1 The World of Space in Flux

Introduction

The space industry is in a period of enormous change. Newly emerging space technology and a myriad of innovative space applications are both in a state of unparalleled growth and market flux. Only the fields of computer science and artificial intelligence (AI) – the so-called cyber-industries – have a similar pattern of rapid technological advancement and industrial ferment. This is not at all surprising in that the space industry has largely become a software-defined extension of the computer industry. Communications satellites, remote sensing and weather satellites, and space navigation satellites currently represent the largest space applications industries. If one stops to analyze the underlying technologies on which these space applications are based, one finds that they are essentially digital processing and sensing space systems in the skies, using specialized digital software and hardware. Digital processing is at their core.

A further look reveals that 'disruptive' space technology, services and applications are being created by what might be called the 'Silicon Valley' effect. Bright young people out in Silicon Valley, and in other parts of the globe where the cyber revolution has spread, all have a new mentality. They are saying: "Let me re-invent the world." And, indeed they are doing just that.

This time of rapid change in the commercial space industry has been called "NewSpace" and "Space 2.0." Regardless of what one calls it, there are suddenly new ways of designing, manufacturing, testing and launching satellites. There has been a radical change in the markets and applications that space systems serve, and the why, where, when and how of the space industry has changed. New space ventures are being started on the basis of crowd-sourcing and 'Kickstarter,' an Internet funding platform for creative endeavors. Many Space 2.0 ventures are launched via financing obtained through the Internet.

New organizations with names such as SpaceX, Blue Origin, Virgin Galactic,

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Kymeta, One Web and Planet are reinventing the commercial space industries. As a result, well-established space industries such as Lockheed Martin, Boeing, Airbus, Northrop Grumman and McDonald-Detwiler are reinventing themselves in order to keep up with the commercial space revolution.

A recent study found that more than 80 angel and venture-backed space companies have been founded since 2000 in this realm of Space 2.0. Indeed, several of these new firms are today big bucks operations and on the verge of becoming billion-dollar concerns. In this book we aim to examine what has allowed these NewSpace ventures to get off the ground – figuratively and literally. In this study we came up with four key factors. These critical success factors were listed as: "(1) Business Philosophy – creating and living an entrepreneurial spirit; (2) Financing – access to early stage risk capital and venture funding; (3) Technology Management – focus on 'spinning-in' technologies and Information and Communication Technology processes; and (4) Framework Conditions – favorable political and legal conditions supporting commercialization" [1].

And some are looking well beyond near-term growth of a new space economy. Stephen Hawking, Elon Musk and even Jeff Bezos have looked into the future and to centuries beyond. Elon Musk has envisioned a million people on Mars. An Asian entrepreneur is planning to build condos on the Moon in future decades. Jeff Bezos has looked to the future in a very logical and pragmatic way: "The Earth is finite, and if the world economy and population is to keep expanding space is the only way to go" [2].

Anyone with vision will see many parallels between outer space and the so-called New World of five centuries ago. But the real challenge is not to create a new space economy for humans in the centuries ahead. That much is fated. Space products and services will grow rapidly in the decades ahead. This is clear to anyone with a vision of the future. No, the challenge is not to repeat the mistakes of the past. Industrial and national leaders need to develop regulatory and legal systems and 'rules of the road' that allow us to not pollute outer space. We need to find a way forward to achieve the longer-term sustainability of outer space activities. In this regard the continuing buildup of space debris in Earth orbit, the ozone hole and pollution of the stratosphere, all suggest an inauspicious start. Without effective guidelines we could end up with space debris around the Moon and several of our nearest planets.

The space economy will, within a decade or so, grow from about $350 billion to a trillion dollar economy. Space products and services will mushroom as global demand grows and we exhaust many of Earth's resources. The real challenge is to undertake this expansion with some sense of ecological care and a wisdom that comes from learning from past mistakes. It is indeed a bit of historical irony that a part of the new space economy relates to recovery from global warming, coping with and even recycling space debris, and other environmental-recovery activities [3].

The Small Satellite Revolution

Students from Stanford University built a new remote-sensing satellite system of 'small sats' that they called 'Skybox.' This network was then renamed 'Terra

Bella' when these young entrepreneurs sold their network to ABC/Google for many millions of dollars in profits. In a tangentially related story, students who attended the International Space University who were inspired by Professor Scott Madry decided to create a new small satellite network that they named Planet Labs. Their three-unit cube satellite Earth-sensing satellites they call 'doves.' This is because when these small sats have their solar array systems deployed on each side in space these three-unit-cube-satellites – about the size of a pigeon – sort of look like birds.

From their mansion in Mountain View, California, these former students are creating a highly capable global satellite system. This growing network of small sats images the entire world in less than a day and generates a huge amount of data. Their network, that has now been expanded to include the satellites from Skybox/Terra Bella in a deal that links them to ABC/Google, has been renamed simply 'Planet.' This amazing start-up company managed to arrange for the launch of eighty-eight of their Dove satellites on a single launch via an Indian rocket on Valentine's Day, February 14, 2017. This 'flock' of 104 cube satellites, each weighing under 5 kilograms (about 10 lbs.), were launched over a span of 18 minutes. This unprecedented number of small sat launches set a new world record for the number of sa tellites launched by a single rocket launcher. The previous record was 39 satellites on a Russian launcher [4]. (See Fig. 1.1.)

Fig. 1.1 The record-setting launch of 104 small satellites on the Indian Polar Satellite launch vehicle on February 14, 2017. (Photo courtesy of the Indian Space Research Organization.)

Complex and Conflicting Trends in Satellite Communications

And these are just two stories about satellite networks developed for remote-sensing services. New developments in the communications satellite field are rampant. Here innovations are spewing forth in a wide range of different ways. At the high end of the commercial satellite market, some of the largest companies are developing huge new satellites that have ten to fifty times the capability of those that were launched just a few years ago. These satellites, known as high throughput satellites, have the ability to transmit at digital rates as high as 140 to 150 gigabits/second. They are being launched by companies such as Intelsat (i.e., their Epic satellites), Echostar/Hughes Network Systems (i.e., their Jupiter satellites), Via Satellites (i.e., Viasat 1 and Viasat 2), and Inmarsat (i.e., their Express satellites) [5].

This high end of the market that involves the deployment of geosynchronous satellites with masses of 5,000 kilograms upward are primarily to support television distribution and broadband data communications, typically using either Digital Video Broadcast (DVB) standards or Digital over Cable System Interface Standard (DOCSIS). These monster satellites have huge solar arrays that can generate well over 10 kilowatts of power and have large antennas that can be used by efficient feed systems to generate even hundreds of beams to allow frequency re-use – just as cellular mobile communication antenna systems do on the ground.

These geosynchronous satellites have become more and more efficient by using higher and higher frequencies, having more on-board power, finding ways to reuse frequencies, plus using multiple digital coding techniques to achieve these higher and higher digital throughput rates.

Thus, at one end of the spectrum there are now massive high throughput satellites (HTS) that require on the order of a quarter-billion dollars to build and launch. These satellites, which orbit almost a tenth of the way to the Moon, can transmit tens of thousands of television and high data rate channels to low cost very small aperture terminals on the ground and require no expensive tracking capabilities. The satellites are big, powerful and expensive, which allows millions of ground antennas – even down to hand-held units – to be very low cost.

Then, at the other end of the spectrum, we have new small satellite constellations. These satellites are designed to operate in low Earth orbit some 40 times closer to Earth than the big geosynchronous satellites. The concept is to deploy a lot of smaller satellites in large-scale constellations of hundreds if not thousands of spacecraft. Such a constellation can then blanket Earth and provide low latency (i.e., minimal delay) broadband data links. These small satellites are thus well-suited for Internet-type services. The small satellites in this case, however, are much bigger than simple cube sats (which are a very compact 10 cm × 10 cm × 10 cm in size – or about the size of a softball).

These types of smaller satellites for communications are thus about 150 to 250 kilograms in size. That makes them 30 to 50 times larger than a Planet 3-unit cube satellites. (See Fig. 1.2.) Yet they are nevertheless some 30 to 50 times

Fig. 1.2 A Dove 3-unit cube sat, about the size of a small bird. (Graphic courtesy of Planet.)

smaller than the giant high throughput satellites like an Intelsat Epic or Viasat 2 satellite. These small satellites for communications services need to be bigger to have higher power, to have bigger antennas to create spot beams needed for frequency reuse and also to have the capability to be pointed with accuracy.

The bottom line is that we are now seeing a great diversity of satellite design and new launch systems to support these quite different types of satellites that range from tiny so-called cube sats, to large-scale constellations of "small" satellites that are 30 to 50 times larger than cube satellites, up to giant high throughput communications satellites that are 30 to 50 times larger still than the small satellites in the low Earth orbit constellations.

Figs. 1.2, 1.3A, 1.3B, and 1.4 show the appearance of these tiny, small and huge satellites which are representative of the great diversity and radical changes that characterize the space industry today.

And the changes that are occurring in the field of satellite communications are more complex and complicated than just the size, mass, shape and capabilities of the satellites. There are a host of other innovations that are leading to key changes in the space industry.

Key Technical Trends Fueling Changes in Satellite Applications

There is a great diversity of new technologies, business models and business practices that are working together to make all of these changes in the space and satellite world possible. The number of changes in just the last few years is really almost staggering. It is hard to keep up with the speed of change and where the changes are occurring. Space applications and services are not for those who cannot keep up with almost constant change. Let's count the ways.

There are key changes in the design and technologies now being used in ground systems. These changes are particularly important to the design and operation of low Earth orbit constellations. There are also significant changes in digital encoding systems that allow for more efficient use of the available spectrum. There are new frequency

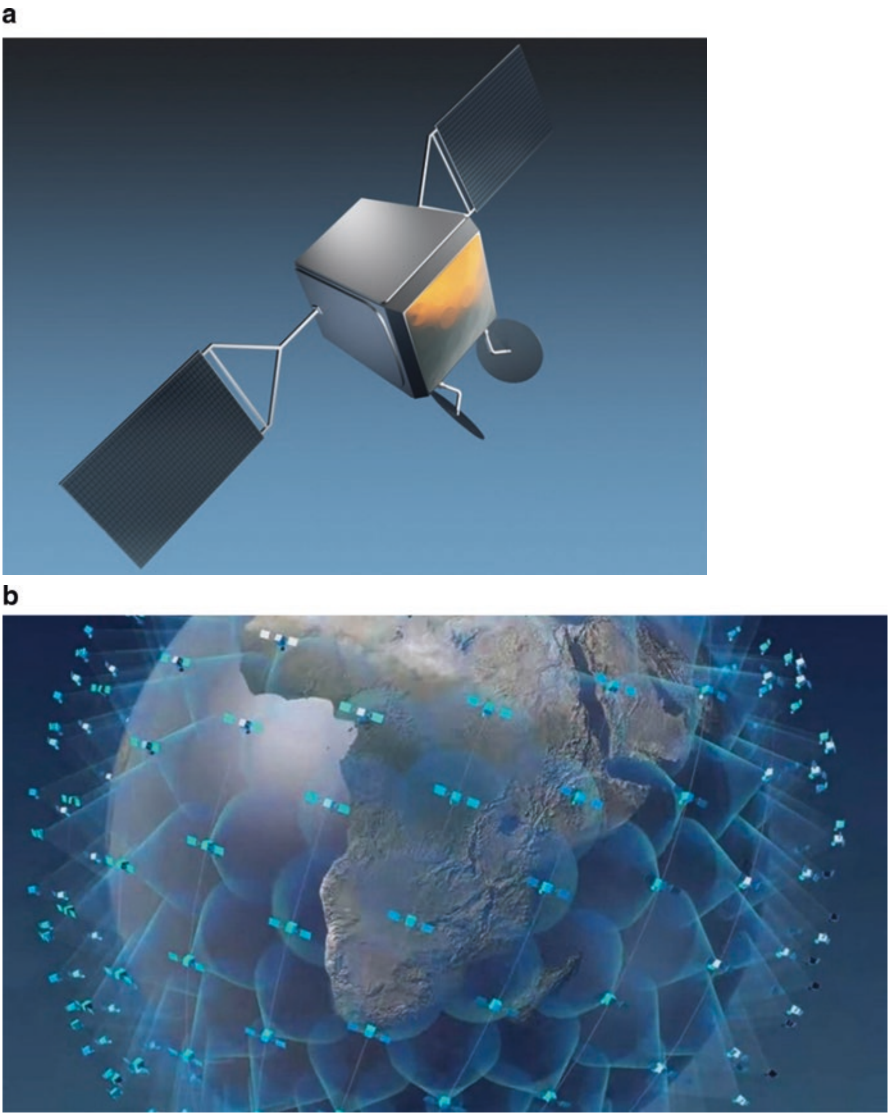

Fig. 1.3 **a.** A mock-up of a small satellite being manufactured by Airbus for the OneWeb constellation. **b.** Representation of the OneWeb satellites deployed as part of a giant 800-satellite orbital constellation. (Graphic courtesy of OneWeb.)

bands that are being made available for some of the new services. There are new ways of manufacturing satellites on assembly lines that allow for faster and lower cost production and quality testing. There are new, lower cost and more capable launch systems. The how and why of these changes and future trends are key elements of this book. The details of these changes are presented in later chapters, but the key highlights are summarized here.

Fig. 1.4 The giant Viasat 2 satellite that has a wingspan of a football field. (Graphic courtesy of Viasat.)

Key Innovations in Ground Systems

The significant factor that Arthur C. Clarke hit on with regard to the use of geosynchronous or geostationary (GEO) satellites was the simplicity they offered on the ground. He explained in 1945 that GEO satellites are essentially stationary 24/7 for 365 days a year. This meant that Earth station antennas on the ground could be continuously pointed to the same location in the skies. That means they could always maintain a link with the satellite above without expensive tracking systems.

As communications satellites became more and more capable with higher power and improved higher gain antennas, smaller and lower cost satellite ground stations became possible. Now there are millions of very small aperture television receive only (TVRO) terminals all over the globe.

The widespread usage of the Internet, with its protocol that was sensitive to satellite transmissions all the way to a GEO satellite and back but involved a quarter of a second delay, created impetus to look at lower orbiting satellite constellations. Further the idea of creating satellite systems for mobile communications and the need to operate with very small satellite handsets also prompted the idea of using low Earth orbit satellites. This was because of not only a shorter transmission delay but also the advantage of less transmission loss.

A satellite signal as it is emitted from a satellite antenna spreads in a circle, and the area of a circle is $A = \pi r^2$. This means that a satellite that is 40 times closer to the ground does not experience

Fig. 1.5 A representation of an electronically generated beam and a Kymeta antenna. (Graphics courtesy of Kymeta.)

40 times less spreading and corresponding weakening of the signal but $(40)^2$. This means that the effective or in power advantage is $(40)^2$ or 1,600. On the other hand, such a satellite has much less coverage of the world's surface, and thus there is a need for more satellites. For global coverage for a constellation that is 40 times closer to the ground you would need perhaps 50 to 60 satellites.

The problem with the low Earth coverage is the need for either a tracking capability to follow the satellite as it passes overhead, or a very low gain or sensitivity to receive the satellite signal. What has changed is that there are now new Earth stations that use what are called meta-materials. These allow new ground antenna systems to generate electronic beams that can track an overhead satellite and both receive and transmit signals to a low Earth orbit satellite as it passes overhead. The leader in the field at this time is a new company called Kymeta that has perfected this technology and is now commercially providing these new types of ground stations that make these new low Earth orbit satellite constellations much more viable. This company has the further cachet of being backed by Microsoft co-founder Bill Gates [6]. (See Fig. 1.5.)

There are other companies, such as Phasor and C-Sat, that are also developing competitive ground antennas [7].

These advances in ground systems and in handheld units based on highly refined application-specific integrated circuits (ASICs) are perhaps as crucial, if not more so, to the advancement in satellite communications services in the years ahead.

Closely linked to this area of development is the creation of new capabilities to support satellite service to Earth Stations on Mobile Platforms (ESOMPs) and Earth Stations in Motion (ESIM). These, too, are now being equipped to operate using electronic beams with continuous pointing capabilities that allow these mobile systems to track satellites in low Earth orbit and to achieve higher gain links with satellites that are constantly moving in space and at the receiving location.

Advanced Coding Systems

Of all the advances in satellite communications, the one that has allowed the biggest increase in efficiency has been the use of digital encoding. The use of advanced COders/DECoders (CODECs) have offered the largest gains as measured by bits transmitted per hertz. The typical digital transmission a decade ago had an efficiency rating of 1 bit/Hz. Today the transmission capabilities, especially with television and high definition television systems, are in the range of 4 bits/Hz up to even 7 bits/Hz. This is like taking a car that had a mileage rating of 30 miles per gallon or 12 km/L up to a spectacular level of 210 miles per gallon or perhaps 84 km/L. Major advances in Trellis coding, Turbo-coding, etc., have allowed tremendous advances. The world of fiber optic communications that has access to the vast amount of spectrum available in the light wave bands is a key to future progress. The details of these advances are provided in Chapter 2 of this book.

New Frequency Efficiencies and Spectrum Allocations

The field of satellite communications is essentially driven by three basic parameters. These are power, radio frequency spectrum and complexity. And the meaning of complexity in this case essentially boils down to digital coding concepts. When one has exhausted the available power that is available for transmission to or from a satellite, and then devised and used the most efficient coding system over a satellite link, the only way to expand one's satellite service capabilities is to find better ways to reuse the available radio frequencies or get new orbital frequency allotments. Such new allotments today would for the foreseeable future come in the form of higher radio frequency spectrum bands. This push up to higher and higher frequencies is the usual way to proceed, since the lower spectrum bands are completely used up by other forms of intensive radio frequency usage.

The new options for satellite communications planners involve the so-called Q/V-bands, the W-bands and even the E-bands. None of these potential newer bands in the millimeter wave band is particularly attractive in that they all involve intense problems of rain and precipitation attenuation, or what is called simply “rain fade.” This means that during rain, snow or fog conditions the radio wave transmission could in effect be ‘bent,’ since the wavelength of the radio wave and size of raindrops are close enough in size that the raindrops act as a sort of lens to distort the signal.

And this is not all when it comes to problems of using the millimeter-sized wavelengths. The frequencies that are being modulated are very high indeed. The equipment needed to operate at these frequencies is difficult to design and build and thus the cost of the radio equipment – both for the satellites and the ground equipment – is today expensive and will likely remain so for a number of years to come. One will need to design satellite systems to be clever, using a number of tricks to cope with heavy rain by reserving power margin and expanded time slots that can be used when rain fade occurs.

At this stage of development the main strategy that satellite operators and manufacturers are inclined to use is to find better ways to reuse frequencies in the microwave and lower millimeter wave bands such as 30Ghz/20 GHz (i.e., Ka bands and the 48/38 GHz – Q/V – bands) rather than migrating to the W and E band frequencies at 60 GHz and higher. The other option still remains, which is to seek even more efficient encoding and digital compression techniques to send more information per hertz.

Of course, the tendency is to push in all of these directions in order to find the best combination of technical advances that give the most bang for the buck; this is to say the most productive and cost-effective solution. The famed baseball catcher and quipster Yogi Berra once said: "When you come to a fork in the road, take it." The satellite industry is indeed pursuing all the forks in the road.

New Manufacturing and Quality Assurance Capabilities

There have been some true breakthrough capabilities in the space applications industry in the past decade with regard to the design, manufacture and quality assurance testing. This has let the cost of designing, manufacturing, and quality assurance testing of satellites to drop significantly. In many instances the designing in of quality into the manufacturing processes has allowed the cost of quality assurance testing to drop dramatically.

New Launch System Efficiencies

For over a half century, the largest barrier to cost efficiencies in the space industry has been the relatively static cost of launch vehicle services. The developing of reliable launchers in China and India and other countries started a downward trend in launch costs. Then a number of new commercial launch companies began to develop new designs and new approaches to developing and deploying rocket systems. Some of these efforts involved developing carrier systems to launch space systems or rocket launchers from high altitude, and a few involved new fuel systems and greater launch safety. Other systems involved new modes of manufacture – even 3D printing, or additive manufacture of rocket engines.

Perhaps most significantly Elon Musk's SpaceX has sought to develop rocket systems that might be reused rather than be considered expendable vehicles. Musk has not only demonstrated that rocket systems can be successfully reused but they can be landed with precision at preset points. His objective is to develop rocket systems that can be reused twenty to twenty-five times with a minimum of refurbishment [8].

And Jeff Bezo's Blue Origin company has indicated that their rocket systems will follow a very parallel path and that his rocket program should be able to support space tourist flights as well [9].

The bottom line is that there is a new array of approaches to launching systems into space that are significantly lower in cost. These new developments are a part of the Space 2.0 revolution.

The Structure of This Book

This book is an introduction to the world of NewSpace and the many changes that are occurring in space industries. The technologies that are being used today owe their heritage as much to companies of Silicon Valley and their emulators around the world than to the traditional aerospace companies and the space agencies. These technologies are thus new, different and in some cases revolutionary. The type of space industries and the new space applications are also different, as we are seeing the spread of new ways to derive value from space services. This then has led to new business models and new approaches to the regulation and governmental oversight of the various types of space industries.

As mentioned earlier, these many changes to the world of space applications are sometimes referred to as either Space 2.0 or NewSpace. This book seeks to cover all of these changes in the world of space and to explain how they have occurred. This first chapter has sought to introduce how and why the space industry has changed in a fundamental way in the past decade and why the revolution will continue for many years to come. The rest of the book seeks to describe these many changes into a greater detail and explain key components of them so that one can see how the various parts form a new whole that is at once exciting and able to offer new opportunities to investors and global consumers. It is also a time of tremendous challenge to engineers, space entrepreneurs and space business leaders, as well as those involved in the regulation and oversight of this totally new era of the space enterprise.

To summarize the contents of the chapters:

Chapter One. The World of Space in Flux. The world of space applications is today in enormous flux. This chapter seeks to identify the most significant changes in space systems technology and changes in market applications that are bringing new participants into the field, and the most vital forces that are reshaping the most important changes in today's space markets. The changes include not only new technologies and applications but new vulnerabilities and concerns that will reshape the future.

Chapter Two: How Satellite Communications Systems Are Changing. The largest, most well-established and perhaps the most profitable space industry today is the satellite communications and network services industry. Today, this largest space industry is changing because almost everything has changed. There are new ways to design, manufacture, and test the satellites plus new types of Earth stations and new launch options. Even the deployment configurations in orbit have changed as well as the latest encoding concepts. Most industries can change because one of their dimensions has changed. Rarely do five major dimensions change at once, and the future promises even greater change as the markets adopt new technologies.

Chapter Three: Key Trends in Remote-Sensing Satellite Systems Systems. The world of remote sensing has seen the same chaotic change as has been experienced in satellite communications. Small satellite systems have not only lowered the cost of building and testing remote sensing satellites but have also dramatically decreased launch costs. Since remote-sensing satellites do not require high gain and larger aperture antennas, the small satellite revolution came earlier to the world of Earth observation, and we now even see remote-sensing satellites capable of delivering hyper spectral sensing services.

Chapter Four: The Growth and Expansion of Precision Navigation and Timing. The big question in satellite applications is when will we see a major revolution in the world of satellite navigation and precise timing satellites? The high cost of atomic clocks has to date not allowed for major breakthroughs in the cost of space systems, but remarkable progress in the decreased cost of user units. The fact that today's smart phones are universally equipped with global navigation satellite service (so-called sat-nav capability) has turned this service into the second largest space application. If it is ever possible to reduce the cost of the atomic clocks it will also create a revolution in space-based systems as well. Even without such a breakthrough, the applications are expanding rapidly, and the number of systems being deployed around the world is also multiplying.

Chapter Five: The New Capabilities of Weather Satellites. Weather satellite systems are still largely governmental operations, but the technology and the capabilities continue to expand. New systems with lightning trackers can pinpoint where storms are most intense and their immediate tracking vectors. There are also new capabilities to track and monitor climate change and also to provide much closer tracking of solar storms, radiation flares and coronal mass ejections. These capabilities are critical to protecting vital resources such as satellites, electrical grid systems and vulnerable pipeline control systems.

Chapter Six: New Uses of the Protozone. One of the most important new areas of space applications are not in space at all but involve the use of the area above commercial air space and below orbital space. This area, sometimes called sub-space, near-space or the protozone, is now an area of intense study with many new applications either under study, in experimental use or actual use. Here there are a number of competing technologies and applications that give rise to many regulatory and safety issues.

Chapter Seven: On-Orbit Servicing and Repurposing of Defunct Satellites. Another space application that has been the subject of experiment and testing for years involves on-orbit servicing. Finally, this technology has reached a level of maturity that it now seems ready to reach liftoff potential. After years of speculation by space experts, there are now beginning to be actual commercial ventures seeking to provide a wide range of in-orbit servicing, retrofit, satellite repositioning and even in-orbit construction and processing.

Chapter Eight: Space-Based Solar Power Satellite Systems. For some fifty years there has been speculation about the potential of solar power satellites and their potential to bring clean energy to the world on a 24/7 basis. Breakthroughs in space technology and ground rectenna system design suggest that these types of systems might be able to become financially viable in the not too distant future.

Chapter Nine: Space Weapons, the Threat of War in Space and Planetary Defense. The divide between civilian commercial activities and defense-related applications is a part of this discussion. The possibility of creating ‘space forces’ and the possibility of conflict in space is one of the major issues that could alter or even reverse the rapid rise of new commercial space applications. Cosmic hazards and manmade nuclear denotations that give rise to electromagnetic pulses are just some of the concerns that space operators must consider, along with frequency interference and orbital space debris.

Chapter Ten: Trends in Chemical Rocket Systems and New Approaches to Launching Satellites. Many of the changes in today's space applications comes from the development of new more cost-effective and flexible launch systems that are more reliable, cost-effective and versatile than launch systems of the past. Many suggest that the whole new Space 2.0 revolution is due to the changes in commercial launch capabilities and their ability to support small satellite launches and other new types of space deployment requirements.

Chapter Eleven: The Longer Term Future of Launch and Propulsion Systems. The revolution in launcher systems and better ways to get space systems in orbit and operate suborbital flights for space systems is, in some ways, just beginning. There are a range of new space technologies that are under research and development. Some of these systems seem on the brink of moving forward, such as electric propulsion systems, while others may still be some ways away from operational service. The status of these technologies and their potential for the future will be examined and explained.

Chapter Twelve: Spaceplanes, Space Tourism and Private Space Habitats. Some of the big new areas of commercial space development that have perhaps made the public most aware of the Space 2.0 revolution have been the developments in the area of commercial spaceplanes and commercial space habitats. The Burt Rutan and Paul Allen spaceplane ride into space in 2004 in order to win the X-Prize in 2004 was seen as the true kick off for these private ventures to fly into space. Billionaires Richard Branson and Jeff Bezos are now racing to be the first to offer civilian rides to space on spaceplanes that make suborbital flights. Meanwhile billionaire Robert Bigelow is now testing an inflatable habitat on the International Space Station as a prelude to offering private citizens the opportunity to stay in space on a private space station.

Chapter Thirteen: Space 2.0 Economic, Business and Regulatory Issues. The future of space applications does not depend on technology or developing new business markets alone. Rather the key to the success of these new space applications may well depend on new regulatory agreements on how to provide legal or administrative guidelines for the operation of these activities. Some of the top issues currently under debate at the national, regional and global level will be discussed.

Chapter Fourteen: The Way Forward. This book will end with summarizing the top trends in the world of space applications that are critical to the future success of commercial space and the potential of space to become one of the leading areas of expanded commercial applications in the decade ahead.

Conclusions

In these fourteen chapters, a brief history of the many space applications and their technological development will be provided. This will be accompanied by a current status review of the many changes that are occurring in ground systems and in the financing and start-up of new ventures in the field. Perhaps most significantly this book will touch on the very latest innovations in technology and space markets. This will allow the tracing of the latest trends to see how they will allow a continued rapid expansion of space systems and services within the next decade. Thus, the rapid evolution of space technologies, services and markets will be reviewed, and key trends for the future explained. In the coming decade, it is quite likely that the multi-billion dollar space industry will make great strides toward becoming a trillion dollar enterprise if current technological, business and regulatory challenges are successfully overcome.

References

1. Frischauf, N., Horn, R., Kauerhoff, T.I., Wittig, M., Bauman, I., Pellander, E., Koudlka, O.: New space: new business models at the interface of space and digital economy: chances in an interconnected world. New Space. **6**(2), 135–146 (2018). https://doi.org/10.1089/space.2017.0028
2. Levy, S.: Jeff Bezos wants us to leave earth for good - inside Blue Origin's mission to an alien future. Wired, **55** (2018). https://www.wired.com/story/jeff-bezos-blue-origin/
3. Pelton, J.N., Marshall, P.: Megacrunch: Ten Survival Strategies for 21st Century Challenges. The Emerald Planet, Washington, D.C. (2010)
4. Berry, E.: India launches 104 satellites from a single rocket, ramping up a space race. New York Times. https://www.nytimes.com/2017/02/15/world/asia/india-satellites-rocket.html (15 Feb 2017). Accessed 17 May 2018
5. Pelton, J.N., Madry, S., Camacho-Lara, S.: Introduction to satellite communications. In: Handbook of Satellite Applications, 2nd edn. Springer, Basel (2017)
6. Why Kymeta. https://www.kymetacorp.com/why-kymeta-connectivity/. Accessed 18 May 2018
7. Phasor successfully completes broadband satellite transmit tests from a moving platform. http://www.phasorsolutions.com/news-1/phasor-successfully-completes-broadband-satellite-transmit-tests-from-a-moving-platform (27 Sept 2016)
8. Wall, M.: Elon Musk says SpaceX will reuse a rocket within 24 hours in 2019. Space.com. https://www.space.com/40581-spacex-reusable-rocket-goal-elon-musk.html (15 May 2018)
9. Wall, M.: Jeff Bezos' Blue Origin to launch reusable rocket again Saturday. Space.com. https://www.space.com/32451-blue-origin-reusable-rocket-launch.html (1 Apr 2016)