, increasing by over 60% per year over the past five years. There are also many uses for the GPS highly accurate atomic timing signal, which is used to time-stamp everything from Internet email packets and stock market trades to managing power distribution networks [5] (Fig. 3.12).

This is followed by other satellite services that include fixed and mobile telecom services, and broadband (Internet) services. Broadcasts to ships at sea and aircraft are included in this segment. The ground infrastructure business makes up some $29 billion annually. Somebody has to operate all these systems, and space provided good paying jobs. Satellite manufacturing is a $14 billion industry worldwide, and it fluctuates each year with the demand primarily for large, GEO satellites. Again the shift to launch thousands of small satellites in low Earth orbit constellations will shift the emphasis, but the global revenues for satellite manufacturing will perhaps not be greatly altered.
Although satellite launching is the most visible part of the space sector to the public, and clearly the loudest, it is a relatively small part of the total space sector, at only about $5.5 billion per year. At this point, only 12 nations have satellite launching capability, although this is an area of growth, especially for the rapidly developing small satellites and cubesats. In the past it was the major launch consortiums such as Ariane Space and the Boeing (i.e., Delta) /Lockheed Martin (i.e., Atlas) United Launch Alliance group, along with Russia and China, who traditionally launched the majority of satellites into orbit. Satellite remote sensing remains the smallest commercial space sector, but it is still a major business, worth about US$5 billion, and this sector continues to grow with new, higher resolution systems and new applications for the imagery data.

Smaller space activities include the insurance of launches and satellites in orbit, consulting and training services, data analysis, and governmental and academic pure scientific research. All told, the space sector is a mature, varied, and global set of interlocking businesses, and it is growing steadily and strongly. It is also in the process of being significantly disrupted, as we shall soon see.

You can see from Fig. 3.13 that the majority of the commercial space businesses lie in satellite telecommunications. Satellite services include primarily geostationary satellite services, which themselves are divided into fixed, mobile, and direct systems. Satellites today carry a significant amount of global voice, video, and data, including rural telephone, Internet trunking, and private corporate networks. Virtually all cable TV systems incorporate satellite systems to distribute their feeds, even though your TV is connected to a cable.

There is a wide range of satellite-provided services such as distance learning, tele-medicine, and tele-presence applications, and communications at sea and in the air. Voice over Internet, or VOIP, now carries much of the world’s telephone traffic,

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Fig. 3.13  Chart of space industry spending by market. (Image courtesy of the Tauri Group.)
and much of this is carried by satellite. The direct-to-customer market provides broadband Internet, data, television, radio and video around the planet. It also includes the growing LEO telecom constellations such as Iridium, Globalstar and Orbcomm, and all of the newly proposed constellations we will soon discuss. Satellite radio has become a major market in the United States, but has yet to catch on globally. And there are new and exciting applications on the horizon.

Although fiber optic provides the majority of these services globally, in remote areas such as the Pacific and other island regions and in the more sparsely settled parts of our planet, satellites are very competitive, due to their ability to broadcast to a broad area without expensive ground infrastructure. These are the commercial telecom markets, and they are worth billions of dollars of revenue each year. National governments, including but not limited to their militaries, are also major users of satellite communications networks.

The recently emerging satellite positioning, navigation, and timing (PNT) market is the second largest commercial space application, originally created by the launch of the U. S. NAVSTAR Global Positioning System, or GPS, in 1979. Global Navigation Satellite Services, or GNSS, is now a US$100 billion commercial market providing a growing range of products and services. These include car, marine, and aviation navigation and positioning, commercial fleet management, emergency services, search and rescue, mapping, time-based systems, and the newly emerging location-based services (LBS). Also included are all of the GPS chips in the millions and millions of cell phones and other systems. GNSS systems, including the U. S. GPS, Russian Glonass, and the yet to be completed European Galileo, Chinese Biedou, and Indian IRNSS, make up a vital, global infrastructure.

A growing and important application is timing. GNSS is at its heart a very accurate timing system, based on atomic clocks, and so it provides a wide range of precision timing services, such as power grids, Internet packet timing, financial transactions, and more. This is not to mention at all GPS-based businesses such as Uber and Lyft, and the emerging self-driving car and truck applications. All of these are dependent upon the free availability of the GPS signal, which is provided globally by the U. S. government without cost.

The third major commercial space market is space remote sensing and digital image processing and derived, value-added products. Remote sensing is as old as the origin of the space age, as this business derives from the original U.S. and Soviet spy satellites that made up a large percentage of the early launches of the space age. Modern space remote sensing is a small but growing commercial business, providing very high spatial resolution imagery of our Earth for a variety of markets, including urban and regional planning, agriculture, forestry, pipeline monitoring, disaster management and response, water quality, ocean monitoring and more. The total international commercial market is about US$5.5 billion, and it is growing at a healthy 11% per year.

A significant part of the space remote sensing domain is the important environmental capabilities that it provides. These range from the very local all the way to global land, water, and atmospheric analysis. These are scientific and public good activities, rather than commercial, but they are a vital part of the benefits of space.
Of course, national security space remote sensing (spy satellites) make up a massive, hidden part of space activities and budgets, and the dual use nature of all this cannot be underestimated (Fig. 3.14).

Also up in the GEO orbit, along with all of the commercial and governmental telecommunications satellites, is a ring of government-operated weather satellites that provide global and constant monitoring of our planet’s weather, including severe weather events such as cyclones, hurricanes and severe storms. Although not commercial systems, these government-operated satellites, currently operated by the United States, Europe, Russia, India, Japan and China, feed global weather and climate data into a vast network of national weather services that provide the raw data for commercial weather companies and services around the world. Global weather data forecasting and products support everything from disaster planning to agriculture and ocean shipping. This sector is generally considered a public good and not a commercial market, but it drives a wide range of commercial weather services that depend upon these GEO satellites.

To learn more about all of these various space applications, see the comprehensive, 1,200-page Handbook of Satellite Applications (Second Edition), a two-volume reference work by the author and his colleagues, Prof. Joseph Pelton and Sergio Camacho-Lara [6] (Fig. 3.15).
Who Does Space?

From the beginning of the space age, space activities have been primarily directed and funded by the governments of the major economic and military powers of the world. The Cold War ‘space race’ of the 1950’s and 60’s pitted the old Soviet Union against the United States, with other major economic powers such as Europe and Japan joining in somewhat later. In the West, the United States developed their early space program, and most work was actually contracted out to the major aerospace corporations with funding and program management by the government agencies such as NASA, DOD and, rather later, NOAA and the FAA. In the past decade, there has been a significant broadening of the field, with newly emerging China, Brazil, Nigeria, the United Arab Emirates, and others establishing significant government space programs.

Some of the most exciting recent developments are ever smaller satellites, down to tiny 10 X 10 X 10 cm cubesats, which have opened up space to nearly everyone. Developing nations around the world are now actively involved in space work, including governments, universities, small startups, and businesses. You will read much more on smallsats later.
Government space programs, largely for national security, human spaceflight, and scientific purposes, remain a significant part of the total spending on space, at about US$70-80 billion, or a quarter of all space activity. There was recently a total increase in this spending, but it is now a far smaller percentage of the total space expenditures than just a decade ago. It will continue to decrease as a percentage of all space activities, as more commercial space programs grow and mature and replace governmental programs.

A recent study by Euroconsult [7] shows the total global space budget of all governments combined to be some US$62.2 billion in 2016, with some 70 countries spending these funds. This is up from 47 nations only a decade ago, so space is growing out to include many more nations than before. The same study also projects that over 80 nations will be spending some US$79 billion by 2026, a very significant increase in both the number of countries involved and the total amount spent. Human spaceflight by the United States, China and Russia makes up the largest total governmental space expenditure, with over US$11 billion being spent by these three nations alone for the operation of the International Space Station and their other human spaceflight operations each year, along with the smaller astronaut programs of ESA, Canada, and Japan. India and the UAE have recently created astronaut corps of their own, and more nations may follow as the cost to orbit decreases. But human spaceflight is very expensive and will remain so, largely due to the conservative nature and redundancy that is required when human lives are involved. Losing an expensive satellite is one thing, but losing a spacecraft and crew is something very different.

The largest national civil space program remains the United States with US$39 billion spent on civil space. NASA only received about half of 1% of the total U. S. budget, with the 2019 budget proposal being some $19.9 billion. This far exceeds any other national civilian space budget, but it is only a relatively small part of the total U. S. space budget. The unclassified national security space budget for the United States is around $12.5 billion, according to the 2018 federal budget, with the majority, over $11.4 billion, going to the U. S. Air Force for their military space activities [8].

The U. S. ‘black’ or classified space budget is, of course, not made public, but the NRO, or U. S. National Reconnaissance Organization, which manages the nation’s spy satellite programs, has an annual budget that is estimated at something over US$15 billion per year for this one agency alone. There are also significant black space budgets for each of the individual military services, NSA, and others. This would make a combined U.S. space budget of something over US$46 billion per year, making it by far the world’s largest national space budget. Nothing else even comes close.

Fig. 3.16 shows a graphical representation of national space spending as of 2016, compiled by the Euroconsult group (euroconsult-ec.com). Other nations’ space budgets are also significant, but are far below that of the United States. China is the second largest spender on space today, with a public budget of some US$5 billion. This is probably more like US$11 billion in total, if you add their equally large, hidden military and black programs. The European Space Agency has a budget of some US$7 billion, made up of contributions from its 22 member states. And this is
followed by the combined individual national European space budgets at US$4.5 billion, and then Russia at just over US$3 billion. India and Japan also have space budgets of over $2 billion.

There are many, many new entrants into the space world, with nations as varied as Brazil, South Africa, Nigeria, Australia, New Zealand, the United Arab Emirates, South Korea, and others having NewSpace agencies and programs, all with quite small but growing space budgets, at least when compared with the United States or ESA.

Another recent report, produced by the Space Foundation, estimates the total global space budget, both commercial and government, to be some US$329 billion in 2016 [10]. This study has $253 billion, or 76% of this, being commercial business activities, with the remainder as government space programs.

Commercial telecommunications satellites are operated in the GEO orbit by a surprisingly small group of international launch service companies. These include Eutelsat, Inmarsat, Intelsat, SES, and Telesat. Interestingly, Intelsat and SES are both headquartered in Luxembourg, which itself has a tiny new space agency, and a token participation in ESA’s overall budget. But it does have very good tax laws, and it has a robust and growing NewSpace cadre of start-ups with support from the government, as we shall see. There are also over fifty smaller, commercial satellite operators around the world, including several in the developing world, and many national telecom agencies. But the majority of the GEO business is managed and operated by these big five players. Direct to home (DTH) services are run by value-added firms such as DirectTV and other TV services around the world. The DTH
market generates very efficient revenue, using far fewer satellites to cover large areas, as opposed to other satellite telecom services such as mobile services (to ships and aircraft), for example. DTH satellites in GEO are money-making machines, far out in space.

The design and manufacture of telecom satellites has traditionally been dominated by a few, major aerospace corporations in the United States, Europe, and in Japan. These include Airbus Defense and Space and Thales Alenia Space in France, Boeing and Space Service Loral (SSL) in the United States, and MELCO in Japan. They have specialized in the design and construction of these very large and expensive GEO telecom satellites, each costing hundreds of millions of dollars to design and build and an equal amount to launch. These are the basis for the global satellite telecom infrastructure, and each can earn hundreds of millions of dollars in profits over their lifetimes of 15 years or so. There is also a large second tier group that builds smaller satellites, including Ball Aerospace and Orbital ATK, now owned by Grumman, in the United States and Surrey Satellite Technologies in the U.K., which is now fully owned by Airbus Defense and Space. These companies design and build smaller research and application satellites, many of which are launched into the LEO orbits. In addition, there are many smaller groups, including a growing number of universities, that build small satellites and the new cubesats, which will be discussed in more depth later. In all, the United States has over 60% of the global satellite building market, followed by Europe. All others are very small players, but this may change in the very near future. This revolution has already begun (Fig. 3.17a, b).

![Image of a state-of-the-art Boeing GEO satellite](image)

**Fig. 3.17 (a, b)** A state-of-the-art Boeing GEO satellite, in its launch and orbital configurations. This huge satellite weighs over 6,000 kg at launch and extends to measuring some 8 X 48 m in orbit. It carries 36 individual transponders, plus several spares, all for direct TV broadcast. (Graphic courtesy of Boeing.)
However, this is changing, as we will see in a following chapter, with the advent of much smaller and less complex smallsats and even tinier cubesats measuring only 10 X 10 X 10 cm, or even smaller.

The ground segment consists of all the satellite TV dishes, uplink stations, computers, and other facilities that are needed to operate satellite systems, as well as the millions of ‘pizza dishes’ that are purchased for satellite TV and small car systems for mobile radio services. It also includes the training and program management, testing, simulation, and research and development aspects of the global satellite business. Traditional players in the space ground segment include Scientific Atlanta, Harris, Hughes Network Systems, and ViaSat, among others. Russia, China, and Brazil also have their own sets of ground segment manufacturers, and this is a relatively simple sector for new entrants to make inroads.

GNSS devices and individual GPS chipsets are a major and growing part of this ground segment market. Literally millions of GPS chipsets are now added to smart phones, tracking devices, car navigation systems and more. GNSS car, marine, and aviation devices are a very large and growing commercial market, led by Garmin and Trimble in the United States, TomTom and Leica Geosystems in Europe, and Huawei in China. Many firms build GNSS chipsets for OEM sales, which are built into a wide variety of products. Again, Russia and China maintain their own manufacturing capabilities that generally are not available in the west.

It is important to note that the satellite launch industry, which figures so prominently in the activities of our current space disrupters, is actually a relatively small segment of the overall space industry, about US$5.5 billion [11]. This has been traditionally dominated by the major launch providers such as Arianespace in Europe, the United Launch Alliance in the United States (which is made up of Boeing and Lockheed Martin), the International Launch Services of Russia (which markets Russian Soyuz and Proton rockets internationally), and China’s Long March launchers. Arianespace had over 40% of the commercial launch market in recent years, but SpaceX has taken a large amount of the global launch service due to its reduced cost structure. A total of only 12 nations have ever launched their own satellites, and India also has a GEO and LEO domestic launch capabilities. There is an entire new group of NewSpace launch options in development, many of which are designed for the upcoming small satellite constellations that are in development. The high cost, danger of delivery payloads into orbit, and lack of options for launching into space have been key limiting factors that restrict the entire space sector.

The satellite launch insurance providers are also an important part of the space launch business, as all large telecom satellite launches are an all-or-nothing gamble, and a launch failure could cost half a billion dollars, not to mention the loss of revenue over the fifteen-year lifetime of a commercial telecom satellite. Launch insurance is very expensive, but can certainly pay off in a loss. Some choose to gamble and not pay for launch insurance, and many nations ‘self-insure’ their satellites at launch. As we move into a more broadly commercial space paradigm, the insurance and legal issues will become even more important as more companies, smaller companies, and more international players become involved.
Lastly, we have the large and growing number of governmental, non-commercial space programs, including human spaceflight, space science, and military and national security activities. Much of this work is still done by large aerospace contractors. So overall, the space sector is a major business today, and continues to grow.

It is important to note that each of these applications — telecom, PNT, and remote sensing — are based upon common elements of basic physical science, engineering, technology, business practices, regulation, and more. They also are enmeshed in a web of space policy, legal, business, trade, and national and international regulatory contexts.

The dual use nature of all space activities is unavoidable, and plays a role in all of the national and international regulatory and political facets of the space domain. Traditional space has been focused on large agency and large aerospace corporations doing low risk, low volume, and very expensive programs. Price was not really a key focus when the government was the only customer, especially in military and national security programs. When you are designing and launching spy satellites worth a billion dollars each, cutting a bit of cost makes little sense, either to the government customer or the corporate managers answerable to their shareholders for a healthy return on their investment. Big government space programs do not lend themselves to cost cutting, efficiency, or radical new ideas.

This is the world of Space 1.0, the existing and prevailing space paradigm, and it is being rocked by a revolution in both technology and mindset. Space 2.0, NewSpace, has arrived, and space will never be the same, as we will see in the following chapter. Disruptive innovation has come to the space community.

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The term NewSpace, or Space 2.0, has been used to describe a new revolution in space businesses and private sector space actors. These terms generally refer to a completely new paradigm and approach to space activities. It is partly generational, and partly driven by new technological, cultural, and economic realities.

NewSpace embodies a radical new approach to space. It is driven by a very different younger generation, and it is an overtly entrepreneurial, private sector approach to how to do space. It is much more connected to the ‘left coast’ Silicon Valley entrepreneur-driven world than to Washington, D.C., governmental bureaucracies, regulations, and major aerospace corporations.

NewSpace is about millennials and non-traditional ideas, approaches, and goals for space. It has turned the space domain on its head in the past few years. And this trend, if anything, is accelerating. The most visible face of the NewSpace revolution is a group of Internet/tech billionaires who are driving this with their own millions, outsized personalities, and entrepreneurial business expertise. There is also a much larger, if less well funded, group of young innovators who are creating a wide range of new businesses and services using a marriage of space and IT. All of the major, existing space players around the world are struggling to react to this, with varying degrees of success.

Most, if not all of these NewSpace innovators have little or no experience in traditional space organizations or agencies. New groups of innovators, investors and practitioners are entering the field with new ideas, new approaches, and new money. We are right at the beginning of this revolution, and it is a fascinating time to be involved.

NewSpace was initially dismissed as a fad, a fantasy, crazy California dreaming, and not to be taken seriously. “A bunch of kids who don’t really understand how things are done. Boy, will they crash and burn,” some said. But NewSpace is now considered a very real threat to the existing status quo of government funding and large aerospace and defense contractor-driven space activities, and it may be too late for the existing dominant players to react successfully, just as it was for those we discussed in Chapter 2 of this book. Disruptive innovation has come to the space
domain, and things will not be the same. In this chapter we will review the current status and future of NewSpace, and look at many of the better and lesser known players and applications, and we will look at all of this through the lens of disruptive innovation, as presented earlier.

What exactly is NewSpace? There are many different definitions, depending on who you ask, but they all have several common themes:

- A Silicon Valley start-up mentality, without the limitations or older views on how space can be done.
- Entrepreneurial risk-taking vs. bureaucratic risk adverse cultures.
- Break through the cost barrier of access to space and the use of space technologies through economies of scale and efficiencies of production.
- Commercially driven decision-making vs. government agencies and bureaucracies.
- Generational and cultural differences, a youthful and different viewpoint.
- An open IT approach, rather than careful and redundant aerospace engineering.
- Release early and often, constant innovation and upgrading, rapid prototyping and launch.
- Expect rapid change and innovation, drive the cycle quickly, move quickly.
- Open Source and commercial off-the-shelf (COTS) software.
- Focused on the end-user needs and not the technology.
- Apps vs. computer programs, or smartphones vs. mainframes. Often summed up as: “It’s all about the Apps.”
- On-board pre-processing and fast delivery of useful information rather than raw data, using new and non-space systems developed in medical and other areas of technology.
- New, radical breakthrough disruptive approaches that are now happening (SpaceX, Planet, etc.) with more on the way.
- Disruptive space technologies, with an emphasis on the disruptive breakthrough gain, rather than a 5% improvement.
- Tech investment, crowd-source funding of startups, space angel investors, citizen science and crowd-sourcing of data.

One of the key characteristics and drivers of NewSpace is the funding of new startups with angel investors. According to the FAA, venture capital and other investment in space startups was the highest ever recorded in 2016, and 2017, and 2018 seems likely to be even higher. These indicators were based on over 100 individuals and groups investing over US$2.8 billion (yes, billion) into over 40 NewSpace ventures in 2016 alone. The new investments include startup financing, debt financing, as well as existing business acquisitions. The average commercial deal size was also 50% larger than the year before. The trend for 2017 and 2018 is expected to significantly surpass 2016 [1]. This is a tremendous sea change in the space domain.

Another recent study showed that over 75% of all venture capital investment in space was coming from funds in the United States. Other sources of funding around the world were under 10% of the total from any other country. NewSpace is a very
American concept in origin, perspective, practice, and funding. But it is spreading to other countries such as New Zealand, and the United Arab Emirates.

It has also been, until quite recently, a fringe movement within the space community, driven largely by a small group of space enthusiasts located in and around Silicon Valley in California, and it has not been considered to be serious by many in the established space world. There is often what seems to be an outsider mentality. NewSpace enthusiasts see themselves at odds with space agencies and large corporations. They are very much the underdog, and they very much like that role.

And it is not only in the United States that the NewSpace movement has not been taken seriously. Europe, in particular, has had a very difficult time adjusting to and responding to the NewSpace concept and threat that it poses. Europe’s space programs are deeply rooted in cooperation between government agencies, public funding, and major aerospace corporations. Drivers for this European approach to space include national pride, a desire for independence from the United States, the need for good-paying and stable hi tech jobs, stable industrial manufacturing policies, and general economic and broader political benefits for Europe. These are the key aspects of traditional European space programs in both the EU, at ESA, and at national levels, with major space players such as France, Germany, and Italy.

The Wild West, Silicon Valley approach to space as just another type of venture capital tech business runs very much counter to the European traditional world view and experience. This is especially true as high-tech commercial startups require significant risk, and the potential impacts that the failure of a new business can bring are viewed very differently by European businesses. In Silicon Valley, past failures are expected and even appreciated by investors. Nobody is expected to get all this right the first time, and there is an assumption that there is a long learning curve to entrepreneurial success. A single bankruptcy or business failure in many European nations carries a major stigma that can preclude future access to getting contracts or funding. Thus, a more risk-adverse approach is required. You had better not fail, and you need to play within the system and its established rules.

Europe in general also originally dismissed NewSpace, saying that it was just an American fad, and Europe did not recognize the revolutionary nature of the change that was taking place. Europe values stability and creating stable and nationally based capabilities within the larger, European community, all well planned and properly coordinated. The plethora of individual, national space agencies and commercial entities, within the larger ESA and EU context, has made it far more difficult to respond to the new threat, once it was recognized to be a threat, and even ESA has established a small presence in Silicon Valley to try to understand how this strange and dangerous beast works.

One telling example of this was a series of statements by Alain Charmeau, the chief executive of the Arianne Group, operators of the very successful Ariane 5 and developers of the new Ariane 6 launch vehicles. In an interview with the magazine Der Spiegel in 2018, Charmeau clearly expressed his reservations about SpaceX. While blaming the U. S. government for subsidizing SpaceX, later in the same interview he admits that Ariane cannot exist without significant subsidies from European governments for the launch services they provide.
Chameau also made a very telling statement regarding reusable launchers such as the Falcon 9. When asked if Ariane will begin reusing launchers, he stated that this would not be possible, due to the need for jobs and reliable schedules. It would take on the order of 33 launches per year to be cost-effective, and he foresees only 5 to 8 guaranteed launches from Europe per year in the near future. He said (in an automated English translation) “If we had ten guaranteed launches per year in Europe, and if we had a vehicle that could launch ten times, we would build only one rocket per year. That makes no sense at all. I cannot tell my teams ‘Goodbye, we will see you next year after building one rocket’ [2].”

This is the fundamental problem facing the established European space agencies and space players. They function in an environment where stability, minimal risk, and stable and high-paying jobs are major political drivers and overarching realities. European producers of space systems face a daunting economic challenge. SpaceX can launch a Falcon 9 for around US$60 million, far below the cost of the current Ariane 5. So Ariane is now developing the all-new, solid-fueled Ariane 6 to more capably compete, but it will still cost some 20 to 25% more than a Falcon 9, and will not even be available until well after 2020. Space is hard.

Obviously, Russia and China are also very different environments for entrepreneurial space activities. Both, while maintaining robust space capabilities and political support, do not have the same entrepreneurial environment for commercial space development.

However, many new players are taking advantage of this change and are getting into the space game. The UAE, the United Arab Emirates, has decided to quickly become a significant player in space, the first in the Arab world to do so. It has dedicated very large amounts of governmental funds to invest in a wide variety of programs, and this has support at the highest levels of the government. A UAE space agency has been established, and funding has been provided to several universities to enhance and create space curricula and research centers. An astronaut corps has been established, and the first UAE astronaut will fly in 2020 on a Russian Soyuz to the International Space Station. It has also created a new fund to support the creation of private sector space activities and is also looking at establishing a space tourism industry; there are certainly plenty of people in the region who could take advantage of this.

Australia is another interesting example of how some nations are radically altering their views about space and their role in the future of space activities due to the NewSpace revolution. It had traditionally taken a very hands-off approach to space and only very recently decided to even establish a space agency. Its approach was to let the United States, Europe, and others develop and launch space systems, and to simply be a user of space applications such as remote sensing, navigation, and telecommunications systems. It incurred no cost and derived significant benefits, and there was a strong bias against creating a local space capability, along with an unusually strong, even unique, bias against the idea of a national space agency. This has changed over the past few years, and now there is a small but thriving space capability, and their new space agency will begin operations in 2019 in Adelaide, South Australia, which is the home of much of the NewSpace activity down under.
The International Space University now runs a summer space program in Adelaide, and Australia, which was one of the earliest launch sites at the beginning of the space age, has rediscovered what space can mean for its future.

Very close to the land down under is New Zealand, who is making a very concerted effort to develop an innovative new economy that definitely includes space. The New Zealand space agency was created in 2016, and it has actively pursued a very active approach to drawing new space sector involvement through positive licensing and commercial incentives. Rocket Lab is actually a U. S. company, but it has a New Zealand subsidiary that has established a private launch facility on the Mahia Peninsula. Rocket Lab has successfully launched its two-stage Electron small launcher rocket, using its own, internally developed and built liquid fuel engines. The engine, called Rutherford, is built largely using 3D printing technology and is sized for small payloads such as cubesats. Its first successful commercial launch has been completed, with 24 small satellites, including satellites from NASA, successfully put into orbit. There are other space activities, including a governmentally funded Centre for Space Science Technology, which seeks to develop innovative space satellite data for economic growth.

New Zealand is also a leader in the use of Open Source software for remote sensing and Geographic Information Systems (GIS) data and analysis for public and private use. The government there is proactively backing entrepreneurs working in the space and other high-tech sectors, and seeks to create New Zealand as a global center of excellence for knowledge-focused business development. In this global and interconnected world, business can now be done from anywhere, and New Zealand intends to capitalize on this by creating a high-tech ecosystem that will attract new, clean, information age businesses and jobs. Most interesting of all, New Zealand has established the Sir Edmund Hillary Fellowship program, which seeks to draw innovative and creative minds from all over the world to establish a new, digital economy. People who are admitted into the program have the possibility, ultimately, to seek permanent residence in New Zealand.

Perhaps more than any other, New Zealand embodies the radical change that NewSpace is bringing. No one ever even thought of it as ever being a player in space, but in the world today, anywhere on the planet with high speed Internet is just as good as the traditional space centers, and small players can innovate much, much faster. New Zealand, over 10,000 km from the U. S. west coast, has put into place very quickly an advanced regulatory perspective and business initiative that would be impossible in a larger, more established nation. It is working very hard to bring innovators from around the globe there. It will be interesting to see how this all plays out, but New Zealand is making waves, and is demonstrating that the playing field is now leveled, and that small and nimble nations can achieve great things in space if they are willing to be bold enough to make a commitment to do it.

And these are only a few examples. The challenges of creating space startups in other, less developed regions such as Africa have a host of economic, cultural, and regulatory challenges. How to extend these concepts to other cultures and regions will be discussed in a later chapter.
This all goes back to the very concept of disruption presented at the beginning of this book. Established players initially do not recognize the threat, and it was outside their experience and comfort zone. They dismissed the threat as not serious, they knew their business, and thus, both American and European governments, space agencies and major aerospace companies have been very slow and ineffective in reacting to the very real threat NewSpace presents. These all, for their own reasons and from their own perspectives, have had a very difficult time devising strategies to counter all this, and it will be interesting to see how this all develops, but the stricter European business culture and regulatory environment clearly plays a part in its difficulty reacting to NewSpace. At the same time, other, new entrants are seeing the opportunity and are making big waves in unlikely places.

**Technology Push vs. User Pull**

One of the key issues in all technology, but particularly in the space domain, is the issue of technology push vs. user pull. The computer world, and all of high-tech, tends to push their newest, greatest toys on the end user community, with little regard or interest in how it is actually going to be used. They just throw it out there. Faster is better, newer is better, more is better. People will find things to do with it. Give it a try.

The tech push model assumes that a new technology will be used, and that new applications will be developed if you make it available. It also assumes that almost any new technology is worth developing, with little concern about the potential negatives or downsides. The tech community believes that the development of new technologies is inherently worth doing, and will be, in the long run, beneficial, or at least will be neutral. The issues of what can be done are much more interesting than what the implications may be. The costs are often not considered until a major problem is discovered.

The end user pull approach, on the other hand, has the end users of a technology, such as a government space agency, drive the requirements that are desired. This process identifies a specific need and then allocates funds and research capabilities to develop that capability as it was identified. Contractors develop to order, and deliver what was requested; it is a much more structured approach, and one that inherently lacks the bursts of radical innovation seen in the tech push model. So even though space is a very complex, difficult, and expensive business to be involved in, a radical new approach has arrived, NewSpace, which has very different perspectives, goals, and toolkits.

Next, we will look at several examples of NewSpace disruptive innovators and innovations that are rocking the space world and that are changing aspects of our lives here on Earth. Space is becoming an important part of the future plans of many nations around the world who have traditionally not been involved. The space economy could grow to over US$1 trillion by 2040, from the current level of US$385 billion.
billion. The vast majority of this growth will be in the private sector, and it will be much more broadly distributed around the planet than ever before [3].

Next, we will look at several case studies of disruptive innovation in the space sector, similar to the examples that were presented in Chapter 2. We will look at how disruptive innovation is breaking the mold of how space is being done today, and how this will change how we do space in the future.

Case Studies

We will now present several case studies of disruptive leaders, technologies, and business approaches that are altering the international space landscape. We have looked in the previous chapter why and how space is such a difficult and expensive place to work, and how we have traditionally done space activities. Now we will consider the new generation of space entrepreneurs, such as Elon Musk and SpaceX, Jeff Bezos with Blue Origin, Richard Branson of Virgin Galactic and Virgin Orbit, Robert Bigelow and his inflatable habitat concepts from Bigelow Aerospace, and finally Dr. Peter Diamandis of the X Prize, all with regard to their innovation in the use of reusable launch stages and engines, habitats and more [4]. This will be followed by a brief discussion of some of the less well known, and yet well-funded, young innovators with space startups who are reshaping the commercial space landscape. We will review and analyze the emerging world of microsatellites, nanosatellites, miniaturization and large constellations, and the major shift from large, expensive, and complex satellites to ever-smaller cubesats in the remote sensing and telecommunications applications. This will include Planet (formerly Planet Labs) and other innovative remote sensing constellation developers, and similar telecommunications systems also relying on large constellations of small and inexpensive satellites in low Earth orbit. Finally, we will also consider the use of new materials, the development of additive manufacturing in space, and other recent innovations that are on the horizon (pun intended).

Elon Musk and SpaceX

Today there are a total of some 90 launch vehicles available for use, ranging from small rockets for cubesats to the most powerful launchers capable of reaching beyond Earth orbit. By far, the three most chosen commercial launchers are the U. S. SpaceX Falcon 9, the French Ariane, and the Russian Soyuz. Other launchers from China and India also have the ability to reach all orbital ranges, including GEO, and maintain a busy launch schedule.

In 2017, a total of 90 space launches were conducted by only seven nations, with the United States conducting 21 of these. The others were from France (ESA), Russia, China, and India, Japan, New Zealand, and North Korea. There were also
five launch failures in 2017, so launch remains a risky business. One remarkable event was the launch by an Indian launcher of a total of 83 small satellites from one launch in January of 2017, setting a new record.

For a comprehensive review of current and planned launchers there is an FAA document [5]. What is extraordinary is that there are over 50 new launch vehicles in development today, ranging from very small launchers to massive rockets designed to go to Mars. With the advent of very small satellites and large LEO constellations, there is a rush of new, very small launch systems in the works to service this new market. Many of these will never become viable projects, but we will have to see which can stand the test of time. In the disruptive innovation model of NewSpace, it is assumed that some efforts will not succeed, and that is part of what is so revolutionary.

**Elon Musk and Reusable Rockets, Spacecraft, and a Mission to Mars**

Elon Musk is clearly a very successful serial entrepreneur, with a personal gift for both starting bold new ventures and maintaining a very high visibility in his activities. Originally from South Africa, he holds both South African, U. S., and Canadian citizenship, and, as of 2016 was ranked 21st on the Forbes list of the world’s most powerful people. He has an estimated net worth of some US$22.8 billion, making him the fifth most wealthy person on the planet (or any planet) [6].

Musk started his entrepreneurial activities with a web software venture called Zip2, which was later acquired by Compaq for US$340 million in 1999. He then started X.com, one of the very first online banks, in 1999. This was one of the very first online banks in the world and was funded at first by Musk and also by his business mentor Greg Kouri, who also played an important role later in SpaceX and Tesla. Musk later merged his X.com with the Confinity electronic banking startup of Peter Thiel and others to create PayPal. The two teams had been major online payment competitors, but found a common purpose and chose to join forces.

PayPal, located in San Jose, California, became very successful, and went public in 2002, generating some US$61 million in revenue to the founders. It was then quickly acquired by eBay just after, for some US$1.5 billion, in order to foster a simple and reliable e-banking and funds transfer mechanism for the eBay platform. It was later spun off from eBay in 2015 into a private company, but the success of PayPal was huge, as was the payoff to its founders, and this laid the foundation of what was to come.

The sale of PayPal to eBay provided Musk with the resources to be able to pursue other venture interests, and he has started a surprising number of very innovative, even daring, companies. These include, in chronological order, the Space Exploration Company, better known as SpaceX, in 2002, the Tesla electric car company in 2003, SolarCity solar power company in 2006, OpenAI in 2015 (focusing on the potential
benefits of artificial intelligence), the Boring company in 2016 with its underground hyperloop transportation concept, Neuralink in 2016 (focusing on human brain and machine interfaces), and several other new ideas are in development.

In all of these, his main preoccupation and passion seems to be twofold. One is to change the way humans interact with our planet, such as the ending of the fossil fuel economy and its replacement with a solar-powered or other sustainable energy global economy. His second focus clearly is on space and his desire to see humanity become a spacefaring and multi-planet species. To achieve this his emphasis is on developing vertically integrated launchers that radically lower the cost of access to orbit and ultimately colonizing Mars in the near future for human occupation. He has stated repeatedly that he wants to make ours a multi-planet species for the safety and redundancy that this provides, in case of a global threat such as Earth being hit by an asteroid or other catastrophe. Many others have considered this, but Musk is actually taking steps to do it. Many doubt his ability to achieve this, but others point to what he has already accomplished.

Elon Musk started SpaceX in 2002 with an estimated US$100 million of the funds he earned through his very successful PayPal venture, which was later sold to eBay. The story is told that Musk flew to Russia to purchase a Russian commercial satellite launch, but was surprised by the cost of what was at the time the cheapest launch option in the world. On the long flight home, he decided that he could design and build his own launcher to revolutionize access to space by making the system reusable, and also by controlling all aspects of production, including building his own rocket engines. Shades of Henry Ford and Malcolm McLean.

Many, including all of the major launch operators and space agencies, dismissed Musk and SpaceX as kids playing with big toys, who knew nothing about this difficult and dangerous business of building and launching rockets. But SpaceX, even after weathering several initial failures, has done what Musk had promised, and he has revolutionized the commercial space launch business. He has developed the first reusable launch rocket, flown the first commercial space capsule that is human rated, recovered and reused the first stage of an orbital launch, made the first commercial flight to the International Space Station, flown the same supply capsule to the ISS three times, and has dropped the cost of launch by a factor of 2. In fact, he has taken over a large share of the commercial launch market from the established market leaders. Talk about disruptive.

Musk’s first launch vehicle was the *Falcon 1* rocket, and, after three successive launch failures, it became the first private rocket to launch into orbit around Earth in 2008 from the Regan launch complex in the Kwajalein Atol in the Pacific Ocean. But the Falcon 1 was limited in payload by its single engine, so Musk moved on to develop the SpaceX Falcon 9 launch vehicle, which was to be powered by nine Merlin engines, compared with the single engine on the *Falcon 1*.

The *Falcon 9* is now the standard SpaceX launch vehicle. It is a new, in-house design and is a two-stage rocket. It is the very first orbital space vehicle capable of full reuse. The heart of the vehicle is the set of nine Merlin rocket engines, which were internally developed and are constructed at the SpaceX facility in Los Angeles. SpaceX is now the world’s largest producer of rocket engines, primarily the liquid
oxygen and cryogenic RP-1 kerosene-fueled Merlin. Eight of the Merlin engines circle around a central engine, allows for the full completion of a *Falcon 9* mission, even if one engine totally fails.

The Merlin engine is used to power both the *Falcon 9* and *Falcon Heavy*. It is produced at the SpaceX facility in Hawthorne, CA, and, as of 2017, four engines per week were being produced.

A *Falcon 9* launch today costs some US$56 to $60 million, and around $90 million for the *Falcon Heavy*, with additional reductions for large buys of multiple launches. Payloads for the U. S. government are more expensive, up to US$100 million, due to the additional paperwork and security requirements that these require. But these prices are still far lower than the competing prices from Arianespace, the United Launch Alliance of Boeing, and Lockheed Martin. To date, there have been over 66 successful *Falcon 9* launches, and as of early 2019 there is a launch manifest of nearly 40 reserved launch customers. No one can match its launch price.

In 2018, SpaceX conducted a total of 21 successful *Falcon 9* launches into LEO, MEO, and GEO, from both Cape Canaveral, Florida, and Vandenberg, California, launch sites, all without a single launch failure. It successfully recovered several first stages (with one failure) both at the launch site and on two mobile landing sites at sea, named ‘Just read the instructions,’ and ‘Of course I still love you.’ This beats its 2017 record of 18 successful launches. It continues to strive for total reusability, and continued experimenting with the recovery in a net of the carbon fiber payload fairings. The *Falcon 9* is now the least expensive launcher commercially available, costing some US$62 million per launch, and SpaceX intends to lower this cost as reusable stages and engines continue to provide additional efficiencies. The *Falcon 9* has proven Musk’s many detractors and doubters wrong, in classic disruptive technology fashion. Existing players such as Arianespace and the American United Launch Alliance (Boeing and Lockheed Martin) have seen their business models come under very serious pressure, and they are scrambling to react. Similar to the case studies presented in earlier chapters, they were both fat and happy, guaranteed governmental payloads and high prices, and convinced that their situation was unsailable. As we have seen, this is a very dangerous position to be in.

The SpaceX orbital capsule, named Dragon, began development in 2004 and has launched multiple times to the International Space Station since 2012, under a commercial supply contract from NASA that could be valued for as much as US$3.1 billion. On the first test Dragon launch, Musk places a huge wheel of cheese inside the capsule, rather than the traditional lead weights. Since the United States has had not ability to launch either astronauts or supplies to the ISS since the retirement of the space shuttle, commercial contracts were offered, with the SpaceX Dragon and Orbital ATK Cygnus winning contracts.

The Dragon provides both pressurized volume and a large, unpressurized volume in the trunk of the support module containing the solar arrays. Although there are several options for ferrying supplies up to the ISS, the Dragon is now the only means of providing significant ‘down mass’ from the ISS to return samples, machinery, and equipment to Earth, with the ability to return up to 3,500 kg per flight, with
a water landing in the Pacific Ocean off the coast of southern California. In 2017, a resupply mission was flown to the ISS using a Dragon and Falcon 9 launch vehicle that had been previously flown to the station. To date, six Dragon re-flights have been conducted using re-flown capsules, and more are on the way. The age of reusable space systems, for both cargo and people, has arrived (Fig. 4.1).

Dragon 2 is the crewed capsule that has just completed its development. SpaceX has created a version of the Dragon for the launching of astronauts to the International Space Station under a NASA contract awarded in 2011. The United States has not been able to launch its own astronauts since the retirement of the space shuttle over eight years ago, and has had to pay Russia big money, some US$81 million per seat and over US$400 million per year for rides on its Soyuz vehicle. This has been a major source of cash for Roscosmos.

NASA has given Boeing and SpaceX contracts to develop and operate crewed launches to the ISS under the NASA Commercial Crew Development program, run by the Commercial Crew and Cargo Program Office. This started in 2010 with funding to five companies for R&D, and was followed in 2011 with US$270 million to four companies. SpaceX and Boeing were selected in 2014 to develop commercial crew vehicles capable of sending astronauts to the ISS. The Dragon 2 is designed to carry six astronauts to and from the space station, and can, of course, be used for other orbital flights, including space tourism.

The Dragon 2 completed its first uncrewed flight in the spring of 2019. It had a perfect launch and automatically docked with the ISS, as planned, and completed
the mission five days later with a perfect landing in the Atlantic Ocean off of Cape Canaveral. All aspects of the flight were successful, which was a very major achievement in human spaceflight. Given this initial success, there will be one test of the same Dragon 2 in an in-flight abort test, and then, presumably in the summer of 2019, there will be the first flight with two NASA astronauts, who are now in training. The crew has been named, and NASA Astronauts Bob Behnken and Douglas Hurley will make the historic first test flight on the Dragon 2 into orbit. NASA astronauts Victor Glover and Mike Hopkins will then make the first launch to the ISS under the NASA contract.

The Dragon 2 is significantly different from the cargo Dragon, including, of course, life support systems for the astronauts, an automated docking system, conformal solar panels on the trunk instead of solar arrays, and a built-in abort rocket system that can be used from ‘on the pad’ throughout the entire launch profile. Although SpaceX has focused entirely on meeting its NASA contract requirements, Elon Musk has stated that the company will certainly seek out orbital space tourism customers once the vehicle is operational (Fig. 4.2).

The next development beyond the Falcon 9 was to add a strengthened central core and two identical side boosters to create the Falcon Heavy. The central core section fires at full power briefly at launch, but then is throttled back. Once the fuel of the outer two boosters is expended, the two side boosters detach and fly back to the launch site for reuse, and the central core booster throttles up to full thrust with a nearly full tank, a very efficient use of thrust and fuel. When it is drained, it shuts down and detaches, and it, too, can return to a landing ship positioned down range. The second stage ignites for the final burn and insertion of the payload into orbit. All three core first-stage rockets and their 27 engines, and the carbon fiber payload fairing, are designed to be fully reusable (Fig. 4.3).

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Fig. 4.2 SpaceX Dragon 2 vehicle crew access ‘clean room,’ high above the famed launch pad 39-A, along with a Disney ride-inspired sign. This is definitely not your traditional NASA approach to human space flight. (Photo courtesy of SpaceX.)
The Falcon Heavy is currently the most powerful active launcher in service, and it ranks as the fourth most powerful rocket in history. It can place some 64 metric tons into LEO, about twice the launch capacity of the next most powerful, the ULA Delta IV Heavy. It can also take some 16.8 metric tons to Mars. The first launch in 2018 was an extraordinary event, with a perfect launch from historic pad 39-A at Cape Canaveral. Both side boosters returned in perfect tandem to their two landing sites, only a few hundred meters apart, even though the central, core stage did not land successfully on the landing ship downrange. The payload, instead of the usual water ballast or lead weights, as it would have been for a government launch test in the old NASA days, was Elon Musk’s original red Tesla roadster, complete with a mannequin in a SpaceX spacesuit at the wheel. The car and its StarMan driver are now in a permanent Earth-Mars heliocentric orbit. On a circuit board inside the roadster was printed “Made by Humans on Planet Earth.” This is not your parents space program (Fig. 4.4).

SpaceX has a contract from NASA to provide commercial resupply missions to the International Space Station, using the Dragon spaceship. They have already completed eleven successful resupply missions, including using the same Dragon capsule several times. The Dragon is currently the only capability for returning large amounts of ‘down mass’ from the ISS. And the next step is another contract from NASA to provide crew launches to the ISS using a crew-certified Dragon 2 capsule, capable of carrying up to six astronauts to and from the station. The first test flight of the human-rated Dragon 2 will be in 2019, and the first occupied flight may come in the same year, with the first astronauts to fly to the ISS on a privately developed spaceship.
SpaceX has not been willing to rest on its laurels with the Falcon 9 and Falcon Heavy. In order to achieve the goal of establishing human colonies on Mars, Musk requires a vastly more powerful rocket to make the long trip to Mars with enough supplies and people to build a colony and stay. This led to the development of what was initially called the BFR, the Big Falcon Rocket, although many considered it stood for a rather racier name, the Big F@#$! Rocket. This has gone through many versions, but it is finally approaching the first tests of its large engines and pogo low-altitude tests. It is designed to launch and land vertically, like the Falcon 9, but is enormous, 9 m in diameter, and has a stainless steel two-stage rocket with a definite ‘retro’ 1950’s look. It will have the ability to launch some 150 tons to LEO, far more than any existing or planned launch vehicle.

It will be powered by a new engine, named Raptor, now under development at SpaceX. The Raptor is a reusable, liquid methane and liquid oxygen-powered engine that is twice as powerful as the existing Merlin engines powering the Falcon 9. There will be a total of 31 engines in the booster rocket stage, and 6 on the starship second stage. The engine is undergoing test firings at this time (Fig. 4.5).

The first paid flight of the starship was announced in 2018, when Musk introduced Japanese billionaire entrepreneur Yasuka Maezawa, who paid SpaceX in September of 2018 to make a trip to the Moon with an eclectic group of as yet announced artists, including musicians, writers, designers, and film artists. This flight would occur no earlier than 2023 at this point, and, if successful, they may become the first humans to leave the gravity well of Earth since the Apollo astronauts some 50 years ago. It is about time.
Musk is planning to use these massive rockets to send people to Mars, and to establish a permanent human colony there. SpaceX is developing detailed plans on how they will do this, and while many doubt the feasibility, others point to their track record and do not dismiss the effort. But going to the Moon and Mars is not the only intended purpose for the starship. Musk has announced that SpaceX is also looking at using the starship system for intercontinental commercial travel in minutes between major population centers on Earth. The point-to-point estimates are a mere 30 minutes between New York and Paris, or between Honolulu and Tokyo. Talk about disruptive.

However, the real goal of the starship is to make possible regular and reasonably efficient modes of transportation for people and goods to Mars, and the establishment of permanent human colonies on Mars. At a public speech, Musk once said that “I want to die on Mars… just not on landing,” and he seems intent on making this actually happen within his lifetime. Massive technical problems must be overcome, but the development and use of the huge starship are the key first steps, and who can say that Musk, given his track record to date, cannot make all this happen? His vision is to make humanity a truly multi-planet species and to do it without governmental funding or controls. He has the financial resources, will, and track record to make big things happen. He might fail, but he just might succeed.

Elon Musk’s other projects here on Earth are no less striking in their vision and potential for disruptive innovation of major, existing markets. His vision of a new approach to how people live is not limited to getting to and living in outer space. He has begun an integrated series of new businesses that all reflect a new, solar-powered lifestyle and economy that is completely removed from the current paradigm of fossil fuel dependency. This goal is to completely remake the relationship between

![Fig. 4.5 SpaceX’s starship and its Super Heavy booster, falling away. Capable of carrying 100 passengers to Mars. (Image courtesy of SpaceX.)](image-url)
humanity and our planet, and to completely remove the fossil fuel paradigm from the modern world.

The Tesla Motors Company was created in 2003 by two engineers, Martin Eberhards and Marc Tarpenning, and it is headquartered in Palo Alto, California, in the heart of Silicon Valley. Elon Musk and two others later joined the company, and all five are considered to be founders of the company. Tesla now produces over 100,000 vehicles per year from their factory in Fremont, California, just to the west of Silicon Valley, and it is now valued at US$50 billion, with revenue in 2017 of over $11 billion. It is the world’s premier electric luxury auto provider and is pushing the envelope on converting personal transportation (on Earth) from fossil fuels to fully renewable electric vehicles.

Musk currently owns some 22% of the company. But there have been tremendous production and other problems with Tesla, and serious problems with meeting production targets and prices. Musk announced a 7% company-wide layoff in January 2019, in order to lower the price of its cars and be more competitive in the international market. Tesla has announced a Model 3, with a lower price of $46,000 that has a 500-km range (310 miles) between charges. It has also developed an electrically powered semi-tractor trailer truck, which is to be in production by late 2019, using four Tesla car drivetrains. The goal is a truck comparable to today’s diesel tractor-trailer trucks that would have a range of 800 km (500 miles) and that could be fully recharged in 30 minutes at sites along major highways. The trucks are also being designed to have fully automated self-driving capabilities as soon as this is allowed by law. The long-term plan also includes smaller vehicles, SUVs, pickup trucks, and more.

In order to have a viable system of electric vehicles, Tesla is creating the Tesla Supercharging Network, which will provide charging stations along all major highways. As of 2018 there are now over 1,400 charging sites, largely in the United States, that can charge your vehicle in about an hour. Some 150 stations are now operating in Europe, and Tesla is placing charging stations in hotels, shopping centers, and other destinations at its own cost to seed the required infrastructure for its vehicles.

One of the disruptive innovations of the Tesla approach is that there are no car dealerships. This is an aspect of the vertical control of the company and product, somewhat similar to the approach of Henry Ford discussed earlier. You can only purchase your Tesla online from the Tesla website, and it is delivered to your door. There are Tesla shops, largely in shopping malls in major cities, where you can look at them and ask questions, but there are no car dealerships in the traditional sense of large, privately owned dealers with large staff and repair facilities who purchase large numbers of autos from the factory and who then sell them to the public (with a significant markup and profit).

This direct sale approach has drawn the ire of existing auto companies and powerful auto dealership lobbies at the state and national levels in the United States and beyond. In fact, 11 states in the United States have had laws passed in their legislatures banning the sale of autos except through auto dealerships, a clear attack directly against Tesla. Another 8 states have laws limiting the number of Tesla stores.
to between 1 and 5 per state, clearly a discriminatory legislative approach to the Tesla threat. There have been numerous lawsuits against Tesla from the dealers association to restrict Tesla’s direct sales, and it is illegal in 48 of the 50 states to buy a car direct from an auto manufacturer. Tesla gets around this by handling all online purchases as an out-of-state purchase through one of the two states where this is legal.

Clearly, this is all a reaction from the powerful, existing auto manufacturers and auto dealership lobbies who are threatened by the vertical Tesla approach. Tesla uses a totally different, and very Silicon Valley, approach to the auto industry that it calls “complex coordination.” In this, the total approach to designing, manufacturing, selling, and repair differ from the traditional Detroit model, now over 100 years old. As noted earlier, it is a vertically integrated approach that includes control of production using massive economies of scale, like the gigafactories to produce millions of car batteries. Again, in a move similar to Henry Ford, Tesla established the Tesla glass group to produce not only the glass components of the cars but also glass components of SolarCity solar roof tiles. Henry Ford established his own glass works for his Model T factory that brought in raw sand by the shipload and produced all the glass products needed for the Model T onsite. Musk clearly has learned this lesson well.

The Tesla electric car is only one component of this grand strategy to wean the world off of oil and gasoline, and to create a new, solar-powered future. In 2016, Tesla purchased the SolarCity corp., the largest U. S. home installation company for residential, rooftop solar power systems. Musk has now developed, and now has available for sale, a variety of solar-powered home and commercial solar electrical power systems. This includes commercial and residential offerings, including a new, solar power-generating roof, which replaces current residential roof shingles with glass solar panels that both act as a traditional roof and also generate electrical power. It also includes large batteries and controllers to store the energy overnight. In typical Musk fashion, the roof tiles are “guaranteed for the life of your house, or infinity, whichever comes first.”

The tiles come in various styles and colors, and there are also non-power generating tiles that look and function the same, if your home does not require a complete power-generating roof. The tiles are created of strengthened glass that is resistant to damage from hail or falling branches, and, once production is fully underway, should be comparable to the cost of replacing a roof with regular shingles. The tiles are connected to one or more Tesla house batteries, called the Powerwall home battery, that are capable of storing electrical power overnight that is generated by the system during the day. The system remains attached to the utility grid, so if additional power is needed, it is automatically used to top up the batteries, and, in the event that more power is generated than used, it can be sold back to the utility. Up to ten batteries can be installed in a single home, but only two can provide sufficient power storage for routine off-grid power, as well as providing emergency power when the electrical power grid is down. When the system detects that the utility grid is down, it automatically disconnects from the grid and continues to power the house using the solar panels or roof. Once the grid is back up, it automatically
reconnects. It is vital that the system disconnect from the grid in this situation, because electrical workers could be electrocuted when working on lines in the area if the house is generating current into the grid (Fig. 4.6).

Nothing Elon Musk does is small in scale. All of these millions of Tesla cars, trucks, and solar-powered houses are going to require batteries, a lot of very big batteries. In typical disruptive innovation style, Elon Musk decided to create the largest battery factory ever conceived, to produce the power that he needs. The first of what he calls his gigafactories was built outside of Reno, Nevada, in the western United States. This massive facility contains over a half million square meters of production space. It was built in partnership with Panasonic, the world’s largest producer of solar cells, and it produces the batteries and other components of the Tesla cars, as well as the Powerwalls and Powerpacks and solar cells for SolarCity.

This massive facility has, of course, solar panels on the entire roof, and strives to generate all of its own power required for production. As if this were not sufficient, Tesla as now followed with a second factory in upstate New York, at the site of an old steel plant near the city of Buffalo. This factory, again in partnership with Panasonic, now produces photovoltaic solar panels and the solar tiles for Tesla/SolarCity. In 2018, Tesla entered into a contract with China to build a third gigafactory near Shanghai, and the factory began construction in 2019 to supply Asia with these products. There are preliminary plans for establishing the fourth gigafactory site somewhere in Europe, when demand is sufficient.

Elon Musk has never been one to shrink away from a challenge, and he proved this by his brash, and ultimately successful, offer to install a massive battery system in the state of South Australia. Australia is the largest exporter of coal in the world, and it also is one of the world’s sunniest countries, a perfect location for large solar power systems. There has been very strong political support at the national and regional levels in support of coal (and other mineral) production and exportation,
and an equally strong political aversion to all types of renewable energy, even though Australia is one of the world’s most Sun-baked of nations, and has very a sparse and widely distributed population. This is similar to its aversion to space and lack of interest in creating an Australian space agency. The state of South Australia also has a history of having some of the highest electricity prices on the planet, and it also has a history of frequent power blackouts and power distribution problems. But the state of South Australia has also, for some years, developed a reputation for being innovative and open to disruptive ideas. In fact, South Australia is the center of Australia’s emerging NewSpace activities and will soon become the home of the newly created Australian Space Agency.

South Australia has made significant investments in solar and wind power, and almost 40% of their electrical power is now coming from these sources. But the problem is that these are less reliable than traditional power generation, and there was a need for a massive battery storage system that could hold the power generated in the day for use at night. So a concept was developed by the South Australian political leaders to announce a plan to address the chronic power outages using solar power and batteries. When Elon Musk got wind of it, he made them an offer they could not refuse. Musk tweeted the Liberal party’s leader that Tesla would provide a massive battery system that would exceed their needs and would deliver it in record time and at a record low price. Concerned that Musk was not serious, they contacted SolarCity to ask if they were really serious. Musk replied publicly via twitter in March of 2017: “Tesla will get the system installed and working 100 days from the contract signature or it is free. Is that serious enough for you?”

The $50 million dollar contract was signed, and the 100-day clock was started. There was tremendous political pushback from the established coal, fossil fuels, and opposing political forces in Australia, but in 54 days, in November of 2017, they

Fig. 4.7 The largest battery in the world, located in South Australia. (Image courtesy of SolarCity.)
threw the switch and powered up the world’s largest lithium ion electrical storage battery system in the world. It is larger than a football field, and the system has worked as advertised. It is located at a massive wind power facility north of Adelaide, and provides over 100 megawatts of power storage and has reportedly already saved South Australia over US$29 million, over ¼ of the original purchase price. When a coal fired power plant suddenly went offline, the Tesla battery immediately delivered some 100 megawatts into the grid, preventing a system-wide blackout (Fig. 4.7).

And this is not all. Tesla has a plan to build a 250 megawatt ‘virtual power plant’ in South Australia, by fitting a system of interlinked solar panels and storage batteries to over 50,000 individual homes in the region. This would not only provide all of the power needed for these homes but also provide ample power to sell back into the grid as well. This is a fascinating example of disruptive innovation and the political and economic forces that array against these ideas.

SolarCity is continuing to push for a renewable energy economy, by pairing wind and solar with large battery parks, and individual homes and businesses that not only provide power for their own needs but can also contribute back to the grid. New systems have been installed in American Samoa and on the Hawaiian island of Kauai, where there is now a 13 gigawatt solar farm with a 52 megawatt-hour battery cluster. More and larger systems are in development.

Musk has plans for more than simply launching other users’ satellites into orbit using his Falcon 9 rockets. In 2015, Elon Musk announced his plan to create a massive new LEO satellite telecommunications constellation. In 2018, the Federal Communications Commission (FCC) in the United States issued a permit for Elon Musk’s Starlink LEO satellite broadband telecommunications concept, which will consist of a staggering 12,000 LEO satellites. This would include 7,518 broadband satellites and an additional 4,425 requested in follow-on FCC requests. This system will cost a staggering US$10 billion to design, build and launch, using Falcon 9 launchers, of course. The system will provide worldwide, very high speed Internet service across the globe, including the developing world regions that currently do not have access to such capabilities. There are over 3.5 billion people in the world, some half of all people living today, who have no access to the Internet, none at all. This includes over 2 billion people in Asia and over 800 million in Africa.

The Starlink system will rely upon a new concept of laser communication between the satellites to pass along data around the network, and will use traditional radio frequencies between the satellites and the ground at either end. The benefit of being in very low orbits is there will be extremely low latency compared with GEO telecom systems, as low as 25 msec, with gigabit speed that will rival fiber optic capabilities. The drawback is the small ground footprint of each individual satellite, requiring the large number of total satellites and complex satellite-to-satellite data links. There will actually be three layered sets of satellites. The first to be launched will be a set of 4,425 satellites in a rather high LEO orbit of around 1,100 km. Next will follow 7,518 satellites at a lower orbit of about 330-km altitude. These would be in the 200 kg size, so not tiny, but far smaller than the large GEO satellites.

Musk has been quoted as saying that he intends to mass produce the satellites and will revolutionize satellite production in the same way that he has revolutionized
reusable launchers. The ground stations would have a small phase array antenna, but will not work with hand receivers or satellite telephones. To give some context to the massive scale of this proposed constellation, there are currently only some 1,900 active satellites working in orbit today. The concern about LEO orbital debris is real, and the FCC has required SpaceX to submit a comprehensive orbital debris mitigation plan as a part of their license.

To date, there are two prototype satellites in orbit, named Tintin A and B, that were launched in February 2018. The low orbit will require an almost constant replenishment of the constellation, so the costs of operation will be very high, but mass production of both satellites and rockets will make it possible. Musk has said that the system is intended to make a significant profit to support his Mars colonization venture, and has also stated that Mars will also eventually require a global telecom satellite system as well. This will be far more possible using a satellite system rather than using terrestrial (Martian) fiber. His plan is to begin launching sometime after 2020, with launches continuing through 2025. It will use the little used V band frequency for satellite-to-satellite laser links, and the familiar satellite telecom Ka band for the ground-to-space final links to Earth. In early 2019, Musk filed a request with the FCC for a license for over 1 million ground terminals for this system. He is certainly thinking big (Fig. 4.8).

Fig. 4.8 A computer simulation of a possible configuration of the Starlink constellation. (Image courtesy of Prof. Mark Handley, University College, London.)
In conclusion, Elon Musk is a powerful force in disruptive innovation across many different fields, including several not even discussed here. In addition to space launchers, Mars colonies, high-speed satellite-based Internet, electric cars, and solar power systems, there is also the Boring Company and the concept of hyper-loop mass transit, and there will certainly be more coming. Without question these are extreme examples of what daring, vision, and lots of your own cash can do. Disruptive innovation has come to space.

Jeff Bezos and Blue Origin

Jeff Bezos is the world’s wealthiest individual, and in July 2018, his personal wealth was estimated at some US$150 billion [7]. He is the founder, president, CEO, and chairman, and is still the primary investor for Amazon.com. Amazon is the largest online commerce site in the world. Bezos also started Amazon Web Service, the world’s largest cloud infrastructure services company.

Jeff was born to a very young couple who quickly divorced. When he was five years old he watched the Apollo 11 launch, and was captivated by the concept of spaceflight and by science and engineering in general. He attended Princeton University and was even the president of the local SEDS chapter there. He briefly worked on Wall Street, but decided to become involved in the Internet revolution and founded Amazon.com in 1994 as cadabra.com, as in abra cadabra, the magician saying, as an online book buying website, and developed the popular Kindle digital book reader (Fig. 4.9).

Fig. 4.9 Jeff Bezos, the founder of Amazon and Blue Origin. (Image of Bezos from the U. S. Department of Defense; symbol courtesy of Blue Origin.)
Amazon quickly became successful and expanded into selling other things beyond books, and it has grown into the largest online store in the world. Amazon is reported to be the second largest single employer in the United States and is also the largest Internet company in the world. Amazon made up some 43% of all online purchases in the United States and brought in some US$136 billion in sales in 2017 alone. Bezos still owns some 16% of Amazon’s stock, and runs its daily operations as the CEO. In addition to Amazon, Bezos’s venture capital company, Bezos Expeditions, provides funding for a wide range of his external investments and ventures. His website, bezosexpeditions.com, has a long list of his investments and interests including investing over $100 million in AirB&B, and some $35 million into Uber, not to mention paying $250 million for the Washington Post newspaper. He has funded a wide variety of humanitarian and educational causes and new ventures as well.

His love of space has led him, in 2013, to search the deep-sea bottom to locate several massive F-1 rocket engines used on the Apollo launches. These massive first stage engines were recovered from over 4,000 meters (14,000 feet) below the surface of the sea, after some 43 years on the bottom of the ocean. One of these engines that were recovered, serial number 2044, was engine #5 of the famed Apollo 11.

Fig. 4.10 The Blue Origin New Shepard launch vehicle taking off in Texas. (Image courtesy of Blue Origin.)
mission, and it now sits in a museum in Washington State. Bezos funded this expe-
dition, at the cost of several million dollars, entirely with his own funds.

Blue Origin is the name of Bezos’ space venture, which was founded in 2000 in
Kent, Washington, near the Seattle/Tacoma airport in the United States. Blue Origin
was very much in ‘stealth mode’ in the beginning, and Bezos provided very little
information about its activities to the public. The Blue Origin name refers to the
Blue Earth as the origin of his, and our, space ventures, and Blue Origin’s motto
“Gradatim Ferociter,” Latin for “Gradually (or step by step) Ferociously,” is fea-
tured on the company’s crest, featuring two turtles, as shown in Fig. 4.10. Bezos
reportedly sells US$1 billion in Amazon stock each year in order to fund his space
activities. Blue Origin has about 1,500 employees at this time and is still growing.
It operates its headquarters and manufacturing facilities in Washington State, its
launch and processing sites at Corn Ranch in western Texas for the New Shepard,
and at Cape Canaveral, Florida for the New Glenn orbital system. They recently
began construction on a large factory in Huntsville, Alabama, for the production of
their rocket engines.

New Shepard is the Blue Origin suborbital tourist rocket system. Testing began
in 2006, and it has now flown three trips into space since 2015 (without passengers)
and has landed safely all three times at their launch and testing facility north of the
small town of Van Horn, located in remote west Texas. This was the first time that a
complete launch vehicle had flown into space and had returned to its launch site (as
opposed to a capsule returning and the launcher being discarded). Named for pio-
neering astronaut Alan Shepard, it is a reusable, vertical takeoff and landing system
that is powered using Blue Origin’s own internally developed and built cryogenic
and reusable BE-3 engine, fueled by liquid hydrogen and liquid oxygen. The plan is
for tourist launches to begin in 2019, but no details, including pricing, have been
made public at this point. The system is designed to be fully reusable and will be
marketed for tourism and for flying experiments into a brief microgravity environ-
ment. The vehicle will launch vertically and accelerate at 3-gs to a speed of over
Mach 3, where the engine will shut down after about three minutes of powered
flight. The capsule is capable of carrying up to six passengers and will be com-
pletely computer-controlled, and have no operator onboard, nor will there be any
ground control.

The system is completely controlled by onboard computers. It will launch verti-
cally to an apogee of over 350,000 feet (66.5 miles) or just over 100 km, which is
just above the Karman line’s ‘official’ edge of space, thus offering astronaut wings
to the passengers. After engine shut down, the capsule will then detach from the
booster, and both will continue their ascent.

There will be a brief period of weightlessness, where the passengers can look out
the large windows and float in a weightless environment. Then, the capsule will
return to Earth on a ballistic trajectory and will land using a parachute, just 11 min-
utes after launch. A small retro rocket will fire just before touchdown, cushioning
the landing in the west Texas scrublands near the launch site. The booster will
relight its engine after separating from the capsule and make a vertical landing on
its launch pad, after relighting its launch engine. All components in the system will
be reusable. Although the company has been very quiet about the specifics of the plan, recent announcements are that paying customers will be able to fly in 2019 or 2020. The price has not been announced but has been estimated by others as to be somewhere around US$200,000 (Fig. 4.11a, b).

The suborbital New Shepard is only the start of the Blue Origin space plans. Blue Origin has acquired facilities at Cape Canaveral for the launch of a new and larger orbital launcher named New Glenn, named after astronaut John Glenn. Blue Origin will build the rockets at a new manufacturing facility at Cape Canaveral, and launch from the existing Launch Complex 36, which had been dormant for some years and is now being refurbished for use. The vehicle is being funded internally by Bezos,
who has reportedly invested some US$2.5 billion to date. The project has also been awarded US$500 million by the U. S. Air Force under their Enhanced Expendable Launch Vehicle (EELV) program. This is a clean-sheet design for a very large rocket that will provide orbital access for both humans and satellites.

Blue Origin has invested some US$220 million for a new engine manufacturing factory in Huntsville, Alabama, and an engine test stand and launch pad, and for the design and construction of the new orbital vehicle at Cape Canaveral. It will be a very large, two- or three-stage vehicle (depending on the need), a full 7 m in diameter, and will use a total of seven new, methane-fueled BE-4 engines for the main stage, and the existing liquid hydrogen and liquid oxygen-fueled BE-3 for the upper stages, which is the same engine now used for the New Shepard rocket. It will be a vertical launch and vertical landing orbital rocket system, with a fully reusable first stage, designed for up to 25 launches, and will be fully human-rated, although there is no capsule in development at this time. It is planned to be able to insert up to 45 metric tons in LEO and 13 metric tons in GEO. The large first stage will land on a mobile launch platform in the Atlantic Ocean for reuse, similar to the approach by SpaceX. As of early 2019, there were four commercial satellite launch customers, with the first launch planned sometime after 2020. The relative size of these, and other, new launch vehicles are shown in Fig. 4.12.

Clearly, the massive New Glenn 3 stage rocket is massive. The adjacent launch pad, LC-11, once used for Atlas launches in the 1950s and 1960s, will be used for engine testing. Of historical interest, LC-11 was the site of the launch of the historic SCORE telecommunications satellite in November of 1958, which was the very first telecommunications satellite launched into LEO. LC-36 and LC-11 are at the very tip of the cape, shown at the bottom of the picture in Fig. 3.9.

New Armstrong is the name of the as yet unspecified next step for Blue Origin, but there is no information available at this time about exactly what it is. Bezos has

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**Fig. 4.12** The relative sizes of current and planned launch vehicles, with the very large New Glenn compared with the mighty Saturn 5 at right. (Image courtesy of Vector Space.)
also stated that he is interested in partnering with NASA and others to create a permanent colony on the Moon using inflatable modules.

Sir Richard Branson and Virgin Orbit, Virgin Galactic, and the Spaceship Company

Sir Richard Branson is a British serial entrepreneur who has become yet another billionaire who is pushing the boundaries of commercial space, all with his own, personal and very exuberant touch [8]. Branson is the founder of the Branson Group, which has a controlling interest in over 400 individual companies that Branson has himself started or purchased.

Branson became an entrepreneur at a very early age and started a youth magazine and later a very successful chain of record stores in the UK back in 1972, when vinyl records were very popular and were the primary means of young people enjoying popular music. He quickly became a serial entrepreneur, enlarging his record stores into what he called Megastores, and creating his own record label that recorded many world-class music acts in his own recording studio to make records to be sold in his stores. Then he started Virgin Atlantic airline in the 1980s, in direct competition with the staid and established British Airways, facing intense political and economic pressure from his competitor and its political supporters.

Branson has always ‘lived on the edge,’ and has participated in a variety of extreme sports and world record attempts. These have included the first ever balloon flight across the Atlantic Ocean in 1987, with fellow adventurer Per Lindstrand of Sweden, which lasted almost 34 hours, and the first crossing of the Pacific Ocean by balloon two years later. He made a total of four unsuccessful attempts to fly around the world in a balloon, and was beaten in this elusive goal by another team in 1999. Then, in 2005, he funded the Burt Rutan designed GlobalFlyer aircraft, which flew around the world unfueled, setting several new world records.

Branson’s estimated personal fortune exceeds US$5 billion, and he personally controls over 400 companies through his Virgin Group holding company from his headquarters in London.

In 2004, Branson bought the rights to the Burt Rutan-designed Spaceship 1, the Paul Allen-funded winner of the US$10 million Ansari X Prize. The original plan was to start commercial flights as early as 2007. Spaceship 1 became the first private craft to fly twice within two weeks to outer space. The X Prize was created by another of our space entrepreneurs, Dr. Peter Diamandis, who will be discussed later. Branson bought the rights and created Virgin Galactic, as a means to conduct space tourism using the updated Spaceship 2 design of Burt Rutan. This required a totally new system, with a new first stage, launcher and a new vehicle that could take several passengers to the edge of space, but was based on the Spaceship 1 concept. The spaceship is carried up to about 50,000 feet by a dual-fuselage carrier aircraft. It is then released and flies a parabolic flight up to about 50 miles. The most
innovative aspect of the Rutan design is that, once in weightlessness, the tails of the vehicle tilt up to nearly vertical, into what is described as ‘shuttlecock’ mode, and the vehicle free falls down through the atmosphere in a stable attitude, with no pilot input required. At around 50,000 feet, the vehicle reverts to aircraft mode and makes an unpowered landing back at its launch runway. It all takes about two hours from takeoff to landing.

A fascinating aspect of this is that Branson was quoted in 2018 as saying that he trademarked the business names Virgin Galactic and Virgin Intergalactic in the 1980’s on the same day that he trademarked Virgin Atlantic, stating “I am an optimist.” No doubt about that. It will be exciting to see what Virgin Intergalactic looks like.

The second Burt Rutan design for Spaceship 2 was an expanded version of the original X Prize winner and its development continued, but not without difficulties. A test flight in 2014 saw the vehicle come apart in flight, killing the pilot, and this led to an expensive and lengthy redesign. There was, as expected, very bad press, and there was consideration of canceling the project altogether. But Branson decided to continue, and the program appears to be back on track. They flew three test flights to over 50 miles altitude in late 2018 and early 2019, including flying the first passenger, the woman who will be in charge of training commercial passengers. It also flew a few NASA-funded microgravity experiments. Several more test flights are planned, and the newest vehicle is now scheduled for its first flight with customers in mid-2019.

Branson has stated that he intends to be on the first flight, and there is no doubt that he will be. He has also said that he wants to take his elderly mother along, as well as his children. The company has received over 600 reservations, either partial deposits or full price, for the US$250,000 ride. This means an initial $150 million revenue stream for the project, once they begin to fly paying customers. But Branson has also said publicly that he has spent between $1 and $1.5 billion of his own money on his space activities – Virgin Galactic, Virgin Orbital, and the Spaceship company (the joint venture company with Burt Rutan’s Scaled Composites, which constructs these vehicles).

A second and third space plane are being built, as well as a second carrier plane, so they continue to move forward towards flying paying customers. Space is big, and it requires big money, really big money, and big ideas, too. Time will tell if these activities will ever make a profit, or if that is even Branson’s ultimate goal. Branson is a wealthy and adventurous person, and he intends to fly into space. He will most certainly be on the first commercial flight they make, and that trip alone might be worth the price he has paid [9] (Fig. 4.13).

In December of 2018, Virgin Galactic made its first test flight with a pilot to an altitude of higher than 50 miles, the FAA’s definition of space, as opposed to the 60-km Karman line. This was the first flight from U. S. soil where people reached that altitude since the last flight of the NASA space shuttle in 2011. The flight profile had the mother ship carry Spaceship 2 up to an altitude of some 43,000 feet, flying from the Mohave Air and Space Port in southern California. The vehicle was dropped, ignited its engine, and soared upwards on a profile very similar to that of
the early X-15 flights, which were flown from the nearby Edwards Air Force Base. It was also announced that the Sovereign Wealth fund of the UAE has invested over US$300 million in the company, has become a 30% owner, and will look at establishing a launch facility within the UAE, where there are certainly many people wealthy enough to afford the quick trip to have a few minutes of weightlessness. If successful, the concept could easily be expanded to other locations, as it only requires a regular airport infrastructure. The current plan is to operate the commercial flights out of a new, purpose-built spaceport in New Mexico named Spaceport America, which is located next to the vast U. S. Army White Sands Missile Range.

Doing tourist hops is only the start of Branson’s space ambitions. He has also created Virgin Orbit, which will use a now-retired Virgin Atlantic Boeing 747-400 passenger liner as the first stage of a small satellite launch system. Also based in southern California at the Mojave Air and Space Port, it is similar in concept to the Orbital Sciences (now Grumman) Pegasus vehicle.

The Virgin Orbit team are developing a new rocket that will be hung under an existing structural attach point designed into the B-747 to ferry a fifth engine to remote locations. The system is capable of carrying up to 38,500 kg (85,000 pounds) on the pylon. Although this feature is rarely used by the airlines, it provides the structural basis for carrying the newly developed rocket and its payload. The B-747-400, named Cosmic Girl, has been withdrawn from Virgin Atlantic service and transferred to the new venture, and the rocket and engine have been designed and tested. A first flight with an inert rocket was completed in late 2018, and the first launch is set for 2019.

The system is capable of launching small satellites up to 500 kg at a wide range of orbital inclinations, including LEO, MEO, and GEO. The LauncherOne rocket is

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**Fig. 4.13** The Virgin Galactic SpaceShip2 VSS Unity returns to the Mojave Air and Space Port after its first flight of over 50 miles up on December 13, 2018. (Photo courtesy of Virgin Galactic.)
a new two-stage design, with a 1.8-m diameter size. The fully composite first stage rocket has a single engine with 327 kN or 80,000 pounds of thrust, burning liquid oxygen and RP-1 kerosene. The rocket is a 21.3-m (70-feet)-long new design. The company is planning to produce up to 2 rockets per month for the growing small satellite constellation market. Payload processing is provided at its Long Beach, CA, facility before mating of the rocket with the launcher at the Mohave site.

The intention is to provide very quick launch services, with as little as nine months between contract and launch for a primary payload, and as little as six months for a rideshare payload. The initial plan is to launch the aircraft for polar orbits out of the Mohave spaceport, and to launch the rocket some distance off the southern California coast into polar, Sun-synchronous orbits, but the aircraft can also launch from Florida for mid-inclination orbits and other locations as well. There are currently discussions to have a LEO low-inclination site in the Pacific, possibly the U. S. island of Guam [10].

Like Pegasus and Stratolaunch, the use of an aircraft first stage allows launches from multiple airports around the world, and takes the rocket above most of the density of Earth’s atmosphere (35,000 feet, or some 10,000 m) before it is dropped and ignited.

Virgin Orbit has received a launch license from the U. S. government and is scheduled to make its first launch attempt in late 2019 (Figs. 4.14 and 4.15).

Richard Branson has also invested in the OneWeb satellite telecommunications system that will directly compete with Elon Musk’s Starlink. OneWeb is a proposed constellation of some 880 satellites, designed to offer global, high-speed Internet services. This system will use an LEO orbit with some 18-20 orbital planes flying at an altitude of about 1,100 km (750 miles), using the existing Ku band. The satellites will be small, on the order of 200 kg each, and a contract has been signed for them to be built by Airbus Space and Defense in France. Virgin Galactic is now under contract to provide 39 launches, using their LauncherOne vehicle, and Arianespace is also under contract to use their (Russian) Soyuz rocket from French Guyana. The

![Image of Virgin Orbit Boeing 747 with rocket below](image)

**Fig. 4.14** The Virgin Orbit Boeing 747 with the rocket below. (Image courtesy of Virgin Orbit.)
The company may increase its constellation to over 2,000 satellites if sufficient customers are found.

Sir Richard Branson is clearly a fascinating example of a self-made serial entrepreneur who has accomplished extraordinary things, in space, in the air, and on the ground. He is clearly evidence that disruptive innovation is not limited to Silicon Valley.

Paul Allen, *SpaceShip 1, and Stratolaunch*

Paul Allen was the co-founder of Microsoft, along with Bill Gates, and he had a lifelong interest in space and aviation. It was Paul Allen who funded the Burt Rutan *SpaceShip 1* venture that won the Ansari X Prize back in 2004. Allen then started the Stratolaunch company, which uses a massive, double-hulled, six-engine carrier aircraft as the first stage to launch vehicles into space. The massive aircraft, which is designed to be the first stage of a new launch system, has gone through several iterations in its development. Originally it was to be two Boeing 747s, joined by a new, central wing that would carry a slightly revised SpaceX *Falcon 9*. This craft would be dropped at altitude to launch payloads into orbit. The design would allow the launcher to operate from any large airport around the world and would take away the need of a large launch complex.

By getting the rocket up to some 35,000 feet (10,000 m) before ignition, it is already out of the densest part of the atmosphere. SpaceX determined that it would require too much modification of the *Falcon 9*, and so SpaceX eventually pulled out
of the concept. The use of two, joined B-747s was then replaced by an all new, and even larger, craft with six engines, which was designed and built by Burt Rutan and Scaled Composites. This is now the largest aircraft, by wingspan, ever launched, at 117 m across. Scaled Composites was planning on designing its own rocket engine and a family of vehicles for launch, including designs for satellites and even a manned rocket plane resembling a small space shuttle.

Sadly, Paul Allen died of non-Hodgkin’s lymphoma in 2018 at the age of 65, leaving a personal fortune of some US$26 billion. Since he had never married and had no children, the processing of his estate may be complicated. His primary holding company, Vulcan, Inc., and Stratolaunch continue in operation, and his sister, Jody Allen, is in charge of his estate. But the future of his many ventures is now less certain. It was announced in January 2019 that all development on the family of second-stage launchers and rocket engines has stopped, and that the massive carrier will now focus on only carrying up to three Pegasus launchers at a time, to be provided by Orbital ATK. The Pegasus is the original air launched space system, but it has seen little business of late with its most recent launch in 2013.

The reason for the cancellation was not disclosed, but this calls into question the viability of the project, as Grumman already has the ability to launch the Pegasus from its existing L-1011 launch plane, and the Pegasus is limited in terms of the size and mass of payloads. We shall see how this project continues, but it does highlight the danger of these innovating and disruptive space projects when a single owner and prime mover is no longer there to drive the project (Fig. 4.16).

Fig. 4.16 The Paul Allen Stratolaunch aircraft at top and original family of launch vehicles, now cancelled, except the three Pegasus launchers at left. (Image courtesy of Stratolaunch.)
Robert Bigelow and the Concept of Inflatable Space Habitats

Robert Bigelow is a U. S. businessman who made his fortune in the commercial real estate and hotel industries. He owns the Budget Suites of America hotel chain and has extensive real estate holdings around the world. His estimated net worth is over US$1 billion. He is originally from Las Vegas, Nevada, and he decided at a very early age that he was going to be involved in space, create his own space companies, and go into space. He has been quoted as saying that he went into the hotel and real estate business specifically to raise sufficient funds for his space endeavors and to make it possible for him to go into space himself [11]. He created Bigelow Aerospace in 1998, and it has focused on the development and use of inflatable space habitats.

Inflatable space habitats have several important potential advantages over steel and aluminum structures such as the International Space Station modules or the Russian space stations. An inflatable can be compressed at launch into a much smaller volume, which can then be inflated in orbit into a much greater volume for use. Bigelow has designed and launched several of these as proofs of concept, and the idea clearly has merit.

The concept first originated in the 1960’s with a proposed ring-shaped space station from the Goodyear Corporation, makers of rubber tires. The NASA TransHab inflatable module was proposed in the 1990s as a crew habitation at the ISS, but this was never built, due to the U. S. Congress passing a resolution banning NASA from

Fig. 4.17 The BEAM being inflated on the ISS. (Image courtesy of NASA.)
conducting work on inflatables. Politics always wins, and, in this case, the existing NASA habitat contractors, led by Boeing, wanted no competition from balloons, and so it got Congress to kill the project by legislation. Paul Bigelow purchased the intellectual property rights to the NASA patents and proceeded to develop his own inflatable designs, founding Bigelow Aerospace in 1999. The company has launched two prototypes, and currently there is a small test inflatable on the ISS, called BEAM, or the Bigelow Expandable Activity Module. This was launched in 2016, and it has worked as advertised, and has reignited some NASA interest in the technology. NASA now uses it as a storage module, and there may be a second, larger Bigelow inflatable flown to the ISS in 2020 (Fig. 4.17).

Bigelow has developed several plans for a commercial, inflatable space station, as well as Moon and Mars habitats. He has said that he intends to spend some US$500 million of his own funds, to build and launch the first commercial, and inflatable, space stations, and that he has already spent over US$275 million so far. In 2018 he created Bigelow Space Operations (BSO) to market and manage inflatable space habitats as space hotels and leased research facilities. The new company will conduct market studies and define the opportunities, and then will market and operate two B330 space habitats, to be launched by 2021. A B330 can be launched on a single Atlas V rocket, full loaded. These will be placed in LEO, and each will be able to house a total of six space visitors in a volume nearly a third of the ISS, some 330 cu. m of usable volume. They are not only looking at space tourists, though they plan to offer the habitats as a ‘space station for rent’ for the price of US$25 million for 60 days, a tiny fraction of the cost of using the ISS. It would also allow tourists, private users, national space agencies, and NewSpace businesses to

Fig. 4.18 A scale model of the Bigelow B330 space habitat, with Robert Bigelow at right. (Image courtesy of Bigelow Aerospace.)
have long-term access to a commercial space station that Bigelow would operate as a landlord [12] (Fig. 4.18).

Bigelow does not have any interest in developing launchers, and so his space station ideas are dependent on the successful development of commercial space transportation systems like the SpaceX Dragon 2, Blue Origin’s New Glenn, and Boeing CST-200 StarLiner. His ultimate goal is to operate commercial space stations and space hotels using inflatable modules, and he has publicly stated that he is prepared to spend fully half of his personal fortune to achieve that goal. He also has developed prototypes of inflatable habitats for the Moon as well. Once the Dragon 2 and StarLiner start flying, it will be fascinating to see how this develops. Inflatable space hotels may be in our very near future.

Although these are the major space billionaires at this time, there are other billionaires with space interests, and there will surely be more as we move ahead. Several other high profile billionaires have significant, if lower profiles, space interests and commercial investments. These include Google’s Larry Page and Eric Schmidt (Chairman of Alphabet, Inc.), who have investments in Planetary Resources, and Mark Zuckerberg, founder and CEO of Facebook, who is an investor in the Starshot US$100 million research project to perform a space mission to the nearby (relatively) Alpha Centauri star within a generation. Several other high-tech billionaires, particularly Bill Gates, appear to have little interest in space activities.

The fact that we see all of these very powerful and influential billionaires developing and self-funding very large commercial space ventures is quite extraordinary, but you don’t have to be a billionaire to play in NewSpace today. There is a second, perhaps even more exciting phenomenon that is equally astounding.

Beyond these very well-funded activities that have just been presented, we see a new generation of non-billionaires – young entrepreneurs who are deeply committed to space, and who are building new entrepreneurial businesses in space. This is a new generation of people, many of whom are of the ‘space generation,’ those who were born after Sputnik 1 and the flight of Yuri Gagarin. These young people bring with them a very different perspective from the pocket protector, crew-cut NASA and aerospace corporation engineers of the heyday of the Apollo project. They bring a new, Silicon Valley, venture capital mindset to their desire to be involved in space, and to go into space themselves. Here come the kids.

**Peter Diamandis, the Serial Space Entrepreneur**

Not all of this generation of space entrepreneurs are household names or fabulously wealthy. One such is Dr. Peter Diamandis, a medical doctor, scientist, inventor, and serial entrepreneur who is making tremendous advances in commercial space. He graduated from the famed MIT aero/astro department and also received an M.D. from Harvard Medical School.
Peter, from a very early age, had a strong desire to go to space and to be involved in space activities. His drive and ambitions have led him to create a string of new ventures that have had a real impact on the NewSpace landscape.

Peter founded the Students for the Exploration and Development of Space (SEDS) at MIT in 1980, when he was a student there. Other founding chapters were also started at Yale and Princeton. In April of 1981, Peter wrote a now-famous letter (famous in the NewSpace community) to *Omni* magazine, complaining about the state of the space program, and asking other students to join him in SEDS and to band together to make a difference [13]. Here is the text of his letter:

**Space Interest Group for Students**

An intercollegiate student society, Students for the Exploration and Development of Space (SEDS), has been formed, and its first chapters have been established at MIT, Princeton, and Yale. The steady deterioration of the U. S. space program's goals and budget endangers our future and demands an organized response from our nation's campuses. The society has as its ultimate goal its establishment as a national student pro-space organization. We invite you and the other students at your college to begin a chapter and join us in our cause.

We see as our primary goal the enlightenment of our government, private industry, and the general populace regarding the benefits of a strong space program. SEDS will provide a forum for the discussion of space-related issues, make plans for the future, and spark the interest needed to develop this new frontier and to secure our future.

Our immediate plans include submitting petitions to Congress and the President, urging the restoration of the solar-power satellite research budget. If you are interested in forming a chapter at your college and in helping these efforts, write to us for further information.

Peter H. Diamandis, MIT Chapter of SEDS 372, Memorial Drive, Cambridge, Mass.

Two years later Peter, along with Todd Hawley and Canadian Bob Richards, founded SEDS-USA as a national organization. The goal of SEDS was to get students involved and make a difference in the space world that they would inherit. SEDS is still going strong, and has chapters throughout the United States and around the world. Jeff Bezos was the president of the Princeton University SEDS while he was an undergraduate student there. But this was only the beginning for Peter.

Displeased with the space education that he had received at MIT and Harvard, Peter, again along with Todd Hawley and Bob Richards and others, decided to create the International Space University in 1987. ISU was to be a revolutionary new concept in space education, with a focus on what they called their “3-I philosophy” of international, intercultural, and interdisciplinary space education. Their idea was to completely change the way that space education is conducted, into a new and open concept that was more focused on the ideas and interests of the new generation of SEDS students and less divided by national and disciplinary stovepipes.

ISU began with its first summer program, held at MIT in 1988, and it has grown into a recognized and positive force in innovative space education. It continues to offer summer programs at different locations around the world, and it also has a permanent campus in Strasbourg, France, where it offers a Masters in Space Studies. This author was at the founding ISU conference at MIT in 1987, and served on the ISU faculty for over 25 programs around the world.
In 1994, Peter started the X Prize Foundation, which offers prizes for new and innovative, high-tech solutions. The concept was based on the Orteig Prize of the 1920s, which offered US$25,000 in 1919 for the first aircraft to fly non-stop from New York to Paris, or the reverse. Several teams were formed, and the prize was famously won by Charles Lindbergh in 1927. The prize concept is to get multiple groups to put up their own money and ideas, in hopes of winning the prize, thus generating multiple new concepts and approaches, rather than the standard approach of signing a contract to single company.

The first, and by far the most visible X-Prize, was the Ansari X-Prize that offered US$10 million for the first private sector vehicle that can fly into space (above the Karman line) twice within one week. It was won by the Paul Allen-funded entry that was designed by famed aeronautical designer Burt Rutan. This generated tremendous publicity and enthusiasm for space, and the winning project was later purchased by Sir Richard Branson to become Virgin Galactic.

One little known aspect of this is that Diamandis and the X Prize did not actually have the $10 million purse. What happened was that the Ansari family took out an insurance policy at a cost of $1 million that would pay off the winner if the prize was won. The insurance company got several very knowledgeable, experienced and established space experts to evaluate the idea, and they all agreed that it could not be won, making it appear to be a safe investment for the underwriter. But it turned into a $10 million loss for the insurance company when Rutan’s design won the prize. Be careful who you ask for advice.

The X-Prize Foundation has now gone on to offer multiple additional prizes, including the Lunar X Prize for a private vehicle that could land on the Moon, drive some distance, and take photos. That was not claimed within the allotted time, but some of the contestants are continuing their development in the hopes of offering commercial, small payload services to those who want to go to the Moon. There are several other prizes, but they are mostly not involving space. These include prizes relating to education, the environment, and healthcare. The X Prize has also spurred the creation of other space prizes, including a series of prizes offered by NASA itself. It was a very innovative and successful concept, and typical of Diamandis’s creative and entrepreneurial spirit.

In 2008, along with Ray Kurzweil, he founded the Singularity University at NASA Ames in Silicon Valley. It is based on the ISU education model but is focused on harnessing the innovative Silicon Valley entrepreneurial environment to address the tremendous societal and environmental challenges facing our species and planet. It has found significant funding from Google and other Silicon Valley companies, and offers several educational and incubator programs. The goal is to create new and innovative ideas that can affect the lives of 1 billion people.

Diamandis is a serial entrepreneur, and he has been involved in a wide variety of startups, including International MicroSpace and Constellation Communications (satellite telecommunications), Zero Gravity Corp. (zero-G tourist flights in a Boeing aircraft), the Rocket Racing league (rocket racing), Planetary Resources (mining asteroids), Human Longevity, Inc. (genetics) and several more. He also has written two award-winning books: Abundance: The Future Is Better Than You Think
in 2012 [14], which rose to #2 on the New York Times best seller list, and the follow up in 2015, Bold: How to Go Big, Create Wealth, and Impact the World [15]. In 2006 he became the first winner of the Heinlein Prize for Advances in Space Commercialization, with a payout of $500,000. Elon Musk won the second award in 2011, and Jeff Bezos won it in 2016. And Diamandis is not done by a long shot; he continues to drive the commercial and entrepreneurial space community with his energy, vision, and business acumen.

And there is an entire new generation of others who are stepping up. They are young, dynamic, not limited by bureaucracy, and finding new and creative ways to make space happen. Planet, formerly Planet Labs, has revolutionized the commercial remote sensing paradigm. It was founded by young researchers at NASA Ames, Will Marshall, Chris Boshuizen, and Robbie Schingler, some of whom attended the ISU summer session program held there at NASA Ames in 2009. They first were involved in the innovative ‘phonesat’ project that flew a standard smartphone, first on balloons and later into orbit, to test if it would operate in space. After the 2009 ISU/NASA Ames program, the concept of Planet, using a large constellation of 3-unit cubesats was born, and there are now over 200 Planet ‘doves’ in orbit, imaging the entire Earth every day.

Made in Space, Inc. was founded in 2010 at the second Singularity University program held at NASA Ames. The concept was to create additive manufacturing (3-D printing) capabilities in space. Four young entrepreneurs, Aaron Kemmer, Jason Dunn, Mike Chen, and Michael Snyder, decided to seek NASA funding to make their summer session project real, were successful, and flew over 400 parabolas in 2011 on NASA aircraft to prove the concept. They won several SBIR (small business Innovation research) awards from NASA, and launched their first printer to the ISS in September of 2014. In December of 2014 a wrench was printed on the station from uplinked files, and additive manufacturing in space is now a reality.

Young people at Made in Space and Planet, and many others, are rapidly changing the face of how space is done. Made in Space flew their printer on the ISS only three years after the concept was born. Planet was founded in December of 2010, and flew their first satellite in April of 2013. By mid-2015 they had over 130 cubesats in orbit and had received over US$180 million in venture capital financing. These second-generation space entrepreneurs are innovative, fast, agile, and operating well outside the Space 1.0 mindset. And there are others coming along. Many of these either started up or are still located in the magical Silicon Valley, where all things seem possible, on this world and in space.

### What Are the Common Threads That We See?

What a fascinating time to be involved in space. We have here looked at several of the most dynamic, future-oriented space entrepreneurs that are active today, and they are re-writing the book on how space is done. We have looked at several fascinating examples of disruptive space innovations and technologies and the people
behind them, in both the traditional business world and in the space arena. Can we find some important similarities between these various people and what they have achieved?

Clearly, these are all dynamic, confident, and capable individuals. They have big ideas, and they also have the courage of their convictions and are capable of organizing large organizations and complex endeavors. They are resilient and have demonstrated the ability to respond to adverse events, which are inevitable in space endeavors.

They also largely have their own large financial resources that enabled them to carry out their activities, mainly without the need for external funding, oversight and interference. Not to say that they do not allow others to invest in their ventures, as they clearly do. These people made billions, largely in computers and high tech (but not exclusively) and have turned these fortunes into doing what they really care about, which is space and the expansion of the human species into space, and getting to go into space themselves. Most of these individuals grew up or were young during the Apollo Moon landings, and remember the promise that space was a priority, and they all had the assumption that we would continue to develop our space programs. Not all are high tech wunderkinds, though. Robert Bigelow does not own a computer and does not use email.

All of these innovators also have faced significant political and economic opposition. No disruptive entrepreneur gets anywhere without facing the wrath and retribution of the established market leaders, and this is the same in all of these space entrepreneurs. They have all faced the political and economic pushback that comes from shaking things up, and they have also faced major failures and setbacks. But they keep pressing forward, and space will never be the same again.

In our next chapter we will look at the amazing new technologies that will be driving this space revolution, in the hands of these innovative and driven personalities and all of those who follow after them.

References


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Chapter 5
Space Technology Drivers of Change

Space can be mapped and crossed and occupied without definable limit; but it can never be conquered. When our race has reached its ultimate achievements, and the stars themselves are scattered no more widely than the seed of Adam, even then we shall still be like ants crawling on the face of the Earth.

–Arthur C. Clarke

This chapter will analyze the most important emerging, new, and disruptive technologies that have already, or shortly will, make an impact in the arena of space, as well as here on Earth. Major innovations such as artificial intelligence, additive manufacturing and GNSS are included, along with less known and less understood emerging concepts such as edge computing and cubesats.

Global Navigation Satellite Services (GNSS)

These Positioning, Navigation and Timing (PNT) satellite services, such as the Global Positioning Satellite (GPS) system, are key to self-driving cars and trucks and air transport, orbital navigation, global digital timing, and more.

The American GPS and its later competitors, including the Russian Glonass, Chinese Beidou, and European Galileo, have revolutionized many facets of our modern world. These include, but are not limited to, ground, air, and marine navigation, precision timing of everything ranging from email packets to stock market transactions, and more [1]. A revolution in transportation, equal to that introduced by Henry Ford and his mass-produced Model T cars, is right around the corner, and will have a major disruptive impact on many different sectors of our society.

Self-Driving Vehicles

Google’s self-driving vehicles have already covered over 1.7 million miles with only 11 accidents. Some of the benefits of this next transportation revolution will include far fewer accidents, fatalities, and insurance claims. We will also see
improved mobility for the aged and those with disabilities, fewer arrests, court cases, reduced accidents due to driving while intoxicated, and vastly improved delivery of goods and services. Satellite PNT systems will provide vital capabilities, and these will soon accomplish the next major leap forward in the intermodal transportation system envisioned by Malcom McLean. And, of course, there will be other, as yet undiscovered, benefits, new businesses, and ideas that we have not yet invented.

Global timing from satellites now provides synchronization of the Internet, power grids, stock exchanges, and more. Satellite navigation systems will enable self-driving cars and self-flying personal aircraft, just like the Jetsons. Jeff Bezos is planning GPS drones to deliver packages direct to your front door, and all of this is on the horizon [2].

However, there are also several major concerns regarding these new innovations in transportation. A chief concern will be the vast number of people who make their living driving who will lose their livelihoods and the residual economic and social impacts that this will have. There are currently over 3.5 million people in the United States alone, who contribute to the overall economy, working as truck drivers. There are, of course, many more working as drivers in the other various transportation sectors such as taxi drivers, Uber and Lyft drivers, ambulance drivers, and the list goes on and on. There are millions more around the world who will also be vulnerable [3].

One must also consider the families of these drivers and then the workers and businesses who depend on them as well. These are the businesses such as highway truck stops, motels, restaurants, and others that rely on these drivers for their jobs. These are jobs, in many instances, filled by employees who are not highly educated. These employees will be much less able to transition to the high-tech jobs in computer programming, database management, and AI that will drive this revolution. Professional driving is one of the few careers that provide a middle-class living without an advanced education. What will these people do? Some experts such as Bill Gates has discussed the possibility of taxation on robotics and other smart systems and the creation of a living wage payment for citizens as we move into this new highly automated age [4].

Peter Thiel is the other, less well known founder of PayPal, along with Elon Musk. He has an excellent quote, where he said “What we wanted was flying cars, and what we got was 140 characters.” While the amount of the Twitter limit has been doubled, we may indeed see the coming of personal flying cars, all made possible by GNSS.

Of course, all of this is enabled by the U. S. Global Positioning System, or GPS, in combination with AI, Geographic Information Systems (GIS), cloud computing, massive databases, vehicle remote sensing, and other components. This is similar to the way that Uber and Lyft have created new businesses by combining GPS, real-time GIS driving instructions, databases, and online payment components to almost instantly match a rider and the nearest available driver. All of these pieces existed separately before, but the genius was in combining the pieces in a new way that met a need. Credible minds believe that the very concept of traditional car ownership
and use will be a thing of the past in little more than a decade. This will have as large a global economic and societal impact as the revolution of Henry Ford and his mass production.

All things have their end, and we may be on the cusp of the end of Henry Ford’s dream of a car in every home. Combine this with electric flying cars and it will be a very different world. Add in drone delivery of everything from pizza to Amazon and FedEx deliveries and there could be significant disruptive impacts in manufacturing, insurance, petroleum exploration and distribution, transportation planning, highway construction, and more. Precision timing, navigation, and positioning from satellites is going to continue to alter our world, and provide an underlying positioning and timing infrastructure for new disruptive innovations, both on this Earth and above it.

Really Big Data and Space

How big is big data? When it comes to digital data and the information that is contained within, it really is relative, but what was big before is tiny today, and what we think of as big today will soon be laughably tiny. When I first started on my own digital exploration and was working on satellite data analysis of our Earth, I worked at a state-of-the-art NASA research facility and had access to some of the very best computer tools and analysis capabilities in the world.

The photo below shows, in the background, a MASSCOMP (Massachusetts Computing Corporation) mini-super computer that I used for Landsat image processing and GIS analysis. That is me on the left, along with Prof. Joe Pelton in the center. It was a very powerful computer at the time, taking up two large racks. It had one Intel 68020 processor with an additional floating-point processor. It had a 40-Mb hard drive, with 8 kb of cache memory, and it included a dedicated color monitor and a text terminal for entering commands. It ran a customized real-time

![Fig. 5.1 1987 Masscomp mini computer in dual racks behind the table, not a laptop in sight. (Photo by the author.)](image)
version of the UNIX operating system, and it cost about US$15,000 in 1986, which is around US$34,000 today. It was a state-of-the-art computer, available to only a few. Today’s tiny laptops and tablets are far more powerful, and the Mac laptop I am typing this on, with my 3-tb external hard drive, massively outperforms it in every way. And tomorrow’s technology will make today’s leading computers look like a Model T Ford (Fig. 5.1).

So how fast is the fastest computer on the planet? Big data requires fast processing speeds, and the continued development of super computers of extraordinary power continues. In the summer of 2018 the new, fastest computer in the world was unveiled by the U. S. Department of Energy. This computer has more than 10 petabytes of memory and can process 200,000 trillion calculations per second, or a computing speed of 200 petaflops. It has an AI-optimized architecture for the analysis of massive datasets, machine learning, and the development of intelligent software. It also cost some US$200 million to build [5]. (See Fig. 5.2.)

We have created more data in the past decade than has existed on Earth since the origin of human beings. IBM reported that way back in 2012, people created some 2.5 exabytes (2.5 billion gigabytes) each day. But what does this mean? How big is big data? What is all this data made of, and where is it stored?

Bytes are a standard unit of measurement for digital data. The term was created by IBM researchers in the 1950’s, and it represents a unit of digital information, most commonly consisting of 8 bits, consisting of a single 0 or 1. Eight bits making up a single byte can represent, or encode, a single character of text, such as a letter, number, or special character (%$), in a computer’s memory. Early systems used 6 or other numbers of bits and other sizes are possible, but 8 has become the standard and represents a ‘power of two’ structure that can, in a single byte, represent values

![Fig. 5.2](image_url) The Summit super computer, at Oak Ridge National Laboratory, TN. (Image courtesy of Oak Ridge National Laboratory, U. S. Department of Energy.)
ranging from 0 to 255. It is now an international standard [6] that is represented by
the symbol ‘B,’ with ‘b’ representing a single bit.

In digital telecommunications systems, including satellite telecom systems, there
is a slightly different meaning, in that a byte is what represents the smallest unit of
distinguishable data, and can vary in size and structure depending on the system of
encoding that is used by a specific system.

The following chart shows the SI (metric) prefixes for bytes. We are all familiar
with the lower ranges (kilo, mega, etc.) from our home computers, but the larger
prefixes are what we need to deal with when we are talking about very big data. We
also need to be aware that the difference between decimal and binary amounts
becomes increasingly larger as we approach big data levels. A kilobyte (Kb) is 1,024
bits of data in power of twos, or 1,000 binary bytes in SI measurement. A megabyte
(Mb) is $1,024^2$ of data, A terabyte (Tb) is $1,024^4$ of data, etc. (See Figs. 5.3 and 5.4.)

Some recommendations for what should follow as new names in the world of big
data would include biggabytes, lottabytes, mongobytes, and overbytes.

Today’s data numbers are truly staggering. To give a sense of scale, the entire
printed collection of the world’s largest library, the U. S. Library of Congress, could
be stored on about 10 Tb of digital data. This number, 10 Tb, is sometimes inform-
ally referred to as a LoC, for one Library of Congress, but that is not official and
is now quickly becoming outdated. In fact, the Library of Congress now maintains
a digital collection of over 240 Tb of digital data, and this is in addition to its printed
books, and it is growing in size daily. This massive collection includes digital mov-
ies, graphics, scanned documents, sounds, and much more.

When we start working with digital satellite imagery data, the numbers quickly go
up. One estimate is that there is now over 2.7 zettabytes (Zb) of digital data in the world,
and the number is growing by the hour [7]. This trend will only continue to explode.

As one example for the space domain, NASA operates its own interconnected
series of Earth science data centers, called the Discipline-oriented Distributed
Active Archive Centers (DAACs) as a part of EOSDIS, the Earth Observing System
Data and Information System. In 2016, NASA’s EOSDIS managed over 17.5 Pb of

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**Fig. 5.3** Data sizes in SI
terms.
data. They added over 7 Tb of data each day, and distributed over 30 Tb of data to over 12,000 individual data users around the world each day. They distributed over 1.5 billion individual data products that year, and this is only the Earth observation data from NASA.

NASA also operates the Center for Climate Simulation at the Goddard Space Flight Center, a part of the NASA High End Computing (HEC) program. This center stores over 32 Pb (petabytes) of global climate data, and runs simulations on a dedicated massive supercomputing cluster. The system includes a large data wall for the visualization of the results of these analyses. (See Fig. 5.5.)
Fig. 5.6 Pleiades utilization diagram. (Image courtesy of NASA.)
Big data requires big processing. The NCCS is a part of NASA’s High-End Computing Capability Project, which integrates supercomputers, data analysis and visualization, networking, and related tools and technologies for NASA research. Their Pleiades supercomputer from SGI has a total of 245,536 cores and a total memory of 935 Tb, capable of processing 173 teraflops/second. On the Sunday afternoon when this was written in the winter of 2018, here is the real-time graphic of Pleiades utilization (see Fig. 5.6).

Humming along at 92% on a Sunday afternoon. And that is only one NASA example. The U. S. government, through its Open Data Project, now offers over 120,000 publicly accessible datasets, all available for free online to anyone. Big data is here and getting bigger every day. Our problem quickly becomes how can we extract useful information out of this flood of data?

The private space services sector is moving fast in the same direction. Planet, the NewSpace operators of the world’s largest constellation of Earth observation cubesats, acquires over 6 million km² of Earth imagery each and every day. The ultra-high resolution commercial satellite provider DigitalGlobe acquires some 3.3 million km² each day, collecting two petabytes of data annually, and currently maintains over 40 Pb of high resolution satellite imagery data on spinning disks in their data center, ready for download to their commercial customers. It also maintains an additional 20+ Pb of data in storage, as well as a complete backup in a second data center. These data are directly accessible by its commercial customers, which include many national governments and private corporations.

The commercial world is undergoing the same revolution, and on an even more massive scale. Amazon, founded and run by Jeff Bezos, who was discussed earlier, is the world’s largest retail company, with almost 60 million customers. It sells over a quarter of a million digital books online, and maintains over 42 Tb of databases. Walmart processes electronically over 1 million transactions every hour, and manages a database of over 2.5 Pb (petabytes). YouTube has over 45 Tb of videos available online, and customers watch over 100 million videos every day. There are a lot of cute kittens out there.

Google is the king of big data, but relatively little is known about the true size of its data holdings and storage and processing capabilities. Recent estimates are that today, Google stores about 15 Eb (exabytes) of data in their data servers around the world, and processes some 3.5 billion requests per day, which is half of all Internet searches around the world. Its data centers process over 20 Pb (petabytes) per day using over 1.4 million dedicated servers running 24/7. More servers and server farms are being added each month as well, just to keep up with the demand. And this is only Google; Amazon, Yahoo, Apple, national governments and private corporations are creating a massive, and at least partly interconnected, digital data world that was unimaginable only a decade ago. And the future will be even more amazing. Big data is here, and there is no end in sight. Today’s big data will be tiny in just a few years’ time.

All of this data has to be stored somewhere, and the creation and management of data centers is a huge industry. Google, Apple, and Amazon all operate their own
big data centers that provide the massive power and cooling that such systems require. One example of a big data system is the NSA’s Utah Data Center.

The U. S. National Security Agency (NSA) is responsible for electronic intelligence data collection and analysis across the globe. In 2014, the NSA opened a massive data center in Utah, code-named Bumblehive, that is capable of storing and analyzing over a yottabite of data, or over one-thousand trillion gigabytes of data. This center is powered by a Cray XC30 supercomputer, capable of 100,000 trillion calculations per second, or one petaflops of processing [8]. The facility is a US$2.5 billion, 93,000 sq. m (one million sq. ft.) complex with a 9,300 sq. m (100,000 sq. ft.) data center. This twenty-building complex contains all required support facilities, including sixty diesel generators and fuel for 3 full days of operation. It requires massive electricity (some 65 megawatts per year) and water resources for cooling the massive array of processors. That’s BIG data, and in only one data center operated by a single government agency, even if it is the biggest. And this particular facility was designed for easy enlargement (Fig. 5.7).

The second largest single database that exists today may be the National Energy Research Scientific Computing Center (NERSC), which is operated by the U. S. Department of Energy and is used for atomic energy experiments and research. It consists, public reports describe, of at least 2.8 Pb of highly classified data that is accessible to only about 1,000 scientists and researchers. Big data and processing with very small access.

Big Processing for Big Data: Data Analytics, Data Mining, the Cloud, the Crowd and Open Source

If you collect big data, you have to be able to process it. Traditionally, in the space remote sensing arena, the raw data was transmitted from the satellite to Earth and was downloaded and processed by trained image analysts working on a single,
dedicated computer system. The process was a combination of science and art, and a trained analyst used his or her experience and knowledge, and mastery of a specific image-processing software, to derive useful products such as land use and land cover or agricultural production. This process was time intensive and was based on the skills and expertise of the analyst. But this is all changing, and the many advances in computing are radically altering how, how much, where, and what useful products can be made from big data.

The terms data analytics and data mining are quite the popular buzzwords these days involving the processing of big data to try to identify trends and patterns that can help us understand what is happening and how to better plan for the future. Today, data analytics is big business, and many commercial companies and government agencies are using these tools, along with AI and related capabilities, to improve production processes, understand their customers, target marketing, develop new drugs, and improve the effectiveness of their operations. This new capability will have major impacts on a wide variety of things that touch our daily lives, including business operations, logistics, healthcare, governmental services, scientific research, crime prevention, disaster planning and response and more. Big data and big data analysis go together, and we are just beginning to see how these are developing.

You probably are at least somewhat familiar with “the Cloud.” What is it? Actually, the cloud is just somebody else’s computer, along with the ability to remotely access somebody else’s computer fast enough so that it seems like it was on your own hard drive. It is also the ability to access remotely very large data storage centers and supercomputing power. The companies that offer cloud-based services keep upgrading the types of services that can be accessed remotely and how data security could be adequately protected.

Amazon Web Services, Inc., was founded in 2006 and developed out of the computer infrastructure that Amazon created for its own needs. It is currently the largest provider of this service, but Apple’s iCloud, Microsoft Azure, and many others also compete for this growing market. These companies provide integrated services, including data storage, virtual machines, AI, analytics, and more, all for a ‘pay as you go’ service. Today’s high-speed Internet makes the cloud possible and removes the requirement for you to have all that computing power yourself.

Edge computing, and the related fog computing, is a recent development that could have major implications for the cloud and space technologies. In some ways, it is a return to an earlier age of computing but in a vastly different way. In earlier days, all computing was done at the source, on your own computer. Networks and the Internet changed all this, and the rapid development of the cloud and now the Internet of Everything will make edge computing inevitable.

What edge computing does is the opposite of the massive data centers discussed above, where all data are fed into enormous central databases and processed by massive parallel processing computers. With the coming of the Internet of Everything, millions and millions of new sources of data will be collected in ways that we can barely comprehend at this time. This is related to the new concept of “sensor deluge” [9] that will be a byproduct of the Internet of Everything.
All of this data cannot be centrally processed efficiently, so edge computing has the data processed and reduced as much as possible at or nearest its source, before passing it along down the network. It also reduces latency across a network for applications requiring high-speed feedback and response. Fog computing, also referred to as fogging, is a closely related concept, and several companies are actively implementing major fog solutions, including Cisco, which originated the term.

The Open Fog Consortium consists of many major computing players working together to establish standards and promote the concept. In a fog network, the designers focus on having data collected and analyzed at the most local, and therefore most efficient, location, as opposed to moving raw data across the network to be processed at a centralized server. Less total data are moved, leading to faster processing. Mist computing is another related, recent term to describe a less computationally intensive implementation of this approach.

These are some of the most interesting new ventures involving distributed processing and analytic power. Crowd sourcing has provided a means of funding a variety of such ventures, both commercial and scientific, and sites like GoFundMe are providing resources for everything from research expeditions to new commercial space ventures. Citizen science has enabled normal citizens, people without professional scientific training, to engage in scientific activities across vast distances and in ways that have advanced many fields of inquiry. Crowds of people using their GPS or other devices can collect massive amounts of data across the world and at no cost. Projects ranging from astronomy to oceanography and archaeology studies have been conducted with great success [10].

A New Generation of Earth Remote Sensing

In satellite remote sensing, we are beginning to see the first space remote sensing on-board data processing, and this trend will continue. As we move into higher and higher amounts of data being collected from many more, low Earth orbit satellites, the ability to download the raw data is becoming a problem. When we only had one or two operational Landsat satellites, with only a few data channels and relatively large spatial resolution imagers, the ability to directly download or store the data on onboard before it could be sent to the ground was manageable.

As an example, the current U. S. Landsat 8 remote-sensing satellite has a single 3.14 terrabyte solid state on-board data recorder as a part of its command and data handling subsystem. (See Fig. 5.8.)

This data recorder has the required radiation hardening to be able to operate in space. And even Landsat has a lossless compression process for its Operational Land Imagery, or OLI, sensor, which can be turned off or on depending on the need. This system creates the first line of data and one line every 1,024 lines (about every 4 seconds) for use as a reference. The data are downloaded to the ground through its X-band antenna at a total data rate of 384Mbps. Such a system is completely
reasonable with today’s capabilities but is not suited for the future, where we will have hundreds and then thousands of satellites (Fig. 5.9).

When we move into hyperspectral imagers, collecting 256, 512, 1,024 or many more channels of very high resolution data, and when we multiply this by hundreds of satellites, the on-board and ground telemetry segments and human processing quickly can become overwhelmed. So we now see on-board data processing with the Planet satellite system, and more will follow this model. This was for many decades an anathema to Earth scientists, who wanted only the raw, original data to be sent to the ground, so that they could control all aspects of the data processing chain. And this is a good idea, especially for developmental or research applications.
But the reality of the data volume collected now and in the future, along with new compression improvements and general technology advances makes the on-board processing of data on the satellite inevitable.

As a second example of what is happening now and what will happen in the near future, the Planet (formerly Planet Labs) satellites operate in a large constellation at low altitudes. They currently have 175 ‘dove’ satellites that use commercial COTS CCD imagers, making up the largest remote sensing constellation now operating. These are 3-unit cubesats each weighing only 5 kg. All satellites use onboard JPEG2000 compression, with each satellite capable of 12.5 Mb per second download speed in the X-band to the ground network. The mission control system is entirely automated using in-house software and is operated by a very small team in one control room. The satellites image the entire world’s surface every day. A ‘normal’ day includes over 200 satellite downloads equaling over 6 Tb of data downloaded to the ground segment. The system is designed to function as a daily line scanner of Earth, useful for a wide variety of commercial, governmental, and environmental applications.

The Planet remote sensing system was originally founded in 2010 by a small group of NASA Ames researchers who had originally created PhoneSat, a mission to fly a cell phone into space and take pictures. It worked, and so they decided to start a commercial remote sensing company using a 3-unit cubesat design. The company, now located in San Francisco, has several hundred employees and now, with over 175 satellites, can acquire imagery of every place on the planet every day. It has also enhanced its capabilities by acquiring Google’s Terra

Fig. 5.10 Founder Will Marshall and one of the tiny Planet doves. (Image courtesy of Planet.)
Bella satellites in 2017, as well as the RapidEye fleet from fellow start-up BlackBridge in 2015 (Fig. 5.10).

**Petabytes to the People**

The Google Earth Engine is a program of Google’s that combines a multi-petabyte, Internet accessible catalog of satellite imagery from Google and other sources, along with other geospatial datasets. Using Google’s equally massive computing capabilities it is able to allow scientists and researchers to conduct Earth-oriented analysis on a scale and at a speed that was unimaginable only a few years ago [11, 12].

The Landsat dataset is the world’s longest continuous remote-sensing data collection and dates back to 1972. The data are processed using APIs that can be written in both Python and JavaScript for the analysis of these very large area or long-time series imagery datasets. The data that are available have been collected by Google from the original sources and are accessible directly through Google’s cloud. These data include the complete Landsat catalog, as said above, many (but not all) NASA MODIS moderate resolution datasets, the entire catalog of the European Space Agency’s Sentinel-1 data, and various ancillary data including global elevation data, global climate data, ocean temperature data, and much more. Users will apply online to be able to access the data, and approved users can also upload their own raster and vector data and can download processed data for use in other environments. The Earth Engine will be provided without cost to educational and research users, but there is also a mechanism for paid commercial licenses for those in the private sector. The scope and scale of the data available and the speed and turnaround of data processing are beyond the capability of almost all current researchers and facilities.

This Google Earth Engine is an excellent example of what is coming [13]. We are looking at accessing massive amounts of data, in the petabytes, and using massive parallel processing computing for fast access to the processed results. The next generation of remote sensing is going to include these, as well as on-board data processing of the data at the source, in order to reduce the amount of data that needs to be transmitted to the ground. We are also going to see much more use of AI in the processing of data, and much more specific application analysis. One limitation is that users will be required to program the API, and there are no user-friendly user interfaces. This limits the utility of the system to those with either Python or JAVA skills, but this will likely change over time.

To sum up, next-generation remote sensing of Earth will be radically different from what we have done since the earliest days of the space age and will include the following:

- Petabytes (1 million Gb) of data
- The “Google-izing” of space remote sensing (20 Pb/day)
• Silicon Valley space-based innovation (e.g., Skybox and Planet)
• On-board processing
• From image processing to RS/GIS data mining, including machine learning, pattern recognition, mega-statistics, derived knowledge, real-time analytics, app-based information delivery, decision support systems, GIS internet of things, etc. etc.

And there are many other emerging technologies that could easily be added to this list in the area of telecommunication satellites, such as on-board processing associated with the need to provide accurate control and collision avoidance of thousands of small satellites in large-scale constellations. Also we are also looking at the new aerial drone revolution, and expanded access to sub-space application in the stratosphere or what is sometimes referred to as the “protozone.” Indeed, routine access to the protozone, between commercial airspace and orbit, could open up a wide variety of new telecom, remote sensing, navigation, and other applications, including responding to disasters and monitoring crops and the environment. All of these are promising new areas for NewSpace uses of very large scale processing. The area of remote sensing is, however, the most intensive use and processing of large datasets in what can be called Space 2.0 and disruptive space technologies. Thus we will concentrate our focus on this space application.

**Open Source Software**

One of the biggest changes we are seeing, and one that is having a major impact, is the maturation and general adoption of Open Source software for computing in general, as well as also for space applications and data. In the early days of space, new software had to be written for each individual launcher, satellite, mission, or space activity, and it was all proprietary code, owned by the government or contractor. As the space industry matured, proprietary software continued to be the dominant paradigm, with government-funded private code being required for each individual program, satellite, or rocket. Given the dual use nature of all space activities, these programs were very closely guarded and carefully controlled as national security assets.

A bit later, commercial uses of space such as remote sensing and mapping became successful businesses, and commercial software dominated. However, these commercial software packages, such as ArcGIS for GIS and Erdas and Envi for satellite remote sensing were, at least partly, derived from the first generations of government-funded software. These proprietary software products were copyrighted, and users could only purchase a limited license to use the code, and they could not own it, nor could they copy, share, or actually see or alter the source code that was provided. They were also very expensive, costing thousands of dollars per individual user license for a single computer.
Although these software programs are still robust and have driven much of the initial commercial use of satellite imagery and related spatial data, including GPS and car navigation systems, their high cost and limitations on use have also limited the growth of these application markets, especially in the developing world.

Open Source software has been around for decades, but it has suffered from its reputation, largely based on reality, that they were not sufficiently mature for serious use. The reputation has been that they are hacks, poorly written, unstable, and simply not reliable for government or commercial purposes, certainly not for space activities.

One of the major changes in recent years in space has been the maturity and explosive development of Open Source tools for a wide variety of uses, including tools specifically developed for space-related activities. For example, the Open Source QGIS remote sensing and Geographic Information System (GIS) software is completely free, runs on all major computer platforms, runs in over 40 languages, and is quickly becoming a standard tool for many uses, including GNSS and drone applications [14].

Apache Hadoop is Open Source software that was developed for reliable, scalable, and powerful general distributed computing. It is based on Java and consists of a suite of software libraries that provides a general framework for the distributed processing of very large datasets across multiple clusters of computers. It was created in 2005 in a project that was originally funded by Yahoo and was created by two software developers, Doug Cutting and Mike Cafarella, to support a new search engine project at Yahoo.

The following year, Yahoo gave the project to the Apache Software Foundation, for Open Source development and release. The concept is that it is designed to be infinitely scalable from a single computer up to thousands of networked servers. Part of the design is that each machine independently has the ability of local computation, storage, and networking. The Apache Hadoop libraries are designed to detect and work around any hardware failures in the network automatically, so that the system will be more robust. In 2008, Hadoop sorted 1 Tb of data in 209 seconds, winning the terabyte sort benchmark record.

So why has Hadoop been so widely adopted? With the creation of multi-petabyte datasets, there is now a need for the ability to routinely access and process these massive datasets, and to derive practical benefits from them. One advantage of Hadoop is that the data do not have to have strictly organized schema, and the system automatically handles the dynamic nature of large, networked computer systems. Individual nodes in multi-computer systems fail routinely, and Hadoop will automatically reconfigure around this. It assumes COTS hardware and is optimized for very large batch processing; it also runs on several different operating systems (Fig. 5.11).

There are several examples of very large configurations, including Yahoo, which had in 2008 a Unix cluster with over 10,000 cores that was involved in every Yahoo search. Facebook, as of 2013, had the world’s largest Hadoop cluster, with over 100 petabytes of data, and that was growing by half a Pb per day. As of 2012, Hadoop was being used in some way by over half of all the Fortune 500 corporations in the
world, including Microsoft, Amazon, and IBM. And Hadoop is Free and Open Source software (FOSS), running many of the world’s largest data engines. Open Source is an important part of NewSpace.

The Internet of Everything, Including Everything in Space

The Internet of Things (IoT) continues to spread and will soon be involved with the operation of smart cities, the resilience of data networks, and a link to cyber-systems everywhere. This is closely linked to implementation of the new 5G wireless networks on a global basis.

The IoT means that virtually all of our devices, from refrigerators to cars to house door locks will be ‘smart,’ wired, and connected. Many of these wireless service capabilities worldwide are closely linked to communications satellite networks. These capabilities will run through GEO-based high-throughput satellites as well as the large-scale constellations now planned for implementation, particularly those that are proposed to operate in the millimeter wave spectrum. This expansion, that will include worldwide systems for industrial controls, supervisory control and data acquisition (SCADA), pipelines, security control, and more, has been described as the move toward the Internet of Everything (IoE).

The increased dependence on Internet of Things technology to control almost everything on the planet – and in space – is a fundamental shift and is a part of the latest stage in the coming cyber revolution that will define much of our future and the increased importance of digital security everywhere, on the ground and in space.
Up to now, the Internet has connected computers with other computers. The Internet of Everything looks to the day, very soon, when everything from cars to toasters to lawn sprinklers to your refrigerator will be wired to the Internet and also have data collection and processing power built in. Although this will have many unforeseen beneficial impacts, it may also have negative consequences that we cannot now foresee.

One example of this is a test project conducted at the NASA Ames Research Center in Mountain View, CA, along with several Silicon Valley companies and the California Emergency Management Agency. The idea was to test a system of sensors in the San Francisco Bay area, where embedded GPS sensors would be able to provide early warning of a local major earthquake. These would trigger a cascade of events that would include automatic notification of emergency management and utilities in the area, shutting off the access to the area’s bridges and tunnels, placing area hospitals on emergency power, and even stopping elevators so that they could not become stuck in between floors. All of this will be done automatically, and in time to minimize the impact of such an event. The test went well, and this is a harbinger of things to come in the dawning world of the Internet of Everything.

Additive Manufacturing – Don’t Launch It, Make It Up There as Well

Additive Manufacturing (AM), also called 3D printing, is a revolutionary new concept, where things are built up by adding layers of viscous metal or plastic to construct complex structures using computer programs and robots, rather than the traditional way of removing bits by using a lathe or other tool to take away structure from a large metal casting. Additive manufacturing has gone quickly from a concept to reality, and its impact has not been lost on the aerospace and space communities. Major aerospace contractors are now using this new technique for complex aircraft parts.

One of the very first to take this new concept into the domain of space was the Silicon Valley startup named Made In Space. It started at NASA Ames in 2010, and quickly made a name for itself when it arranged for the launch of the first additive manufacturing system, called the 3DP, for 3D printer, to the International Space Station. Its second-generation device, named the Additive Manufacturing Facility, or AMF, was launched in March of 2016 and is owned and operated by Made In Space and is used onboard by NASA and others as a commercial service. The facility has already manufactured a wide variety of parts, tools, and more.

One of MIS’ goals is to leverage the unique characteristics of space, including microgravity, to harness new additive manufacturing potential in space and on Earth. This includes very large space structures, complex tools, and replacement parts, and also the 3D printing of components in space for improved performance here on Earth (Fig. 5.12).
The basic idea is not to have to build and launch every complex part of every device into space, but to simply launch the basic raw materials and the software defining the part, which is to be created in an additive manufacturing facility and just build it up there. Only the raw materials and the software for the new device would be ‘launched.’ This could be a game changer for space, significantly reducing the cost and time to get replacement parts and new tools up to the space station or anywhere else in space. This is particularly true for long-term space occupation, or colonies on the Moon or Mars.

One Made In Space project, which could enable a new generation of space capabilities, is called Archinaut. This is a system that includes what is called the Extended Structure Additive Manufacturing Machine (ESAMM), which is able to manufacture very large structures like trusses, antennas, and fuel tanks; all of these are all much larger than the ESAMM itself. Also under development is a system that would be able to repurpose launched components after arrival in orbit, allowing for the reuse of materials using additive manufacturing processes. Reusing materials already launched for new purposes would significantly reduce the need to launch expensive materials from Earth.

In early 2019, the U. S. Air Force announced that it has approved a recent startup to test and launch a 3D printed rocket engine from Launch Complex 16 at Cape Canaveral in Florida. The startup, named Relativity Space, was begun only three years before. It was founded by young people who had earlier worked at both Blue Origin and SpaceX, and has its headquarters in Los Angeles, CA. They have

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**Fig. 5.12** The additive manufacturing facility on the International Space Station, with a plastic part floating in front. (Image courtesy of Made In Space.)
developed the concept for a huge 3D printer the size of a small industrial building, appropriately called the Stargate, which they eventually want to launch into orbit as an on-orbit manufacturing system. They also want to build, test, and launch at the cape rocket engines and spacecraft that would be entirely 3D printed.

The company occupies a large facility at the NASA Stennis Space Center in Mississippi, where it is testing its engines and technologies. Now it has an agreement to launch from the Cape at LC-16, which was the site where Titan rockets were once launched, and also where the Apollo Service Module engine was tested. The name of the proposed vehicle is Terran 1, and it supposedly would only take some 2 months to print from raw materials, and launch a 1,200-kg payload into LEO. All this for a proposed cost of US$10 million for a launch, or about US$10,000 per kg into LEO, about half of today’s commercial cost. The company’s website states that its rocket design would have only 1,000 parts, all created using additive manufacturing, as opposed to over 100,000 parts using today’s current technology (Fig. 5.13) [15].

What does this have to do with space?

The ability to manufacture parts on demand in space, and to dramatically reduce the complexity and time to manufacture space engines and rockets on the ground, is a revolutionary new concept. 3D printing will allow the production of space components and entire engines and vehicles using the same printers without any dedicated tooling or machines. It could radically enable our ability to create and also to maintain habitats on the Moon, Mars, and beyond, by the repeated repurposing of existing materials into other, new uses, and more.

Fig. 5.13  The Relativity Space Stargate 3D printer; note the human for scale. (Image courtesy of Relativity Space.)
Artificial Intelligence, Machine Learning, Deep Learning, and More

Artificial Intelligence, or AI, is one of the key emerging and formative technologies of our times, and it will impact every aspect of our lives sooner than you might think [16]. AI is founded on the basic concept that machines can be created that will simulate human perception and intelligence. Many consider the field to have begun with a Dartmouth College workshop in 1956, where participants considered how the new computers could achieve human cognition and intelligence, far beyond the reach of computers of that time. Researchers generally view AI in both narrow and broad, or general, terms. Narrow AI systems operate within fixed boundaries, such as Siri, web bots, tax preparation software, and related tools. General AI systems will exhibit human-like intelligence, in ways that could be impossible to tell if it was a human or a machine that is doing the work. The most famous example, and certainly the most relevant here, would be the HAL 9000 computer from the several Arthur C. Clarke books and the Stanley Kubrick film 2001: A Space Odyssey. HAL, the Heuristically programmed Algorithmic computer, was a sentient machine that became all too human.

AI holds tremendous potential for improving many aspects of our lives, ranging from the economy to the environment to medicine. But it also poses new and uncertain challenges and has the potential of massive loss of jobs as machines ‘learn’ to process complex data in ways that have been the exclusive domain of humans. It also has the potential of increasing socioeconomic gaps as well. Large amounts of governmental, scientific and business funding are flowing into AI research, and it is starting to generate real results, according to the U. S. Government Accountability Office in a 2018 report [17].

Siri, Alexa, and the AI Virtual Assistants

We already are seeing the first AI applications, in cloud-based virtual assistants such as Siri, Amazon’s Alexa, Google Assistant, and multiple other ‘chatbots’ who interact with us as if they were humans. These devices, used on your smartphone or laptop, or in Amazon’s Echo and similar ‘smart speakers,’ can do a variety of voice-activated tasks, and can also control smart devices and manage a home automation system. Alexa is Amazon’s cloud-based AI voice service that was introduced in 2014. In 2015 Amazon announced a US$100 million venture capital fund, the Alexa Fund, available to developers of digital voice assistants. In early 2019 it was announced that Amazon’s Alexa has sold over 100 million units, with over 28,000 different devices sold by over 4,000 different manufacturers. The Alexa device is capable of doing over 70,000 different ‘skills,’ and there is an active third-party development capability to add more skills and to incorporate it into additional devices, ranging from home speakers to cars to smart houses.
And soon it will be smart spacecraft and space habitats. In 2018 an AI assistant was launched to the International Space Station. Named CIMON (the Crew Interactive Mobile CompanioN), it is a free-flying ball with a screen ‘face,’ and was developed by Airbus. It is designed to assist the (human) crew in conducting experiments, doing maintenance, taking photos and videos, and even simply chatting and talking. It was 3D printed on Earth and communicates by converting astronaut speech into text, which is then downlinked to the IBM Watson natural language computer on Earth, which parses a response that is then sent back up and converted back to speech on the station. Although CIMON is still just in the experiment stage, it points to the future of the use of AI assistants in space (Fig. 5.14).

There are many complex ethical and regulatory issues, determining acceptable risks and ethical decision making. What will be the impact on jobs, employment, training, and the world’s economy? We will discuss this in a chapter to come.

**Feature Identification and Change Detection**

Many innovative remote sensing start-ups are basing their businesses on using AI, machine learning, and related tools such as deep learning, for near real-time processing of their data. There are numerous small teams that believe that AI will provide the basis of a new wave of satellite imagery utilization to both improve the speed of analysis as well as the quality.

Now that we have hundreds of satellites imaging the entire Earth every day, the problem is no longer a lack of imagery but how can we sort through all of the raw data quickly enough to generate useful information. AI will play an increasingly important role in this, and the large number of recent startups with venture capital indicates significant interest in this new technology.
The singularity is a concept that has been proposed, which is deeply concerning in this regard. The concept is that AI, ever faster computing, and related technologies will lead to the existence of what is referred to as Artificial Super Intelligence, or ASI. This non-living intelligence could enter into a runaway reaction of ever faster and more capable self-improvements, leading to an artificial intelligence that would far exceed human abilities. This could lead to unimaginable consequences for human civilization and the future of our species.

Artificial intelligence, machine learning, and related capabilities will become key drivers in the development of computing and space very quickly. Natural language computing with AI will provide a wide range of technical services for both human spaceflight and satellite applications, driving new markets and businesses. It will also raise many new and troubling questions for the future as well.

Small, Smaller, Smallest

One of the most visible and tangible aspects of the so-called NewSpace entrepreneurial world are what are widely known as smallsats or cubesats. Today there are a large number of small satellite constellations that have been deployed or under planning for deployment in coming months or years [18]. These smallsat constellations are primarily being designed to provide remote sensing or communications services, but are also being designed for scientific experiments, for prototype testing of new satellite technologies, and other innovative applications such as a systematic survey of radio frequency usage.

Currently there about 3,000 operational satellites in orbit, but there are on the order of 20,000 new satellites that are at various stages of deployment with the overwhelming number of these being smallsats, ranging from about 4 to 5 kg at the lower end up to about 500 kg at the higher end.

The innovations associated with smallsats are numerous and fundamental. Indeed many of the new approaches can be considered ‘disruptive’ in terms of performance, manufacturing process, design, cost and/or operational capability. Some of these changes relate to: (i) more effective and efficient design, manufacture and quality verification and validation techniques and processes; (ii) exploitation to take advantage of miniaturization of sensors and components; (iii) beneficial leverage of new ground systems technology, including new electronic tracking technology, metamaterials, and phased array systems; (iv) more rapid prototyping and improvement of design; (v) innovative use of less expensive and off-the-shelf materials; (vi) new sparing and resilience strategies; and (vii) use of new types and more cost efficient launching arrangements, including the use of reusable launch systems, several of which are specifically designed for these smallsats.

These above changes are indicative of the innovative thought processes that abound within the small satellite community of design engineers, entrepreneurial business leaders, and regulators that seek to encourage rapid innovation in the newly invigorated commercial space community. This, in turn, has led to a further
revolution of thinking within civilian space agencies, defense and military agencies, and traditional aerospace industries that have now embraced smallsat technology and systems, new launch vehicle design, and other disruptive space technologies. Smallsats are made for frequent updates and frequent launches. The entire concept of satellites is moving from the creation of huge and vastly expensive satellites that take decades to develop, build, and launch, to constellations that are updated rapidly. It is very Silicon Valley, constantly pushing the boundaries.

**Reusable Space Rockets**

The most immediate and clearly impactful revolution in space is the reuse of rockets and spacecraft, and the great potential savings that this makes possible in lowering the cost of launching things into orbit and beyond. As pointed out previously, the very first rocket to reach what we now consider to be outer space, or an altitude of 100 km (60 miles), was one of Werner von Braun’s A4 rockets launched from the German Peenemünde launch complex on October 3, 1942. Also known as the V2, the A4 was the world’s first true space rocket, weighing over 2 tons and containing all of the component parts of every rocket launched since. It had liquid fuel, a gyro-controlled guidance system, rudders and control fins, and the ability to go beyond the edge of outer space. And since that seminal day, every rocket since has been, just like the A4, a disposable, use once and crash into the ocean – a very expensive way to do business.

The cost of access to space has been the primary limiting factor in making our access to space a more commonly used resource. Rockets are extremely expensive due to their complexity, required high reliability, exotic materials, and complex engineering. Using disposable rockets has been the standard paradigm, and the cost of this has made accessing space a capability only available to the largest and wealthiest nations. The current price of getting a kilo of anything into orbit has been about US$20,000 for some time. NASA has stated that they want to reduce this significantly, but Elon Musk’s goal is to make this cost about US$2,000 per kilo within a few years, and eventually only US$200 or so. That would clearly be a game changer for getting lots of things and people into space. Like Henry Ford’s Model T or Malcom McLean’s containers, cheap and ready access to space would be a huge change with many unknown consequences.

Of course, the price charged is not ever the actual cost of launching, and there are many different ways to compute the actual cost, real cost, price charged, overhead, etc. But the fact is we are talking about huge costs to put things in space, and this makes space inaccessible [19].

Elon Musk has repeatedly stated that having one-use rockets was as ridiculous as throwing away a new Boeing 747 and its engines after each flight across the Atlantic, and that he was determined to make space travel affordable by making rockets reusable. And not only the rockets; his goal is to reuse the rocket stages, engines, payload fairings, electronics, and more. (See Fig. 5.15.)
The actual cost of fuel, liquid oxygen and rocket-grade kerosene, is only about $200,000 for a \textit{Falcon 9} launch to LEO, and SpaceX’s ultimate goal is to reassemble and relaunch rockets in a matter of days. This is a total paradigm shift from every rocket from the A4 to today. There is also a move to smaller launch vehicles, in order to provide cost-effective launch for the growing number of cubesats and smallsats. Innovators at SpaceX, Blue Origin, Virgin Orbit and others seek to make the cost of access only a fraction of the cost of doing business in space. Reducing this cost will make many new applications possible, including space tourism, new and innovative scientific and commercial satellites, and it will open up space to many nations around the world that do not currently share the benefits of our access to space.

\textbf{The Silicon Valley Paradigm and the New Vision of ‘Left Coast’ Space}

Anyone who has worked in or spent much time in Silicon Valley knows that there is something very special about it. Exactly how it is special is a matter of much discussion and speculation. There are many explanations and ideas, but everyone who has spent any time there knows that there is something very exciting and dynamic about it. Clearly, it is the center of disruptive IT innovation and now NewSpace. But why?

The roots of Silicon Valley go deep, and, as is often the case, it all began as something of an accident. There is a recent and very interesting book on the origins of all this, \textit{Troublemakers: Silicon Valley’s Coming of Age} by Leslie Berlin [20], who is
the project historian for the Silicon Valley archives at Stanford University. This book covers the very early years, and it is a very interesting story.

All things have humble beginnings, and this story is no different. Palo Alto, in the South Bay area of San Francisco, was the home of the ailing mother of one William Shockley, who moved there to care for her, and who then founded the Shockley Semiconductor Laboratory in Mountain View, way back in 1956. This was one of the very first semiconductor firms in the world, and the first high tech company in what was to become Silicon Valley. He had previously worked at Bell Labs and was one of the patent holders for the first transistor there at Bell Labs.

Shockley was evidently not an easy person to get along with at Bell Labs, or to work for at Bell Labs, so several of his employees left a year later to start their own venture, Fairchild Semiconductor, which produced the very first practical silicon integrated circuit for commercial use. Before this, semiconductors were made from much more expensive and difficult to work with germanium, and silicon can be made from just sand. Two of these men, Gordon Moore (of Moore’s law) and Robert Noyce, the inventor of the integrated circuit, then left Fairchild to start their own company that they called Intel (for INTegrated ELectronics) in Mountain View in 1968, and Silicon Valley was firmly established as the place to be. Intel was started with US$10,000 from a venture investor named Arthur Rock, who became the Chairman of the Board. Intel is now headquartered in nearby Santa Clara and is the second largest, and second highest valued, maker of semiconductor chips in the world. It had revenue in 2018 of over US$70.7 billion.

In those early days, there was a fortunate coming together of several vital components that were needed to create a technology hub. Stanford University, located near Palo Alto, quickly saw the potential of cooperating with these new businesses, and offered evening advanced degrees for people working for these companies. It also began tailoring computer science offerings and research to align with them. Stanford University had been founded in 1885 by former California governor and railroad millionaire Leland Stanford and his wife, Jane. It was created on a farm of theirs near Palo Alto, in honor of their only son who had died at an early age.

The Stanford provost after the Second World War, Prof. Frederick Terman, recognized the opportunity of these new tech companies that were setting up in the area, and he began trying to lure other high tech companies to Palo Alto, and to encourage faculty and students to start new ventures. Stanford would offer them leases of Stanford land and allow them to have access to Stanford faculty, facilities, and graduate students. Dr. Terman invested some of his own money to allow two of his former students, named Hewlett and Packard, to move their new computing business from a one-car garage in Palo Alto to the newly established Stanford Industrial Park in 1947. It is a little known fact that Steve Wozniak designed the Apple 1 computer while he was working at H-P, and he offered it to them first, but they refused, so he started his partnership with Steve Jobs. H-P went on to become the largest manufacturer of personal computers and was the 11th most valuable brand in 2009.

Having a receptive world-class university in the neighborhood was invaluable, and many new ideas and companies came directly out of Stanford’s academic and
incubator programs. Stanford has long had a very entrepreneurial culture, and the number of tech startups from there include Hewlett-Packard, Cisco, Silicon Graphics, Sun Microsystems, Yahoo, and Google. It is notable that private companies that have been created by Stanford graduates or faculty, either while there or after, generate an amazing US$2.7 trillion in income per year. This is reported to be equal to the 10th largest economy on the planet, if it were for a country [21].

There was also an early and important, if often harder to see, federal government and military presence that quickly also became involved. Space was a very early, if rather secret, part of Silicon Valley’s development. The NASA Ames Research Center was located at the Moffett Field naval base in Mountain View and Sunnyvale way back in 1939, as the second facility of the NACA, the National Advisory Committee on Aeronautics. It became part of the newly formed NASA when it was created in 1958. NASA Ames had the finest large wind tunnels in the world and so became a center of excellence in computational fluid dynamics, space informatics and simulation, and other tech-centered space research.

NASA’s advanced research in both space and aeronautical areas provided its own funding, research, and resources to the mix in Silicon Valley, and it had strong ties with both academic and commercial players there. NASA Ames is today the home of the NASA Advanced Supercomputing Division (NAS). NAS is responsible for NASA’s High End Computing Capability project, NASA’s High-End computing program, and the Strategic Capabilities Assets program, among many others. NASA Ames is the Silicon Valley version of NASA, and it is perhaps the most dynamic and risk-taking of all the NASA centers, largely due to its location and partnerships with valley-area collaborators.

NASA Ames links with the many IT firms and universities in the region are strong, providing joint projects, student internships, research facilities, and more. Google today has a very large presence at NASA Ames, and in 2014 the Planetary Visions LLC subsidiary of Google signed a long-term, 60-year lease for the NASA Ames Research Park, once the Moffett Field Naval base, adjacent to the NASA facility. This agreement gives Google control of some 400 hectares of facilities, including hangars, two runways, flight operations facilities, and many former navy buildings. Google will have paid NASA a total of US$1.16 billion over the next 60 years in rent, and will invest an additional $200 million in infrastructure improvements [22]. Google and NASA Ames are tight.

The military was very interested from the beginning in the computing and integrated circuit work in Silicon Valley for its advanced aircraft, rockets, and spacecraft, and it funded several early projects and products. The Air Force Space Systems command established a facility in Palo Alto in 1957, to be operated by the Philco division of Ford. But it quickly outgrew this location, and the U. S. Air Force established the Satellite Test Center (called “the STICK”) in 1960 in Sunnyvale, by purchasing land from Lockheed, next door to NASA Ames, later named the Sunnyvale Air Force Station. This facility was involved in the nation’s earliest, super-secret Corona spy satellite system and later became part of the Air Force Satellite Control Network, providing global antenna networks for military, intelligence, and NASA spacecraft. Even later it became the Onizuka Air Force Base, named for the air force
astronaut who died in the Columbia space shuttle disaster. Sunnyvale’s Onizuka Air Force Base housed the famous Building 100, known locally as the “Blue Cube,” which became the Air Force Space Operations facility, responsible for many super-secret National Reconnaissance Organization spy satellites and other DoD payloads, including the space shuttle. It was one of the most secure facilities in the region and was deactivated in 2011 and later torn down (Fig. 5.16).

Lockheed Space and Missile Systems moved to Sunnyvale, next to the navy’s Moffett Field, also home of NASA Ames, back in 1956. This was when agriculture was still the primary employer in the area, and there were almond and fruit groves throughout the region. Lockheed, in deepest secrecy, built the earliest U. S. spy satellites of the Corona program in Sunnyvale, between 1960 and 1972. They later built the Navy’s Polaris and Trident ballistic submarine missiles there, and also major parts of the Hubble Space Telescope and many other satellites as well.

Although Stanford provided the early basic research and development for the valley, it was Lockheed, the air force, NASA, and other military contractors who brought in the large military and space contracts that played a huge role in the economic development of Silicon Valley and its role in IT and space. At its height, Lockheed alone employed over 25,000 workers in Sunnyvale and in the South Bay region, and it provided huge contracts to local start-ups and providers of a wide variety of high tech systems. And they still build commercial satellites there today.

And then there were the ‘two Steves,’ Steve Jobs and Steve Wozniak, originally working in Job’s parent’s garage in Los Altos, who together founded Apple Computer in Cupertino on April Fool’s Day, 1976. This is a long and interesting story and does not need to be told here, but let us just say that from this humble start...
to build a kit personal computer in a garage, Apple, in August of 2018, was estimated to be worth just over US$1 trillion, the first trillion dollar company in American history [23].

From these early days, Silicon Valley has grown into the world’s preeminent high-tech and innovation center [24]. The breadth and depth of the technical, human, and financial resources are staggering. More than 1 out of every 4 corporations that have their headquarters in California are in Santa Clara County, the heart of Silicon Valley. And the money for new ventures flows freely. There was just less than US$100 billion of venture capital invested in 2018 in the United States, and fully a third of all of these venture capital investments in the entire United States were made in the Silicon Valley/San Francisco area. This alone makes it the world’s primary high-tech startup focus, and the global center for scientific innovation. These are massive numbers and represent triple the total venture capital investment just a decade ago [25].

Today the valley region has over a quarter million well paid IT and computer workers, and some 45% of people there have a bachelor’s degree, while 20% have advanced degrees, double the U. S. average. It is the location of the headquarters for 40 of the Fortune 500’s largest companies, including Google, Apple, Intel, Tesla, Yahoo, Cisco, Adobe, Oracle, eBay, Netflix, Facebook, PayPal, Intuit, and many more. Not to mention the hundreds of startups and hopefuls who want to be the next generation of Internet and tech billionaires.

We should consider exactly how this process works for those with the next big idea. A very short version is this: You need money to start a new tech venture, in space or on the ground, and so you need to find it. If you are a billionaire, you are set, but most of the rest of us need to find funding, and this is difficult. You can try crowdfunding using GoFundMe, indiegogo, kickstarter, etc. After this usually comes the angel investors. These can be family, friends, associates, incubators, or, more often now, there are established networks and sources for angel investments. Many are retired, very successful individuals, who just enjoy helping young people with new ideas take hold.

Angels are, as their name implies, more interested in the idea and founders, and they are very different from venture capital sources. An angel investor will provide initial funding, often but not always, in return for equity in the new startup. There are well over a quarter million angel investors in the United States today, and there is a growing and active angel investor network to connect people with the right initial funding sources, often for up to millions of dollars. Some 40% of all angel investments in the United States are made in Silicon Valley. These are all considered seed funding, to get a new venture off the ground, and are often provided well before the company or idea becomes profitable.

Next come the venture capitalists, who are very different. They have one interest, and that is making a very large return on their investment. Venture capital is private equity provided in return for a part ownership in the venture, all with an eye towards a quick ‘exit strategy’ to get out as soon as a sufficient return is available via an initial stock offering, merger, or acquisition. Most new ventures fail, and so investors seek a very high return, often 10 to 30 times their investment in only 5 to
Startups go through a series of funding rounds as they grow and gain success, starting with Series A funding. This is where Series A preferred stocks are offered to investors, founders, family, and friends, often in a range of $1 and $10 million. This is followed by Series B, once the company is established and beginning to be successful but needs a new level of staff, facilities, funds, and more. Series C may follow for much more money, sometimes for acquisitions of competitors or major capital expansion (Fig. 5.17).

Each series is for larger and larger amounts, and each often attracts different types of investors. The risk level is lower with each round, as the company has demonstrated more and more success; so later investors generally receive less of a return, but with less risk. Ultimately, the goal is for the venture to go public with an IPO, an initial public stock offering, thus repaying the initial angel and venture capital investors handsomely. Or the venture fails, and all lose their investments.

Most estimates are that up to 90% of all tech startups will fail. Thus the large return required by investors, because only 1 out of 10 of their investments may succeed. Equity crowd funding is growing in popularity, where large groups of investors share both the risks and rewards [26].

As shown in Fig. 5.18, the vast majority of venture capital in the United States flows into California, and most of that goes to Silicon Valley and the larger San Francisco Bay region [27].

This means there is a lot of money in Silicon Valley, a lot of money for investing and also for living well. The San Jose census statistical region has the third highest
Gross Domestic Product (GDP) of any place in the world, by far the highest in the United States, and the first, third, and fifth most expensive zip codes to live in in the United States are located here [28]. In addition to the billionaires, there are many thousands of what are called “single digits,” or single digit millionaires here, but the cost of living in the valley means that they can only enjoy a modest standard of living at best. Housing, office space, and legal advice (and everything else) are very expensive, as supply and demand drives the costs ever upward, quite literally, through the roof. How expensive? Housing in Paris is almost 50% less, and Dubai is 12.5% less. Housing costs are astronomical. This is one reason the big tech companies provide many basic services for their workers, such as cooking and laundry, as many of them must live in two-room extended stay motel suites for years before they can afford a down payment for a tiny condo in the area. But they keep coming.

There are also thousands of lawyers and many law firms specializing in intellectual property law, plenty of tech guns for hire, lots of angel and not-so-angel investors, excellent research universities, government contracts, military spending, NASA research, and people simply live and breathe high tech, innovation, and making money the Silicon Valley way. Disruptive innovation has found a home.

Attempts to replicate it have had very mixed results. Boston has its Route 128 Corridor, North Carolina has its Research Triangle Park, and even Kenya has its ‘Silicon savannah.’ Many have claimed success, but there is still only one center of the entrepreneurial universe, and that is Silicon Valley.

What is it about the valley? Can it be quantified? Can it be replicated? Any attempt to replicate the valley without seeing it as a living and dynamic “ecosystem” for entrepreneurial activities is probably doomed to fail. An ecosystem, in the traditional ecological context, is an open system, where energy and components interact in ways that sustain and maintain the system over time. It is an environment where a diverse community of organisms is linked together through various energy flows.
and biological cycles that operate both internally and externally, between parts of the ecosystem and between the ecosystem and its larger context and environment.

In this active entrepreneurial ecosystem, we can see the various organisms, including innovators, skilled workers, investors, lawyers and intellectual property specialists, bankers, regulators, and more, all interacting. In terms of energy flows, clearly we have money and capital, expertise and experience, new technologies and inventions, new ideas and intellectual property, and, on the other end of the energy flow spectrum, you have expenses, taxes, lawsuits, debt and energy leaving the system.

This is, clearly, a simplified concept, but you can get the idea. In a robust entrepreneurial ecosystem such as Silicon Valley, all of these components are in place, well exercised, and are strong. There is a very rich amount of venture capital, technical experience, facilities, IT, physical infrastructure, legal expertise, and more, and all in abundance. The flow of resources into and within the system, of people, and money and ideas, are strong and constant. New sources of funding, ideas, technologies, and people are constantly refreshing the system.

In a more marginal system, such as an attempt to establish a new version of the Silicon Valley model elsewhere in the United States or around the world, you can see how the lack of any or all of these components creates limitations that inhibit the creation and functioning of the system, and that there are many difficult problems that are sometimes impossible to overcome. As in any complex and living system, strength breeds strength, and weakness leads to more of the same. The size and strengths of the Silicon Valley system, in all its components, makes it very difficult to compete with. It is very difficult to create such an ecosystem from scratch, and many attempts are doomed to failure or minimal success.

One of the major differences in NewSpace is the presence of so many venture capital and angel investors and so much available money. Venture capital, angel investors, and entrepreneurs are all seeing space as just another high-tech area to invest in. This is totally changing the space landscape. Commercial space has always had a very arms’ length relationship with the financial investment and banking community. Space was, traditionally, the domain of government agencies such as NASA or large aerospace corporations such as Boeing and Lockheed, and there was very little interest in smaller ventures, new ideas and startups. Space simply was not a commercial startup business. The first wave of space commercialization in the 1990s, with the proposed LEO telecom constellations such as Teledesic, Iridium, Orbcom, and Globalstar, attracted billions in Wall Street big bank financing. The bankruptcy of all of these ventures left the traditional Wall Street banking community with a very bad taste in their mouths for commercial space, along with billions of losses. Wall Street has had very little good to say about commercial space since, with the exception of a small interest in the launch insurance sector. Then Silicon Valley discovered space, and they saw it from a completely differently perspective. Failure there was seen as an essential element of eventual success. The Silicon Valley mindset was now applied to space in a totally new way, and venture capital helped to make space ‘cool’ and just another high-tech business.
Another key component is the unique work culture in play there. For one thing, there is a very open approach to hiring and moving within and between companies. A key aspect of this is the lack of stifling non-competition agreements that are common in other tech environments such as Boston and New York. The free flow of people and ideas through the system only enhanced the dynamic nature and strength of the system. Workers and ideas in the valley move much more freely between projects and companies, and back again. There is a free flow of concepts, experience, toolkits, approaches, and, ultimately, results. People learn fast, and they also pass information and techniques along. Silicon Valley workers are very much about more than their work and are very involved in outside projects such as developing Open Source tools or working with groups like Geeks without Borders and similar projects. Ultimately it is all about the money, but it is also about doing exciting and challenging work.

One of the most important aspects of all of this is the radically different mindset and approach of the laid back, California, “Silicon Valley perspective,” which is totally different from Wall Street in New York, or Boston, another successful high tech center, or India or Luxembourg. We are seeing a shift that includes what is almost a diametrically opposed approach to what was the world view of the traditional aerospace companies that grew out of the military-industrial complex.

The very ‘laid back’ and informal work culture actually masks an intense drive and work ethic [29]. Product deadlines are measured in weeks, not in months, and there is an emphasis on getting things done NOW, and not worrying if it is perfect. The culture is to launch early and often, and to constantly update and improve. Learn as you go, and the perfect is definitely seen as the enemy of the good there. Experimentation and innovation are highly prized, and new and creative ‘out of the box’ approaches are the norm. People there despise bureaucracy and top down directives and want management to get, and stay, out of the way so that they can make things happen. There is very little tolerance for rules and policies or corporate directives. Do it now and make it happen or get out of the way… all with a very laid back and informal, lounging around on the couch playing foosball while drinking a mocha latte vibe. It is a very real contradiction, and it makes it a unique place to work.

Of course, this is not for everybody. Wall Street arbitrage specialists simply don’t get it, let alone suit and tie European aerospace corporate executives. There is also a very different relationship with failure. Failure in the valley is seen as a learning experience, a part of the process, and not the end of it all. People are laid off, ventures fail, stuff happens, but the ethos there is to have a strong resilience and just get back at it, but learn important lessons for your next try. There is an assumption that you will never get it right the first time, and venture capital firms often look at past failures as learning to figure it out, not indications of a lack of ability. There is no ‘one strike and you are out,’ like in some places. One common statement is “Fail fast, fail often, fail better, and fail forward.” This is very different from other industries and other tech centers.

However, here is the most important point. In a very real sense, this unique Silicon Valley culture is highly attuned to the fast-paced disruptive innovation and S
curve onslaught that was presented back in Chapter 1. Silicon Valley totally FEEDS off of the energy, speed, and dynamic nature of disruptive innovation and rapid-fire technological changes of today and tomorrow. This is its natural element, and Silicon Valley is perfectly attuned to the fast forward, this week is different from last week, nature of the ever-increasing speed of technological change we all now face. This is one of the major reasons why it continues to be so successful. It has a really fast clock speed, and that speed, and the process of constant innovation and development it creates and thrives on, makes it very difficult to compete with. Silicon Valley gets it done this week, NASA or Boeing might have a prototype in a year. And so risk taking is the norm. Every decision is made without sufficient data. Move forward and figure it out. Risk is just a part of the process leading to success. Mark Zuckerberg of Facebook once said “The biggest risk is in not taking risks. In a world that is changing rapidly, the only strategy that is guaranteed to fail is not taking risks.” Lots of money, lots of talent, lots of risk takers, and lots of prior success simply add up.

This really is the key to why this place is what it is. The entire culture and work ethos is highly attuned to the rapid-fire onslaught of tech waves that are washing over us. While others are swamped, they are surfing and having a ball.

And it is also just a really, really nice place to live and to work. The weather is wonderful, the ocean, the mountains, and San Francisco are all nearby, and the “California mellow” lifestyle of outdoor dining, music, culture, and an invisible but palpable energy make it a really nice place to be.

However, all is not perfect down in the valley, and there are real issues and problems that have been mentioned. Working 70 hours a week and living in an extended stay motel and eating take out and having your employer do your laundry hardly makes up a balanced lifestyle or sustainable life. It is one reason there is such a youth-oriented culture there.

One interesting question is: Where are all the women? Is this simply an exercise in young male ego, dominant aggression, and an overabundance of testosterone? Why are there so few women, at least so far, who are driving these kinds of enterprises and major changes in the valley and in the NewSpace domain? Gwynne Shotwell, the president and CEO of SpaceX, is a welcome outlier, and she was the eleventh person hired at SpaceX, but there are few others in leadership roles. The numbers are no better for minorities. This is a very male, white, and young place. Also the agism of all this is a real issue, at least for those with gray hair. Where are all of the older, and hopefully wiser, graybeards? What will happen to all these wunderkind when they turn 50 and need glasses to read? Can you age gracefully there? If you made your billion, maybe you can, but what happens to the others when their run is over?

One personal observation is that there is also a pretty rude and aggressive aspect of this ‘mellow’ place. Steve Jobs and quite a few successful innovators there were not really nice people to work for. They were often downright cruel and scathing to their employees. This has contributed to a culture where, if you want people to think you are brilliant and the next superhero, you act like a total jerk. Many think they
are Dilbert, and every boss is an idiot and can scream at you because he or she is a genius.

Finally, there needs to be much more of a social consciousness regarding the impact of the tools and tech that are developed there. The recent data scandals at Facebook and others, and clear evidence of foreign weaponization of social media in recent elections, show us that these are not neutral technologies. The negative impacts of tech need to be considered much more that they are at present. So Silicon Valley has some growing to do in terms of finding out how women, minorities, and the elderly have something important to contribute, and how dangerous its toys can be. But even with all that, it is the place for disruptive innovation, and that will not be changing anytime soon.

There are some interesting questions about how all this works, or doesn’t work, for space. Planet has, at least partly, succeeded by following these approaches. It launches often, and if something fails it already has the next generation already built. But fail early and often does not work in human spaceflight, and so there are some differences between at least some aspects of space and Silicon Valley, but they will figure it out.

New Space 2.0 Markets and Applications

The ultimate result of all this will be, far sooner than most of us can imagine, an entirely new world where space is a fundamental aspect of our lives, and that will include our going routinely into space. Just as Henry Ford, Malcom McLean, and Steve Jobs created new technologies that we cannot now envision not having as a part of our daily lives, and that are major drivers of our global economy, space is poised at a threshold where all of these new technologies and disruptive innovators will create a world where space is simply a part of who we are and what we do.

Driving a car today is simply part of our lives, no matter where you live. Checking your email or getting directions on your smartphone is something that we no longer question and feel disturbed when they are not available. But these, and many other disruptive innovations, created new realities that were unthinkable just decades before. We no longer get dressed in our finest clothes to take a commercial airliner to visit family or go on a business trip. Low cost, commercial flying is just a part of our lives today, as are overnight delivery of anything you need. And soon, perhaps very soon, space will become simply a part of our lives that we don’t even think about, or at least don’t think is something all that special or exciting.

Remember, it was just over a hundred years ago, in 1903, that the Wright brothers made their first, historic, controlled, heavier-than-air flight from Kitty Hawk, North Carolina. They flew for only 59 seconds and covered a distance of just under 260 m in that first flight. That is less than the wingspan of a Boeing 747. Just two decades later, in 1927, Charles Lindbergh accomplished what was then considered to be impossible, when he flew the nearly 6,000 km from New York to Paris in 33 hours non-stop, winning the Orteig Prize of $25,000 (equal to some $350,000
And it was only a decade later that DC-3s and other planes were routinely offering commercial air service around the world. By the 1960s Boeing jets were crossing the Atlantic in 8 hours on a daily basis, quickly replacing the steamships that took a week to cross the vast ocean.

And today, commercial, global aviation is just a part of our world. It is also a tremendous economic generator, with airports, business travel, global tourism, FedEx and overnight Amazon deliveries, and billions of dollars of Boeing and Airbus aircraft sales. Not to mention global general aviation, with thousands of smaller airports and airplanes used for hundreds of commercial purposes, or just for the joy of flying through the air and looking down on our beautiful world. Think about this and apply it to space, and it appears we stand on the edge of a massive paradigm shift, driven by the disruptive innovators of NewSpace.

It may indeed be a reality that within a decade, space tourism will be no more unusual than taking a cruise vacation is today. Let us take the cruise industry as an example of what we mean. Cruising is a massive, global industry today, one that hardly existed a few decades ago. Today, there are over 500,000 beds available on cruise ships, and the cruise industry carried over 26 million passengers in 2017. This industry employs over a million people, many from developing countries, and has a $126 billion annual economic impact around the globe, much of it, again, in developing nations. The industry is paying over $40 billion in wages and salaries each year, and purchases similar amounts of supplies, again all around the world. There are over 300 cruise ships of ever-larger size in service today, with 50 new, massive cruise ships currently under construction, costing a combined estimate of over $51 billion.

One of the massive new cruise ships can cost as much as US$1.4 billion, weighing over 230,000 tons, measuring over 360 m long, and is capable of carrying over 6,600 passengers and a large crew. And the cruise liner market continues to grow. (Figures provided by the CLIA 2019 forecast [30].)

Think about that, a billion and a half dollars per cruise ship, and all the costs of crew, fuel, food, marketing, etc., and it will still make a profit every year, all because people will pay good money to have the experience that it offers. What might be the potential market for space tourism? How soon might we have large space tourism habitats offering a week at a luxury guest suite, out of this world food, and a room with a view like no other? How about extreme sport holiday excursions to the Moon, to asteroids, and, yes, even to Mars? What new Olympic sports could be played in space?

Today many people cannot imagine not taking a cruise every year. Might we be saying the same thing about space excursions in a few years? How did we ever live without it? How did we ever live without seeing that amazing view of Planet Earth? It might not be that far from now.

Even more likely to be on the horizon soon could be our flying from any major city to any other on the planet in 30 to 40 minutes using point-to-point, fully reusable rockets such as the SpaceX Starship. Might this be the DC-3 or Boeing 707 of the next wave of international travel? What would the economic impacts be of such a radical and disruptive technology? How soon might it be when traveling between
any major cities on the planet within an hour is just the way it is… how did we ever live without it? Can you believe people used to spend all day flying from New York to Australia? All day? How about FedEx packages that will be sent from Tokyo and arrive in New York before they were sent! That will be cool, and worth a lot of money.

The real result of NewSpace and our disruptive space innovators could be entirely new space markets and applications that we really cannot clearly see at this point. We will still rely on telecom, navigation and timing, and remote sensing satellites in the future. A new reality of on-orbit satellite servicing, 3D printing and recycling of satellites, building and rebuilding satellites in orbit, commercial space habitats, space tourism, and, eventually, people living and working in space, on the Moon and, after that, on Mars may soon become reality rather than science fiction.

And there is much more. Solar power satellites could potentially provide unlimited electrical power to Earth with zero toxic emissions or waste. Think of what that could mean to both developed and struggling nations, to have a reliable and clean source of electrical power without emissions or pollution. China announced in early 2019 that they will place a solar power demonstration system in orbit by 2025, and place a megawatt power system in orbit by 2030 [31].

Disruptive, empowering, and maybe much closer than we might think.

Mining of extraterrestrial resources is another game-changing concept that has great potential. Billions of tons of rare metals and minerals, not to mention water, are just beyond our grasp, but they are there, and they will, most certainly, be gathered and used at some point in the future. There are complex regulatory, political, and economic issues to be solved, but as soon as this becomes economically feasible, and that may not be that far away, these will be addressed, and your new self-flying car may be made with nickel and iron mined from an asteroid. Does this sound ridiculously farfetched? What would the Wright brothers have thought if you told them about a Boeing 787 flying nonstop from London to Cape Town in 12 hours with 330 people? What would Leonardo DaVinci think of the Apollo Moon landings? Only if we think boldly can we see the future as it will unfold.

**Space as a Fundamental Part of the Human Destiny**

What is even more extraordinary is the potential that all this has for an emerging perspective that space is a fundamental and transformational aspect of the human experience and is a vital component of the future of the human species. One of the earliest and most unexpected byproducts of the early space race between the United States and Soviet Union was the ‘discovery’ not of space but of Earth. This was embodied in a statement by Apollo astronaut Bill Anders, one of the first three humans to leave the gravity well of Earth and fly to the Moon on the Apollo 8 mission in December, 1968. He said: “We came all this way to explore the Moon, and the most important thing is that we discovered the Earth” (Fig. 5.19).
Our initial, tentative reaching out into the vastness of space generated a new understanding and appreciation of the fragility and loneliness of Planet Earth, hanging in the black vastness of space, alone, fragile, and precious. The new crop of space entrepreneurs, such as Elon Musk, Jeff Bezos, and the others, share a very visceral and emotional connection to space and space exploration as a fundamental aspect of human destiny. They want to create new businesses and services, to be sure, and they want to make money, but they also are deeply committed to expanding humanity into space, to make humanity a spacefaring species, and to make humanity a multi-planet species. They also share a desire to spread the experience of being in space, of seeing the beauty of our blue planet, of floating weightless in space, to a broad segment of humanity, not to mention a desire to be among the first to go themselves.

It would be a very good thing to have the leaders of the world’s nations hold a U. N. General Assembly session in orbit, with the beautiful Earth slowly rolling beneath them, visible through gigantic picture windows, with no borders visible. Perhaps then our leaders would realize the precious gem that they are responsible for, both to this generation and to those who follow after us, and see the futility of wars and foolishness of environmental destruction. Who is to say that this cannot come to pass? A century ago it would have been inconceivable that the world’s leaders could all fly to New York in a day for a U. N. meeting and then fly back home the next, but today it doesn’t even make the news.

This is a fundamental shift from the Space 1.0 view of governmental space agencies and their contractors, and the aerospace corporate view of space as a niche business or market segment with a very small number of professional astronauts. Transforming this into Space 2.0, we are now on the edge of seeing space as...
a fundamental part of the human experience and human future, to be experienced and shared broadly by all, young and old, and not only by a few, highly trained professional astronauts, while pursuing space from new, bold, entrepreneurial and business perspectives. What if paraplegics could live out their lives in the weightlessness of orbit, moving effortlessly around their habitat with a push of their fingertips, forever freed from their wheelchairs? Why not?

Since Yuri Gagarin first flew in space in 1961, only just over 500 humans (out of the more than 7.53 billion living today) have been launched into Earth orbit, and only 24 have ever left Earth’s low Earth orbit and ventured to the Moon. The largest number of people to be in space at any one time ever was over 20 years ago, back in 1995, when a total of 13 people were in orbit, with 7 on the space shuttle *Endeavour*, and 6 on the Russian *Mir* space station. Neither of these space systems are even operating today. We are about to see a radical change in how we do space and how we think about space, and this will have repercussions in ways that we cannot even begin to understand. But it is time to start trying to see the future that may soon unfold.

In this chapter we have looked at some twelve major new and disruptive technologies and innovations that are rocking the space world today. But it is not just what each of these major new technologies will bring. It is the cumulative and synergistic combination of them all that will drive explosive new innovations, markets, and realities.

There is a class of rocket fuel that is called hypergolic, which refers to the explosive reaction of simply putting two appropriate chemicals in contact with each other, a fuel and an oxidizer, and BANG! The hypergolic reaction requires no source of ignition, and once ignited, it cannot be controlled, except by separating the two. It is the simplest type of rocket engine, requiring no valves or pumps, and can also be among the most dangerous. It is not hyperbole to refer to the synergy and explosive interaction of these new, disruptive space technologies as hypergolic. What will truly change our world is the explosive interaction of these, and this will create new and amazing businesses, tools, services, and markets. But more than that, it will create a new reality where space is just a part of the everyday human experience. In the past, most disruptive innovations occurred in isolation, one at a time. But here we are seeing a radical and unprecedented vortex of technologies that all interact and drive new capabilities that we can barely begin to understand. Fasten your seatbelts, it is going to be an interesting ride!

In our next chapter, we will consider how NewSpace and all of these extraordinary new technologies can, potentially, make a real impact on the lives of the billions of people on Earth who have so little, and for whom space is an abstract and irrelevant concept. NewSpace can be much more than billionaires playing with big rockets; it can make a difference in the lives of billions of poor people around the world.
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Chapter 6  
Disruptive Space Technologies and the Developing World

I don’t pretend we have all the answers. But the questions are certainly worth thinking about.

– Arthur C. Clarke

This chapter will analyze how these disruptive innovations can impact the future of the “other 3 billion” people of the developing world who currently are in great need and who do not benefit from space activities at all. We will also consider how these disruptive space technologies could help support attaining the U. N.’s 17 Sustainable Development Goals (SDGs). This discussion will make a case for how disruptive space technologies could help set the stage for more than simply new businesses and innovation in the developed world, or for making billionaires even more wealthy. This chapter explores how such innovations might help fundamentally alter how space will impact the developing world.

The sad fact is that our modern world is divided into haves and have-nots. The organization Oxfam International, in 2019, reported that the richest 26 people in the world, several of whom are discussed in this book, have wealth equal to over US$1.4 trillion, more wealth than fully one half of Earth’s population of 7.7 billion people has [1]. The human population of our planet has increased dramatically, and it was only in about 1825 that the population of Earth exceeded 1 billion; in 1900 it was only about 1.8 billion. As far back as the time of Christ and the early Roman Empire there were only perhaps 150 million of our ancestors here. Going even farther back, way back in the time of the ancient Egyptian and Sumerian empires some 4,000 years ago, there may have been only about 7 million humans on the planet. This is a staggering population increase in a very short period of time, as shown in Fig. 6.1, and it is one that is certainly unsustainable in the long run, no matter how fast computers can calculate or how many satellites we have in orbit [2].

The truth is that we just do not know how to manage the human population increase we continue to face, and poverty is a key component of this global population pressure. The fact that over 3 billion people today, nearly half of all of us, live on less than US$2.50 per day is a staggering statistic. According to UNICEF, one billion children today live in poverty, and fully 80% of people alive today live on less than US$10 per day [4].
Most of the world’s poor have no access to clean water and sanitation, nor do they have basic medical care, nor do they have schools for their children. All this, while the most wealthy one fifth of us, living in the developed world, control over three quarters of all the world’s financial resources.

To be fair, for much of human history, at least as far back as the settling of people into towns with agriculture, it is likely that most people lived in some level of what today we would call poverty, with a very small group of elites enjoying a surplus of material goods. The Industrial Revolution of the past several hundred years has provided a broad improvement in the reduction of poverty around the world, even as the world’s population has skyrocketed, as shown in Fig. 6.2. But while the percentage of people in poverty has declined, the total numbers living in poverty have skyrocketed, driven by the global population boom. Most of the world’s poor live in sub-Saharan Africa and Asia, but poverty exists in every nation and every region.

In June of 2018, the international space community, which is actually quite small, gathered together in Vienna, Austria, to celebrate the 50th anniversary of the very first meeting of the U. N. Conference on the Exploration and Peaceful Uses of Outer Space, known as UN COPUOS. This celebration included both a symposium for the UNISPACE+50 and the 61st regular meeting of COPUOS. The first COPUOS was held in 1968 and was followed by two additional conferences, in 1982 and 1999. The third meeting concluded with publication of the Space Millennium: Vienna Declaration on Space and Human Development, or simply the Vienna Declaration, which consisted of 32 specific recommendations to address the issues of providing access to space to all humankind.

![Fig. 6.1 Estimate of the human population. (Image from Wikicommons [3]. https://commons.wikimedia.org/wiki/File:Population_curve.svg.)](https://commons.wikimedia.org/wiki/File:Population_curve.svg)
Fig. 6.2 (a, b) (Top) The percentage of people living in poverty from 1820 to 2015, and (Bottom) the total number of people living in extreme poverty. (Images courtesy of the author, Max Roser. Additional charts and data are available at https://ourworldindata.org/extreme-poverty.)
In September of 2015 the nations of the world adopted a new sustainable development agenda that contained 17 goals to be achieved over the next fifteen years (Fig. 6.3).

The 17 Sustainable Development Goals seek to address the major problems facing our planet, including poverty, clean water, education and more. Identifying these universal needs is relatively simple. The difficult part is finding ways to actually address these in practical and realistic ways. This will not be simple, and it is not the first time these issues have been addressed. These goals follow the U. N.’s eight Millennium Development Goals [6] (MDGs), which were targeted for 2015 and which were largely unsuccessful in showing any measurable progress towards the eradication of poverty and providing universal primary education. These are not easy issues to address.

Space technology, and the amazing benefits that these can provide to the people of Earth, can play an important role in helping us to realistically address the global population, environmental, and economic challenges that we face. This is the goal of the U. N. 2030 Agenda for Sustainable Development. In October of 2018, the General Assembly of the United Nations passed a resolution acknowledging the importance of a cooperative effort to fulfill the Space2030 Agenda, along with its implementation plan. This plan is being developed by COPUOS for consideration by the General Assembly in 2020, and it provides a practical roadmap and overriding vision of space, and our access to space as one of the potential key drivers for assisting the reduction of global poverty and the division between the haves and
have nots of the world. The Space2030 Agenda calls for five broad areas and objectives, including:

- space governance (U.N. treaties and principles on outer space, COPUOS guidelines, General Assembly resolutions on outer space)
- capacity-building (in the use of space science and technology and their applications for the benefit of all countries)
- resiliency (disaster risk reduction, near-Earth objects, space weather)
- interoperability (including work done by the International Committee on Global Navigation Satellite Systems (ICG) and other current and new coordination mechanisms, such as the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG))
- space for sustainable development (efforts by the Committee and its member States as well as UNOOSA to meet the 2030 Agenda for Sustainable Development).

Space, and our access to data about our planet that we can only acquire from space, can become key sources of data for driving the protection of our planet and the achievement of the sustainable development goals. The extraordinary developments that are part of NewSpace can have a tremendous impact on these goals, and on the lives of billions of people, if we can only give some consideration to these needs, as well as our desire to innovate, profit, and explore. Creating new space business ecosystems that are relevant and appropriate for the rest of the world should become a part of the NewSpace universe. There are now various initiatives around the world, such as Geeks Without Frontiers, that are dedicated to using new space technologies to address issues such as global education, global healthcare, and other aspects of the U.N. Sustainable Development Goals [7]. We need more of these initiatives.

In preparation for the U.N. COPUOS UNISPACE + 50 celebrations in Vienna in 2018, the McGill University’s Institute of Air and Space Law held a special Manfred Lachs conference to explore ways that space technologies and applications could aid in the achievement of the U.N.’s 17 Sustainable Development Goals, which are discussed more fully in the next chapter.

One of the outcomes of that meeting was the development of a chart that identified the many ways that space systems, and particularly NewSpace technologies, applications, and services, could aid in the achievement of these goals. This is summarized in Chart 6.1 [8].

The scope of space services that can be used to accomplish the U.N.’s goals as provided in Chart 6.1 is clearly very broad and comprehensive. The problem is to move from possible opportunity to actual implementation on the ground and in space. Too often it is assumed that for developing economies to benefit from space technology and systems that they must have the ability to manufacture and launch satellites and operate these types of space systems themselves. Although this is becoming more possible with NewSpace approaches, this is actually not the case. Virtually all nations in the world can and do use some elements of application satellites such as those for communications, networking, broadcasting, remote sensing
**Chart 6.1** Analysis of how space systems can aid in achieving the U.N.s 17 Sustainable Development Goals. (One-time license provided by Joseph N. Pelton for use here. All rights reserved.)

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<tbody>
<tr>
<td>No Poverty (Goal 1)</td>
<td>New jobs via telework, opportunity for remote services, training in remote villages</td>
<td>Broad distribution of information on birth control, nutrition, vaccines, etc.</td>
<td>Improved information to support fishing, farming, forestry, mining, etc.</td>
<td>Reduced losses of crops, housing, infrastructure</td>
<td>Improved farming and fishing via precision geo-location</td>
<td>In Future Lower cost clean energy to rural and remote locations</td>
<td>Potential for job creation by manufacturing uncomplicated small satellites</td>
</tr>
<tr>
<td>Zero Hunger (Goal 2)</td>
<td>More efficient agricultural &amp; fishing processes</td>
<td>Broad distribution of information on nutrition &amp; birth control</td>
<td>More productive farming &amp; lower cost food</td>
<td>Less crop loss due to unpredicted storms, flooding, typhoons, hurricanes</td>
<td>Improved farming and fishing via precision geo-location</td>
<td>TBD</td>
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<tr>
<td>Good Health and Well-Being (Goal 3)</td>
<td>Tele-health and remote medical services</td>
<td>Broad distribution of information on birth control, nutrition, vaccines, etc.</td>
<td>Detection of crop or tree disease</td>
<td>Detection of solar flares &amp; ozone holes</td>
<td>Ability to precisely track spread of disease &amp; pandemics</td>
<td>TBD</td>
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<tr>
<td>Quality Education (Goal 4)</td>
<td>Quality tele-education programs, remote testing programs</td>
<td>Educational radio &amp; television, access to global news</td>
<td>TBD</td>
<td>Less destruction of schools &amp; educational infrastructure</td>
<td>Cost savings on school transport</td>
<td>In Future Clean energy to remote locations for tele-education</td>
<td>Distribution of information, knowledge sharing in satellite design/operation, etc.</td>
</tr>
<tr>
<td>Goal</td>
<td>Telecom &amp; Networking Sats &amp; HAPs</td>
<td>Remote Sensing Sats</td>
<td>Meteorological Sats</td>
<td>Navigation &amp; Timing Sats, Sats &amp; HAPs</td>
<td>Telecom, additional Information</td>
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<td>Gender Equality (Goal 5)</td>
<td>Tele-educational programming</td>
<td>Global news and TV broadcasts</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td>Clean Water (Goal 6)</td>
<td>Tele-education on water purification &amp; sanitation</td>
<td>Broadcasts on water purification &amp; sanitation</td>
<td>Detection of polluted waters; storms with acid rain, etc.</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td>Affordable Energy (Goal 7)</td>
<td>Tele-education on energy savings &amp; building clean energy systems</td>
<td>Broadcasts on energy savings &amp; building clean energy systems</td>
<td>Aid in finding good locations for wind farms, geothermal energy, &amp; tidal energy</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td>Decent Work and Economic Growth (Goal 8)</td>
<td>Telework, village training, tele-banking, tele-services</td>
<td>Open university training</td>
<td>Support for new construction &amp; design of infrastructure related to climate change</td>
<td>TBD</td>
<td>TBD</td>
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(continued)
### Chart 6.1 (continued)

**Examples of Space-Based Services that Aid U. N. Goals for Sustainable Development**

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<tr>
<td>Industry, Innovation and Infrastructure (Goal 9)</td>
<td>Tele-education, Internet based innovation, Internet-based technology incubators, protective security for infrastructure</td>
<td>Educational radio &amp; television, access to global news</td>
<td>Aid to more productive mining, fishing, farming, forestry, and transport</td>
<td>Support to new construction &amp; design of infra-structure related to climate change</td>
<td>Support to new construction &amp; design of transport systems</td>
<td>In Future Lower cost clean energy to cities, rural and remote locations</td>
<td>Develop space industry and associated infrastructure in countries without existing government or commercial space actors</td>
</tr>
<tr>
<td>Reduced Inequalities (Goal 10)</td>
<td>Tele-education, Internet-based learning &amp; data bases</td>
<td>Educational radio &amp; television, access to global news</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>Small satellites can lead to new industry and produce marketplaces for traditionally less-sophisticated entities</td>
</tr>
<tr>
<td>Sustainable Cities and Communities (Goal 11)</td>
<td>Substitution of tele-services and tele-work for physical transportation</td>
<td>Educational radio &amp; television, access to global news</td>
<td>Key topographic information for transport on, water and sewer planning</td>
<td>Key information related to protection of city infrastructure from violent storms</td>
<td>Improved traffic &amp; transportation control</td>
<td>In Future Lower cost clean energy to cities, rural and remote locations</td>
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6 Disruptive Space Technologies and the Developing World
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<tr>
<td>Responsible Consumption and Production (Goal 12)</td>
<td>Tele-education, tele-work satellite services can be provided worldwide</td>
<td>Broadcasts on tele-work, conservation, energy savings &amp; building clean energy systems</td>
<td>Monitor hazardous waste locations, atmospheric pollution, oil spills, garbage scows, etc.</td>
<td>Note changes in weather &amp; climate due to industrial activities</td>
<td>Accurately pinpoint sources of pollution</td>
<td>In Future</td>
<td>Lower cost clean energy to cities, rural and remote locations</td>
</tr>
<tr>
<td>Climate Action (Goal 13)</td>
<td>Tele-education, tele-work, satellite services can be provided worldwide</td>
<td>Broadcasts on tele-work, conservation, energy savings &amp; building clean energy systems</td>
<td>Track ice-cap &amp; glacier melting; measure ocean and atmospheric temperatures</td>
<td>Track changes in atmospheric temperatures, intensity of storms, solar activity</td>
<td>Pin point location of atmospheric &amp; oceanic sensors</td>
<td>In Future</td>
<td>Lower cost clean energy to cities, rural and remote locations</td>
</tr>
<tr>
<td>Life Below Water (Goal 14)</td>
<td>Tele-education, global Internet access; track location of endangered species</td>
<td>Satellite broadcast TV &amp; radio can strengthen education, civic activism, and knowledge of law</td>
<td>Detection of water &amp; ocean pollution, coral bleaching, fish depletion, etc.</td>
<td>Track ocean storms &amp; hurricanes</td>
<td>Determine exact location of sensors &amp; ocean buoys</td>
<td>TBD</td>
<td>(continued)</td>
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<tr>
<td>Life on Land (Goal 15)</td>
<td>Tele-education, global Internet access; track location of endangered species</td>
<td>Satellite broadcast TV &amp; radio can strengthen education, civic activism, &amp; knowledge of environmental law</td>
<td>Track animals &amp; endangered species</td>
<td>Monitor violent storms and provide flood &amp; high wind warnings</td>
<td>Determine exact location information of earthquakes, volcanos, and coordinate rescue operations</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Peace, Justice and Strong Institutions (Goal 16)</td>
<td>Low cost Internet and satellite telecommunication access can strengthen education, civic activism, and knowledge of law</td>
<td>Satellite broadcast TV &amp; radio can strengthen education, civic activism, and knowledge of law</td>
<td>Time stamped remote sensing data has been used to prosecute crimes against humanity</td>
<td></td>
<td></td>
<td>TBD</td>
<td>International cooperation in space activities by various nations can lead to the creation of strong institutions; ability to monitor state activities can increase effectiveness of truth and confidence building measures</td>
</tr>
<tr>
<td>Partnerships for the Goals (Goal 17)</td>
<td>Satellite manufacturers &amp; service providers can help promote telework, tele-education and tele-health</td>
<td>Satellite manufacturers &amp; satellite broadcasters can help promote tele-work, tele-education and tele-health</td>
<td></td>
<td></td>
<td></td>
<td>TBD</td>
<td>International cooperation in space can lead to mutual respect and ideological alignment that will motivate achieving other goals collectively</td>
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Prepared by Joseph N. Pelton, Ph.D., Manfred-Lachs Conference, Montreal, Canada, May 2017
and Earth observation, meteorological satellites, and precise navigation and timing or GNSS. With the advent of NewSpace systems and technology, more and more developing countries are also now able to participate in the design, manufacture, and operation of small satellite systems that actually meet their needs and specific economic and cultural contexts.

As impressive as the new space technologies and services are, and the wide range of areas where space systems can add in terms of agriculture, fishing, forestry, mining, economic development, ecological and environmental protection, education, and healthcare, it must also be recognized that there are major drivers of human development that must be addressed at the macro level if there is to indeed be true progress with regard to the U.N. Sustainable Development Goals. Futurist Edward Cornish, founder of the Futurist Society, has defined these six primary drivers of change in human society. He called these the DEGEST factors. They include: **Demographic Growth**, **Environment**, **Governmental Regulatory and Economic Policy**, **Energy**, **Societal and Cultural Norms and Beliefs**, and **Technological Innovation** [9]. Chart 6.2 sets forth these six factors and what is driving global change within these six dynamics.

**Conclusions**

Unless these six factors can be understood, controlled and modulated by human society in a proactive and dynamic way, the chances for positive change on a global scale will be limited, and the positive influences brought about by new space services will be muted or possibly even negated.

In short, positive influences brought about by NewSpace services will only make a meaningful contribution if these six major drivers of global change are addressed and redirected in a positive and sustainable direction. Human population growth must be proactively mitigated, or it will happen by natural, even catastrophic natural processes such as pandemics or global conflict, with disastrous results. Environmental and energy goals must be re-gear toward achieving global energy and environmental sustainability. Governmental and economic policies must also be changed from goals of constant expansion to sustainable economies. Societal and cultural values as well as technological goals must be re-directed toward sustainability over such current goals as constant economic growth and profit.

The need for moderation and equity have been noted for some time in such books as *The Limits to Growth*, *the Population Bomb*, *GAIA*, others that have noted the world’s environmental, energy, and ecological limits as global population continues to expand toward as many as 12 billion people and 80% urbanization by 2100.

The reality is that advanced technologies and space systems can only provide a part of the overall answer to the goals of not only equity but sustainability for our planet. Indeed, without achieving these goals, our ability to expand into space may itself be threatened.
In the next chapter, we will consider the international and national regulatory, treaty, and legal contexts for space activities and their relationships with disruptive innovation in the space arena.

<table>
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<tr>
<th>DRIVER OF GLOBAL CHANGE</th>
<th>REASON FOR TREND TO INCREASE</th>
<th>REASON FOR COUNTER TREND</th>
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<tbody>
<tr>
<td>Demographic Growth</td>
<td>Seeking DNA heritage; heirs; expansion of family labor force; lack of access to birth control</td>
<td>Limited tax deductions; taxes on large families; high cost of supporting and educating large families; widespread and low cost access of birth control</td>
</tr>
<tr>
<td>Environmental Change Driven by Humanity and Increased Resource Consumption</td>
<td>More people; more manufacturing; more housing &amp; buildings; more transportation usage; more chemical pollution released</td>
<td>Pollution controls and fines; renewable energy and resources; electric vehicles; well insulated buildings</td>
</tr>
<tr>
<td>Governmental, Economic, and International Regulatory Policy</td>
<td>New types of industrial growth and corporate malfeasance; international trade issues and tariffs; need for revenues to run governments; international security concerns; warfare and threats to national security; extremist or terrorist activities</td>
<td>Deregulatory pressures; effective and well-functioning economic, trade or political alliances; lessening international tensions; absence of warfare and terrorism</td>
</tr>
<tr>
<td>Increased Energy Needs</td>
<td>Industrial and economic expansion; population growth; increasing wealth and higher standards of living</td>
<td>Renewable energy systems; fuel efficiency &amp; electrical vehicles; improved insulation systems; reduced population</td>
</tr>
<tr>
<td>Societal and Cultural Changes and Conflicts</td>
<td>Sexual and LGBT rights; cultural liberation; women’s rights; religious extremism; economic, financial or information gaps; ethnic and cultural intolerance</td>
<td>Cultural and religious tolerance; ethnic integration and racial tolerance; limited immigration or absence of ethnic, cultural or religious migration</td>
</tr>
<tr>
<td>Technological Innovations</td>
<td>Push for increased productivity; industrial profitability; political, educational, economic, business, or financial incentives to produce innovations</td>
<td>Labor contracts; religious or cultural rejection of technology; refusal to share or license technology</td>
</tr>
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</table>
References

8. Joseph N. Pelton, “Improved Legal and Regulatory Processes to Protect the Planet” Manfred Lachs Conference, McGill University Institute of Air and Space Law, May 2017
Chapter 7

Regulations and Treaty Frameworks for Disruptive Space Innovation

There is hopeful symbolism in the fact that flags do not wave in a vacuum.
— Arthur C. Clarke

This chapter will consider the international and national regulatory and legal frameworks for the space world, and how this should, and in a number of cases does not, serve the revolution that commercial space is undergoing. We will also consider ways to advance this important, and often overlooked, aspect of what it takes to engage in and encourage innovative new space activities.

International law is defined between States, and it is consent-based, meaning that nations may agree or not to abide by international laws, and there is no recourse other than negotiation or, as a last resort, war. The concept and implementation of international law as it is relevant to space is similar to issues such as the ownership of oceans and international maritime rights. The U. N. Convention on the Law of the Sea (UNCLOS), also called the Law of the Sea Convention, was signed in 1982 and went into effect in 1993, and was the result of the third U. N. Conference on the Law of the Sea, which took place between 1973 and 1982. It defines the rights and responsibilities of States relating to the oceans, such as navigation, liability, ownership of marine resources, and the boundaries of national, coastal limits [1].

Given the inherently international nature of space activities and spaceflight, it became quickly apparent after the launch of Sputnik 1 and the flight of Yuri Gagarin that new international rules and agreements, similar to the Law of the Sea, would be required. Traditional aviation concepts of national air space would not apply in orbit or outer space, and new issues of liability and responsibility were needed. Since that time, there has evolved a set of international treaties, guidelines, standards, and international norms of behavior that guide international relations in space. There were also created a series of international institutions dealing with space, primarily through the United Nations. The oversight and regulatory bodies include the U. N. General Assembly, the U. N. Committee on the Peaceful Uses of Outer Space, the U. N. Office of Outer Space Affairs, and several U. N. specialized agencies. The most important of the U. N. specialized agencies in this respect are the International Telecommunication Union (ITU), the World Meteorological Organization (WMO), and the U. N. Office of Disarmament Affairs. In addition, there are various international standards organizations that provide a forum for nations to engage each other.
regarding space issues and assist in developing with international standards and regulatory policy.

The current global space governance structure is made up of five international treaties and international agreements, plus the United Nations and its various international specialized agencies and committees, interagency committees of the world’s space agencies, and norms of customary international law, as well as a number of non-binding principles and guidelines for space activities.

These international treaties and international agreements, after ratification by a nation’s legislature, have the force of law. The most important of these, the Outer Space Treaty (OST), provides a number of freedoms, such as the freedom of access to space, as well as obligations, including the obligation to formally register launches and satellites with the United Nations and to assist stranded astronauts. Finally the Outer Space Treaty sets some prohibitions of conduct, such as appropriating territory in space or the locating of nuclear weapons or weapons of mass destruction in outer space. The 1967 Outer Space Treaty, or in its full name: *The Treaty on Principles Governing the Activities of Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, is thus the original foundation of international space law. The full text is presented in Appendix A of this book. It was created to provide an initial framework for the various new legal issues raised by nations sending satellites and humans into outer space. It was primarily negotiated between the United States and the former Soviet Union, the two major spacefaring nations of the time. There was much negotiating and back and forth between the United States and the USSR, but these two space powers, plus the other members of the original U. N. Committee on the Peaceful Uses of Outer Space (COPUOS), finally agreed on a final treaty text in 1967 [2].

As of 2018, a total of 107 States have signed the treaty, and an additional 23 States have signed it but have not yet ratified it. The treaty includes the following principles:

- The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind.
- Outer space shall be free for exploration and use by all States.
- Outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.
- States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner.
- The Moon and other celestial bodies shall be used exclusively for peaceful purposes.
- Astronauts shall be regarded as the envoys of mankind.
- States shall be responsible for national space activities whether carried out by governmental or non-governmental entities.
- States shall be liable for damage caused by their space objects.
- States shall avoid harmful contamination of space and celestial bodies.

There have been four follow-up space treaties. These are 1) the Rescue Agreement of 1968, which provides for the rescue of astronauts, 2) the Space Liability
Convention of 1972, which provides for the assignment of liability for space activities such as damages caused by a falling satellite or other causes; 3) the Registration Convention of 1976, which requires launching states to register and get licenses for the launch of satellites, including commercial launches, and 4) the Moon Agreement.

The Moon Agreement of 1979 is an example of a space agreement that has not achieved broad adoption. The full name is The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, and it proposed that all celestial bodies, including the Moon, and their orbits should be considered a ‘commons’ of the international community, similar to Antarctica or the high seas. The treaty was, in part, based on the Law of the Sea, which states that all resources on the seafloor are common property. It also considered all celestial bodies to be demilitarized zones and not to be subject to the sovereignty claims of any country under the concept of ‘common heritage of mankind’ [3].

Because of these and other aspects, the Moon Agreement has failed to be ratified by any of the major space nations. Today, only 30 nations, who are all essentially non-spacefaring nations, have ratified the treaty. Therefore, sufficient nations have ratified the Moon Agreement so that it has entered into force, but the United States, Russia, China, France, Germany, Italy, the U.K., Spain, Canada, Japan, or India have not signed, and none have indicated a willingness to do so.

In the United States in July 2014 a bill entitled the “American Space Technology for Exploring Resource Opportunities in Deep Space” (The Asteroids Act) was introduced. This initiative was folded into the Space Act of 2015. The full name of this act was “Spurring Private Aerospace Competitiveness and Entrepreneurship Act of 2015.” Title IV in this act seemed to offer to U. S. companies the right to engage in resource extraction from celestial bodies [4].

The provisions of Section 402a states: “(a) U. S. entities engaged in commercial recovery of an asteroid resource or a space resource under (the Act) shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States” [5].

The primary feature of these treaties is that they are negotiated between nation States, and that these States can be held responsible for the actions of private entities and individuals’ space activities conducted within their borders. In fact, under current international space law, there is no formal recognition of private space activities. All space activities are legally under the control of the individual States, and States are responsible in full for all space activities, as conducted both by the government and by the private sector or individuals. States incur responsibility for non-compliance with the treaties, even if they are private companies or individuals within their borders whose actions are in question. So if a U. S. company claims ownership of a part of space, this is considered to be a claim of ownership by the State under the treaty. If an individual launches a rocket and does not register the launch, it is the State who is responsible, not the individual. Even if a satellite owned by a private entity is registered with the United Nations by a launching state and the satellite is then sold to another entity, who then sells it to someone else in a
totally different country, the launching state is legally responsible for any liabilities. These provisions are greatly out of step with today’s realities as far as NewSpace activities are concerned, but this is still the regulatory environment that legally exists today [6].

The Committee for the Peaceful Utilization of Outer Space (UN COPUOS)

The United Nations plays a pivotal role in international space activities. The primary entity within the United Nations that is responsible for international space activities is the Committee for the Peaceful Utilization of Outer Space (UN COPUOS) and its administrative arm, the U. N. Office of Outer Space Affairs (UNOOSA) that among other functions maintains the official registry of objects launched into space. COPUOS was created in 1959 as an ad hoc committee of the United Nations after the 1957 launch of Sputnik 1, and it was created as a permanent committee the same year. The official mission of COPUOS is:

…to review the scope of international cooperation in peaceful uses of outer space, to devise programs in this field to be undertaken under United Nations auspices, to encourage continued research and the dissemination of information on outer space matters, and to study legal problems arising from the exploration of outer space.

This committee was instrumental in the negotiation and adoption of the five space treaties that are currently in place. It is mandated to work, on behalf of the United Nations and its member States, to expand international cooperation in space and to strengthen the international legal regime governing international space activities. Much of the work is done in its two primary, standing subcommittees, the Legal Subcommittee and the Scientific and Technical Subcommittee, which were created in 1962, and these meet every year.

The Scientific and Technical Subcommittee has several working groups, including those working on space-related aspects of global health, the use of nuclear power sources, long-term sustainability of space activities (which has now concluded its work), and a group comprised of all the separate groups. The Legal Subcommittee has working groups dealing with the status of the five outer space treaties, and the definition and delimitation of outer space, a very important and complex topic.

This organization also plays a very critical role in working to encourage and enable space capabilities for developing nations, and to strengthen the economic and social benefits of space for all peoples of Earth. The COPUOS committees and working groups are where the difficult work of finding ways to advance into space together is done [7].

It is very difficult, often contentious, and slow work. The committee has continued to address emerging issues, including the formation of the Inter-Agency Space Debris Coordination Committee (IADC), which is responsible for developing
guidelines for minimizing orbital debris in space, and the Working Group on Long-Term Sustainability of Outer Space Activities. COPUOS has the difficult job of overseeing the several space treaties, and it also is entrusted to monitor the various treaties, conventions, and international agreements relating to outer space. There are currently around 85 member states and additional memberships are being processed.

There are also organizations that have permanent observer status, including the International Telecommunication Union, most of the leading space organizations such as the International Astronautical Federation, the International Institute of Space Law, the Association of Space Explorers (whose members include all of the flown astronauts of the world), the Secure World Foundation, the International Association for the Advancement of Space Safety, the Space Generation Advisory Council, and other relevant international space entities [8].

To support the work of the committee, the U. N. Office of Outer Space Affairs (UNOOSA) acts as the professional secretariat for the COPUOS committee. UNOOSA staff is made up of professionals in a variety of space topics; they manage the space-related activities within the U. N. structure. UNOOSA is primarily located at the U. N. offices in Vienna, Austria. Beyond acting as the secretariat for the committee, UNOOSA is also responsible for maintaining the U. N. Register of Objects Launched into Outer Space, and for implementing the U. N. Secretary-General’s responsibilities under international space law. (See Fig. 7.1.)

![Diagram](image_url)

**Fig. 7.1** The organizational structure of the U. N. Office of Outer Space Affairs (UNOOSA). (Image courtesy of UNOOSA.)
The current director of UNOOSA is Simonetta di Pippo of Italy, and she and her staff are responsible for implementing the space mandate within the U. N. Secretariat to promote international cooperation in the rapidly evolving peaceful uses of outer space. The structure has two groups: the Committee, Policy and Legal Affairs Section, and the Space Applications Section. The former is the group that provides secretariat services and staffing for the COPUOS committees. The Applications section serves as the secretariat for the International Committee on Global Navigation Satellite Systems (UNICG, discussed later) and conducts a wide variety of activities in support of the U. N. Program on Space Applications. This involves organizing and conducting a variety of applications workshops, projects, and educational programs in the space application areas of remote sensing, satellite navigation, meteorology, disaster management, tele-education and more. These programs are primarily presented in developing nations for the benefit of nations not currently involved in space activities, and they often include international space experts from around the world. Since 1971, they have conducted over 150 training programs around the world for over 7,000 participants [9].

Also under the UNOOSA organization is the UN-SPIDER, the U. N. Platform for Space-based Information and Disaster Management and Emergency Response, which has additional offices in Bonn, Germany, and Beijing, China. UN-Spider oversees the activities of the International Charter on Disaster Management that connects providers of remote-sensing data with disaster managers and provides near

![An example of a remote-sensing image used for disaster management.](Illustration courtesy of UN-SPIDER.)
real-time access to data in major disasters around the globe. The charter has been activated some 594 times in 125 countries since it was created in 2000, and was activated 44 times in 30 nations in 2017 alone [10]. (See Fig. 7.2.)

The UNOSSA staff also maintain a 24/7 hotline for disaster managers, and also has an extensive public disaster portal. (See Fig. 7.3.)

The UNOOSA website (http://www.unoosa.org) maintains a data repository with all documents related to the committee and their subcommittees’ work. They make for very important reading for anyone interested in the subject(s) of this book. The annual reports of UNOOSA are also very interesting reading and are available through the main UNOOSA website.

UNOOSA hosts the UNISPACE conferences (on the exploration and peaceful uses of outer space). These aim to provide a platform of global dialog on issues related to space exploration and exploitation. They are organized by the United Nations to further the cooperation in the peaceful uses of outer space between States and international organizations. There have now been four, UNISPACE I, II, and III, and in 2018 there was UNISPACE + 50. These events have been held in Vienna, Austria, where UN COPUOS meets and where UNOOSA has its offices.
The International Committee on Global Navigation Satellite Systems (UNICG) is under the auspices of the U. N. Committee on the Peaceful Uses of Outer Space. This committee was established in 2005 to promote voluntary cooperation and information sharing between those nations that operate GNSS Position, Navigation, and Timing (PNT) satellite systems. UNOOSA staff act as the secretariat for the committee, and the committee seeks to promote interoperability and compatibility between these systems, and to promote peaceful additional uses of these systems around the globe.

There are many specialized agencies of the United Nations that are important to coordination of space applications worldwide, but perhaps the two most important are the International Telecommunication Union (ITU) and the World Meteorological Organization (WMO).

**The International Telecommunications Union**

The ITU manages radio frequencies around the globe, and it is the primary international body responsible for telecommunications, both terrestrial and in and with objects in outer space. So the ITU is the forum for the allotment of radio frequency spectrum for wireless and satellite services, assignment of GEO orbital slots and satellite constellation orbits, intersystem coordination of the satellite networks of the world, the creation of standards for effective and non-interference of satellite operations, and many other critical functions. The most important forum of the ITU for satellite services is now known as the World Radio Conference, which typically meets every four years, and it agrees to the allotment of RF spectrum for the three districts of the globe. These are Region 1: Europe, Africa and the Middle East; Region 2: North and South America; and Region 3: Asia and Australia-Asia.

Several of the key issues that are outstanding at this time are: (i) the pressure to divert radio frequency spectrum from satellite services to the ravenous demand for broadband cellular service; (ii) problems of intentional and accidental interference and jamming; (iii) cyber security issues; and (iv) the constant demand for new services for interface standards between terrestrial communications systems and for seamless interconnection with the ever expanding forms of digital communications devices and systems. These are constantly challenging issues to address and solve, and a key reality is the fact that the ITU does not have enforcement powers nor authority to overrule its member states, which now number almost 200 countries [12].

**The World Meteorological Organization (WMO)**

The World Meteorological Organization is the U. N. specialized agency that is concerned with Earth observation, meteorological satellites, and space remote sensing. In this role, the WMO has orchestrated a number of significant innovations. These
include the creation of the World Weather Watch (WWW) program, which allows meteorological satellite systems from around the world to integrate the data generated from satellite networks. The WWW program is run by the Global Observing System (GOS) and gathers observations of land, ocean, air, and space from the member countries of the WMO for the purpose of making weather analyses, weather forecasts, as well as issuing storm warnings and providing environmental analysis and data on climate change [13]. (See Fig 7.4.)

The key to how this process works with regard to satellite operations is through what is called the Coordination Group for Meteorological Satellites (CGMS), which first came into being in September 1972. The European Space Agency (then called the European Space Research Organization), Japan, the USA, observers from the WMO, and the Joint Planning Staff of the Global Atmospheric Research Program convened in Washington, D.C., to discuss how there could be greater compatibility and cooperation among the various satellite systems. Today the CGMS has grown to include a large number of national meteorological organizations and space agencies from China, France, Korea, Japan, the United States, India, UNESCO, the International Ocean Commission, Russia, and ESA. Eumetsat acts as the secretariat for this organization.

Closely associated with the CGMS are other international bodies that have been formed to help develop coordination with regard to remote sensing operations. These groups include the Committee on Earth Observation Satellites (CEOS) and the Earth Observation International Coordination Working Group (EO-ICWG), the Group on Earth Observation (GEO), and the Space Frequency Coordination Group (SFCG). Although many aspects of space applications can be highly competitive, the actions of the WMO have served to bring together the many space programs

![Fig. 7.4 Space-based components of the Global Observation System (GOS) (Image courtesy of GOS.)](image-url)
around the world to cooperate in the area of meteorology and Earth observation for the common good of all [14].

**Regulatory Issues Facing the Commercial Space Sector**

One of the most important issues facing the commercial space sector and NewSpace is that the international treaty and regulatory context that we work within is simply out of date and desperately needs updating and revision, but this actually happening is highly unlikely. Although this initial structure has served the major spacefaring States well, the primary international treaties and international agreements were crafted at the very beginning of the space age, and have very little to do with the current political, economic, or technological realities – let alone the future. Created in the early days of space, when only the United States and USSR were major players, we now face a very different and more broadly distributed use of and interest in space. And now comes the NewSpace revolution, and there are many, very serious new international issues that need to be addressed. The formerly clear boundary between outer space and national air traffic management and national sovereign air space is now blurred.

The NewSpace tourism ventures, such as Virgin Galactic and Jeff Bezos’ Blue Origin New Shephard, will soon be crossing this boundary, and we still do not agree on where the boundary between national air space and outer space lies. Unlike our international ICAO, the International Civil Aviation Organization, which is responsible for the management of our international aviation regulatory system, in space we do not have any similar international space safety standards.

There is also no space traffic management system, and we simply do not have any capability to monitor and control vehicles in the protozone boundary zone, nor do we have any international operational procedures for this new generation of aerospace vehicles. We will quickly require all of these, and more, once Elon Musk and others come through with their plans to fly hundreds of people between major international cities around the globe in 30 minutes using his new BFR Starship. The existing legal and regulatory system that is in place with the ICAO simply does not exist for aerospace vehicles, and this is a major looming problem. Space situational awareness, or space traffic management systems, was the thing of science fiction until very recently, but it is now becoming a very real and important need that must be addressed, both by new technical systems and also by new regulatory and legal regimes.

The same could be said for multiple emerging issues, or problems on the horizon, if you prefer, such as orbital debris tracking and management, needed policies and regulation of active debris removal, the regulation of operation of private space stations for tourism, industry, and science, and the newly arriving concept of on-orbit servicing, refueling, repair, and even construction of satellites in orbit. All of these things, and many more, are on the horizon, and many will be conducted not by national space agencies but by new commercial and NewSpace startups. And then we have the totally new domain of the mining of natural resources in space.
Are we heading for a new ‘Wild West’ in space, where private actors engage in a free-for-all? Mining of space resources is a very hot topic, and several very well funded new ventures have been created to begin the mining of the Moon, asteroids, and other space bodies. Many say that this is directly against the Outer Space Treaty prohibition of the appropriation of outer space objects. How can you take and mine the metals in an orbiting body without having appropriated it? Is it possible to claim ownership of these?

An even more difficult issue will be the continued blurring between commercial and military uses of satellites and the potential weaponization of private and commercial space assets.

**NewSpace Regulation**

In May of 2014, in Montreal, Canada, the second Manfred Lachs conference was held. The group formally endorsed unanimously the Montreal Declaration (in the Appendix of this book), which called for an international, interdisciplinary study of the question of the status of global space governance. This includes major issues and potential recommendations for the future.

Thus began a multi-year process, involving many of the world’s leading space figures, of creating a comprehensive study to make recommendations on the issues and potential solutions of making the international space legal framework more aligned with the current and future realities. The result was a very large book, *Global Space Governance: An International Study*, published by Springer in 2017 [15].

The Fifth Manfred Lachs International Conference on Global Space Governance and the U. N. 2030 Agenda for Sustainable Development was held on May 5-6, 2017, in Montreal, Canada. This, and a series of previous meetings, produced the Montreal Declaration of 2017. The conference was held to address the important question of what are the governance mechanisms related to global outer space activities that should be adopted to achieve the U. N. Sustainable Goals (discussed in Chapter 6). The vital issue of the legal regime of outer space and global space governance must be addressed more fully to both protect the space environment and secure a sustainable use of outer space for all peoples of Earth.

The extensive published volume considers in detail the international, regional, and national issues of space governance, as well as covering all of the disciplinary and applications issues relating to telecommunications, remote sensing, PNT, space mining, space launchers, solar power satellites, orbital debris, space traffic management, and even space migration and terraforming of other planets. A variety of summation questions are included in the executive summary [16], which are outlined here:

1. How do we achieve a fair, equitable, and practical balance between space activities involving national governmental activities on one hand and private commercial space ventures on the other? And, how is that balance achieved and
administered under an international regulatory authority and via enforcement mechanisms?
2. How do we go about clarifying the concept of a “Global Commons” when applied to outer space?
3. What principles and rules of international law can be logically and practically extended from Earthbound activities to the realm of outer space?
4. Do we need separate regulatory processes, practices, and enforcement procedures with regard to military operations, civil governmental activities, and private commercial space activities?
5. What about significant new technological trends and the legal issues they give rise to in terms of regulating outer space activities?
6. Do international specialized agencies of the United Nations as well as international intergovernmental organizations around the world need enhanced authority to cope with the new era of space commercialization and expanded off-world industries and commerce?
7. Will military and strategic considerations involving the primary space powers become the determining factor in developing international regulatory processes for outer space activities?

Regional and National Policy and Regulatory Issues

Commercial space is restricted by international and national laws and legal frameworks. Within the broad, international legal structure, each nation provides its own legal and regulatory structure for commercial space activities, and these including civil and criminal law, policy, intellectual property rights, military and dual-use management, international technological and scientific competitiveness, and other aspects.

The United States has clearly been the leader in the commercial space phenomenon, and it is worth considering why and how this is. Clearly, the free market capitalist financial system in the United States is conducive to these activities. The United States has a fully developed entrepreneurial ecosystem that includes individual and corporate entrepreneurs, large amounts of venture and angel capital, top-tier research universities, stable financial institutions, robust patent and intellectual property laws, and a mindset of individual achievement and personal profit. People come from around the world to create their new ideas in the United States, and places such as Silicon Valley, Boston’s Route 128 corridor, the Research Triangle in North Carolina, and others exist to support and incubate such ideas, and to profit from them.

Another key issue that is little discussed is the question of corruption, or the lack of it, in space entrepreneurial success or failure. Although the United States has many faults, it maintains a legal, banking, tax, and intellectual property structure that is relatively corruption free at all levels, from the local to the individual state to the federal level. The need to pay bribes to get office space, a business license, or to
win a legal case does not, broadly speaking, exist in the United States in the way that it does around the world. Indeed, there are very serious penalties if you engage in any of this. The game is simply much less rigged in the United States than it is in most of the nations of the world, and that is one reason why money and ideas flow from around the world into the United States for realization.

Institutional graft and corruption, and the stifling impact that this has on innovation and new commercial ventures in any field, is far more plentiful in emerging space entrants such as India, China, South America, the Middle East, Africa, and Asia. It may not be polite to discuss, but the prevalence of multiple levels of official corruption around the world is a huge inhibitor to high-tech commercial innovation and the conversion of new ideas into major new products and markets, in space or here on the planet. This is particularly true for space activities, which require large amounts of capital, licenses, infrastructure, intellectual property management, and other resources to get off the ground (literally). A stable legal and regulatory structure, an entrepreneurial ecosystem, and the expectation that this will not change, has played an enormous role in making the United States the place to innovate.

Other regions, like Western Europe and the EU nations, also have stable legal and economic environments, but they lack, or at least have lacked in the past, the entrepreneurial freedom to fail and the mindset of an open marketplace of venture capital that turns new ideas into revolutionary new markets and profits. The highly regulated national and European business environments have not been conducive to high-tech entrepreneurial ventures, but this is changing. Richard Branson has done quite well in the U.K.

Small but new players such as Luxembourg, long a mainstay in commercial satellite telecom giants such as SES, has now created a national space agency, but with a twist. Their new agency, located within the Ministry of the Economy, will focus on creating an industry ecosystem focusing on NewSpace, space jobs, and the development of a space-capable workforce. Luxembourg has been able, in rapid fashion, to attract new and growing space companies, including having several Silicon Valley and Japanese startups relocate offices there. These are focusing on space mining and space resource utilization, remote sensing, and more. Made In Space, the successful Silicon Valley startup building additive manufacturing systems for use in space, has located their European offices there, as well as Hydrosat, a remote sensing startup, and a lunar rover group called CubeRover. Even more importantly, the new agency will establish a Luxembourg Space Fund, initially resourced with 100 million Euros, to provide dedicated venture capital for NewSpace startups that will locate there. This fund will be a public-private partnership (PPP), consisting of both government and private funding, and is a very important step for Europe in creating a NewSpace ecosystem. Tiny Luxembourg has a population of less than 600,000 (half of which are not citizens), and occupies an area of less than 2,600 sq. km, or less than 1,000 sq. miles. But it has a strong commercial and business focus, experience in major space telecommunications businesses, financial stability, significant available capital, excellent infrastructure, a leading university, as well as the second highest personal income ranking in Europe. Luxembourg is
seeking to become the NewSpace center of Europe and is off to an excellent start. In this case, smaller may very well be better.

Let us move from tiny Luxembourg to massive India. Many nations around the world are recognizing the requirement for a new legal, policy, and financial structure to support commercial space, and individual States are defining new, commercial space laws to try to create a new regulatory and legal structure that is more conducive to commercial space activities, and the money and jobs that they can create. One interesting example is India, which is, at the end of 2018, involved in creating a new, national commercial space legal framework.

India has become a major space power over the past decades. Led by its national space agency, ISRO, India has developed its own launchers and a robust remote sensing, telecommunications, and satellite navigation and PNT capability; it has achieved over 70 launches and a successful mission to Mars. It is even starting its own astronaut program, but all of this activity is from a national agency-led governmental program that involves the existing corporate and academic sectors. A new bill in the Indian congress, which is expected to pass in early 2019, provides a structure for commercial space activities. This includes new laws regarding commercial space licenses, laws for the protection of the public health and also for national security considerations, and a regulatory framework for commercial space companies and businesses. The protection of orbital and Earth domains from pollution, commercial, financial and criminal liability, and related commercial issues are all addressed in the new laws.

It will have to be determined how this actually is put into practice, and the impact it will have on enabling a new generation of Indian commercial space activities, but India is making a real effort to address the needed national policy and legal issues of commercial space.

Very few nations around the world who are interested in commercial space have in place such updated legal structures. They simply do not exist, by and large, around the world, and this will have to change if other nations want to get in the game. But even the best laws on the books do not make up for the problems of official corruption, stifling regulatory requirements, excessive governmental interference, the lack of intellectual property rights, and the lack of stable financial, institutional, and political environments. These are much more difficult to create and maintain.

It is clear that the current international space regulatory and treaty system is out of date, and the new paradigm of commercial space cannot thrive without a new global space governance regime and revised national regulatory structures. We are not going to be able to achieve and maintain the sustainable use of outer space for all peoples of Earth without a new and updated system of international and national space governance. Unfortunately, how we can achieve this is uncertain. There is very little likelihood that a new set of comprehensive space treaties will replace the existing ‘Big 5.’ There are simply too many players now, with too many competing interests and perspectives. So, at an international level, how can things move forward?

For one thing, there needs to be more reliance on general norms and ‘soft power’ rules of behavior in space. The five space treaties will remain the foundation of
space activities, and so we need to have a renewed focus on them, including what they do and do not actually mean. Those nations who have not yet ratified them, and this list includes several new space actors including Iran and many African States, should be encouraged to do so.

The primary U. N. organizations relating to space, COPUOS, the ITU, and the UN Office for Outer Space Affairs (UNOOSA), should be more broadly recognized as the key international players in space, and it would be reasonable for their roles and structures to be expanded and even restructured. This would include how decisions are made in COPUOS, its future mandate, funding, and decision-making process and executive structure. Newly active space nations, and especially those who have growing NewSpace ecosystems, need to become more proactively involved in international space regulation activities, and they should actively engage in the work of COPUOS. As there will not likely be any new binding space treaties, the NewSpace ecosystem globally will have to rely upon non-binding international and bilateral agreements, as well as evolving national regulatory structures. Remember that existing market leaders do not like being disrupted, and legal, regulatory, and policy processes are a favorite venue for the solidification of existing players and the denial of new entrants into new markets. Nobody likes being disrupted.

It will become increasingly difficult to balance all of the competing needs, perspectives, objectives, and financial interests in the NewSpace era. How this can be done within the existing treaty context is uncertain at best. How do we balance the freedom of exploration and use of outer space with the prohibition of appropriation of celestial bodies? How do we balance the interests of developed vs. developing space nations, private vs. governmental interests, peaceful uses vs. military applications, national vs. regional or international goals, and more? Are 10-minute space tourists really the emissaries of all mankind? Private space activities will have to be properly regulated by States, and the staffing, funding, and mandates for these national regulators will have to keep up with the pace of new private space activities.

There will also have to be a learning curve for NewSpace entrants on these issues of national and international space law, which is not really a focus of most small startups. One recent example is illustrative. A ‘stealth’ Silicon Valley startup in the United States named Swarm Technologies was fined late in 2018 by the U. S. Federal Communications Commission (FCC) for illegally launching into orbit and operating four microsatellites. Their concept is a constellation of some 100 tiny microsatellites that would provide ‘Internet of things’ services. The FCC is responsible in the United States for all regulatory approval of radio frequency use for satellites, regardless of the launching location. The FCC denied Swarm’s application in late 2017, due to concerns that the tiny communications microsatellites would be impossible to track from the ground by the U. S. Space Surveillance Network, and might increase space debris due to a collision in LEO with other satellites. Its innovative communications satellites are only a quarter the size of a traditional 1-unit cubesat. But Swarm secretly launched its satellites on an Indian launcher in January 2018 anyway, without the required U. S. governmental approval and licenses (Fig. 7.5).
Swarm’s satellites worked for a week, until the FCC regulators found out, initially from amateur satellite trackers who noticed the new satellite transmissions. The FCC quickly ordered Swarm to cease all communications with the satellites and began an investigation. Their investigation discovered additional illegal use in high-altitude balloon tests and other frequency violations. Under international law, it is the U. S. government that is responsible for these actions of a U. S.-based private company. The company later had its application approved and is now in communications with these four satellites, and has launched additional ones as well.

The tiny satellites now have micro radar reflectors as a part of their design, in order to increase their ability to be tracked by ground-based monitoring systems. But the $900,000 fine, along with a 5-year mandatory compliance plan, was a warning to the NewSpace community that unauthorized launches and frequency use will not be tolerated by the U. S. government. The FCC issued an Enforcement Advisory in April of 2018, warning broadly about the potential serious consequences for any failure to comply with federal licensing regulations by telecommunications companies in the United States. “We will aggressively enforce the FCC’s requirements that companies seek FCC authorization prior to deploying and operating communications satellites and earth stations,” Rosemary Harold, chief of the FCC’s Enforcement Bureau, said in a press release announcing the fine. “These important obligations protect other operators against radio interference and collisions, making space a safer place to operate.”

This situation unfolded in the United States, with its robust enforcement and regulatory environment, but what will prevent another ‘stealth’ space startup from secretly launching picosats from a less responsible launch site, and using ground receiving networks located in other, less regulated States? The danger is clear. There will be no easy answers here, particularly as wave after wave of new technologies wash over our world at ever faster rates, and we will soon have new launching...
States, all competing for new business. The Silicon Valley paradigm includes a healthy disregard for the rules, and breaking the ‘old’ rules is seen as simply a part of the fun of the game, but one has to wonder if outer space is the proper venue for such attitudes.

Conclusions

In conclusion, the international space legal and policy structure in place was initially created in the early days of the space race. The current and future situation is now, and will be, radically different, and we need a new and more relevant international space legal structure. But this will be extremely difficult to bring about, given the many different and conflicting national space perspectives and interests.

The Manfred Lachs conferences and report do provide an excellent path forward, but we will have to see how this unfolds, and the difficulties will be many. Individual States also need to review and update their national space legal and policy structures to take into account the reality of NewSpace and commercial space activities both now and in the future. National legal and policy issues always lag behind technological developments, but, in the past, this was not really a problem. Now, with wave after wave of new technologies washing over us at unprecedented rates, we are at a significant disadvantage, and the effects of this are already being felt. How can our national and international legal and policy frameworks find new ways to not only respond effectively but guide this process? Is that even possible? The States that are able to proactively harness the legal and policy needs of NewSpace will be handsomely rewarded.

In the next chapter, we will look at some of the downsides of the disruptive innovation of NewSpace and the revolution in computing and our modern hi-tech world, and how these downsides might possibly be mitigated.

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Chapter 8
The Downsides of Disruption and How We Might Manage Them

The Information Age offers much to mankind, and I would like to think that we will rise to the challenges it presents. But it is vital to remember that information – in the sense of raw data – is not knowledge, that knowledge is not wisdom, and that wisdom is not foresight. But information is the first essential step to all of these.


This chapter will consider the downsides of disruption in economic, social, political, and even personal contexts. There is a saying that “Everybody wants to develop a disruptive technology, but nobody wants to be disrupted,” and this is very true. This chapter will present several examples of how technological disruptions have had negative impacts upon both disrupters and those whose markets and businesses have been impacted by disruption. The chapter will also consider some of the costs and dangers of space disruptions as we now understand them.

When the world’s first dedicated container ship, the SS Ideal-X, left New Jersey, loaded with containers for Texas in April of 1956, a reporter from Texas was on hand and asked one of the longshoremen on the dock, an official of the International Longshoremen’s Association, what he thought of it. “I’d like to sink that son of a bitch” was his answer” [1].

He was right to be concerned; he saw the end of his world sailing away before his very eyes. In little more than a decade, the waterfronts around the world were changed forever, and thousands of dockside jobs were lost, never to return. Entire local ethnic groups that had relied on working on the docks had this source of income and stability taken away, and they were very ill prepared for retraining for the high-tech new jobs in the field. Thousands of workers lives, and the lives of their families and communities, were torn apart. The new container ports moved to larger, more open locations, and the traditional docks and their associated neighborhoods, businesses, and manufacturers were sent into a spiral of decay from which they never recovered. Disruption hurts.

However, the move from the first container shipments to a global network was a very difficult and long process for more than the longshoremen and their dockside neighborhoods. Most of the established, profitable shipping companies were initially unwilling to incur the large, up-front costs of converting from break-bulk cargo to the new container paradigm. This would require new equipment, new docks, new ways of doing business, etc., and this was not welcomed at all. They
faced major costs in new container ships, new container facilities, cranes, the containers themselves, tracking systems, new marketing costs, and more. Several of them simply added containers onto their existing, general cargo vessels, gaining none of the efficiency that containerization could provide.

This half-hearted response that gained nothing showed their reluctance to change. There were also the costs of interlining with the trucking and rail networks, which were separate businesses that were equally unenthusiastic about the new costs and disruption of their existing business models. The existing dock workers and labor unions fought the expected job losses hard, and won major economic concessions and major legal challenges, and huge political pressure were brought to bear to stop, or at least slow down, this danger to their established dominance of the ports and docks. It took a full decade of economic, political, and social change to bring about the dominance of the container system for international shipping. Eventually, everyone saw the writing on the wall, and they made the changes, accepted the costs, and did their best to move on into a very different world.

Initially, even the railroads, which now ship massive trains of double-stacked containers from container ports far inland for a very sizable profit, were strongly against the idea. They had their own version of break-bulk cargo handling, and all of the sorting and restocking of boxcars was done by railroad personnel. The railroads charged a handsome fee for this, and they were very uneasy with the locked box idea that would remove this important source of their income.

Over the course of a decade, the major docks around the world were going through a painful cycle of attempted renewals that failed, and virtually all ended up closing. Many were left to rot while others were successfully reborn as business parks or new housing developments. Hundreds of businesses that had operated near the docks in order to easily load their products for shipment by sea closed and moved to less expensive locations. A container can be shipped by truck or rail from anywhere, and there was no longer a need to be located close to your port of embarkation. New locations more appropriate for the new container model, with large, open areas for rows upon rows of containers and easy access to highways and rail, became the new centers of global trade.

For every new innovation that disrupts a market, there are going to be losers. Many of these may be groups and locations that are little able to react, retrain, or recover. This is often the case with the working class, whose jobs are lost in the never-ending search for increased efficiency and automation. Labor costs are always a significant part of any business, and efficiencies that reduce these costs are always attractive, and also always impact people and their lives.

As stated earlier, employment in the 19th century was often highly structured around types of jobs. A single ethnic group often dominated the work of loading and unloading ships in individual ports. This type of ‘jobs structure’ provided an important economic benefit to what were often the lowest on the economic ladder. In the Pacific Northwest of the United States this work was controlled by the local native American communities; in New York City it was the Irish and Italian immigrants; in Baltimore it was Polish Catholic immigrants; in the south it was blacks who had to have their own, separate unions and work parties from the white unions, and so
on for employment in 19th America. And the same story played out around the world. Local communities, often minorities, controlled the docks and fought fiercely to maintain their hold. The containerization of global trade completely upended this existing system, and stevedores around the world found their jobs lost with little chance of retraining for jobs in the new, more technical (and efficient) system. Social impact was inevitable, and little concern was given to those who were displaced. Watch the 1954 film *On the Waterfront* sometime, to see an excellent representation of the 1950’s New York Harbor docks (actually Hoboken, New Jersey), warehouses, and union corruption.

Large and important spatial changes were also created by the new container paradigm. The previous docks around the world were no longer appropriate for the new container yards. Manhattan Island in New York City was once lined with wharves and warehouses, but the new container system required large yards for storing and accessing hundreds of containers, and so large, open, and previously unused edges of New York Harbor in New Jersey soon dominated the shipping industry, as it does today. San Francisco lost out completely to Oakland, on the other side of the bay. The same pattern occurred globally, with new shipping channels dredged for the ever-larger container vessels and old docks either abandoned or, more hopefully, redeveloped for new uses like the London docklands and the wonderful Cape Town, South Africa, harbor area, which has become a very successful tourist attraction and huge, new economic engine for the city and region (Fig. 8.1.).

Other old docks have not been so lucky. Another impact was that many businesses that required shipped cargoes or who shipped abroad large parts of their production tended to be located close to the docks. When the docks moved away and containers could be filled and shipped from anywhere, many businesses left the

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**Fig. 8.1** The wonderful Victoria and Albert Waterfront tourism complex in Cape Town, South Africa. Once a thriving dock, then an abandoned eyesore, it is now a major economic engine for Cape Town’s thriving tourism industry. (Image by the author.)
docklands for places with cheaper rents and lower wages. This compounded the loss of the traditional docks by losing local industries and their jobs and taxes.

It is little discussed, but containers have also created a new and frightening international security threat, as these millions of locked containers can very possibly contain something quite different from what is listed on the manifest. Concerns have grown about drug and human smuggling, and even the routing of a chemical or nuclear ‘dirty’ bomb right to the front door of a capital city or parliament building. It is simply impossible to fully inspect every one of the millions of locked containers constantly moving around the world. New technologies, such as mobile X-ray scanners, have been developed, but the millions of constantly moving containers can never be fully inspected.

A second group of the disrupted are very different from the low-end manual laborers who lose their jobs. These are the very powerful – the corporate leaders, the political figures, and the economic elite who had benefited handsomely by the current status quo, and who will fight any disruptive change that will negatively impact them. The economic history of the machine age is full of examples of powerful economic and political interests that have fought, often ruthlessly, to retain their positions of power and who have taken a dim view of the disruption of their positions of power. Economic power is inherently aligned with, and creates, political power, and the battle over disrupted markets inevitably is waged in the political as well as the economic arenas. Specific regulations and tariffs are often placed like roadblocks in the way of the new entrants.

We should consider how our investigation of NewSpace disruptors relates to this example of shipping containers. Who will win and who will lose around the world? There will certainly be winners and losers. Elon Musk has created three companies, SpaceX, Tesla and SolarCity, in just over a decade with a combined market-capitalization of over US$40 billion or so. These private companies employ some 32,000 people, and all have extensive growth plans far beyond this. Each of Musk’s complementary set of ventures also shares a common view of visionary societal progress in addition to revolutionary technological change. The evolution of society away from fossil fuels to solar-based power for both housing and transportation, are politically charged issues.

Powerful existing political and economic forces want to maintain the existing paradigm, but are also fundamentally conflicted by the overtly free-market capitalism of Musk’s activities. Even in the conservative southern states of Texas and Florida, where Musk has put major facilities and where he employs large numbers of workers and intends to locate a major new launch facility, the large aerospace corporations and their powerful political allies have repeatedly tried to stop him through political and regulatory means.

Musk once said in an interview that he cannot get any member of the Florida or Texas congressional delegation to return his calls. In his South Australian power ventures, he is going up against very powerful coal and mining interests, and their powerful political allies. With Tesla, he has taken on the powerful auto manufacturers, auto dealers, oil companies, and more. These senior politicians are closely aligned with the existing aerospace industry leaders, who make sizable political
contributions, and these politicians take a dim view of such disruption. It takes resilience and personal courage to withstand this type of concerted pressure, which is often done out of the spotlight of public view. Clearly, being a disrupter requires some very thick skin, and lots of lawyers as well [2].

Jeff Bezos has certainly learned this difficult lesson as well. He is likely to lose fully half of his vast fortune, due to private investigations by the *National Enquirer*, a strong ally of President Donald Trump, which exposed an illicit romantic affair by Bezos, which is now leading to his divorce. The likelihood that this was related to Trump’s hatred of the *Washington Post*, which Bezos owns, cannot be discounted.

Beyond the retribution of powerful people being negatively impacted by disruptions, however, society is now facing a much more fundamental and dangerous disruption. Some analysts have suggested that disruptive technologies born of artificial intelligence (AI), robotics, additive manufacturing, and other high-tech industries will lead to a 40% level of job obsolescence across the global economy within the next generation. This type of disruption will impact not only jobs and family incomes but other key areas such as taxation, governmental revenues and services, and even political stability [3]. Cars, trucks, delivery vehicles, perhaps even commercial airliners and container ships at sea may soon, within our lifetimes, have no humans on board. What happens to the millions of people holding these jobs that will be lost in this massive transformation?

So how do we view these processes? Is it only based on if we as individuals or corporations would benefit or be harmed? What are the boundaries between these, and how do societies manage the broad effects of disruption?

**Creative Disruption, Destructive Creation, or Just Destruction?**

Beyond space launchers and rockets, the NewSpace revolution also brings with it major issues involving the massive amounts of digital data now being collected and analyzed about our world, and ourselves. There are many important questions that must be raised and, hopefully, addressed.

Who has access to all of the data being collected? Who decides who has access to this information? If massive amounts of jobs are replaced by robotics, artificial intelligence, and 3D printing and additive manufacturing, what do people do for a living? If there is a gigantic reduction in income tax revenues, how are governmental revenues sustained at a time when the social safety net might very well have to be substantially expanded to cope with large-scale unemployment?
AI and digital privacy are among the largest concerns that come with an ever more interconnected digital world. AI, the Internet of things, big data, facial recognition, and all of these related technologies will have tremendous implications for personal privacy in the digital world. Alexa, Siri, Google Assistant, and the other AI speaker systems record everything you say after you say after the keyword is spoken to begin interacting with the system. These data are stored in corporate databases and could be, potentially, used for a variety of illegal and intrusive activities, either by the companies, by hackers, or by governments. In 2018 a group of private researchers created an Amazon ‘skill’ for Alexa that recorded users without their knowledge and sent the transcripts of their conversations to the people hacking the system. In the same year, Amazon sent over 1,700 recordings of an American family’s private conversations in their home to a person in Europe who had no known contact with them. Amazon initially denied the event, and then dismissed it as a very rare incident. Courts and legal authorities have access to all of these data through the legal process of getting a subpoena from a court, and, in at least one case, these data have been used in a criminal prosecution. The Internet of Things will soon mean that every device in your house, from your refrigerator to your TV, will be connected, storing, and sharing data. Who gets access to all this?

Facial recognition systems are currently in use in a variety of contexts around the world – in airports and stores, on highways, and at major sporting events. Most people have no idea that their identities are being recorded and checked against criminal databases when they are out in public places. Highway systems routinely record automobile make and model, and registration numbers and check these against databases of stolen vehicles. GPS systems record your location constantly, and these data are stored and are accessible to your smartphone manufacturer and police, again via a court subpoena.

All of these capabilities, taken together, make possible a ‘Big Brother’ Orwellian world like even the most malevolent dictator in the past never dreamed possible, and would love. Who will control all of this? How can the interests of the private citizen and a free society be defended in the face of such pervasive and intrusive invasion of every aspect of our lives? If massive tech corporations and governments record and store every conversation we have, where are the rights of the individual being protected? Every Google search we make, every purchase we buy, and every location we visit is recorded, stored, and sold behind closed doors. High-resolution satellite images of every corner of the globe are recorded multiple times each day. How can individuals be secure in their daily lives from intrusion? This condition has led to the coining of the term of the “total surveillance society,” and this danger is very real.

The potential for abuse at many levels is simply overwhelming and, given human nature, will certainly occur. If we can do it, we will. The recent political issues of ‘fake news’ and false political websites certainly are troubling. Video tracking of citizens and other surveillance systems are now in place around the world in China,
Russia, the United States, the United Kingdom, and an increasing number of other countries [4].

There are three, broad areas of abuse possible here, individuals or groups of hackers, private corporations, and governments. Any of these could be a major concern, but the more likely scenario is that these will be combined together in ways that make it even more dangerous and difficult to monitor and address. Governments currently use corporate tech surveillance to get around legal restrictions on their activities. They use individuals and groups of hackers to do work in the shadows. Who monitors and controls all this? The state of Illinois in the United States passed a Biometric Information Privacy Act, one of the first such laws in the country, requiring that companies who collect biometric data be clear about their use.

There is a vast and, at least in the United States, legal market for buying and selling personal data about all of us, and it is only loosely regulated and controlled. Data brokers around the Internet are scooping up vast amounts of personal data on just about every aspect of our lives, and then sell these data, or compilations, or email lists, etc., to other brokers, governmental agencies, insurance companies, and even to individuals. You would be shocked to know how much of your personal habits, what you buy, where you shop, which drugs you use, how much you drink and travel and have in the bank is up for sale. The data broker industry is extremely opaque, for good reason, and there is very little oversight, and even less opportunity for people to see and, if needed, correct, what is out there about us. Big data can quickly become bad data. The dangers are very real.

Politicians are big customers of these data mining services, buying vast amounts of data for targeting election mailings, canvassing, and robocalls, so they are rather uninterested in limiting the reach of these services.

The Equifax and other large-scale privacy breaches, the complexity of End User License Agreements (EULAs), and opting out of intrusive means of gathering information only seems to increase. They want it to be difficult, and it is.

Corporations made a very lucrative business out of purchasing information about us, and they sell it to businesses for millions of dollars each year. Who checks to see the accuracy of this wealth of data? Who is legally, morally, ethically responsible? A sad recent development is that there are now companies with websites that offer to buy your personal data directly from you for a very small payment. Are private companies ‘moral’ enough to have this power? Are governments? Is anyone?

The new Internet of Everything also has potential dangers. Who will have access, who can turn on my house lights or unlock my door? How can we prevent illegal spoofing, etc. How can the negative effects be mitigated? Who will be held accountable?

The European General Data Protection Regulation (GDPR) is the first systematic effort to provide privacy protection to the general populace in Europe, but early indications that most people are generally not able to use these new legal protections on any truly effective scale [5]. How can the effects be mitigated?

We have a related emerging issue that will require attention, and that will impact all aspects of how we do space activities around the world. This is the increasing
roboticizing of low-end jobs and the continuing displacement of workers by automation. The ultimate goal of efficiency is quickly replacing a significant fraction of our workforce with automated systems that require no paycheck or retirement benefits. In the United States over 3 million people are employed as drivers of delivery trucks, cabs, and other commercial vehicles, but these jobs may not exist in the next decade. What will happen to these people? But on the other hand, driverless vehicles, businesses and services will open up new opportunities for the elderly and handicapped to enjoy more mobility and will surely decrease the number of alcohol-related automobile accidents and fatalities on our roads, as well as reduced carbon fuel emissions. Someday we may have commercial aircraft and great container ships at sea with no human crews, entirely controlled by AI computers. This driverless vehicle revolution is, of course, made possible by the U. S. Global Positioning System, as well as GIS mapping, AI, powerful portable processors, and related networking, computer and database advances. The glass is never either quite half empty or half full; the only certainty is that the contents are quickly changing.

More and more higher end jobs that had been safe from automation are now being viewed as ripe for conversion. This started with low-end, manual jobs, such as robotic welders now doing the majority of welding in automobile assembly lines around the world (Fig. 8.2).

Recently in Japan a fast food restaurant announced its robotic burger flipper, making perfect hamburgers with no breaks, sick days, or paycheck. Check-in kiosks are now the norm at airport counters and hotels around the world. These jobs are gone forever, and many more jobs, even entire classes of work, will soon vanish.

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Fig. 8.2  The Tesla production line. (Image courtesy of Tesla.)
And with the major advances in machine learning and AI, this process will soon begin to affect higher-end jobs requiring decision-making and the use of complex judgment, not just assembling parts on Henry Ford’s moving assembly line.

One recent commentary, by the head of Sun Computers no less, said that the majority of diagnostic medicine will soon be done by AI, and many human physicians will no longer need to be trained or be employed. A recent study found that a ‘deep learning convolutional neural network’ on a Google super computer produced better results than 58 dermatologists in the diagnosis of malignant melanoma [6]. This has been countered strongly by physicians who stated that the human aspect of the doctor/patient relationship and the ability to treat the patient as a complex and whole human being will ensure the guiding role of the human healer, preferably in concert with the powerful AI and other computer supporting systems, but still with a human touch. Additional advances in robotic surgery mirror these developments.

On the one hand we have potential for tele-medicine bringing much needed improved medical care around the world, and eventually offworld, but at what cost in the number of physicians required and the loss of that important human touch in human healing? Robotic welding of car bodies is one thing, but do people really want to trust their health and their lives, and those of their families, to a computer and robot? What happens when the robots do a statistically better job over thousands of patients than the doctors at your local hospital? What if only the rich can afford such care? The questions are many. And of course, automation involves not only robots but expert systems and artificially intelligent algorithms that can replace service jobs as we automate retail payment systems, accounting, sales, insurance and banking functions, and so on across the service industries [7].

How will the global economy function if robots create the world’s goods and automatically distribute them? What if AI systems ordered the goods and checked out groceries or other products as consumers shopped in all the world’s stores? In such a world, few would have jobs or the income to purchase them. What will be the social, political, and human impacts? The current private capital system is strongly backing these technological changes. Market forces are strongly rewarding companies who reduce payroll through automation with higher stock valuations, positive ratings, and other means. Without changes to our global economic systems and current regulatory processes, automation will only continue to increase. With changes to the current drivers of change discussed in Chapter 5, automation will continue to accelerate.

How can the economy function if the working class and a growing number in the educated strata have no prospects for long-term employment? Who will buy what the machines produce and deliver? Some nations, particularly in Europe, are considering a guaranteed annual income for all citizens. Even Bill Gates, the founder of Microsoft, has indicated that as robots replace workers, it would be logical to tax the robots since this would in effect be an income tax. The only change would be that the ‘workers’ would be automated machines or algorithms [8].

The problem would then start to become circular, in capitalist economic terms. If we indeed did tax automation, AI, and roboticization of our economy, economists would ask what is the profit motive behind the automation to the company? This
will become a major global economic, societal, political, and regulatory question much sooner than most people realize. The fourth industrial revolution will be rapidly upon us, and may not be kind. Robots and IA will soon be able to replace a huge number of human workers. What about you? Is your job safe? What about your children’s prospects for their future?

Finally, as if we have not discussed enough disturbing issues here, we have the emerging issue of our reliance on a totally digital world, and what might happen if we lose it all. There is a very real possibility that, long in the future, our digital age might be considered a lost age. What happens when we build a world based on this, and we lose power?

### The Potential of a Global Power Outage and the Permanent Loss of Digital Data Archives

There are two likely scenarios for this, one natural and one manmade. The human-made cause could be a nuclear electronic magnetic pulse, or EMP, that could be triggered by one or more nuclear blast in the stratosphere. Such an attack would instantly create massive electrical current and voltage surges that would, potentially, destroy computers and electrical grids across a vast area [9]. Computers and electrical components would be permanently damaged.

The naturally caused version of this global disaster would be a massive solar coronal mass ejection, or CME. This would generate a gigantic solar storm with billions of ions blasting Earth that would be equivalent to the gigantic CME event known as the Carrington event of 1859. Such an event could cause a widespread power outage, such as occurred with the Montreal event of 1989 that burned out a number of transformers and caused a blackout reaching from Chicago to Montreal and Quebec City. There was also the so-called Halloween event in 2003 that caused a major blackout in Scandinavia. Such events appear to occur every 150 years or so. In the Carrington event, which occurred well before the world had electricity or computers, telegraph offices caught on fire, but no other electronics were there to be vulnerable. Today, in a digital world filled with electronics, the results could be much more devastating, not only in terms of power but also pipelines, airline avionics equipment, the Internet, and our electronically stored data, bank accounts and much more could be at risk [10]. It could take years to restore global power networks, and the economics of a digitally interconnected world could be turned on its head.

Ancient Sumerian cuneiform does not look like such a bad medium; at least we can read these writings over 4,000 years later. How many of your digital files will be readable in only a decade? Our vast knowledge base is quickly being created, stored, and retrieved only in digital format, and we, as a society, need to consider how our global knowledge base can be secured against such a possible catastrophic event, or simply digital format obsolescence.
Conclusions

The economic benefits of disruptive technologies can turn out to be short term in nature. There are dystopian science fiction novels such as Player Piano, which was Kurt Vonnegut, Jr.’s first novel. This novel eerily envisioned a society where only a few scientists and engineers had jobs. The vast mass of people lived a squalid life characterized by only being consumers of shoddy products, with no meaning, and filled with no hope for the future [11].

Creative minds can define a better future, but only with more innovative and insightful views about how to transition to a future where jobs and many tasks are shared with smart machines and software. Disruptive technologies, automation, and AI not only will change our lives and the very definition of work; these smart tools will force us to think more clearly about a desirable size for a human population, environmental sustainability, the meaning of economic throughput and prosperity, the optimum role of government in society, and what is the purpose of life in world filled with smart tools and capabilities. These are not things that people are accustomed to thinking about; indeed, they are in the realm of science fiction. Disruptive technologies are more than disruptive in only a business and economic sense.

These changes force us to think about what environmentalist Tim Morton has characterized as ‘hyper-objects’ [12]. These are very large and profound changes that occur over such a long period of time and that have such a large impact on societies and the global economy that most people simply say: “This is above my pay scale,” or “This is far beyond something that I can personally affect.” They then feel it is something that they can safely ignore. The problem is solved by ignoring it, simply because it is just too enormous for someone to personally cope with it. Tim Morton invented the term in the context of climate change, but disruptive technologies in the form of AI, robotics, and automation are indeed another type of hyper-object.

The importance of the array of disruptive technologies that are impacting our jobs, our lives, and our sense of self and its impact on global society are too important to ignore as a hyper-object. That is somebody else’s problem. No, the meaning of disruptive technologies and their impacts on our lives in the 21st century will be profound. This is one hyper-object that we are economically, socially, and culturally obligated to think about. The impact of these changes are profoundly important, and in many cases could be beneficial in terms of our physical health, our economic prosperity, and our ability to cope with complex problems such as climate change, and yes, our access to outer space. Yet we also must seek ways to understand and mitigate the negative impacts as well.

We are nearing the end, and in our next chapter, we will consider the top twelve things to know about disruptive technologies and space innovation.
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Chapter 9
The Top Twelve Things to Know about Disruptive Technologies and Space Innovation

Every revolutionary idea seems to evoke three stages of reaction. They may be summed up by the phrases: (1) It’s completely impossible. (2) It’s possible, but it’s not worth doing. (3) I said it was a good idea all along.

– Arthur C. Clarke

This chapter will present the top twelve things that everyone should know regarding the radically changing world of disruptive space technologies. First, a quick recap. We have taken a long look what disruptive innovation is, how it works, who benefits, who loses, and what this has to do with space and particularly the NewSpace or Space 2.0 revolution. We have learned a great deal from previous instances that first came from historical examples and then most recently from the now rapidly changing space sector. We have explored the new and emerging technologies that are changing our world and their potential impacts on the ‘other 3 billion’ people with whom we share our spaceship Earth. We have considered the international legal and policy implications, as well as the downsides of disruptive technologies in the 21st century. So what should you take away from all of this?

The Top 12 Takeaways

1. We are in a period of unprecedented disruptive innovation in many segments of modern society, and this is now quickly becoming the norm in many aspects of the space sector. The traditional actors in space activities, i.e., large and well-funded national governmental agencies and major aerospace corporations, are being confronted by a radical new set of ideas, approaches, and technologies, and they are in many ways trying to adapt to these changes. This process is another example of disruptive innovation, as we have seen in earlier chapters, and it is still playing out. There will be major new winners and losers, and it is still too early to pick which is which. Even NewSpace ventures that fail, go bankrupt, or are absorbed into other entities may still bring about important changes and trigger important innovations that others will use. Some of the first key space innovators, such as Teledesic, Iridium, Globalstar, and Orbcom, all went through bankruptcy, from which some recovered and others did not. Yet all of
these entities impacted the commercial space sector and brought key innovations to the fore.

2. The speed of change is accelerating to the point that it is difficult to manage, anticipate, or respond to in a timely manner. There will be tremendous benefits from all this, but there will also be major economic, political, and societal impacts and perhaps even substantial losses, including many that will be very difficult for us to mitigate. Just because a technical or business innovation is significant and ‘disruptive’ does not insure its initial or long-term success in the business world. Nor does it mean that it will be a net positive influence on the world.

3. The cost of launch to orbit is being significantly reduced, opening up many new innovations through small satellites, cubesats, and large LEO constellations. Elon Musk and Jeff Bezos, among others, have upset the traditional launch market and have drastically reduced the price to orbit by creating reusable launch systems. This trend will only continue and accelerate. They are creating the framework for an emerging space tourism market, or at least a space adventures market. Ultimately this process will send thousands of ordinary (if well-funded) people into space, a number that will dwarf the 500 or so astronauts that have flown during the early space agency missions. This trend in new launchers, which is driven by disruptive technologies, will only continue and even diversify. Currently there are a number of new very small launchers focusing on the smallsat and cubesat launch markets. Sir Richard Branson and his Virgin Galactic enterprise have not only developed a space plane for space adventure flights, but this has evolved into his Launcher One enterprise that is now contractually committed to launch smallsats for the OneWeb constellation.

4. The smallsat revolution is rapidly altering the way people undertake space projects. This trend will continue and accelerate. Cubesat constellations are on the verge of replacing the traditional, large and expensive GEO satellites for many of the traditional satellite applications. This is especially true of remote sensing, where miniaturized sensors are able to accomplish many tasks, including hyperspectral sensing and now even active radar sensing. Small satellites are also making inroads into the telecommunications satellite business for network and rural connectivity markets.

   The challenge for advances by smallsats in the communications field is now driven by achieving ground systems that are cost effective and can provide electronic tracking capabilities at lower costs. Finding long-term and reliable market strategies will be required, and the emerging issues of orbital debris and congestion must also be addressed.

5. There are also going to emerge new and novel applications that will create new markets that do not yet exist. These will likely be related to on-orbit servicing, rendezvous and proximity operations, more use of small satellites for frequency monitoring (i.e., Hawkeye 360), and the use of small satellites to locate prime asteroids for possible resource extraction and planetary protection. Solar power generation and human exploration and settlement of the Moon and Mars will come, and we will eventually become a multi-planet species.
6. The potential problem of space debris, which could result in an inability to access orbit, must be addressed in the near future. New advances in active debris mitigation, debris re-purposing, 3D printing, and reuse of satellites must continue. Smallsats and disruptive space technologies such as Electro-Dynamic Debris Eliminators (EDDE) may be crucial to that future. We must protect our access to orbit, and the issue of space debris must be addressed. The associated Space Situational Awareness capabilities must be developed and put into place.

7. Other types of outside-the-box thinking will be a part of our space future. These new initiatives, such as more use of hosted payloads, combined or clustered missions on a single small satellite, onboard data processing, as well as new high-altitude payload systems deployed in the stratosphere that begin to make more use of the protozone (subspace) will be a part of that future. Space traffic management to make space safer will also need to consider the transiting between national airspace and outer space. We will need space control systems for hypersonic transport via the stratosphere or protozone, so that space planes, HAPS, and UAVs, and stratospheric freighters and research stations do not collide in tragic accidents. Also, environmental concerns must be addressed with regard to the launchers and space planes that release solid particulates, so that they do not pollute the stratosphere, where Earth’s atmosphere is over a hundred times thinner than at sea level.

8. Space is rapidly opening up to the people from all nations and will continue to be more and more relevant to the people and needs of the developing world. Space has traditionally been the domain of the super powers and the wealthier developed nations and large corporations. Even when other nations became interested in space, they usually paid an American, European, or Japanese company to build their ‘national’ satellite, and then paid another to launch it. This is rapidly changing, due to several factors, including the cubesat revolution and the reduced cost to orbit. New applications that are focused on developing world needs are being introduced, and these are being developed internally by people in countries around the world such as South Africa, New Zealand, Indonesia, and others.

9. Individuals and small groups continue to drive the innovation cycle, and this will only increase. Large, established corporate aerospace organizations and government agencies are struggling to react to the pace and scale of the NewSpace revolution. This is a classic example of the disruptive innovation cycle. The space industry will look very different in ten years, and it is not possible at this point to know who will emerge on top. But it is clear that there will be many more players, many more satellites, many more nations, and many new applications on the horizon. We are in a time of major flux, and there will be new winners and new losers, but the conversion to agile, private, bold innovators will continue.

10. The international regulatory and treaty context for space is woefully outdated and hinders the development of new ideas and activities. How this can be changed is not clear but changing it is a must. The Outer Space Treaty and the four other subsidiary international agreements now provide the basic
international legal and policy framework for space. These treaties, created in the 1960s and 1970s, never anticipated the current situation with significant private and commercial systems operating in space. The Liability Convention is rather obsolete or creates the wrong incentives for today’s space players.

The whole field of small satellites and the services they could provide were simply never anticipated. Thus, in many important ways, the current international structure of space law fails to represent the realities of where we are, let alone anticipate where things will be in a few years as the NewSpace revolution continues to unfold. How the international community will find a path to a new and more relevant legal and regulatory framework for space is still unknown, but this is needed now more than ever. This will be one of the most difficult issues to be addressed.

11. Space is precious real estate and has become an invisible but essential part of our modern world. We are rapidly polluting the useful orbital regions, especially LEO, and we face a real danger of polluting LEO to the point where we will not be able to access space. We must do a better job of protecting our access to space, reducing orbital pollution, mitigating space debris, and ensuring that access to space will be available to all in the future. This will require a balancing of the needs of all nations, and the recognition that investments in space are expensive and technology difficult to develop, yet the ‘commons of space’ need to be used to benefit all nations and all peoples.

12. It will be the integration and synergy of all these that will create the new future of space. Each of these individually could have significant impact on our world and how we utilize space to benefit all nations and peoples of the world. It will be the cumulative and integrative whole that will create a radically different future, one significantly altered from the world we know. So many new technologies not directly related specifically to space, such as AI and big data, will combine with smallsats and cheaper access to space to drive many improved current applications, and will also create novel, new markets that don’t even exist today. The speed of the disruptive innovation cycle will continue to spin up at an ever-increasing rate. Companies representing new ideas and applications will be created, have their prime, and be subsumed by the next wave in increasingly rapid fashion. This will have a potentially radical impact on how space developers, investors, regulators, and individual consumers live and work. It will significantly impact jobs and employment as well.

**Disruptive Technology and Change**

The benefits of space will also continue to spread more broadly around the world and have a real potential to make significant improvements in the lives of people on the planet who live in poverty and who do not currently have access to the benefits that we have in the developed world. These positive benefits can include access to
communications, information, education, healthcare, and in better ways of farming, forestry, fishing, mining, and providing governmental services.

There will certainly be a shakeout in the many NewSpace launchers and constellations. Many of these will not survive, and this is to be expected. But even the companies and concepts that do not survive will provide new opportunities in other, newer ventures.

The Silicon Valley entrepreneurs, quite unknowingly, may drive a new wave of technology that can reduce poverty, improve health and education, and increase security and prosperity for the poorest and least connected to space on our planet. At least this is the hope. There are certainly many entrepreneurs in Africa and Asia who have simply been unable to get into the game, but that is quickly changing. There are currently space startups in South Africa, South America, Australia, Malaysia, India, New Zealand, and across Asia who are bringing new ideas and perspectives that will certainly be more aligned to the needs and hopes of the less developed regions of the world. We need to support and encourage these efforts.

Finally, there will be major and sometimes severe societal impacts coming out of all this, and we are little prepared for the changes that all this will bring. This will go far beyond the loss of jobs and moving of businesses due to new players in these different markets, as explored in the earlier chapters. It will go far beyond what we now can see in automation, AI, and robotics. Technology, in a much larger sense than NewSpace technologies and players, is going to reduce the total number of jobs in a massive way, and this will happen more quickly than most people think.

In fact, it is already happening. People will simply no longer be required to design, construct, and ship products around the world. Machines will become more and more capable of doing more and more tasks that have always required people. This will move quickly beyond robot welders doing repetitive tasks into advanced tasks such as banking, financial activities, and medical diagnostics. The free market economies of the world will actively seek out and reward the lower cost models that reduce payroll and other human costs. This will have massive societal impacts, and not for the better, at least in the near term. Many of these negative impacts will be in the developed world economies, and they will be felt more and more by those with advanced educations and upper level job training.

However, if there are no jobs, who will have the money to buy what automation creates? This is one of the biggest questions that society will face in the coming decades, and we really have no answers. Some ideas that have been floated include placing a significant tax on robotic and automation businesses, and putting this new revenue into social programs. And there are even proposals for a guaranteed minimum income in several Scandinavian countries, but this is not likely to happen in the United States in the foreseeable future. In addition, the vast amounts of personal and private data being collected, sifted, and sold will continue to grow and remains largely unregulated. Living in the new Total Surveillance Society may not be what most people on the planet want to see, but it is fast approaching. Whoever has the ability to collect and sell our information will be able to weaponize every click, call, and trip to the grocery; this must become an issue for our political leaders, for which
we must demand answers. They will not want to do this, but the overarching need for public understanding of these issues will require this.

Ultimately, it is clear that we are on the edge of a great revolution in space. In our next and final chapter, we will make some final conclusions, and make a few predictions for the future.
Chapter 10
Final Conclusions and Predictions for the Future

Prediction is very difficult, especially if it is about the future.
— Arthur C. Clarke

We are nearing the end of our journey. This book has tried to view disruptive innovation in the space sector as one in a continuing series of such innovative processes and activities that have occurred over a very long period of time. More will follow in space and in other areas of technology. Disruptive innovations and their impacts upon our world are subjects of much scholarship and analysis, and these studies have produced several very useful insights that are relevant to the current status and future of space. Space and commercial space businesses are clearly different from most traditional businesses, in that they are not mass-market goods like boxes of cereal, at least not yet. But the entire space domain is undergoing a radical period of change, driven by the new, entrepreneurial Silicon Valley explosion in NewSpace ideas, money, and energy.

And this change is driving entire new families of low cost launchers and satellite constellations, containing hundreds if not thousands of small satellites. Most of these constellations are for telecommunications and remote sensing, but other new uses may follow. These systems will change the architecture, the business plans, the financing, and much more about how we do these two primary space applications. It will impact who funds them, and how they are delivered to the people of our planet. It also has tremendous potential for benefiting the poorer people who share spaceship Earth with us, who are in desperate need of many basics that access to space can help to provide.

This is not to say that there will not remain a role for large and powerful GEO communications satellites to provide television broadcast services and perhaps mobile satellite services as well. Yet even for these large and powerful satellites, the NewSpace revolution will impact how these satellites are manufactured and tested, launched, operated, and financed. Fresh thinking will percolate throughout the aerospace industry around the world, and it will be a positive and transformative change [1].

There are tremendous potential benefits in store, but also major challenges, including international and national legal and policy issues that must be addressed in this vastly different world we are entering. These will be among the most difficult
problems to solve. Developing new technology is relatively easy; it is international relations that are really hard.

Although there are many exciting ideas about the potential use of space for things such as resource extraction for rare materials or generating electrical power using solar power satellites, the most important societal and commercial benefits of space today are Earth-orbiting satellites and the many useful services that these can provide. Satellite telecommunications; positioning, navigation and timing (PNT); and remote sensing provide vast commercial opportunities and markets, as well as important societal benefits and potential for the developing world.

The Vision

What is driving this process is a new generation of space entrepreneurs who see space as simply the next frontier for their version of youthful private enterprise and creative disruption. Youthful exuberance and drive have combined with billions of dollars in private funding and a generation that has grown up with the expectation that they, too, might be able to go into space. It has become an explosive and unstoppable force.

Robert Goddard (1892-1945), the American rocket pioneer and developer of liquid-fueled rockets, stated in his high school graduation oration: “It is difficult to say what is impossible, for the dream of yesterday is the hope of today, and the reality of tomorrow.”

This clearly is true in our context of disruptive innovation and space, and the cycle of innovation and technological development has shown us that, both in the three older examples presented in Chapter 2, and our for our new space pioneers, more today is possible that we ever dreamed of only a decade ago. But the dream must always come first, and once the dream is hatched, it is only a matter of time, technology, and money before it can come to pass.

So we have a set of driven individuals, entrepreneurs, and also visionaries, who see a different future, and then who have the drive, experience, and access to large amounts of money who can make amazing things happen. What really sets these people apart from the rest of us is vision, the ability to see the world differently, and to then have the courage and resources to enable that vision and create a bold new reality.

“If I’d asked people what they wanted, they’d have said, ‘Faster horses,’” is a famous quote attributed to Henry Ford. Just giving people what they want is not what disruptive innovators do; they give people things that never existed before, and then make people wonder how they ever lived without it. Jean Case, the chairman of the National Geographic Society, in her book, *Be Fearless: 5 Principles for a Life of Breakthroughs and Purpose* [2], called this the ability to peek around corners, the ability to see things that others cannot see, and then to share this vision and make it a reality. This is a powerful ability, and it is rare to find. It also does not happen
equally in space or in time. For better or worse, the United States of America is the current nexus of entrepreneurial ability and action.

Of course, sometimes these visionaries get it wrong, sometimes in a really big way. One of the most fascinating things to take away from this study is how often really smart people get things completely wrong. Over and over again we see intelligent, skilled, and experienced leaders in their fields bet on the wrong side of technology, or totally misunderstand what aspect of a new idea will be important. Malcom McLean drove his company into bankruptcy when he guessed that oil prices would stay low, Jobs did not want the iPhone to begin with, and later refused to allow external apps, and on and on. Prediction is hard, especially about the future, and hindsight is so very clear. But it is surprising how many times people have just bet on the wrong horse at pivotal times. This process is accentuated when disruptive innovations are rapidly introduced, when the status quo is quickly disrupted, and the usual metrics are no longer valid.

Ultimately, it is the end users and consumers who discover what is really valuable about new technologies, and not the people who invent or create them. Steve Jobs was completely opposed to allowing external apps on the iPhone, but the market, and developers, demanded this, and they eventually prevailed; it was this that made the difference. The killer app was not a smartphone, or even the new, touch screen interface, but the fact that you could choose from among literally millions and millions of apps, and this became the difference that made the difference, and put billions into the bottom line at Apple as well. This fact, of what the end users would find interesting or not, cannot always be predicted.

There are now rumblings in the international financial markets, asking if we have reached ‘peak iPhone,’ and if the massive growth in smartphones may be coming to an end. Eventually, everyone who can afford these expensive toys will have one, and then the situation will begin to change and possibly change quite radically. Will even the mighty iPhone, icon of a generation, someday fall victim to the disruptive innovation curve? Will Apple get fat and happy and not see the next wave approaching? Will Apple’s current management be smart enough, as was Steve Jobs, to find the next revolutionary product and have the courage to kill its own golden goose? Or will it be some 15-year old kid in San Jose, or perhaps in Shanghai or Cape Town? Will Elon Musk see the next, radical threat to his reusable rockets? What will replace chemical rockets that nobody will see coming? Will Silicon Valley finally become too expensive and too set in its ways, and be passed by before it can see it coming? It may happen. Someday, all this too shall pass.

It is so much easier to look back and ask why others did not see so clearly the next wave approaching, but it is rather harder to predict, as we have learned, especially about the future. Think about the enormous responsibility, if you were a member of the Board of Apple, to make decisions that will impact billions in profits and the life of the company? Courage and foresight are rather simple sitting in your chair and reading this book, but considering the difficulty of asking where the current smartphone paradigm will go and how it might end is a fun and useful exercise.
The only certainty is that one day the iPhone and its clones will look like an ancient technology, as we look at the early ‘brick’ cell phones that they made look so pitiful. The trick is to find ways to understand and foresee when and how it will happen. And the same goes for our generation of space disrupters. One day SpaceX will also become old and out of phase with the changing times. All things in their time. It is so much more difficult to see it coming than to watch it after it hits you. Can we learn to do this? It should be possible; by studying the past history of disruptive innovations we can see the patterns.

As stated at the very beginning of this book, many words ago, it is fascinating that a single person or small group of people, or a single idea or technological development, could have such tremendous impact on markets, societies, and individuals. How does this occur, and how many times it has happened, and what motivates and inhibits this amazing process of radical technological disruptive innovation? Why does it occur in one place and time and not another? Can it be fostered and managed, or does it simply ‘happen’ unannounced and, like the wind, disappear in its own time? Can it be harvested and focused?

One important aspect is the ephemeral and fragile nature of these activities. Organizations led by charismatic leaders such as Jobs, Musk, and the others often fail quickly once that leader is no longer at the helm. Space X had several early launch failures that nearly destroyed the company. If Bezos’ or Branson’s first commercial tourist launch crashes with fatal results for the paying customers, the entire company could fail after years and millions of dollars invested. Paul Allen sadly passed away in 2018, leaving his many space activities in an uncertain status.

We all know that space is hard, and privately funded space programs can quickly be derailed by a single failure or the loss of their charismatic leader. This is fundamentally different from Henry Ford’s Model T or McLean’s containers. A fatal car accident or even the loss of a massive container ship at sea does not bring the intense publicity and media scrutiny of a failed rocket launch, let alone a failed landing on Mars with hundreds of Mars colonists. Space is hard, but space is also very visible, and space failures are very difficult to hide from the public, or from potential or existing investors, insurers, or government regulators.

How the future will see this amazing generation of space visionaries is beyond our view today, but they will eventually be placed into a larger historical context. Some will be honored, some will be forgotten. This may be the bright beginning of a new and vital future, or perhaps it may be a blip that will have little significant impact; we simply cannot know. But hopefully we are at a turning point, and we will soon see a far more accessible and useful relationship with space.

There has to be a spark, something to turn dreams into reality, to turn cash into hardware. One of the major factors of what we today call NewSpace was the promise of space that was presented in the mid-1950s and 1960s by promoters and advocates such as Werner von Braun, through his TV appearances and many magazine articles, and the reality of the post-Apollo space world. Those who grew up in this time, including this author, remember the amazing promise of space as it was presented to us.
Von Braun, through Walt Disney and his very popular Sunday evening television show called Disneyland, made a brilliant case for what was in store. With fantastic graphics and animations, we were shown what was soon to come: astronauts floating in space, huge, round, rotating space stations orbiting Earth, manned bases on the Moon, and more. Disney animator Ward Kimball produced and directed several of these episodes. These also included von Braun describing missions to the Moon and even live action segments of actor/astronauts in spacesuits in space vehicles. Von Braun was a captivating speaker and had an amazing story to tell, and these shows, along with many articles in major magazines, made this all seem possible and very real. Watch for yourself [3]. It contains an early simulation of the Apollo 8 mission to the Moon that was not too far off (Fig. 10.1).

Millions of American families watched in wonder, and these shows were a tremendous hit. They fired the public imagination. When von Braun then went on, only a decade later, to create the mighty Saturn V and NASA actually sent people to the Moon, along with the live and color TV images beamed back to us, it was as if the future had arrived, and it was exciting beyond words. Those who remember those times, including our NewSpace pioneers such as Branson, Allen, this author, and all the others, were ready to go. And it could have been very different after Apollo. Von Braun and his team had created an extraordinary roadmap of space exploration that is now, sadly, nearly forgotten. He envisioned an even larger rocket than the mighty Saturn 5, called the Nova, made plans for new launch complexes just north of the Apollo pads, and put together plans for permanently occupied Earth orbiting space stations, a permanent presence on the Moon, and much more.

In 1969, just after the successful landing of Apollo 11 on the Moon, NASA stood at a crossroads. We had ‘won’ the space race with the Russians, and the question now on the table was, “Now what?” Richard Nixon was president, and he hated John Kennedy and everything he stood for, and the space program was very much seen as Kennedy’s program. Nixon had no interest in space, and no interest in
funding this vision when there were other pressing political and economic priorities on Earth.

Von Braun and the NASA Marshall Space Flight Center he led submitted a detailed 20-year plan for the post-Apollo era, and it was striking in its vision and audacious in its scope. In 1969, in the glow of the successful Moon landing, the newly re-formed NASA Space Task Group met, with Vice President Spiro Agnew presiding.

The Marshall Space Flight Center’s plan included a fully reusable space shuttle launch vehicle, to be ready by 1975. This would carry up the building blocks of a permanently occupied Earth space station very soon after, and that would provide a permanently occupied orbital post, as well as the way station for returning to the Moon and beyond. The plan included continued production of the Saturn V along with a powerful new, nuclear upper stage called NERVA.

Together, the shuttle, orbiting station, and powerful rockets would lay the foundation for a manned Mars spacecraft that would include a Mars Mission Transit Vehicle and a Mars landing vehicle, called the Mars Excursion Module. This new Mars set of vehicles would first be tested in low Earth orbit, starting as early as 1978, to be followed by the first manned Mars launch in 1981 and first landing on Mars in 1982 [4]. Yes, a Mars landing by NASA astronauts in 1982.

The von Braun Mars plan would use two identical Mars vehicles making the trip together. These would require a total of 6 Saturn V launches and would be assembled in LEO at the orbiting space station. This dual-vehicle design would provide for needed redundancy for such a long and dangerous mission. Each vehicle would have a crew of six, with sufficient expendables for 12, or both crews, if either vehicle failed at any point in the mission profile. (See Fig 10.2.)

The trip out would take 270 days, and there would be up to 80 days on the surface of Mars and then a 290-day return trip, for a total mission of some 640 days.

![Fig. 10.2 The dual 1969 von Braun Mars expedition vehicles, with habitation module in center, Mars lander, and robotic probes at right. (Image courtesy of NASA.)](image-url)
Both Mars landers would have a launch mass of over 40 tons and would support a crew of three astronauts for up to two months on the surface. Three astronauts would remain in Mars orbit on each of the two orbiting vehicles, launching a series of 12 sample-return probes down to the surface, observing the planet and Martian moons, communicating with the Mars base, and maintaining the vehicles for the long trip home.

Both landers, looking like much larger Apollo command modules, would land very near each other, creating a single Mars base. Either of the two Earth return vehicles could carry back all 6 astronauts if needed. They would conduct experiments and explore on the surface, rendezvous with the Mars orbiting vehicles, and then make the long trip back home. And as if this was not exciting enough, each mission would also include an orbital flyby of Venus, taking advantage of the orbital conjunction of the planets and making scientific measurements from their vehicles as well as launching several Venus landers that would be sent down to the surface of that mysterious planet. The astronauts would finally return to the Earth orbiting space station where they began almost two years before, rather than making an Apollo-style water landing. There they would unload their samples and cargo, undergo quarantine, and then make the final trip back home on the space shuttle.

Even this was not the end of von Braun’s audacious plan. All components of the program, except for the Mars landers and planetary probes, were to be fully reusable, and a successful initial mission would lead to a series of repeat missions that would be flown during each of the following three Mars launch windows: in 1983, 1986, and 1989. These would, together, lead to a permanent Mars base by 1989, with a staff of some 50 persons, living and working on the surface of Mars. The total cost of this bold plan, the new space shuttle, the orbiting space station, and the creation of a permanent, manned Mars base in twenty years and have four manned flybys of Venus, was estimated by the NASA Marshall team to cost US$7 billion per year for the twenty years of the plan, essentially the cost of the Apollo program. It was an astounding plan, and yet highly detailed. In fact, the first Mars mission launch date was set for November 12, 1981, with a return to Earth on August 14, 1983.

The plan was approved, as presented by the committee, in its entirety. But there was absolutely no interest in this by Nixon and his political appointees at NASA headquarters and in the Congress. The plan went nowhere, and sadly, von Braun was sidelined by President Richard Nixon and his NASA administrator, Thomas Paine, who ‘promoted’ him to a do-nothing job at headquarters in Washington as the NASA deputy associate administrator for planning. This was done only seven months after he presented his plan, forcing him out of his beloved Marshall Center where he had worked since he was a young German scientist arriving at the end of World War II. He was quoted as saying: “We can lick gravity, but sometimes the paperwork is overwhelming.”

The only aspect of the plan to survive was the space shuttle, which was designed to be a space truck and assist in the launching of all the pieces of this grand plan and to shuttle, between the orbital station and Earth. The shuttle was approved, a truck with nowhere to go and much less to build, although it did build most of the
ISS. Even worse, the cost-cutting, compromise shuttle design approved by Nixon that was finally built was so flawed that two crews died before it was shelved. Seven people were lost on the *Challenger* in 1986 and seven more onboard *Columbia* in 2003.

Von Braun resigned from NASA just two years after being banished to headquarters, knowing that his grand vision was never to be realized. He died of cancer in 1977, five years after he retired, and some four years before the space shuttle’s first flight. When he died, it had been three years since an American had flown into space, and the U. S. space program had largely vanished. His vast plan for space exploration was simply put on the shelf and forgotten. He was a bitter man towards NASA at the end, as his grand vision was never understood or appreciated by Nixon and his followers.

Vision takes you only so far, when you are a government employee and the only customer for your dreams is the government. At his retirement from NASA in 1970, his salary was US$36,000 per year. Later, his federal pension paid him about US$1,400 per month. He became a Vice President at Fairchild Industries, working on educational telecommunications satellites, but his health failed soon after. He was quoted at the time in the *New York Times* as saying, “I would like to devote any time now to help implement some space projects I feel are of particular importance,” he said. “I think I can do this best in private industry where the tools of progress are being made.” He had given up on the government and NASA to achieve any real space achievements. His grave marker in Alexandria, Virginia, says the following:

WERNHER VON BRAUN
1912 – 1977

PSALMS 19:1

Psalms 19:1 reads: “The firmament showeth his handiwork.” So Werner von Braun and his NASA team could have developed, launched, and operated a fully occupied Mars base, Moon base, orbital space station, orbital space shuttle, and more, *over thirty years ago*, if we had only had the vision and courage and political will to make these dreams into reality. And it was not only von Braun and his NASA team who were disappointed and disillusioned. Many others were also deeply disappointed that, with this powerful future within our grasp, it was simply put on a shelf and forgotten. We won the space race, let’s move on. Perhaps the mistake was in making it all simply a race to be won, and not a more long-lasting and more permanent set of goals.

However, all this was not completely forgotten, not by the generation of children who were captivated by his vision, and when NASA failed to fulfill it, it was a new generation of individuals, entrepreneurs such as Elon Musk, Jeff Berzos, Richard Branson, Peter Diamandis and others, who stepped up with their own vision, money, and talent, and who decided “If not now, when? And if not me, who? Let’s go.”

It can be said that the lost promise of the post-Apollo NASA space program laid the very seeds for the current generation of private space pioneers today. Those of us who grew up watching Disney and von Braun, and who saw the amazing
achievements of Apollo on our home TVs, were astounded and deeply disappointed that we simply gave it up and moved on to something else.

NASA had no ability to launch astronauts into space for a total of six years between the last flight of Apollo in 1975 and the much-reduced and flawed space shuttle in 1981. As if that was not bad enough, we are once again in exactly the same situation, with no ability to launch American astronauts into space on American launchers since the shuttle was retired in 2011, now a full eight years ago, a longer gap than the first. Such a lack of vision on the part of the American politicians was deeply disappointing to these ‘children of Apollo’ who grew up with the promise of an unlimited vision of space and our role in it. Certainly this was one of the key factors in the current private space entrepreneur generation: “If you can’t do it, get out of my way, and I will.” And they are.

What about the larger societal effects and consequences of disruptive innovation? Does anyone care who gets disrupted, as long as you make your millions and get out in time? And who gets to decide what happens to those who are negatively impacted? Should societies and their representatives in government require taxes or some means of providing for those who are impacted?

And how do we create a society that is capable of adjusting to this new, rapid cycle of technological change? Thomas L. Friedman, the Pulitzer prize-winning author, in his recent book *Thank You for Being Late: An Optimist’s Guide to Thriving in the Age of Acceleration*, has looked at this issue in detail [5]. Friedman describes what he calls a ‘supernova’ of three, interconnected, and ever-faster accelerating global processes: technology, the commercial market, and global climate change. Interestingly, he also presents Hadoop as a key tech innovation. But he makes the very powerful points that our current education, patent law, and governance structures are simply incapable of managing the speed of events today, and that it will only become more of a problem. But, in the end, he is quite positive about the future and our ability to rise above the problems we face due to our natural human capacity to adapt. Let’s hope he is right.

Ultimately, the question is not only how these innovators can create new futures, but also, and equally, how can these negative impacts on so many people be mitigated. Disruptive innovation may be an overall societal good, or perhaps it may not be, but will be impossible to mitigate the effects? Millions of people with good paying jobs today will have a much less secure future due to automation and the robotization of the work force. What is the role of government in mitigating these effects? At some point, the invisible hand of the ‘market’ will no longer be able to balance the economy, and its incessant drive for low cost of production. Who decides these questions in our ever-accelerating technology spin is only recently being seriously considered, and there are few guides in the past, given our current situation.

One researcher, Dartmouth College professor of computer science Prof. Hany Farid, has said that “Google and other tech giants need to get more serious about how weaponized this technology can be…. We have to understand the harm and slow down on how we deploy technology like this.” [6]

Silicon Valley is famous for not asking permission and for being willing to break the rules. It is part of what makes it vital and dynamic, but the power of these new
capabilities must be taken into account when deciding how we let these loose on the world. We must come to grips with the moral and ethical impacts of these powerful new tools, and this is a concept that is barely ever considered or even discussed. We also need to view our new space technologies with the same critical eye.

Another key issue is when and where these types of disruptive innovation can occur. Silicon Valley is a unique and amazing place, mentality, and mindset. But don’t forget that Sir Richard Branson did all his innovative and disruptive ventures from London, and Peter Diamandis started out in Boston and only later migrated to California, as did Branson, who is still based in London. But when it came time to build and launch, he and Elon Musk at the others set up shop in California.

Many places around the world are trying to replicate Silicon Valley, but these are likely to have limited success. There is so much momentum and such a coalescence of resources there that it is a tremendous magnet for people with ideas, and people with money who want to back the next big idea. The amount of tech talent, intellectual property lawyers, and big money, along with its track record of success, make it a powerful magnet for those who can afford to work there. And it is also one beautiful and very pleasant place to spend your time. Sitting in an outdoor café on Castro Street in Mountain View is a mighty fine place to think big.

However, there are large barriers to entry for this South Bay version of heaven. First of all, you have to be able to get there, and millions of the people with really good ideas around our planet cannot even get a visa to live in the United States. And secondly, you have to be able to afford it, and Silicon Valley is one of the most expensive places to live in the world. Nothing there comes cheap, not housing, or advice, or legal assistance. Success and demand have driven the cost of living and working there, quite literally, through the roof, and stories of young techies renting a walk-in closet for US$1,000 per month are in the papers every now and then.

So how can innovation work in a given time and place and not another? As discussed earlier, it is useful to think of this as an ecosystem problem, with multiple, interlocking, and interdependent components. Think of it as an innovation ecosystem. To borrow the analogy from ecology, innovation centers such as Silicon Valley are complex systems that require multiple sources of input, energy, resources, and internal regulation. All ecosystems take time to develop and to acquire a balance. It cannot be planted and just add water. Silicon Valley has all the parts, and has the years of success that build upon success.

And how can these powerful forces of innovation and development be harnessed for the benefit of the millions on the planet who have so very little? Is that even possible? Will this only happen if someone can make enough profit on the venture? Space technologies can provide so many benefits for the least among us, and it is the hope that the NewSpace moguls will make an effort to do this, or even better, will help African and other entrepreneurs to make this happen themselves.

We have looked at a wide range of phenomenon. People, small groups, large corporations, cultures, and nations all have both created and been affected by these innovations. We have looked at several examples of traditional and space-related disruptive innovation, and how these have been studied and measured. But the world of humans and our societies, laws, and cultures are far more complex than a simple
curve, and there are many more than one cycle at work at any single a time. Christiensen’s S curve is a useful idea, but it is very simplistic and does not really reflect the complex reality of disruptive innovation in the context of its time.

There is one innovation or new thought that we can add to this approach to disruptive innovation. It is a concept, which is derived not from economic or marketing theory but from the French Annales school of historical analysis. The Annals school was founded in France in the 1920’s, and it had a second and larger burst of energy largely advanced by Francois Braudel and his colleagues in France in the 1980’s [7]. The Annales school approach deals with the long-term trends and cycles in history, focusing more on complex and intertwined patterns rather than simply on the lives and actions of powerful princes and kings. The professors were interested in how societies both are shaped by, and at the same time actively shape their world, in various cycles within cycles of political, social, and cultural contexts.

Three general observable patterns or general concepts were advanced in this context of both social and economic and political change. Key among these are what were called the concepts of the longue durée, or long term trends and cycles, the conjuncture, or the conjunction of particular conditions at a particular moment in time, and the évènement, or keystone events, which, together, play important roles in how the history of human societies and their technologies unfold [8]. In other words, the Annales school looks at cyclical patterns of enduring and persistent socio-economic aspects of our world.

This set of ideas, which has not really been considered in the economic literature relating to S curves and disruptive innovation, has relevance to our topic, and it brings an additional and important aspect of complexity to the discussion. There are certainly detractors of this approach, who point out that the longue durée approach highlights and over-emphasizes various aspects of socio-economic events that clearly leave a major mark, while not sufficiently considering more transient elements that may, indeed, have played major roles. Nonetheless, the concept of many interlocking cycles of cycles, emphasis on the unique conjunction of multiple factors that come together in a unique combination, and the idea of keystone events, all bring a complexity that much more closely replicates the process of change in human societies and the role that disruptive innovation plays in this process.

So instead of a single, rational series of neat and equal S curves, as shown in Chapter 1 (which serves a useful purpose), we now have a more complex pattern of multiple, intertwined cycles of different temporal contexts, causes, and effects. Social, political, economic, and technological cycles both intersect and overlap, and these both enable and inhibit the successful adoption of new technologies. Every historical context is unique, and every situation brings with it a new combination of cyclical patterns and unique events.

An example of a much more detailed, and perhaps more realistic, type of complexity is often represented in the scientific literature, especially in the environmental sciences. The chart below shows the approximate chronology of what are referred to as Heinrich’s events, or the generation of large numbers of icebergs due to climate alterations in the distant past. (See Fig 10.3.)
The complexity of this graph takes into account the many different cycles and events that make up complex typical natural cycles and patterns. This approach is worth considering in the context of disruptive innovation and modern economic, societal, and political events.

A second concept that could be very useful in the next stage of analysis of disruptive innovation would be to add an inherently interdisciplinary, even a transdisciplinary, perspective regarding the causes, inhibiting factors, and resulting impacts of these major innovations. Traditionally, the analyses have been viewed within a single academic perspective, largely in the business and economic school view. They also lie within the subtle and difficult to perceive boundaries of a single, western, or more specific U. S. cultural viewpoint.

One of the more interesting innovations in the academic communities in the early 21st century has been a move towards pursuing a much more inclusive and interdisciplinary framework for complex social science and physical science studies. No single academic perspective or set of concepts can adequately model or encapsulate the complexity of phenomena that involve all of the varied factors that go into something as multifaceted as disruptive technological innovation. We must consider things as different as economic markets, market trends, international and domestic political and trade policies, cultural aspects of individual psychology, group dynamics, social anthropology and cultural perceptions, and much more, in order to actually develop a workable theory of disruptive innovation. Much more than economic theory and S curves will be needed.

This is one of the reasons that attempts to relocate Silicon Valley ecosystems in Australia or Kenya or South Africa are likely doomed to limited success or outright failure. Economic theories must take into account that it is people, people living within a given culture and political reality at a given time, who make big things happen. We must include the complex cultural differences as well as similarities within each culture at each specific time in history in order to come to a fuller understanding.
of how innovations are created, succeed, or fail, and the multifaceted impacts that they have on societies and, ultimately, human lives. Interdisciplinary studies seek to combine the several different academic traditions, languages, and approaches to study a complex phenomenon, but what is really needed is a truly transdisciplinary approach, where individuals from different cultures and academic perspectives seek to transcend these differences and find a way to work together that both brings the best from each, while questioning and synthesizing them into a more complete whole that can actually comprehend such a complex phenomenon.

There are many current examples where scholars are crossing these boundaries to look at the complex intertwining of the social, physical, and natural sciences. One such transdisciplinary approach, far removed from space and high tech, is the emerging domain of historical ecology, which seeks to combine the socio-cultural, natural science, and physical science aspects of cultural historical analysis over time [10]. Historical ecology is also deeply connected with the Annales School.

This approach of considering multiple, overlapping patterns and cycles of not only economic but also cultural, social, economic, regulatory, and other factors may help to explain why some innovations had to be repeatedly introduced, like the shipping container example that we presented previously [11]. This is a pattern that we will see many times. It seems that good ideas are often repeatedly introduced, only to finally find the right confluence of factors. While the Annales School traditionally focuses on very long-term historical cycles, historical ecology looks at the complex interplay between social and natural sciences to understand the complexity of historical activities. These may very well be useful in looking at the causes and effects of disruptive innovations. With the developments in computing, machine learning, big data, and more, this will perhaps soon be within our grasp.

Where We Stand Today

We have made significant progress in becoming a spacefaring species. From the pioneering concepts of Konstantin Tsiolkovsky, Herman Oberth, Werner von Braun, Sergei Korolev, Robert Goddard and others, we laid the foundation for the beginning of the space age. Since the old Soviet Union launched the very first ‘artificial’ satellite named Sputnik 1, or “Traveler,” in October of 1957, some 40 nations have had built or launched or operated satellites in space.

Today, about 2,000 working satellites are in various orbits around Earth, providing a wide variety of practical, commercial, and scientific benefits. There is also much, much more space junk and debris that litter the orbits around our planet, and this is a very serious problem that we must address. We are on the edge of launching perhaps some 20,000 new satellites into orbit, if the new constellations proposed are all actually built and launched. This is an order of magnitude more working satellites that will need to be monitored and properly deorbited. Some nine nations now have the ability to launch their own satellites, and this list is growing quickly. There are over 90 different space launch vehicles in operation today, if we count all of the
different models and versions, and over 50 new ones are in development, many to serve the new, small satellite market. Most of these will not survive the technical and economic realities, and ultimately we will be left with a much smaller set of proven and capable systems for reaching Earth orbit and beyond.

As far as humans in space, only three nations, the United States, the old Soviet Union (and now Russia), and China have launched people into space, but humans from many more nations have traveled beyond our atmosphere since Yuri Gagarin first flew in 1961. As of 2018, just over 560 people from 32 nations have traveled into space, with the vast majority being professional astronauts coming from the United States and Russia. The United States has sent over 360 people so far, largely due to the carrying capacity of the space shuttle, bringing up to seven astronauts at a time. Only two people have made seven trips into space each, and we have spent something over a total of 135 person-years in space in total.

The largest number of humans ever to be in space at the same time was in July of 2009, when thirteen people from five countries were at the joined Russian Mir Space Station and U. S. space shuttle. Six people are on the ISS as this is written. Only 24 people have ventured out of low Earth orbit, in the Apollo Moon missions from 1968 to 1972. Twelve men walked on the Moon, and three made the voyage to the Moon twice. The longest single space flight was by the Russian Valeri Polyakov, of some 438 consecutive days. As of 2019, the man with the longest total time in space is the Russian cosmonaut Gennadi Padalka, who has spent a total of 878 total days in orbit, done on several different long-duration missions. The International Space Station, a tremendous success in international space cooperation, has now been continuously occupied for over a decade, but at a tremendous cost of about US$150 billion dollars to launch and operate on the part of the United States, plus additional billions of dollars of investment by international partners. And it has merely circled Earth some 400 km (250 miles) above the surface of Earth, not really a very long way from home.

The farthest any humans have ever been from Earth was the ill-fated crew of Apollo 13, who looped around the back side of the Moon at a distance of some 401,056 km from Earth, before their safe return, and that distance was an accident. Yes, the farthest any of us have been from home was an accident. In some ways we have come so far, but in others we have not gone that far at all from home. NewSpace is making great strides in this direction, with the emphasis on getting thousands of people into space, as one-time tourists or permanent emigrants to Mars.

Our robotic satellites have gone much farther that we have, exploring our Moon, the planets of our Solar System, and beyond. Our robotic rovers and orbiters are working on and above Mars as you read this, and in some ways we have imaged Mars better that we have our own Earth. We currently have two rovers, and one new stationary lander, on the surface, and six orbiters that have made it successfully to Mars. But going this distance has been very difficult. Since the first attempt in 1960, roughly two-thirds of all of the Mars missions launched have failed, either on launch, on the way, or on landing. Space is still hard, and the farther we go the harder it becomes.
Our recent NASA *New Horizon* mission to Pluto, now demoted to dwarf status, was a part of NASA’s New Frontiers program. It sailed beyond Pluto, over 6.4 billion km (4 billion miles), to take the first close-up images of a body named Ultima Thule beyond the edges of our known Solar System in the Kuiper Belt. Ultima Thule was the term used by the ancient Romans for places “beyond the known world.” Great name. The farther we go, the more difficult it is, but we keep trying and we keep getting better at it. We have sent at least one robotic spacecraft to the each of the other planets in our Solar System, and we have sent a handful of probes beyond our own, out-of-the-way little corner of the Milky Way.

The *Voyager 1* probe is our most distant human-built emissary, and the farthest and fastest manmade object ever launched from Earth. It left in September of 1977 and is traveling at a speed of some 17 km/s (38,610 mph). It has passed out of the Solar System and is now in interstellar space, at a distance from Earth of 137.9 AU, and it is beyond the edge of the Solar System (about 18.8 billion km away). It takes about 38.16 hours for a message to reach it from Earth at the speed of light.

The probe is still recording and capturing some data, but its nuclear power source will continue to decay, and it will lose the ability to communicate sometime between 2027 and 2030. It should reach the inner edge of the distant Oort Cloud in about 300 years, and take some 30,000 years to transit this vast and little known area. In about 40,000 years it will come within about 1.5 light years of the star Gliese 445, and then continue forever into the vastness of space. Silently moving away from Earth, along with its twin *Voyager 2*, who has just recently broken free of the Solar System and the Sun’s influence, it has begun its own journey into a different corner of the vastness of interstellar space. We are moving out and exploring our neighborhood.

So we have come a long way, and we are moving at an even faster pace, thanks largely to the new paradigm and new innovations of a group of visionaries and disruptors. We cannot ignore the fact that NASA and other established agencies continue to play a very important role in all of this, and have funded much of the research and development that supports enabling technologies that make NewSpace possible. There is now, and will be for the foreseeable future, a major role for NASA and other governmental space agencies. NASA’s science and applications activities continue to push the envelope of our understanding of space, and will do so in the future. We will see how our traditional space agencies and NewSpace newcomers find a new equilibrium moving forward, but government-funded and directed space science has an important role to play in the future.

And there will also most certainly be a winnowing of all the NewSpace entrants in the near future. So many have jumped into the launch, satellite construction, and constellation operation markets that there is going to be an inevitable natural selection process. The market can only support so many dedicated smallsat launchers, and with SpaceX, India, and the traditional GEO launchers also offering piggyback services, we will see how many of the new entrants will survive. Surely, several will not. Remember that we went through a period of new LEO telecom service entrants before, and all failed and cost their investors dearly. But this is the natural process, and those who survive will go on to fill needed new markets, and those who do not
will send their talent and ideas on to other, newer ventures that have not yet been launched. Space is hard, and there will most certainly be numerous failures in the new round of startups, and that is not, in and of itself, a bad thing.

We have quoted the prescient Arthur C. Clarke at the start of each chapter of this book, and his vision and perception are stunning. Joseph Pelton has written a wonderful book about his predictions, and they are many and have proven to be incredibly accurate [12]. But the most important of Clarke’s quotes was perhaps this: “Only if what I tell you appears absolutely unbelievable, have we any chance of visualizing the future as it will really happen.”

If we take this as our starting point we can begin to understand what our future, and the future of space, will look like. The future of space will be much more ‘out there’ than we have begun to consider here, and the only certainty is that whatever guesses we make would likely be wrong, and much less amazing than what will come to pass. One thing is for sure, though. Our future will be in space, and, barring a catastrophe such as a massive asteroid or comet impact or nuclear war, our species will become a spacefaring and multi-planetary one. Of this, you should have no doubt.

Margaret Mead (1901-1978), the American anthropologist, once wrote that: “Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has.”

This seems particularly appropriate in the context of the future of space and disruptive space technologies. Although it is true that it took nearly half a million

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**Fig. 10.4** A Falcon 9 launch from Vandenberg as viewed from the SpaceX facility in Hawthorne, California. (Image courtesy of SpaceX.)
people to work on the Apollo Moon program, as well as billions of dollars, it never would have happened without the extraordinary vision, ambition, and drive of a few key individuals. Throughout the story of humans reaching for space, there have been extraordinary individuals who, against all odds, created the future. Von Braun, Kennedy, and others made the marshaling of hundreds of thousands of people possible through their individual efforts.

Each of the examples presented in this book, both in the space arena and others, were driven by an individual with a vision. A vision of the future, and the drive and determination to turn that vision into reality. While many people work at SpaceX in Hawthorne, California, and the other sites, it is the vision of Elon Musk that brought them there and that rides each vehicle into space. Just as it was for Werner von Braun and the others, it is the only thing that ever has. Ultimately, in the history of human innovation and creation, it is individuals and small groups that actually conceive of and create new ideas and turn them into new realities (Fig. 10.4).

Johann Wolfgang von Goethe (1749-1832), the famous German philosopher, wrote: “The moment one definitely commits oneself, then Providence moves too. Whatever you think you can do, or believe you can do, begin it. Action has magic, power and grace.”

This second lesson adds to the first. Action has power, and having all the ideas in the world means nothing if you cannot put that concept into action. All of the innovators presented in this book, from Henry Ford and Malcom McLean to Elon Musk and the other children of Apollo, have exhibited the power of action. They did not wait for others, they did not ask permission, and they did not fear the consequences of the decisions they made. Begin it, do it now.

Napoleon was supposed to have said “L’audace, l’audace, toujours L’audace.” Boldness, boldness, always boldness. Or it could be translated as daring, or audacity, but the meaning is clear. You must be bold and be willing to take chances if you dare to do great things. All of the people we have discussed in the proceeding pages shared this vital trait. Boldness, and a willingness to ‘push the envelope,’ to put it in space-speak, is a key ingredient in this story. Begin it.

Finally, Nelson Mandela said: “The greatest glory in living lies not in never falling, but in rising every time we fall.”

Each of the people we have looked at in this book has also had major failures and setbacks. Henry Ford’s first auto venture was a failure, Malcom McLean bankrupted his company by betting on the low price of oil. Richard Branson had a terrible failure with his Virgin Cola, which was meant to take on Coke and Pepsi. Steve Jobs was fired from Apple and his NeXT computer was a failure, etc.

SpaceX blew up their first three Falcon 1 launchers in a row, in 2006, 2007, and 2008, but Elon Musk launched a fourth; he had learned from his mistakes and pressed on. It was the same with getting his first stages back. They failed numerous times, and there was even a very funny video of all the failures that was posted on the Internet, but, in the Silicon Valley model, failure is expected. Failure is valuable. You learn each time you fail, and you figure it out. Each of these innovators and visionaries had their failures and setbacks, but they all got back up and learned from their failures and tried again until they succeeded. They all had the courage to take
big chances and to roll the dice, knowing full well that they might fail. Courage is a large part of action. Getting back up after you fail is another. Each of these people failed many times, but they got back up. How many brilliant entrepreneurs and their amazing ideas never made it to market because they simply gave up after their first few failures? The line between genius and madness, between persistence and obsession, is a fuzzy one, and clearly there is a time to give up and try something else. But having the courage to try again and again is an aspect of what makes a successful disruptive innovation concept into a new reality. The ability to learn from your mistakes and adapt with your next venture is also a common feature we see. This is an inherent part of the Silicon Valley model. Fail early and often, but learn each time. Ultimately, it is the courage to get up and try again that leads to success. Get back up and try again, but learn from your mistakes first.

**Final Conclusions**

Humans have an extraordinary ability to create new tools; perhaps Homo habilis (Handy man) would perhaps have been a better name for our species than the Hominid species that lived some 2.1 to 1.5 million years ago in Africa and who ranged out into the rest of Eurasia. (See Fig 10.5.)

Homo habilis were some of the very first stone tool makers, and their stone tools were a major step, long ago in our distant past, in making the transition from living in their world to shaping their world. We are still tool makers and tool users, and we

**Fig. 10.5** (Left) An Oldowan stone tool, from over 1.5 million years ago, made by Homo habilis. (Image courtesy of José-Manuel Benito Álvarez. Used with permission.) (Right) The SpaceX Dragon 2 human spaceflight capsule, which flew in 2019. (Image courtesy of SpaceX.)
have learned to build amazing machines to get to and do useful things in space. But we are much better at creating tools and things and data than we are at understanding what it all means and addressing the consequences of our actions. Once again, Arthur C. Clarke said it best: “The Information Age offers much to mankind, and I would like to think that we will rise to the challenges it presents. But it is vital to remember that information – in the sense of raw data – is not knowledge, that knowledge is not wisdom, and that wisdom is not foresight. But information is the first essential step to all of these.”

We are terribly lacking in the wisdom part of this. We are excellent at creating, launching, and operating sensors in space, and in generating petabytes of data to send down to the ground to analyze with our powerful computers. Our space remote sensing satellites now routinely map our world on a daily basis. Indeed, we are now flooded with digital data. We are also very good at processing the data using computers. As discussed earlier, new sensors and new techniques such as AI and machine learning are also revolutionizing the ways that we extract useful information from all of this raw data. What we are still very poor at is becoming wiser or making better decisions based upon all of this. We can call this the “From Data to Information to Knowledge” paradox. We are really good at building the tools, collecting the data, and processing it into useful information. We are very poor, at least so far, at the knowledge part.

Fig. 10.6, from NOAA, which is the U. S. operator of geostationary weather and climate satellites, shows the progression from petabytes of raw data down to much smaller amounts of useful information and useful knowledge. We are very good at this, and the NewSpace revolution will only increase the speed and magnitude of this process, with new satellites, data systems, analysis methods, and applications.

Fig. 10.6 From petabytes of raw data to megabytes of useful information. (Image courtesy of NOAA.)
Another way we can think about this process is that we are going from photons to electrons to neurons. We create amazing digital sensors and, in the remote sensing context, we design and operate sensors that collect photons and convert these into electrons or an electrical current, and store it all as digital data. We transmit the raw data down to the ground, where computers process it and, ultimately, human analysts and their neurons study the data and present the results to decision makers, who then consider the meaning and significance of what we have learned. These are all then to be used for some useful human purpose. Perhaps it is basic science, to better understand the processes driving our Earth, like the ozone hole, or practical analysis of polar ice, deforestation, or water pollution.

It is hoped that in the future our elected leaders, the powerful, the captains of industry, and the decision makers, would all then incorporate this information, this knowledge, to make better decisions for our people and our planet. Alas, this is not yet the case. In the United States today we have elected leaders who serve in our Congress and who are on the committee overseeing NASA and NOAA and their budgets who refuse to believe in global warming, despite the overwhelming scientific evidence to the contrary. Somehow, we must find a way to actually make better decisions based on what we learn from all of the amazing technologies that we create, and for which we pay very handsomely.

This is true broadly, regarding all of the disruptive technologies that we have considered here. One concern is that humans are ever eager to create some new toy, with very little consideration of the impacts and effects that these bring. Homo habilis! If we can do it, we will do it! We will find out later what problems it will bring to us. It is deeply ingrained in our DNA, and it is part of what got us here, so we might as well accept that this is a part of our destiny. We love our toys. In the distant past, a new but dangerous disruptive development might have only impacted a small group of people or remote geographical area, but in today’s integrated and networked world, the impacts can be massive, global, and immediate. This will be even more the case in the decades to come.

In this unprecedented age of rapid technological change, how can we both accept and mitigate the negative or damaging aspects of what we are developing, while at the same time, improve the chances that our leaders, both politically, economically, and socially, will make intelligent decisions based upon the flood of data that we generate? Ultimately, these are all only tools in our hands, and it is up to us to be wise developers and good users of these NewSpace technologies, and all the wonderful other things that are still yet to come, on this planet and beyond. It is time for us to truly become Homo sapiens: the wise ones.

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Appendix A: Glossary of Terms

Active debris removal (ADR): Refers to a space-based activity designed to accomplish the active removal of debris. It could involve using various techniques to de-orbit them from Earth orbit. This is in contrast to passive systems that lead to the ultimate uncontrolled de-orbit of a space object due to gravitational effects, atmospheric drag, or other natural effects such as space weather. (See passive systems to promote deorbit of space objects.)

Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (“The Moon Agreement”): This agreement, popularly known as the Moon Agreement, was signed on December 5, 1979, and was the fifth and last of the major space agreements adopted by the U. N. General Assembly. The Moon Agreement reiterates many of the provisions of the Outer Space Treaty. It also introduces the concept of “common heritage of mankind” to describe celestial bodies and their natural resources. This has proven to be one of the more controversial space agreements with far fewer countries actually ratifying it than the other four space agreements adopted in the 1960s and earlier in the 1970s.

Airspace: The definition of airspace and outer space as well as the demarcation between the two has not officially been decided yet. Commercial airspace is that which is regulated for aircraft safety and this extends from the ground up to 20 km. Military airspace extends beyond these altitudes. Some define airspace as extending up to the Van Karman line, which is the point where it is physically not possible for aircraft to fly, which is 100 km from the surface of Earth. States have “complete and exclusive sovereignty over the airspace above [their] territory” as per Art. 1 of the Chicago Convention.

Asia-Pacific Regional Space Agency Forum (APRSAF): Established in 1993 to include participants from the Asia-Pacific regions for the purposes of coordinating and enhancing space activities of the region, the members of this group constitute private companies and organizations, governmental bodies, international organizations as well as independent entities. It supports space-related projects and holds annual meetings and workshops.
Asia-Pacific Space Cooperation Organization (APSCO): This is also an organization covering Asia-Pacific that seeks cooperation within the region in space technology and applications. Sixteen countries became members of the organization that was established in 1992 and its Convention was fully signed and came into full force in 2002.

BRICS: This is an acronym that refers the countries of Brazil, Russia, India, China and South Africa. These are often referred to together in the context of industrial and technological development.

Centre National d’études Spatiales (CNES): This is the French National Space Agency.

China National Space Agency (CNSA): This is the official space agency for China.

Committee on Space Research (COSPAR): This committee, also known as COSPAR, was established in 1958 with the main objective to promote international cooperation in the scientific research that relates to uses of outer space. Its main goal is to achieve effective circulation of relevant information at the international level. It was established by the International Council for Science and hosts annual conferences, workshops, and assemblies.

“Common heritage of mankind”: This phase is explicitly stated in Article 11, Paragraph 1 of the Moon Agreement. It was an attempt to formally characterize celestial bodies, and presumably their natural resources, as being a part of common community of interest for humanity. This phrase is also used in Article 136 of the U. N. Convention on the Law of the Sea of 1982 with regards to the Deed Seabed and utilization of its natural resources. The exact meaning of the phrase is now in some international dispute.

Commercial Spaceflight Federation: This is an organization of companies seeking to develop new commercial systems related to spaceflight, including operators of spaceports, developers and operators of space planes, and other related activities. It was originally organized as the Private Spaceflight Federation but subsequently changed its name to include all types of commercial spaceflight activities.

Commercial Space Launch Amendments Act of 2004: A U. S. law regarding commercial space launchers. This is also known by the acronym CSLAA.

Commercial Space Launch Competitiveness Act of 2015: This is most recent act covering U. S. regulation of commercial spacecraft flight and commercial space activities. This is the act that in Title IV addresses the regulation of space mining activities.

Consultative Committee on Space Data Systems (CCSDS): An international committee whose mission is to coordinate the collection and use of space data.

Cubesat: This refers to a quite small cube-shaped satellite that is 10 cm x 10 cm x 10 cm and has a mass of around 1 kg. Cubesats start at 1 unit and increase to up to 6 units, which are six times larger than a basic cubesat.

Customary law: Custom is one of the sources of international law (as per Art. 38 of the ICJ Statute) and consists of State practice and opinion juris. Customary law could be defined the whole range of rules that emerge from the practice that
is followed by States and is believed to be binding without involving conventional law.

**Data Relay Store and Forward Services:** This is a type of service that a limited number of low Earth orbit satellites in orbit can provide by storing uploaded data messages and then downloading them when over the desired location. The University of Surrey Satellites (UoS) were pioneers in perfecting this type of small satellite service. This data relay only service can sometimes be referred to as B2B (or business to business) service.

**Defense Advanced Research Projects Agency (DARPA):** This defense agency of the United States was originally established as the Advanced Research Projects Agency (ARPA). It has the charter to develop the most advanced, state-of-the-art technology for the United States defense and has played a key role in space technology and systems development, including smallsat technology.

**The Disaster Charter:** This is the short and more popular name for the “Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters.” This Disaster Charter was established in 2000 and was negotiated as the result of discussions and proposals carried out at UNISPACE III. The charter provides remote sensing data in a timely manner and at no cost, and it has been activated over 400 times. Entities such as the GEO (Group on Earth Observations), (GMES) Global Monitoring for Environment and Security and STDM (U. S. Space Technology Disaster Management) contribute to the charter.


**DLR:** This acronym in German is expressed as *Deutsches Zentrum für Luft und Raumfahrt*. This is the German Aerospace Center, which is, in effect, the German National Space Agency.

**Dragon:** The SpaceX capsule that can sit atop the *Falcon 9* and *Falcon 9 Heavy*. It comes in cargo and crewed versions for resupply to the ISS, space tourism, and other missions.

**Dual-use satellites/payloads:** Satellites and payloads that can be used for both civilian (mainly commercial) and military purposes simultaneously or alternatively. Sometimes this represents a single spacecraft used for both military and civilian communications using the same payload. In other cases there can be a satellite with several payloads, with some payloads used for civilian purposes while other payloads used for military purposes.

**Due diligence:** This is a legal term used in domestic and international law. In international legal usage it refers to the principle that States should consider the consequences of their activities before undertaking them and abstain from them if it is foreseen that they will cause harm or hinder activities of other States; or alternatively they should take all necessary steps to avoid such consequences. Same
concept characterizes also the manner in which space activities should be undertaken under the terms of the Outer Space Treaty.

**Due regard:** This concept refers to the obligation of States to undertake their activities in a manner so as not to cause harm to other States. The difference of the term from due diligence, is that the former refers to the stage of operation, whereas the latter to the stage of preparation. In space law, the term is met in Art. IX of the Outer Space Treaty.

**Electron launch vehicle:** This is the new launch vehicle developed by Rocket Labs of New Zealand and California that is a NewSpace company seeking to develop a low cost launcher for small satellites.

**EMI:** Electromagnetic interference

**Equal non-discriminatory sharing/uses of outer space:** This notion was introduced in the corpus juris of space law with the Outer Space Treaty and later reiterated in the Moon Agreement and requires the equal participation of States to the sharing and uses of outer space “irrespective of their degree of economic and scientific development.”

**Equitable sharing/uses of outer space:** In contrast to an “equal sharing,” “equitable sharing” of the benefits that emerge from the uses of outer space refers to a “balanced sharing” according to the needs, capabilities and financial investments of the States and not necessary equal sharing from the results of space-related activities. The Moon Agreement establishes this notion as it refers to benefits that result from the uses of natural resources of celestial bodies. The exact meaning of this phrase is also a matter of some international dispute.

**European Space Agency (ESA):** This is the integrated space agency that includes most European nations. It has a different member from the European Union. This difference in membership and the different financial terms that apply to these international agencies sometimes complicate the administration and financing of space activities in Europe.

**European Commission (EC):** This is the authority with its various Directorates under which the European Union (EU) operates.

**European Union (EU):** This is the name of the integrated organization that provides elements of regional government for Europe and for which the “Euro” is the common currency.

**EUTELSAT:** The European Telecommunications Satellite organization.

**Extremely Eccentric Earth Orbit (EEO) or Highly Eccentric Orbit (HEO):** This is a very highly elliptical orbit. It is also sometimes known as the Molniya orbit, since this was the first satellite system to use this orbit for practical purposes to operate a network of communication satellites for the very northerly Soviet Union.

**Fault-based liability:** In contrast to the absolute liability as founded in Art. II of the Liability Convention, fault-based liability requires the existence of fault by the State in order to attribute liability to it. This kind of liability is provided in Art. III of the Liability Convention for damages caused elsewhere than on the surface of Earth.
Federal Aviation Administration (FAA): National aviation authority of the United States that is responsible for the “advancement, safety and regulation of civil aviation.” Within its jurisdiction fall also air traffic control activities. The FAA Office of Space Transportation (OAST) is responsible for licensing and oversight of the safety of commercial space activities.

Federal Communications Commission (FCC): This is the U. S. regulatory commission that is responsible for the assignment and allocation of radio frequencies in the United States, including those used for space communications and those used at very high altitudes (i.e., the protozone).

Femto-sat: This is the smallest class of satellite with its size being considered to be in the 10 to 100 grams range, or up to about 4 ounces.


GAGAN: GPS Aided Geo Augmented Navigation system. The Indian version of the GPS satellite navigation system.

GEO: Geostationary Earth orbit.

Geosynchronous Earth Orbit (GSO): This is very similar to Geosynchronous Earth orbit (GEO). GSO is almost a theoretical concept because a perfect GSO satellite would always remain perfectly in the equatorial plane. The pull of the Moon’s gravity and anomalies in Earth’s shape and density are constantly pulling a GEO satellite either north or south of the equator. After a satellite builds up inclination that it is 7 degrees above or below the equator, it is considered to be outside the protected area accorded to GEO or GSO satellites.

Global Positioning System (GPS): This is the name of the NAVSTAR satellite positioning and timing system operated by the U.S. military to provide precise navigation and timing.

GLONASS: This is the Russian GNSS satellite system, which is expressed in the original Russian as GLObal’naya NAvigatsionnaya Sputnikovaya Sistema.

GNSS: Global Navigation Satellite Systems, the generic name for the various national GPS satellite systems.

HAPS: High Altitude Platform Systems. Winged aircraft that operate at very high altitudes, well above the height of commercial aviation, but below satellite orbital altitudes.

IAASS: International Association for the Advancement of Space Safety: Established in 2004, IAASS is a non-profit organization that has as objective the achievement of broad international cooperation for the advancement in the field of safety of space systems.

IAC: International Astronautical Congress.

IAF: International Astronautical Federation.

IAU: International Astronautical Union.


International Bank for Reconstruction and Development (IBRD): This is the specialized agency of the United Nations that addresses world banking and especially financing and development for economically developing countries. See IMF.
International Civil Aviation Organization (ICAO): U. N.-specialized agency that was established in 1944 in order “to manage the administration and governance on the Chicago Convention.” ICAO adopts SARPs (Standards and Recommended Practices) through the member States to the Chicago Convention and with a purpose to achieve safe, secure, economically, and environmentally sustainable aviation. It is made up of the 191 member States of the convention.

International Council of Scientific Unions (ICSU): This is the global council that includes the Committee on Space Research (COSPAR) and the International Astronautical Union (IAU).

International Court of Justice (ICJ): This is the international court that interprets international law and decides case where treaties, conventions, or other established international space law might be in dispute.

International Global Navigational Satellite Service (GNSS): This is another way of describing positioning, navigation and timing PNT satellite services such as the U.S. GPS.

International Maritime Organization (IMO): This is the specialized agency of the United Nations that addresses all aspects of International maritime services and operations and safety, including communications. This organization was previously known as the International Maritime Consultative Organization (IMCO).

International Monetary Fund (IMF): A specialized agency of the United Nations addressing the financial needs of the least economically developed nations.

INMARSAT: International Maritime Satellite Organization.

INTELSAT: International Telecommunications Satellite Organization.

Iridium: This was the world’s first low Earth orbit constellation that deployed small satellites to provide mobile satellite communications to subscribers using small handsets for voice and data communications. This initial system experienced bankruptcy and had to be restructured financially. The Iridium Next system, with second generation satellites, have recently been fully deployed using SpaceX Falcon 9 rockets. The Iridium Next satellites have piggyback payloads that are to be used to support so-called (FAA-NEXTGEN) position determination to support aircraft precise navigation.

Indian Regional Navigation Satellite System (IRNSS): This is the PNT satellite system operated by India. It is different from most other systems in that it is regional and does not operate on a global basis; it consists of both GEO and MEO satellites.

Indian Space Research Organization (ISRO): The Indian Space Agency

International Standards Organization (ISO): This is the international standards agency that is key to many international technical standards used by governments and commercial organizations to insure quality and international standardization.

International Telecommunication Union (ITU): This is the U. N. specialized agency for information and communication technologies. It is the oldest U. N. agency, as it was established in 1865. It is located in Geneva, Switzerland, and its legal framework consists in the ITU Convention, the ITU Constitution, and the ITU Radio Regulations.
International Traffic in Arms Regulations (ITARs): Regulations that control the traffic (export and import) of articles and services that relate to defense purposes. They constitute, in essence, implementation of the 22 U.S.C. 2778 of the Arms Export Control Act and are issued by the U. S. Department of State. Any small satellite designer that uses components involving U. S. suppliers should be aware of these regulations and the restrictions that apply.

ITU Convention: This is the Convention of the International Telecommunication Union, which has an internationally agreed treaty.

ITU RR: International Telecommunications Union Radio Regulations.


Launcher One: This is the small rocket launcher being developed by Virgin Galactic to offer the ability to launch small satellites into low Earth orbit as soon as 2019. This launch system is under contract to provide some of the launches to support the deployment of the OneWeb satellite constellation. (See SpaceShip2)

Launching authority: The legal entity that authorizes the launching of space objects into outer space. This is a concept that is distinct from the “launching state” and is often linked to licensing entities. The launching entity is also often the “launching state,” as noted in the registration with the U. N. Office of Outer Space Affairs.

Launching State: The State that launches or procures the launching of a space object, or a state from the territory or facilities of which the launch takes place (Art. I of the Liability Convention and Registration Convention).

Liability Convention: Convention on International Liability for Damage Caused by Space Objects, March 29, 1972. After 10 years of negotiations, the UN COPUOS Legal Subcommittee adopted resolution 2777 (XXVI) in 1971, which introduced the Liability Convention. The convention entered into force in 1972 and covers liability issues that emerge from space activities by distinguishing between absolute liability and fault-based liability. It is a victim-oriented treaty, as it provides for absolute liability for damages caused on the surface of Earth, and fault-based liability for damages occurring in outer space.

Low Earth Orbit (LEO): This does not indicate a specific orbit but a range of orbits below the inner Van Allen radiation belts. Typical LEO orbits range from 300 km to 1,500 km. Many of these are polar, Sun-synchronous orbits for remote sensing satellites. The International Space Station is in LEO.

Long-Term Sustainability of Outer Space Activities (LTSOSA): The UN COPUOS has established a Working Group on the Long-Term Sustainability of Outer Space Activities. It has made a number of recommendations related to orbital debris, space traffic management and other issues. The outcomes regarding the recommendations can be seen in UN COPOUS documents and in the International Study on Global Space Governance (2017).

MEO: Medium Earth orbit. This orbital range is the domain of PNT satellite constellations and is about 20,000 km in altitude.

Micro satellite: This type of small satellite is often built by smaller manufacturers for specific purposes – often for military or governmental missions. Satellites of this type are often in the 20 to 99 kg size range.
Millennium Development Goals and Beyond 2015 (MDG): These U. N. goals, as originally adopted by the U. N. General Assembly, have now been overtaken by the Sustainable Development Goals for 2030. (See SDG.)

Nanosat: A nanosat is another term referring to small satellites without a precise meaning, but often with a mass in the 1 kg to 10 kg range. This is sometimes meant to be the same thing as a cubesat.

NASA: U. S. National Astronautical and Space Administration: NASA is an independent agency of the executive branch of the U. S. federal government that is responsible for the civilian space program and undertakes aeronautics and aerospace research.

NewSpace: This is the current revolution in commercial space activities, also called Space 2.0 or Silicon Valley Space.

NGOs: Non-governmental organizations.

OECD: Organization for Economic Cooperation and Development.

Office of Outer Space Affairs (OOSA): This unit of the United Nations supports the operations and activities of the U. N. Committee on the Peaceful Uses of Outer Space. It implements decisions of the General Assembly and supports the meetings of UN COPUOS, its Legal and Scientific and Technical Subcommittees, and its various Working Groups. It was formed in 1962 and is currently located in Vienna, Austria.

On-orbit servicing: The installation, maintenance, and repair activities on an object in orbit (a satellite, space station or space vehicle, for example) in order to extend the life of the object through refueling, or enhance its capabilities through updating or repairing components. On-orbiting servicing can consist of manned or unmanned missions. There is much concern that this activity could be used to conduct espionage or destroy satellites.

OneWeb: Large-scale low Earth orbit constellation of some 800 satellites plus spares that is under contract for manufacture by Astrium AirBus. Sir Richard Branson is a major investor. This is only one of the truly large-scale “MegaLEO” concepts that is in actual production for launch. Its primary goal is to provide broadband Internet services to areas that are underserved around the world.

Orbital space debris: Space debris refers to defunct manmade objects in space and objects caused by a variety of purposes including exploding batteries and fuel tanks, collisions between satellites, and debris itself colliding with other debris. Also known as space junk, it can consist of old satellites, spent upper stage rockets, fragments from disintegration, and debris from erosion or collisions.

Outer space: There is no multilaterally accepted definition of what outer space consists of, mainly due to the lack of agreement as to the delimitation between airspace and outer space. Although many theories present different perceptions (e.g., spatialist approach, functionalist approach, aerodynamic lift theory, etc.), the most widely accepted point where outer space begins is 100 km above the surface of Earth (von Karman line). As a result, outer space can be defined as the area that expands above the airspace starting at approximately 100 km above the surface of Earth. Others have suggested that 160 km, which is the minimum
altitude needed to sustain an LEO satellite in orbit, might be an appropriate altitude for outer space to begin and the upper limit of the so-called protozone.

**The Outer Space Treaty (OST):** This is the key space treaty that is formally known as the “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,” signed on January 27, 1967. Thus the Outer Space Treaty was opened for signature in January 1967 and entered into force in October 1967. The OST established the basic framework in international space law through core principles. It has currently been ratified by 104 States.

**Passive device de-orbit systems:** These are devices that can be activated at the end of a satellite’s lifetime to create atmospheric drag to assist with the de-orbit of a low Earth orbit satellite.

**Peaceful uses:** From the outset, space law was drafted as centered on the uses of outer space for peaceful purposes. Although there is no specific provision that prohibits the use of space for military purposes, it was generally agreed during the negotiations of the Outer Space Treaty that outer space can be used for military purposes as long as not in an aggressive manner. Hence peaceful uses can entail military purposes but not belligerent acts.

**Piggyback launches and piggyback payloads:** A launch may include one or two or even more primary payloads plus a number of smallsats as “piggybacks” that provide additional launch capacity beyond that needed for the prime launch objectives. In addition to these auxiliary launch arrangements, a satellite may have a primary mission objective, but it can also include a number of “piggyback” packages that can be carried on and powered by the prime satellite platform. Piggyback launches and piggyback packages on larger satellites open up a wide range of opportunities for smallsat space missions that are just auxiliaries to larger and much better funded space missions.

**Planet (formerly Planet Labs):** This remote sensing small satellite company was originally known as Planet Labs but is now known simply as Planet, and deploys 3-unit cubesats known as “Doves” that provide global coverage of the world with rapid updated coverage due to its large network of LEO satellites. It is the largest operator of Earth observation satellites. It has acquired the Terra Bella system as well from Google, and Google is a shareholder. It is located in San Francisco, CA.

**Position, Navigation, Timing Services (PNT):** This satellite-based service is also known as Global Navigation Satellite Services, or GNSS. This is a generic term for the many such systems now operating such as the U.S. Global Positioning Satellite (GPS) system, the Russian Glonass system, the Chinese Beidou system, the Japanese Quasi Zenith system, the Indian Regional Navigation system, and the planned European Galileo system now being implemented.

**Protozone:** Due to the unclarified demarcation between airspace and outer space, the area above commercial space and below outer space is sometimes referred to as the “protozone.” This region can be characterized as the area below which satellites cannot sustain orbital flight (i.e., 160 km) and above commercial airspace (i.e., above 21 km).
“Province of mankind”: The concept of province of mankind was referred to in the outer space treaty and later reiterated in the Moon Agreement. The term was meant to establish outer space as accessible to all states, and to build foundations for a free use and access of outer space by all countries.

**Radio frequency (RF):** Radio frequencies are electromagnetic wave frequencies within the range from around 3 kHz to 300 GHz. They include, for example, frequencies used for communications or radar signals. A range of radio frequencies, especially those allocated to a particular purpose, is referred to as a spectrum.

**Radio Regulations Board (RRB):** This is a part of the ITU that is concerned with the radio regulations adopted by the ITU plenary sessions of the World Radio Conference.

**Registration Convention:** This is the international convention that is formally known as the Convention on Registration of Objects Launched into Outer Space, signed on November 12, 1974. The Registration Convention was adopted by the U. N. General Assembly in 1975 and entered into force on September 15, 1976. It mainly addresses the issues that can arise with respect to the State Parties’ responsibilities concerning their space objects and requires that Launching States formally register with the U. N. Office of Outer Space Affairs all objects launched into outer space.

**Remotely piloted aircraft systems (RPAS):** This refers to drone aircraft and is a term used by the International Telecommunication Union in reference to spectrum allocations for communications to such aircraft systems.

**Res communis:** *Res communis* is a Latin term that was used in Roman law and refers today to the concepts of public domain and is often linked to the concept of “common heritage of mankind.”

**RFI:** Radiofrequency Interference.

**Rocket Labs:** This startup NewSpace company based in New Zealand and California is developing a low-cost launcher for small satellites called the Electron. It was planned for a launch to the Moon in a bid for Moon Express to win the Lunar X Prize in 2017. The reported cost of this launch is $5 million (U.S.). It has had two successful launches to date.

**S Curve:** A way of mapping disruptive innovations as introduced by Prof. Christiansen, which graphically describes the introduction, adoption, and final replacement of a disruptive innovation.

**Secure World Foundation (SWF):** This is a non-governmental organization that addresses issues related to space safety, cosmic hazards, orbital space debris and other issues involving conflicts in or misuse of space. It is based in Boulder, Colorado, and has offices in Washington, D. C.

**SEDS:** Students for the Exploration and Development of Space, a student organization created in 1980.

**Smallsat:** This is a general term referring to satellites that are typically 500 kg or less in mass and which have been designed so as to be lower in cost by such means as the use of off-the-shelf components, miniaturized components, or as an auxiliary mission involving the launch of a much larger satellite. Such small
satellites can be quite small, as characterized by such terms as femtosat, picosat, nanosat, or cubesat. These small satellites can be simply one of a kind projects or they can be one of a very large-scale constellation. Most small satellites are launched into low Earth orbit (LEO). But they can also be deployed in different orbits for scientific missions or even into deep space, such as to look for suitable asteroids for the purposes of space mining.

**Soft law:** Soft law can be contrasted with hard law. Contrary to the latter, soft law does not have binding force. It can be described as a quasi-legal instrument.

**Solar flares/storms:** These consist of a flash of brightness observed near the Sun’s surface that ejects radiation from the Sun. There are some occasions when in addition to the flare there is also an ejection of ions into space from the Sun’s corona. These events that are particularly destructive are called coronal mass ejections (CMEs). The solar wind, solar flares, and solar storms are monitored closely by meteorological satellites such as those deployed by NOAA, which sound alerts to all satellites to power down due to powerful solar storms. Small satellites in low Earth orbit are generally more protected than satellites in GEO orbit.

**Space Data Association (SDA):** This is an organization now incorporated on the Isle of Man that was created by operators of commercial satellite networks so as to exchange information and to obtain warnings of possible conjunction of satellites. This started with just four satellite operators, but today has nearly fifty participating satellite operators in various types of orbits.

**Space plane:** There is no exact definition of a space plane. The usual understanding of this term is a reusable winged vehicle that, by flying in a parabolic, non-orbital flight pattern, can achieve flight above a 100 km altitude (i.e., the commonly accepted start of outer space). This is so that passengers can experience about 4 minutes of weightlessness and see Earth as a great big blue marble against the dark sky of outer space, or to fly scientific experiments.

**Space Situational Awareness (SSA):** This term refers to all the systems and programs that exist in order to enhance awareness of what are the exact orbits of manmade and natural objects that exist in close proximity to Earth. For instance, the space situational awareness program of the European Space Agency (ESA) aims to support Europe’s independent utilization and access to space. It was authorized at the November 2008 Ministerial Council, was formally launched in January 2009 and was extended until 2019. The new S-band radar system that is being implemented by the United States in Micronesia in 2017 will increase the ability of this system from being able to track, in low Earth orbit, about 22,000 objects the size of a baseball to a being able to track about a quarter million objects the size of a marble. These SSA systems were initially created to track missile launches, but now play a key role in tracking orbital debris as it continues to grow.

**Suborbital spaceflight:** A spaceflight whose trajectory intersects the atmosphere or surface of the gravitating body from which it was launched. Thus, although the spacecraft reaches space, it does not complete one orbital revolution.
**Surrey Space Centre:** This is the small satellite design, develop, and fabrication center at the University of Surrey that is now owned by Astrium AirBus.

**Sustainable Development Goals (SDG) of the United Nations for 2030:** These are 17 specifically set goals with 169 specific targets for global development that have been endorsed by the U. N. General Assembly that set forth clear objectives for improvement in such areas as agriculture, environment, economic growth and employment, health and education, etc. These goals replace the so-called Millennium Development Goals now that the 21st century has arrived.

**TCBM:** This is an acronym for Transparency and Confidence-Building Measures. It frequently relates to customary or well-publicized defense or military uses of space and practices that if used consistently can allay concerns about actions that might be misconstrued as offensive military uses of space systems.

**Telemetry, tracking, and control (TT&C):** These are the three basic elements of operation to maintain a satellite or spacecraft in orbit or on a trajectory. Telemetry involves the relay of data from the ground to a spacecraft to operate it in space. Tracking is the process of keeping exact information as to the location of a satellite in orbit or on a trajectory. Control (or command) is the sending of instructions to a satellite or spacecraft to perform some function such as to activate a component, operate a switch, fire a control thruster, or otherwise make the space vehicle operate in a proper manner.

**Terra Bella:** This global constellation of remote sensing cubesats provided rapid video updates using only a network of 3-unit cubesats in low Earth orbit. This system that uses commercial off-the-shelf components was originally undertaken by a group of graduate students from Stanford University and was named Skybox. Subsequently the system was purchased by Google and renamed Terra Bella and then sold to Planet, formerly Planet Labs.

**U. N. Conferences on the Exploration and Peaceful Uses of Outer Space (UNISPACE):** The UNISPACE conferences aim to provide a platform of global dialog on issues related to space exploration and exploitation. They are organized by the United Nations to further the cooperation in the peaceful uses of outer space between States and international organizations. There have now been UNISPACE I, II, and III and in 2018 there was UNISPACE + 50. These events have been held in Vienna, Austria, where UN COPUOS meets and where UNOOSA has their offices.

**U. N. Convention on the Law of the Sea of 1982 (UNCLOS):** This is the very broadly agreed convention involving the international oceans and seas. Provisions from the UNCLOS are sometimes considered as legal precedent or useful guidelines with regard to outer space.

**U. N. Coordination of Outer Space Activities (UNCOSA):** Program with the responsibility to coordinate space activities to the UN level.

**UN COPUOS:** This is the U. N. Committee on the Peaceful Uses of Outer Space: The UN COPUOS was created by the U. N. General Assembly in 1959 to review the international cooperation in peaceful uses of outer space, encourage research programs, study legal problems arising from the exploration of outer space, reg-
ister objects launched into space by launching States, and undertake space-related activities that needed to be undertaken by the United Nations.

**UN COPUOS Space Debris Mitigation Guidelines:** This is a series of non-binding and voluntary regulations approved by the United Nations after being agreed to by the UN COPUOS in 2010, after years of discussions on the problem of space debris. Although they urge States to limit debris caused during their space operations and minimize respective risks to the environment of outer space, they are in the form of guidelines and recommendations, and thus cannot require States to follow them.

**U. N. Educational, Scientific and Cultural Organization (UNESCO):** A specialized agency of the United Nations, headquartered in Paris, with responsibility for scientific matters. It also considers space-related matters. It is currently creating an encyclopedia on space and has a newly created Space Council.

**University of Surrey Satellites (UoS):** This is the name given to space satellites developed and fabricated at the Surrey Space Centre.

**U. N. Office for Disarmament Affairs (UNODA):** The UNODA, originally established in 1982 under a different name, became the UNODA in 2007. Its purpose consists of the promotion of nuclear disarmament and non-proliferation, the strengthening of disarmament regimes regarding weapons of mass destruction, chemical and biological weapons, as well as disarmament efforts with respect to conventional weapons such as landmines and small arms particularly used in contemporary conflicts.

**U. N. Office for Outer Space Affairs (UNOOSA):** UNOOSA is a part of the Secretariat of the United Nations. It reinforces the decisions of General Assemblies as well as those of the UN COPUOS. It was established in 1962 and is currently located in Vienna.

**U. N. Platform for Space-based Information for Disaster Management and Emergency Response (UNSPIDER):** UNSPIDER is implemented by the U. N. Office for Outer Space Affairs (UNOOSA). Its main purpose is to provide universal access to all countries, as well as relevant organizations, space-based data, and services with respect to disaster management.

**Unmanned Aerial Vehicles (UAVs):** Aircraft that operate without a human pilot aboard. The degree of autonomy can vary, as the flight of UAVs can operate under remote control by a human operator or by onboard computers (fully or intermittently autonomously). They are commonly known as drones or unmanned aircraft systems.

**U.S. Commercial Space Launch Competitiveness Act of 2015:** This is currently the latest U.S. legislation that covers the commercial development of new spacecraft and space systems for the United States. Title IV of this act covers the issue of possible future extraction of natural resources from space objects, or space mining.

**Van Allen radiation belts:** The Van Allen radiation belts are the layers of energetically charged particles in two orbital bands around Earth. These layers (or “belts”) are held in place around the planet by its magnetic field.

Wide Area Augmentation Service: This is a ground-based system used to augment the accuracy of the U. S. operated NAVSTAR-GPS system. This becomes of greater importance as satellite-based navigation plays an increased role in next generation aviation and space traffic control.

World Economic Forum (WEF): The mission of the World Economic Forum (a Swiss non-profit foundation for public-private cooperation) consists of the improvement of the state of the world by engaging diverse world actors such as business, political, academic, and other leaders of society in order to shape global, regional, and industry agendas.

World Intellectual Property Organization (WIPO): This organization, headquartered in Geneva, Switzerland, is concerned with the protection of intellectual property such as copyright, trademarks, and especially patents.

World Meteorological Organization (WMO): This international organization is a specialized agency of the United Nations. It is concerned with coordinating worldwide efforts related to weather forecasting, monitoring and warning, climate change, and space weather – especially the most dangerous solar storms such as X-class flares and coronal mass ejections that can harm spacecraft and critical global infrastructure.

World Radio-communication Conferences (WRCs): World Radio-communication Conferences are periodically convened for the purposes of the review and revision (if necessary) of radio regulations. These radio regulations are agreed globally and regulate the use of the radio-frequency spectrum and geostationary-satellite and non-geostationary-satellite orbits. Once known as the World Administrative Radio Conferences (WARC), these are held approximately every four years.
Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies

Ratification advised by U.S. Senate April 25, 1967
Ratified by U. S. President May 24, 1967

Proclaimed by U. S. President October 10, 1967
Entered into force October 10, 1967

The States Parties to this Treaty,
Inspired by the great prospects opening up before mankind as a result of man’s entry into outer space,
Recognizing the common interest of all mankind in the progress of the exploration and use of outer space for peaceful purposes,
Believing that the exploration and use of outer space should be carried on for the benefit of all peoples irrespective of the degree of their economic or scientific development,
Desiring to contribute to broad international co-operation in the scientific as well as the legal aspects of the exploration and use of outer space for peaceful purposes,
Believing that such co-operation will contribute to the development of mutual understanding and to the strengthening of friendly relations between States and peoples,
Recalling resolution 1962 (XVIII), entitled "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space," which was adopted unanimously by the United Nations General Assembly on 13 December 1963,
Recalling resolution 1884 (XVIII), calling upon States to refrain from placing in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction or from installing such weapons on celestial bodies, which was adopted unanimously by the United Nations General Assembly on 17 October 1963,

Taking account of United Nations General Assembly resolution 110 (II) of 3 November 1947, which condemned propaganda designed or likely to provoke or encourage any threat to the peace, breach of the peace or act of aggression, and considering that the aforementioned resolution is applicable to outer space,

Convinced that a Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, will further the Purposes and Principles of the Charter of the United Nations,

Have agreed on the following:

Article I

The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.

Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.

There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation.

Article II

Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.

Article III

States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding.
**Article IV**

States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.

The Moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military maneuvers on celestial bodies shall be forbidden. The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration of the Moon and other celestial bodies shall also not be prohibited.

**Article V**

States Parties to the Treaty shall regard astronauts as envoys of mankind in outer space and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of another State Party or on the high seas. When astronauts make such a landing, they shall be safely and promptly returned to the State of registry of their space vehicle.

In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other States Parties.

States Parties to the Treaty shall immediately inform the other States Parties to the Treaty or the Secretary-General of the United Nations of any phenomena they discover in outer space, including the Moon and other celestial bodies, which could constitute a danger to the life or health of astronauts.

**Article VI**

States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty. When activities are carried on in outer space, including the Moon and other celestial bodies, by an international organization, responsibility for compliance with this Treaty shall be borne both by the international organization and by the States Parties to the Treaty participating in such organization.
Article VII

Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies.

Article VIII

A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body. Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their component parts, is not affected by their presence in outer space or on a celestial body or by their return to the Earth. Such objects or component parts found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.

Article IX

In the exploration and use of outer space, including the Moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty. States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose. If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment.
Article X

In order to promote international co-operation in the exploration and use of outer space, including the Moon and other celestial bodies, in conformity with the purposes of this Treaty, the States Parties to the Treaty shall consider on a basis of equality any requests by other States Parties to the Treaty to be afforded an opportunity to observe the flight of space objects launched by those States.

The nature of such an opportunity for observation and the conditions under which it could be afforded shall be determined by agreement between the States concerned.

Article XI

In order to promote international co-operation in the peaceful exploration and use of outer space, States Parties to the Treaty conducting activities in outer space, including the Moon and other celestial bodies, agree to inform the Secretary-General of the United Nations as well as the public and the international scientific community, to the greatest extent feasible and practicable, of the nature, conduct, locations and results of such activities. On receiving the said information, the Secretary-General of the United Nations should be prepared to disseminate it immediately and effectively.

Article XII

All stations, installations, equipment and space vehicles on the Moon and other celestial bodies shall be open to representatives of other States Parties to the Treaty on a basis of reciprocity. Such representatives shall give reasonable advance notice of a projected visit, in order that appropriate consultations may be held and that maximum precautions may be taken to assure safety and to avoid interference with normal operations in the facility to be visited.

Article XIII

The provisions of this Treaty shall apply to the activities of States Parties to the Treaty in the exploration and use of outer space, including the Moon and other celestial bodies, whether such activities are carried on by a single State Party to the Treaty or jointly with other States, including cases where they are carried on within the framework of international intergovernmental organizations.

Any practical questions arising in connection with activities carried on by international inter-governmental organizations in the exploration and use of outer space, including the Moon and other celestial bodies, shall be resolved by the States Parties to the Treaty either with the appropriate international organization or with one or
more States members of that international organization, which are Parties to this Treaty.

**Article XIV**

1. This Treaty shall be open to all States for signature. Any State which does not sign this Treaty before its entry into force in accordance with paragraph 3 of this article may accede to it at any time.

2. This Treaty shall be subject to ratification by signatory States. Instruments of ratification and instruments of accession shall be deposited with the Governments of the United States of America, the United Kingdom of Great Britain and Northern Ireland and the Union of Soviet Socialist Republics, which are hereby designated the Depositary Governments.

3. This Treaty shall enter into force upon the deposit of instruments of ratification by five Governments including the Governments designated as Depositary Governments under this Treaty.

4. For States whose instruments of ratification or accession are deposited subsequent to the entry into force of this Treaty, it shall enter into force on the date of the deposit of their instruments of ratification or accession.

5. The Depositary Governments shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification of and accession to this Treaty, the date of its entry into force and other notices.

6. This Treaty shall be registered by the Depositary Governments pursuant to Article 102 of the Charter of the United Nations.

**Article XV**

Any State Party to the Treaty may propose amendments to this Treaty. Amendments shall enter into force for each State Party to the Treaty accepting the amendments upon their acceptance by a majority of the States Parties to the Treaty and thereafter for each remaining State Party to the Treaty on the date of acceptance by it.

**Article XVI**

Any State Party to the Treaty may give notice of its withdrawal from the Treaty one year after its entry into force by written notification to the Depositary Governments. Such withdrawal shall take effect one year from the date of receipt of this notification.
Article XVII

This Treaty, of which the English, Russian, French, Spanish and Chinese texts are equally authentic, shall be deposited in the archives of the Depositary Governments. Duly certified copies of this Treaty shall be transmitted by the Depositary Governments to the Governments of the signatory and acceding States.

IN WITNESS WHEREOF the undersigned, duly authorized, have signed this Treaty.

DONE in triplicate, at the cities of Washington, London and Moscow, this twenty-seventh day of January one thousand nine hundred sixty-seven.

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Montreal Declaration – Adopted on May 31, 2014

The 2nd Manfred Lachs International Conference on Global Space Governance, held at McGill University in Montreal, Canada, on May 29-31, 2014:

Having brought together over 120 experts from 22 countries (space-faring and non-space faring nations) involved in various aspects of space activity and regulation;

Having served as an objective venue for the conduct of international and interdisciplinary deliberations on different aspects and perspectives of global space governance;

Recognizing that the current global space governance system that was created during the 1960s and 1970s has not been comprehensively examined by the international community since its establishment;

Recognizing that the concept of global governance is comprehensive and includes a wide range of codes of conduct, confidence building measures, safety concepts, international institutions, international treaties and other agreements, regulations, procedures and standards;

Noting that numerous developments have occurred in the world in general, and the space sector in particular, with serious implications for current and future space activities and for the sustainable use of space for peaceful purposes for the benefit of all humankind (i.e., the global public interest in outer space);

Believing that the time has come to assess the efficacy of the current regime of global space governance and to propose an appropriate global space governance system that addresses current and emerging concerns;

HEREBY resolves by consensus to:

1. call upon civil society, academics, governments, the private sector and other stakeholders to consider establishing a Working Group to prepare for and convene an international conference to deliberate and agree upon recommendations to governments and relevant international organizations aimed at the establishment of a global governance regime for peaceful and sustainable space exploration, use and exploitation for the benefit of all humankind; and
2. ensure that the proposed international conference is held as soon as possible with global participation by all key stakeholders (i.e., state and non-state actors) including: international intergovernmental organizations; relevant regional...
organizations; non-governmental organizations; appropriate state ministries (departments) and space agencies; academic institutions; appropriate commercial enterprises; and concerned individuals;

3. call upon the McGill University Institute of Air and Space Law to take the lead in initiating, completing and broadly distributing through all forms of media, an international interdisciplinary study that examines drivers of space regulations and standards prior to, and in support of, the proposed international conference, targeting a global audience;

4. ensure that the above-mentioned study examines, inter alia:

   a) changing global economic, political and social conditions and space infrastructure dependence;
   b) identification and assessment of all known space threats;
   c) space opportunities and the need for sustainable and peaceful use, exploration and exploitation of space for all humankind;
   d) safety, technical and operational gaps to be filled; and
   e) appropriate space governance standards, regulations, arrangement, agreements and institutions relevant to current and emerging issues of space activities.

Done in Montreal, this thirty-first day of May 2014.
Scott Madry, Ph.D., is a specialist in remote sensing and Geographic Information Systems for regional environmental and cultural applications, including archaeology, environmental studies, and disaster management. He is a research associate professor of archaeology at the University of North Carolina at Chapel Hill and was a member of the faculty of the International Space University in Strasbourg, France, for nearly 30 years. He was involved with the International Space University since its founding in 1987 and has taught in over 25 ISU summer programs around the world. He was on the resident ISU faculty in Strasbourg, France, for three years, and was the Program Director of the Southern Hemisphere Summer Space Program, held most recently in Adelaide, Australia, for three years.

Madry is also the founder and president of Informatics International, Inc., an international remote sensing and GIS consulting company located in Chapel Hill, NC, and is the Executive Director of the Global Space Institute. He specializes in natural and cultural resource management and disaster applications using space systems. He received his Ph.D. in 1986 at UNC-CH, and worked at the Institute for Technology Development, Space Remote Sensing Center at NASA for three years, and then taught at Rutgers University for nine years before teaching at ISU and moving back to UNC-CH. His research includes remote sensing, GIS and GPS applications, and he has done work in North America, Africa, and Europe. He was co-editor-
in-chief of the 1,200 page, two-volume *Handbook of Satellite Applications* for Springer Publishing in 2012, with a second edition published in 2017, which has had over 370,000 downloads to date. He is the author of several other books through Springer Press as well.

Madry has given over 150 short courses and educational programs in 30 countries around the world. He is very involved in Open Source GIS, remote sensing, and GNSS, and has taught QGIS/GRASS courses. He is an advanced disaster instructor with the American Red Cross and has deployed to multiple disasters with them, mostly as an Emergency Operations Center liaison, but has worked in several other capacities. He is also active with the GISCorps in providing remote data analysis in disasters. He was awarded, along with other GISCorps volunteers, the 2012 President’s Volunteer Service Award by President Barack Obama, and received a second, gold award in 2016 for his work with the American Red Cross. [http://scottmadry.web.unc.edu](http://scottmadry.web.unc.edu)
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