Manfred "Dutch" von Ehrenfried

STRATOSPHERIC BALLOONS

Science and Commerce at the Edge of Space

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Dedication

This book is dedicated to all of the scientists, graduate students, engineers, technicians, managers and administrators that supported the scientific balloon flights of past generations; to the corporations and organizations that have pioneered the use of stratospheric balloons for commercial applications; and to the international scientific organizations and commercial enterprises that also strive, in their own unique way, to advance the state of the art of ballooning.

A special dedication goes to those students, of all ages, who are participating in ballooning as part of their studies of science, technology, engineering, and mathematics. While they may not yet know their future career paths, it is to be hoped that some of them will join the next generation of balloonists and that their participation will lead to a better understanding of our place in the universe. At least we know from others who blazed the trail before them, that their lives and society will be enriched by their efforts.

This book is also dedicated to those in a position to guide NASA in its use of balloon programs for the advancement of science, including the Science Mission Directorate at NASA Headquarters which funds the Balloon Program. Within that organization are the various science divisions that manage, support, and fund scientific balloon missions.

And this book is dedicated to the organizations that conduct balloon missions, notably the Wallops Flight Facility of the Goddard Space Flight Center, which includes the Balloon Program Office and their operational site; the Columbia Scientific Balloon Facility.

And last, but not least, this book is dedicated to the students who have actually taken part in launching balloons as part of their studies. Not only have they been working towards graduating, they have been learning the fundamentals of balloon operations including pre-flight preparations, flight operations, recovery, and post-flight analysis. This book is therefore dedicated to the next generation of balloon scientists, engineers and technicians, for they are the future.

Foreword

The following are comments by three eminent scientists who spent their early formative careers launching instruments and payloads on balloons into the stratosphere.

Dr. John C. Mather and Dr. George F. Smoot shared the 2006 Nobel Prize in Physics for their work on the Cosmic Background Explorer that led to the "discovery of the black body form and anisotropy of the cosmic microwave background radiation". As an astronaut, Dr. John M. Grunsfeld helped to service and repair the Hubble Space Telescope. He went on to become NASA's Chief Scientist.

Their balloon experiences surely made lasting impressions on them and helped to define their scientific interests and future paths. They are truly an inspiration for young students and future scientists, as well as to those who are already involved in ballooning.

Dr. John C. Mather
Senior Astrophysicist in the Observational Cosmology Laboratory
NASA's Goddard Space Flight Center

I got my start in scientific ballooning at the University of California, Berkeley. I was looking for a Ph.D. thesis project in 1970, after two years of graduate school classes on particle physics and relativity and quantum mechanics and studying in the library, and I was giving up on my dream of being a theoretical physicist like Richard Feynman. I really wanted to build something. I felt my hands itching to hold a screwdriver. I found Paul Richards and Charles Townes and Mike Werner, who were all thinking about how to measure the newly discovered Cosmic Microwave Background Radiation. I said yes, I want to play! So the first project was to build an instrument and take it up to White Mountain in eastern California, on the east side of the Owens Valley. We built it and it worked, and we learned a new technology, but it wasn't surprising, it just agreed with expectations that the cosmic background seemed to have a temperature of about 3 degrees Kelvin.

Then Paul went off to England for a sabbatical and came back with an idea for a balloon payload that could get an instrument above most of the interference of the Earth's atmosphere. It would be a satellite on a string, as I called it. The plan was to make a new kind of interferometer, which Paul had learned about in England, called a Polarizing Martin-Puplett, and use it as a spectrometer. It would measure the temperature of the cosmic background radiation at wavelengths from about 0.5 mm to 5 mm if we were lucky. It would have to be immersed in a bath of liquid helium, it would have to fly to an altitude of 40 km, and it would have a window that would open up after the payload had reached the target altitude. It had all the ingredients of a satellite, except it wasn't going to really be in outer space. It had a big battery (although no solar cells, it wouldn't operate in the daytime), a radio transmitter and receiver, some command processors, a magnetometer so that we would know which way we were pointing, electronics boxes to operate the motors and detectors, and a big rotating momentum wheel to control the orientation. It fit inside a 2 m cubical frame made of aluminum. We built it up and tested it in the lab at Berkeley until it seemed to work the way we hoped and expected. David Woody and I were now the lab partners working on it, so we loaded it into a big yellow university truck and drove it to the National Scientific Balloon Facility at Palestine, TX.

This place was chosen because it was very flat and not very populated, and at the right latitude so that once in a while the high altitude winds would die down and we could get a very long flight. It's a beautiful place in its own way. Many of the neighbors and staff at the base were watermelon farmers in real life, and those melons sure are juicy and sweet! At any rate we got there, set up our equipment, and got ready for the flight. We'd never seen anything like it before. The balloon is a gigantic bag of very thin polyethylene, and there is a method to unroll it and fill it partially with helium while our part, the payload, is suspended from a huge modified earthmoving machine called Tiny Tim with jaws 7 m in the air to hold the payload, until the balloon was ready to pull it up. The launch is done at dusk so the equipment will reach altitude just after dark. After a lot of fiddling and fussing, and discovering that the antenna had fallen off the payload because I'd made a bad solder joint, finally we were all ready, and up it went. It's an extraordinary sight, rising slowly and then faster, going not quite straight up, and almost out of sight.

But alas, the helium gods were not appeased. We used to keep a little Buddha in the lab and rub his tummy for good luck, but that wasn't enough. By the time our equipment reached the planned altitude, the motor turning the screw in the interferometer wouldn't go, and the preamp for the detector was sending out a big signal even though it shouldn't. We got zero scientific data and I wondered what I would do next. We got the payload back – it comes down on a parachute if we're lucky. We drove back to Berkeley with it and set to work. David thought of a way to build a test chamber to find out what was the matter, using Styrofoam boards and dry ice, which would get our big cubical frame down to the right temperature, about minus 70°C. He found out that we had three different reasons for failure. Two would have been found with the dry ice test, but the third we would have missed. The motor had rusted up because water got inside because of the 100% humidity in the evening in Texas and the cooling from the boiling liquid helium. That never would have been discovered in Berkeley.

I set to work writing my thesis. A little before that I had gotten a job offer from NASA in New York City, so I had to hurry and get finished before the golden coach turned into a pumpkin. The thesis was about the working experiment at White Mountain, and the design of the failed balloon payload. It was enough to let me finish school and take a job. My plan was to become a radio astronomer, and to give up on this cosmic background radiation work – it's much too hard for a young person. Meanwhile David and Paul and the rest of the team rebuilt the apparatus and fixed the problems and got it ready to fly again. That time it worked.

Little did I know that NASA was preparing to ask for new satellite mission proposals. A few months after I took my new job, the announcement came out, and my new boss, Patrick Thaddeus, asked for ideas. I said, my thesis project failed but we should try it in outer space. He recognized that this maybe could work, so we called our colleagues and agreed to write a proposal. I did a lot of typing and copying and editing and we sent it in. I didn't think we had a chance.

But we did. After exploring some other possibilities with us, NASA decided in 1976 to form a new scientific team and to assign an engineering team to develop the idea at NASA Goddard Space Flight Center in Greenbelt, MD. I was now 30 years old and suddenly the head scientist for an outrageously creative and difficult concept. Fortunately, I was now embedded in a team of senior people who knew what to do and how to think, and we made it work. I'll skip over a few details to say the Cosmic Background Explorer (COBE) was launched successfully on November 18, 1989 and it worked immediately. Within weeks we announced our first measurements (made with the upgraded version of the balloon payload) to the American Astronomical Society and received a standing ovation. Two years later we made our second announcement and got first page news coverage around the world. After that, more people went into the subject, an industry grew about measuring the cosmic background, and in 2006 I got a call from Stockholm.

What did I learn from ballooning? First, it's a great start for a career. Balloon payloads are small enough that a student can learn everything about one, and know something of many engineering disciplines: optics, electronics, mechanical, thermal, cryogenics, telemetry, computers; the works: teamwork, working full blast for a deadline. Second, it's humbling. Knowing that all your work can fail because of a lack of testing really changes people. And third, it's empowering. If we can build a little thing and open up a new domain of science, then let's keep on going! Who knows how far we can go?

Dr. George F. Smoot
University of California, Berkeley and the Lawrence Berkeley National Laboratory.

I have had extensive experience with scientific ballooning, having spent more months in Palestine, TX, than I would otherwise have expected.

As a young scientist it was very exciting and challenging and often dangerous to our equipment etc. From it, I learned the key disciplines of structure, check lists, and sufficient design and testing.

Once the balloon lifts off with your equipment slung beneath it, you can no longer fix it except in very limited ways – if you prepared properly ahead of time. With space research, when your satellite launches on the rocket, you'll never physically touch it again. You can only fix things you have put in redundancy. You need to have made it well in order to survive the rigors of the launch and the environment of space or near space. In that way, satellites and balloons are very alike. Their primary difference is cost and time line. Also with a satellite you usually get a much longer flight.

Before the three satellite experiments, we always had successful balloon-borne prototypes of the experiments. These all produced significant scientific results before the satellite experiments and were pioneer stages and the satellite results the next generation. That means I made three sets of campaigns to the scientific ballooning facility(ies). We were fortunate to recover fairly often with minimal damage to our equipment. We had seven flights on the first program and on one the pressure shell was destroyed, but we were able to replace it.

The second program – a CMB version – had three successful flights: two in the north hemisphere covering the northern sky and only one in the south where the payload was lost in the jungles of Brazil for nearly a year and suffered severe damage.

A next generation CMB program had multiple flights with first generation, and then a second generation with more resolution and pixels. So we not only got to develop the instrumentation, techniques and software, but we also were getting cutting edge scientific results.

Dr. John M. Grunsfeld
Astronaut and former NASA Chief Scientist

As an undergraduate physics major at the Massachusetts Institute of Technology, I was captivated by the study of cosmology, black holes, and neutron stars – the physics of the universe. After working on a theory project with Professors Ken Brecher and Philip Morrison it was time to decide on a thesis project. Professor Morrison advised that if I wanted to be a theorist, I should do an experiment in order to understand the issues with making a real measurement and how crucial experimental physics is to unravelling the mysteries of the universe. I joined a group at MIT that was building a small experiment for a high-altitude balloon to observe a highly magnetic neutron star orbiting an ordinary star, called an X-ray pulsar. This sounded exciting, but at the time I had no idea how it would change my life. My job was to prepare the sensitive detectors at the heart of the little telescope, and work with John Vallegra, whose Ph.D. thesis depended on the success of the mission, and others assembling the rest of the balloon payload. I already knew I loved building things from summers working construction jobs, and building and launching model rockets. Growing, preparing, and testing the mercuric iodide crystals at the heart of the X-ray detectors and getting them to work in the laboratory gave me great pleasure. I am at heart an optimizer, and I wanted those detectors to have the best energy resolution and efficiency possible. At the time, I did not realise I was also learning the essential elements of a field called systems engineering, and also project management. As a physicist working alongside other students who were studying mechanical engineering and electrical engineering, we had to perform all the duties that are required to engineer and manage any high-tech project.

After about a year of work we packed up and delivered the little X-ray telescope to the National Scientific Balloon Facility in Palestine, Texas in early summer of 1980. I had just graduated but wanted to see the project through, at least my part of making sure the detectors would perform. Our whole team relocated to Texas, including our advisor Dr. George Ricker. George went on to build instruments for the Chanda X-ray Observatory, and was Principal Investigator for the High Energy Transient Observatory-2 and also the Transiting Exoplanet Sky Survey Explorer. I learned an incredible amount from George about how to manage a group of talented individuals all working towards a high-performance challenge like building and fielding a scientific balloon payload. The biggest impact of the whole expedition was seeing my first balloon launch there on the plains of East Texas. In the early morning twilight, I marveled at the teamwork of the NSBF staff as they laid out the delicate balloon. With the coming of the dawn the team began to fill the balloon with a bubble of helium until the balloon slowly came to life and lifted off the launch pad. A huge industrial vehicle, named “Tiny Tim”, held the payload and drove along to position itself underneath the balloon until the whole chain of balloon, parachute, and payload were in a straight line up to the sky. At that moment, Tiny Tim released the payload and slowly the balloon ascended. I heard the thin polyethylene material rustling as the balloon climbed, heading towards its destination 130,000 feet above us. For me it was a magical experience – I had discovered the romance of scientific ballooning.

I went on to the University of Chicago in 1981 for my Ph.D., and specifically selected a group led by Professors Peter Meyer and Dietrich Muller who were working on projects using scientific balloons to study the composition of high-energy cosmic rays. I flew several balloon payloads while a graduate student at Chicago and loved every expedition. I was also given a lot of responsibility for the execution of the missions and this furthered my education in managing groups of scientists, engineers and technicians, and especially the logistics necessary to perform a scientific expedition. Following my Ph.D. I took a job at the California

Institute of Technology working with Professor Thomas Prince, again because of the group's involvement in scientific ballooning. While there I also applied to the astronaut program and in 1992 was accepted into the 14th group, reporting to the NASA Johnson Space Center.

Over the course of my career as an astronaut, flying five Space Shuttle missions, including three to upgrade and service the Hubble Space Telescope, I frequently looked back at my time doing scientific ballooning. The NASA scientific ballooning program provided me with the complete and quintessential scientific experience, going from concept to hardware, observations and scientific analysis of the results – all in the time frame of a few years. I'm convinced that knowing how to build instruments, repair them in the field, the logistics of undertaking a balloon expedition, and the technology involved in commanding and controlling the payloads, all prepared me to fly in space and perform spacewalks to fix the Hubble and my other missions.

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NASA astronaut and Chief Scientist

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Thanks everyone, I hope you like the book and find it a handy quick reference.

Preface

There is a very silent realm where few people have been but many have studied from afar. Some even dare to play there, if just for a few hours. Some have spent their entire careers studying the place, as vast as it is. I am speaking of that thin envelope that blankets the Earth, in relative terms no thicker than the skin on an apple. It provides us with the air and moisture we need, and shields us from the harmful radiation and particles that would surely annihilate life. In particular, I'm addressing that portion of our atmosphere we call the stratosphere. This is a huge and potentially dangerous place that even astronauts scurry through on their way to space.

While this portion of the atmosphere varies with latitude and with the season, we can approximate the definition (for the purposes of this book) as altitudes between roughly 18 km (60,000 ft) and 50 km (164,000 ft). This swath of very thin air is a region that we are seeking to address for both scientific and commercial reasons. It is above the weather, but below orbit. To reach it costs a fraction of the cost of using launch vehicles and spacecraft to conduct experiments from orbit.

There are literally thousands of people who study this area today, and there were thousands before them. Most of them used very special kinds of balloons to give them the information they wanted. Some of these vehicles are quite sophisticated, as they need to be in order to investigate the broad range of sciences they support.

To be a bit more specific, this book will describe what is happening today in the world of science as well as the world of commercial uses of the stratosphere with balloons. This book will cover the new world of 21st century balloon flights. It is hard to believe there have already been 2,300 stratospheric flights since 1962. The pace seems to be increasing. In 2018 there were 181flights and in 2019 there were 218 flights. The 2020 numbers are lower because of the Covid-19 pandemic. Most of the recent flights have been commercial rather than scientific. As of this writing (in late 2020), there are about a hundred commercial balloons flying today all over the world.

Balloon-borne instruments have studied the atmosphere in many wavelengths, studied the Earth and the heavens, and have used or invented a wide variety of instruments to obtain the desired data. Observations have ranged from bacteria and viruses in the upper atmosphere to dust clouds in distant galaxies. This new era of balloon flights makes use of the digital world, the "internet of things" and interconnectivity. While the internet seems to rule the world, roughly half of the world's population is not connected to it and hence are excluded from the socio-economic benefits of digital connectivity. Most of us can't image a world without the internet, yet billions of people long for the day they achieve access to it. Many nations can't afford the necessary infrastructure. But there is another way! There have been thousands of commercial stratospheric balloon flights, most having to do with providing internet connectivity to unserved or underserved populations.

What was once the realm of the scientists, now there are down-to-Earth balloon applications related to the survival of people who have just suffered a disaster such as a hurricane, tornado, or flood. It is now possible to provide broadband phone service for natives in the remotest villages. It is now an era of providing seamless communications and navigation to maritime shipping, surveillance of drug traffickers, illegal border crossings, and of course military applications. These new applications have required the expansion of real-time operations, coordination with both national and international users of airspace, and rapid recovery of payloads in remote areas. Balloon flights can often go from one country to another, and even from one continent to another. There are some countries which do not permit balloons in their air space, regardless of their purpose. This impacts mission planning, site selection, navigation, flight and recovery operations.

The invention and perfection of the "super-pressure" balloon, together with the state of the art of meteorology, offers the seemingly uncanny ability to not only control a stratospheric balloon but also to control – to some degree – its relative position and time over a particular site. Although not as precise as for example a geostationary satellite, it is possible to control a balloon to a sufficient degree to acquire the desired target of interest at a considerably reduced cost.

There are now many applications for balloons that would have previously been considered folly, and not that long ago either. While we expected that someday tourists would want to go to space, we didn't envision them going to 100,000 feet in a novel gondola with WiFi, a bar, music and rest rooms. This is actually being planned today. It brings new meaning to the expression "up, up and away"! For only $X, you too can be a "Stratonaut" and be awarded a Certificate to prove it! While that sounds bizarre, there is now another company that will improve your company's brand by lofting your product or logo into the stratosphere and taking photos and video for streaming to your customers and prospects. KFC has already sent their new Zinger sandwich up to 30 km (100,000 ft). While many students are learning about science and launching their simple experiments to the stratosphere, others have seen the financial potential and have started businesses to launch your favorite photos or possessions and take a picture of them with the curvature of the Earth in the background as a prized possession for only $X. It will be interesting to watch the explosion of commercial applications for stratospheric balloons.

This book will discuss these scientific and commercial balloon flights from sites all across the world. It includes explanations of the many types of balloons, their applications, launch locations, and the companies that produce them. Included is NASA's Balloon Program and their launch capabilities and facilities. There is also a list of the international organizations and their balloon programs. Also included is a partial list of balloon flights that have made contributions to unique scientific discoveries, as well as what numerous scientific organizations, including NASA, have contributed to the history of ballooning.

One of the major focuses of the book is the role student's play in ballooning and the importance of keeping them interested in studying the sciences, technology, engineering and mathematics. There are literally thousands of students – of all ages – actively involved today in launching balloons and learning from those experiences. Many schools and universities have balloon education programs with hands-on experience. Similarly, corporations actively involved in ballooning have education programs at their home offices. These activities feature in the chapter entitled "Educating the Next Generation". It is to be hoped this book will inspire students to stay involved in ballooning, for they truly are the next generation of scientists and engineers that will explore the world and the universe beyond. The book gives interesting topics to study and includes over 100 images, many hours of videos, and references to the literature.

Three Nobel Prize winners and other internationally renowned scientists spent their early careers using balloons to carry their instruments into the stratosphere. Along the way, young graduate and postgraduate students assisted their principal investigators and fellow scientists in conducting experiments. They now carry the torch that lights the path to new discoveries of the 21st century.

It is hoped that this book will contribute to young people's interest in ballooning and inspire them to study the sciences, technology, engineering and mathematics subjects that are essential for many careers.

Manfred " Dutch" von Ehrenfried
Cedar Park, TX, USA
Winter of 2020-2021

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1

Introduction

A Brief History

Balloons have been around for over two hundred years. Some accounts go back three hundred years. Louis XVI and Marie Antoinette loved to watch them. So did Benjamin Franklin and his son, who witnessed some of the first flights. Certainly one of the first scientists ever to go aloft was Jacques Charles, French inventor, scientist, mathematician, and balloonist. Today, we know him best by Charles' Law that describes how a gas expands as the temperature increases; conversely, a decrease in temperature will lead to a decrease in volume. This fundamental law of physics is known to every balloon scientist. But two thousand years earlier, Archimedes of Syracuse discovered an even more basic law when thinking about "floating bodies" and buoyancy. Balloons are, indeed, floating bodies buoyed up by the weight of the air they displace.

Balloons have been used for just about anything you can think of, be it for good or for ill. It only took eleven years after the first untethered balloon flight for the French to realize the military applications of the technology. The first use was on June 2, 1794 for reconnaissance during an enemy bombardment. Fast forward less than a hundred years and Thaddeus Lowe was telegraphing a message to President Lincoln to demonstrate the balloon's application during the Civil War. He soon became Chief Aeronaut of the newly formed Union Army Balloon Corps. Of course, there was a little bit of unrecognized technology transfer going on even then. Count Ferdinand von Zeppelin, then aged 24, was visiting the U.S. and observing Lowe's flights. He took his new found knowledge back to Prussia and certainly capitalized on what he learned about balloons.

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Fast forward only to the end of the 19th century, and there were two French meteorologist sending up sounding balloons with instruments. Two Prussians, Professor Reinhard Süring and Dr. Arthur J. S. Berson ascended in balloons to take temperature and pressure readings. At 10.8 km (35,432 ft) they dozed off from lack of oxygen, but luckily they awoke in time to land safely. Professor Richard Assmann and Leon De Bort published a paper in 1902 that vertically separated the atmosphere into the troposphere and stratosphere. A quarter of a century later, the Manual of Meteorology said this was "the most surprising discovery in the whole history of meteorology".

While this book is not a history of human balloon flight, there was certainly some balloon science going on at altitude during the 1920's and 30's but the frailties of man clearly showed it was not the place to be for very long. Many people died in balloon accidents caused by everything from fire, hypoxia, and altitude sickness to crashes. It was clear that more science could be obtained with uncrewed flights.

If ever there was a "first family of the stratosphere" then it would be the Piccards. This includes Auguste Piccard, his twin brother Jean, Jean's wife Jeannette, and their son Don who, with Ed Yost, was the first to cross over the English Channel in a hot air balloon, plus Bertrand, grandson of Auguste, who, with Brian Jones, was the first to fly around the world in a balloon.

Advance just another generation or so to WWII and the Cold War and we saw the Japanese bombing the U.S. using balloons, and the U.S. using balloons to spy on Russia and to explode nuclear weapons in the atmosphere.

Now we are using balloons for science as well as commerce, even for providing internet services to remote areas and to those impacted by natural disasters such as hurricanes.

Today

This book is all about balloons rising through the troposphere and deep into the stratosphere, even into the mesosphere. For the general observer the troposphere reaches beyond the tops of the thunder clouds, which can go as high as about 20 km (65,600 ft). Most of the clouds you see are in the troposphere. But there can also be clouds in the stratosphere, which extends from the top of the troposphere up to what is generally defined as the top of the second layer at 50 km (164,000 ft), although this boundary varies with latitude. One can rarely see the clouds in the mesosphere; for example, noctilucent clouds or night shining clouds, which are tenuous cloud-like phenomena that occur in the upper atmosphere. They are the highest clouds and are located in the mesosphere at altitudes of around 50 to 85 km (164,000 to 279,000 ft). This is an area above the maximum altitude for aircraft and balloons, but below the minimum altitude of orbital vehicles. The mesosphere is the least understood portion of the atmosphere. It is of scientific interest but is beyond the current capabilities of balloons, although a couple of balloons have reached the lower levels for short periods. Sounding rockets have only brief access to the mesosphere and provide much less data.

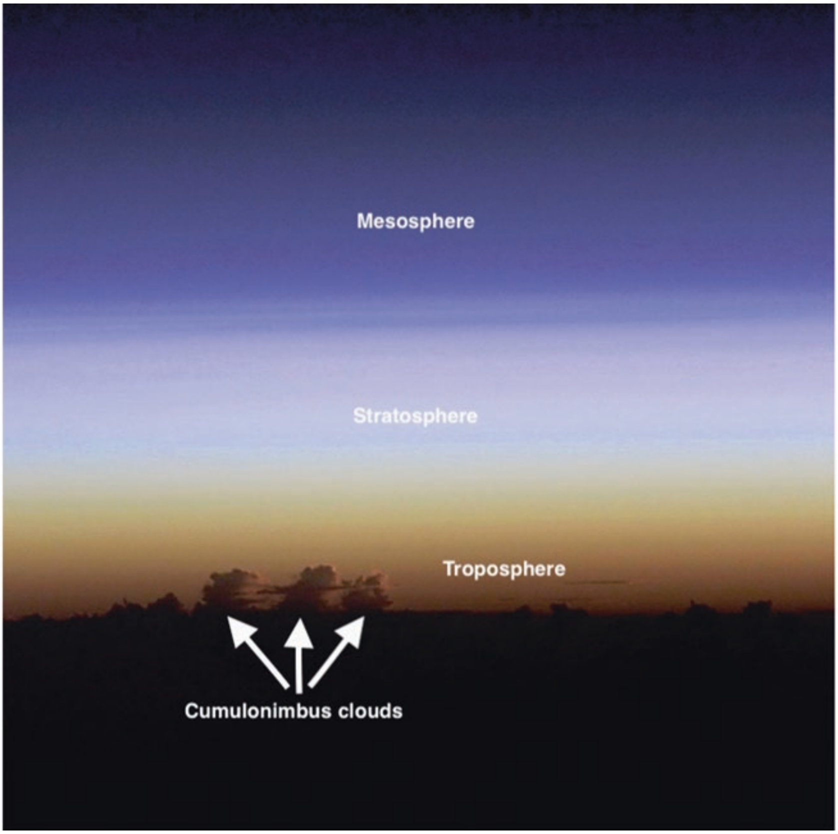

Fig. 1.1 The atmosphere. A look at our atmosphere from the U.S. Space Shuttle with cumulonimbus clouds, the troposphere (orange), stratosphere (white-blue), and mesosphere (dark blue) areas indicated. Photo courtesy of NASA.

Balloon flights in the lower troposphere have to contend with various winds and the decrease of temperature and pressure with altitude. In the upper troposphere there have been major problems due to the extremely low temperatures and their effects on the envelope of the balloon. The temperature averages −51°C (−60°F) near the tropopause, the boundary with the stratosphere. The film of the envelope can become very brittle. Balloons have failed and their missions lost. NASA and their balloon manufacturers made major efforts to investigate this problem and to develop and test alternate films to solve it; successfully. Then in the stratosphere the temperature begins to increase, attaining an average of −15°C (5.0°F) near the mesosphere.

The stratosphere is stratified (layered) in temperature, with warmer layers higher and cooler layers nearer the Earth. This increase of temperature with altitude is a result of the absorption of the Sun's ultraviolet radiation by the ozone layer. This is in contrast to the troposphere below, in which the temperature decreases with altitude. Temperatures also vary within the stratosphere as the seasons change, reaching particularly low temperatures in the polar winter night. The winds in the stratosphere can reach nearly 209 km/h (130 mph) in the southern polar vortex. Balloon scientists seem to love to fly astrophysics balloons there, watching them circumnavigate Antarctica and then recovering their payloads nearby.

Over just the past generation the sophistication and complexity of payloads has steadily increased, in some instances potentially yielding scientific returns that can rival or exceed what can be accomplished in a much more expensive orbital mission. In fact many instruments and components flown, tested and developed on balloons are later adapted for spacecraft.

Scientific balloons have been perfected with the unique capability for ultra-long duration flight above 99.5% of the atmosphere, widely referred to as the edge of space. They are unique in being able to maintain sustained flight altitudes in the upper stratosphere, enjoy a relatively short development time from the inception of a scientific research project and flight, and expand the frontiers of Earth and space sciences at low cost. Scientific balloons carry considerable payloads and can enter the stratosphere and remain there for extended periods of time, all the while obtaining data to provide a better understanding of the world, or in some cases the universe. The demand for balloon flights outstrips NASA's ability to launch them. At any given time there is often a backlog of missions waiting for flight which both delays the delivery of science to the community and increases its associated cost.

Launch Sites

Scientists are very particular about where they want to launch their precious balloon payloads. They have spent years designing them for a specific purpose and have spent a lot of time, energy and money on them. Some want to go as high as possible, some want to carry as much weight (payload) as possible, some want to stay aloft as long as possible, and some want to go to a specific geographical area or look in a particular direction. All of these different requirements dictate a launch site, or a select number of sites. Hence, considering the number of nations involved in ballooning there are many sites around the world.

NASA operates several sites for those missions designed for test and technology evaluation that offer safety and satisfactory air traffic control. Some of those also satisfy scientific requirements. NASA has agreements with the National Science Foundation (NSF) to use their site at Williams Field in McMurdo, Antarctica as well as agreements with Australia, Sweden, New Zealand, Brazil, and others. International scientists also use these as well as their own launch sites. This book discusses all the different organizations, both foreign and domestic, involved with stratospheric balloons. There are tens of thousands of people all over the world involved in scientific ballooning, not counting those involved in sport ballooning and world competition.

Some commercial companies have developed their own launch site capabilities and have made arrangements with their sponsor countries. For example, Loon launches many flights from Puerto Rico, Kenya and other countries where they support the government by providing internet services. World View Enterprises launches balloons from their Tucson, AZ facility. Those wanting more northern latitudes use sites in Norway, Sweden and Canada. There are also launches from sites in France, Spain, India, Hawaii, China and Japan.

Small balloons such as weather balloons are launched from hundreds of locations all over the world. It is interesting that high school and college students often use small balloons for experiments that are launched locally, in coordination with air traffic control.

The Future

There are balloons planned for the near future whose wide-field-sky imaging capability meets or exceeds that of the Hubble Space Telescope, expanding on that heritage of discovery at a fraction of the operational cost. The operational cost of Hubble is $98 million per annum and it is over subscribed. So scientists are employing the latest in balloon design and instrumentation to achieve their objectives. Because many flights were canceled in 2020 owing to the Covid-19 pandemic there is a backlog for the 2021 manifest. Antarctic flights must fly in the austral summer, hence there is a relatively short window in December and January for observation and recovery of their experiments.

Commerce

While science teams are developing the latest designs and preparing for the next season of ballooning, there is another group who are new users of balloons: the "commercial" balloonists. Balloons have progressed into many aspects of the world of commerce. Once balloon meteorologists and engineers had conquered the winds they were no longer at their mercy. The hot air balloonist would drift anywhere and everywhere, even into power lines, houses and lakes, but modern balloonists have learned to exploit the winds to their advantage. Even Columbus knew he had to use the wind for both speed and navigation on the ocean. These new balloonists have used the latest state of the art in meteorology to pick and choose the best altitudes to navigate to their desired targets and even to "persist" in the vicinity of their targets. In effect balloons are now providing a needed and marketable set of services, rather than just drifting with the wind and acquiring scientific data along the way. Nevertheless, the flight controllers cannot always tame the winds and many a payload has been lost at sea.

Delivering internet services to unserved and underserved regions of the world, the Loon Project is somewhat representative of balloon commerce up thru 2020.

This service also includes providing emergency services on a demand basis when a disaster strikes. They have learned to launch constellations of balloons, using an autolauncher that puts one balloon up after another. Up until 2021, they have been launching more balloons than NASA or anybody else.

Other international companies are also competing for this type of service. One, the High Altitude Platform Station (HAPS) Alliance, has the target of ensuring member companies can collectively advocate for HAPS business development with the relevant authorities in various countries to create a cooperative HAPS ecosystem, develop common product specifications and promote standardization of HAPS network interoperability. All of these activities are key to the Alliance's aim of creating new value by providing telecommunications network connectivity worldwide through the utilization of high altitude vehicles including balloons and aerostats. Other balloon commerce is structured to provide basic services across the spectrum to the point of designing, manufacturing, launching and recovering customer payloads, be these scientific, commercial, safety or military. There are such companies all around the world.

One company, World View Enterprises built a huge balloon complex in Tucson, AZ and started off by providing internet services and supporting some scientific missions, then expanded to providing a broad range of services for both science and commercial flights. In 2019-2020, they continue to develop their Stratollite balloon and Stratocraft gondola, making several test flights called GRYPHON. Two of the original owners of World View Enterprises started another company, Space Perspectives to provide flights for tourists to the edge of space. They have plans to launch tourists from the Kennedy Space Center's Space Shuttle landing area and recover them in the Atlantic Ocean for return to Florida on a ship. They are also considering other locations including landing in the Gulf of Mexico and off Hawaii in the Pacific Ocean.

The vision of the commercialization of stratospheric balloons has reached the point where a company can advertise their products by photographing them from 30 km (100,000 ft) with the curvature of the Earth in the background and stream the images to the internet, and then to their customers and prospects. But this is nothing new. Even the Montgolfier brothers teamed with wallpaper manufacturer Jean-Baptise Reveillon to construct their balloon with beautiful, embellished art to advertise their wall paper designs.

But the well-funded companies have some competition. There are high school children who, for a modest price, will launch just about any small, lightweight object into the stratosphere, including a picture of a wedding couple or a bobble head doll of Captain Kirk, and provide an image of it with the curvature of the Earth in the background. In addition to basic laws of physics they have learned the rules of supply and demand – the tools of finance and entrepreneurship. The balloon world has evolved from Noble Prize winning science to the essence of human nature.