Sky Alert!

When Satellites Fail

Les Johnson

Sky Alert!

When Satellites Fail

Springer

Published in association with
Praxis Publishing
Chichester, UK

Les Johnson
Madison
Alabama
USA

SPRINGER–PRAXIS BOOKS IN POPULAR SCIENCE
SUBJECT *ADVISORY EDITOR*: Stephen Webb, B.Sc., Ph.D., M.Inst.P., C.Phys.

ISBN 978-1-4614-1829-0 ISBN 978-1-4614-1830-6 (eBook)
DOI 10.1007/978-1-4614-1830-6
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2012947008

Cover design: Jim Wilkie
Project copy editor: Christine Cressy
Typesetting: BookEns, Royston, Herts., UK

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Dedicated to my parents, Charles and June Johnson.
Although they are no longer on this Earth,
they shall never be forgotten.

Acknowledgment

I would like to thank my long-time friend and colleague, Dr James Woosley, for contributing Chapter 15 and for being part of the brainstorming sessions that ultimately led to this book being published.

About the Author

Les Johnson is an author of popular books about space exploration and a science-fiction novelist. He also serves as the Deputy Manager for NASA's Advanced Concepts Office at the Marshall Space Flight Center in Huntsville, Alabama, where he was a co-investigator for the JAXA T-Rex Space Tether Experiment and PI of NASA's ProSEDS Experiment.

His popular science books include *Living Off the Land in Space* (Springer/Copernicus, 2007), the 2008 PROSE Award finalist, *Solar Sails: A Novel Approach to Interplanetary Travel* (Springer/Copernicus, 2008), and *Paradise Regained: The Regreening of Earth* (Springer/Copernicus, 2009). His science-fiction novel, *Back to the Moon*, was published in hardcover (2010) and paperback (2012) by Baen. His latest science-fiction book, *Going Interstellar*, was published in May 2012.

During his career at NASA, he served as the Manager for the Space Science Programs and Projects Office, the In-Space Propulsion Technology Program, and the Interstellar Propulsion Research Project. He twice received NASA's Exceptional Achievement Medal and has three patents.

He earned his master's degree in physics from Vanderbilt University (Nashville, TN) and his BA at Transylvania University (Lexington, KY). He participated in the International Space University's 1993 Summer Session Program in Toulouse, France. Les has numerous peer-reviewed publications and was published in *Analog*. He is a frequent contributor to the *Journal of the British Interplanetary Society* and has been a member of the American Institute of Aeronautics and Astronautics, National Space Society, the World Future Society, and MENSA.

Contents

Chapter Summaries

Much of the world now depends upon space technology economically, politically, and militarily. Without satellites, many of our factories and distribution systems would break down and our "just in time" inventory systems would at least temporarily stall, interrupting the flow of food, medicines, and commodities to our stores and markets. Without spy satellites, our military would be operating blind, thereby increasing the likelihood of conflict through fear and opportunism by our potential adversaries. We have become dependent upon space – and we are mostly ignorant of that fact.

The exploration and use of space began in 1957 with the launch of Sputnik 1 by the Soviet Union. Since then, the nations of the world have launched over 8,000 spacecraft. Of these, several hundred are still providing information and services to the global economy and the world's governments. Over time, nations, corporations, and individuals have grown accustomed to the services they provide and many are dependent upon them. Commercial aviation, shipping, emergency services, vehicle fleet tracking, financial transactions, and agriculture are areas of the economy that are increasingly reliant on space.

For example, the Global Positioning System (GPS), a network of satellites in low-Earth orbit (LEO) developed to provide precise position information to the military, is now in common use by individuals and industry. Another example is communications. Since Telstar-1 initiated worldwide television transmission in 1962, now-ubiquitous cable television signals are sent to local providers via satellite relay. The science of weather forecasting is now totally dependent upon continuous real-time information from multiple satellites circling the globe. These are but a few examples of areas in which we now depend upon space technology.

As we've grown dependent upon space, so have we been sowing the seeds of a problem that might ultimately deny it to us. Dead satellites, spent rocket stages, and bits of debris from a satellite deliberately obliterated in orbit make up a sizable portion of an estimated 500,000 pieces of debris now circling the Earth – any one of which is traveling fast enough to destroy a functioning satellite if it were to collide with one. According to the experts, we are dangerously close to the point at which a runaway series of collisions could pump so much debris into orbit as to make it essentially unusable.

Unfortunately, space is now a potential area for conflict. The detonation of one or more nuclear weapons in Earth orbit could have two disastrous consequences for inadequately protected satellites. First is the immediate damage to spacecraft electronics from the high-energy electromagnetic pulse generated by the bomb. Without functioning electronics, a spacecraft becomes

L. Johnson, *Sky Alert!: When Satellites Fail*, Springer Praxis Books, DOI 10.1007/978-1-4614-1830-6_1, © Springer Science+Business Media New York 2013

an orbiting piece of junk. The second is the longer-term degradation and loss of spacecraft electronics resulting from repeatedly passing through the artificial radiation belts that would be created from the detonation of a nuclear bomb in orbit.

The threats to our satellites are not all made by the human race. The Earth periodically experiences geomagnetic storms. These storms occur when a solar wind shock wave strikes the Earth's magnetic field after some increase in solar activity like a flare. Associated with these storms are dramatically increased radiation levels which are potentially damaging to spacecraft and their electronics.

Part 1: How We Might Lose Our Satellites

Chapter 1: Orbital Debris

The human-caused orbital debris problem is bad and getting worse. There are currently over 500,000 nonfunctional spacecraft and pieces of junk orbiting the Earth at five miles per second or faster. Despite the fact that the space around the Earth is big, pieces of debris do collide with each other and with functioning spacecraft. When a collision happens, many more pieces of junk are created, increasing the risk for the remaining satellites. In early 2009, two satellites collided with a relative speed of over 26,000 miles per hour. Both satellites were destroyed and the debris cloud, consisting of hundreds of individual pieces, quickly spread out around the Earth. Each new piece of debris is now a threat to other spacecraft. Studies indicate that a cascade effect of collisions forming debris, causing yet more collisions and more debris, etc., could result in LEO becoming unusable within the next 50 years.

Chapter 2: Space War

In 2007, China destroyed a satellite in space and significantly increased the Earth-orbiting debris population. Shortly thereafter, the United States did the same, albeit in a manner that did not significantly increase the orbital debris problem. It is possible that an emerging space power, any country with the capability of launching a satellite into space, could intentionally collide strategically targeted rockets with a few operating spacecraft, causing a cascade of debris formation.

Rogue states with nuclear weapons pose another risk to our space infrastructure. Experiments in the 1960s showed that the detonation of a nuclear weapon in LEO might produce an artificial radiation belt around the planet that would persist for years, potentially damaging or destroying a significant number of satellites as they pass through it. Alternatively, detonating a few nuclear weapons optimized to produce intense bursts of radio noise called an electromagnetic pulse (EMP) could knock out satellites' electronics almost immediately.

Chapter 3: Solar Storms
Solar storms happen and, when they do, the effects on satellites can be devastating. For example, two Canadian telecommunications satellites were disabled by a solar storm in 1994. The first recovered in just a few hours. The other didn't recover for six months.

The Space Age began about 50 years ago. We've been monitoring solar activity for longer than that, but we have no idea whether the space radiation conditions we've enjoyed since the dawn of the Space Age are the norm or whether the relatively benign conditions we've experienced will end tomorrow with a more active Sun sending intense radiation into space – frying our satellites in the process.

Part 2: If We Were to Lose Our Satellites ...

Chapter 4: The Global Positioning System (Military Uses)
Since 1995, a network of between 24 and 32 American satellites have been orbiting the Earth, providing continuous reliable position and navigation services to users around the world. Built to support the needs of the US military, the system is now widely used by individuals and commercial companies for navigation, surveying, tracking shipments and commerce, and many other applications that require precise timing and location information. It has been so successful that other countries are now building their own satellite systems to provide similar services.

Many consider the Gulf War of 1990–91 to be the world's first war won using space. America and its allies used space reconnaissance, GPS, and GPS-guided munitions to rapidly decimate the Iraqi Army. America's former Cold War adversaries had supplied Iraq with arms and the brief conflict showed that the application of space technology was a critical element in their rapid defeat. Soldiers, tanks, aircraft, and ships use GPS to know where they are. GPS-guided bombs struck with precision unrivaled in the history of warfare. If an adversary were to strike when we're scrambling to operate without GPS, how well would we be able to respond?

Chapter 5: Economic Fallout
According to the US Department of Transportation, there are more than 10 million trucks in the United States alone. A large fraction of these trucks use GPS to help them navigate from the factory to the store, from the supplier to the manufacturer, or from the producer to the consumer. The companies which own many of these trucks, or the companies that contract with the independent owners, gather data from the GPS devices on board the trucks to help them manage the delivery of food to the grocery stores, raw materials to the factories, and medical supplies to the pharmacies and hospitals. If the satellites were to go off line, this complex chain of food, raw materials, and supplies would break – with serious consequences.

Chapter 6: The Global Positioning System and the Average Person

If you need help navigating in a strange city, you are likely to use your GPS receiver. For under $200, you may purchase a fully functional GPS receiver that will help you get safely from Point A to Point B. They are now a standard option in many rental cars. Have you bought a house or some land recently? Chances are that a survey was performed using GPS's ability to provide highly accurate position knowledge as a part of the process.

Scientists use GPS data in their study of earthquakes and of the Earth's atmosphere. It is difficult to find a realm of modern life that is untouched by GPS. How would we adapt if GPS were to disappear?

Chapter 7: Spy Satellites and Military Communications

Modern satellite reconnaissance is used for all aspects of military information gathering – detection and imaging of adversary command, mobilization, and training areas; tracking of ground forces, ships, and aircraft; and intercepting communications. Much of the leverage available to American and European troops on the modern battlefield is due to the advantages of military reconnaissance. If this advantage were lost, troops in the field would lose both strategic and tactical superiority, resulting in longer and more protracted battles, greater casualty rates, and less chance of achieving battlefield advantage. And, without satellite tracking and communications, the logistics of supporting combat troops around the world would be nearly impossible.

Chapter 8: Communications

Immediately after the events of 9/11, the number of cell phone calls spiked. Today, cell phone companies use GPS timing signals to help them quickly and efficiently route calls. Without GPS, cell phones might become paperweights. Retail stores, gasoline stations, and other businesses use satellites to approve credit card transactions.

Where do most people go for their up-to-date information in a crisis? Television. If our communications satellites go down, national and international news channels will go down with them – as do all satellite television and cable television stations.

In addition to satellite-guided munitions and real-time satellite imagery, the United States' military advantage depends upon reliable global communications. It is estimated that more than 75% of all military communications are transmitted via satellite. And if those satellites were to go silent . . .

Chapter 9: Weather Forecasting

Once upon a time, in Galveston, Texas, there came a hurricane. To the citizens of Galveston, the day began much like any other except for the gathering storm clouds on the horizon. By the end of the day, thousands of people were trapped on an island that was about to be ravaged by a hurricane that no one saw coming. Eight thousand of them died. This was in 1900.

Once upon a more recent time, in that same city, residents knew of a coming storm called "Ike" long before it made landfall in their beautiful city. Satellites and aircraft tracked the storm since its formation off the coast of Africa and with this information, forecasters were able to warn the residents of Galveston of the impending storm with enough lead time for all who were in harm's way to evacuate. Had the satellites failed, how many aircraft would it have taken to continuously monitor the 29-million-square-mile Atlantic Ocean during the six-month hurricane season in order to prevent a repeat of what happened in 1900?

And hurricanes are far from being the only reason we rely on our satellites for weather forecasting . . .

Chapter 10: Remote Sensing: Environmental Monitoring and Science

For over 30 years, we've been able to monitor global climate patterns and changes using satellite remote sensing. Much of what we've learned about the cycles that drive our climate and our technological civilization's impact on the global ecosystem has come from satellite observations. Without updated information from space, we would be crippled in our ability to monitor atmospheric changes, global rainfall patterns, and other climatological indicators – leaving policy makers to make decisions without the most significant part of their data in hand.

Satellite systems make regional and global resource monitoring possible. This is because it is very difficult and costly to conduct ground and aerial surveys over large areas and then to coordinate the individual surveys by joining them together. To collect data on a global scale, one must use the unique vantage point provided by space systems. One of the most successful applications of space imaging is monitoring the world's agricultural production, including identifying and differentiating most of the major crop types: wheat, barley, millet, oats, corn, soybeans, rice, and others. Feeding the world is only possible because of our ability to monitor food production and rapidly adapt to changes in the distribution system – and, in our modern world, both of these require space satellite systems.

Satellite remote sensing has also been successfully used in identifying mineral resources, particularly when the data from various types of space-based sensors are combined and compared. Locating future sources of raw materials suddenly becomes much more difficult and costly without satellite data.

Chapter 11: The International Space Station and Human Space Flight

Any event that creates a serious hazard for unmanned satellites in space creates a direct threat to the life of those on board manned spacecraft or space stations. The International Space Station (ISS) has been continuously occupied for over nine years and its crew size was recently increased to six. What would happen to the station and its crew if some event caused it to become uninhabitable?

Chapter 12: Effects on Scientific Research Satellites

The loss of such assets as the Hubble Space Telescope or the Chandra X-Ray Observatory may not directly impact the lives of people on the Earth, but we would be inestimably poorer without the breadth and depth of knowledge about the universe that we obtain from them.

Part 3: What Can We Do?

Chapter 13: Reduce the Growth in Orbital Debris
Fortunately, the world's spacefaring nations are aware of the growing threat posed by orbital debris and are taking steps to prevent the problem from getting worse. Unfortunately, the problem is already serious and it will not get better on its own. Most countries now require that new spacecraft either de-orbit or move out of the way when their missions are completed. Scenarios and approaches for reducing the growth of orbital debris are presented.

Chapter 14: Reduce the Amount of Debris in Space
Technologies to remove some of the debris circling the Earth are being assessed and systems to actually begin removing space junk may come on line within the next decade or two:

- space and ground-based lasers might push smaller pieces of junk into orbits that will more quickly decay, causing them to burn up in the Earth's atmosphere;
- for mid-sized orbital debris, such as nonfunctional satellites, a small propulsive device that attaches to the "dead" spacecraft and moves it out of the way is required;
- large pieces of debris, like spent rocket stages, will require much larger propulsive devices to be attached; in some cases, it may make more sense to boost the debris to a higher orbit where it is not at high risk of impacting another satellite (instead of causing it to enter the Earth's atmosphere and burn up).

Chapter 15: Harden against Space Radiation (Contributed by Dr James K. Woosley)
Some amount of hardening against space radiation is already incorporated into satellite design. However, as we learn more about the space radiation environment and particularly solar flares, the risk appears to be greater than was first supposed. Future generations of satellites must be shielded or include protective measures against the worst-case radiation loads of the most intense solar flare foreseeable. This hardening will also be helpful in the worst-case event of a nuclear detonation in space.

Appendix A: More on Orbital Debris
From close calls and near misses to the rapid increase in the number of debris objects, the orbital debris problem is technically complex and legally difficult to address.

Appendix B: The Kessler Effect as Originally Described
The seminal paper from Dr Don Kessler, as originally published in the *Journal of Geophysical Research*, is a call to arms for dealing with the growing orbital debris problem.

Appendix C: (Selected) Spacecraft Failures and Anomalies Due to Solar and Geomagnetic (Solar Event-Induced) Storms or Orbital Debris Impacts
A list of selected spacecraft involved in solar event-induced failures and anomalies with a brief description of each event.

Appendix D: International Agreements Governing Orbital Debris and Space Weaponization
A look at the legal implications for orbital debris removal and space weaponization with reference to international agreements and treaties.

Introduction

It might begin with the accidental collision between two orbiting satellites – a rare occurrence, but it has happened, most recently in 2009. It might be the opening shot of new kind of war, begun with a foreign power destroying a critical spy satellite – China demonstrated the capability when they destroyed an aging weather satellite in 2007; the United States followed suit only a few months later. It might even be caused by a large blast of radiation coming from the Sun causing a spacecraft to malfunction and crash into another.

Whatever the initial cause, the result may be the same. A satellite destroyed in orbit will break apart into thousands of pieces, each traveling at over 8 km/sec. This virtual shotgun blast, with pellets traveling 20 times faster than a bullet, will quickly spread out, with each pellet now following its own orbit around the Earth. With over 300,000 other pieces of junk already there, the tipping point is crossed and a runaway series of collisions begins. A few orbits later, two of the new debris pieces strike other satellites, causing them to explode into thousands more pieces of debris. The rate of collisions increases, now with more spacecraft being destroyed. Called the "Kessler Effect", after the NASA scientist who first warned of its dangers, these debris objects, now numbering in the millions, cascade around the Earth, destroying every satellite in low-Earth orbit.

Without an atmosphere to slow them down, thus allowing debris pieces to burn up, most debris (perhaps numbering in the millions) will remain in space for hundreds or thousands of years. Any new satellite will be threatened by destruction as soon as it enters space, effectively rendering many Earth orbits unusable. But what about us on the ground? How will this affect us?

Imagine a world that suddenly loses all of its space technology. If you are like most people, then you would probably have a few fleeting thoughts about the Apollo-era missions to the Moon, perhaps a vision of the Space Shuttle launching astronauts into space for a visit to the International Space Station (ISS), or you might fondly recall the "wow" images taken by the orbiting Hubble Space Telescope. In short, you would know that things important to science would be lost, but you would likely not assume that their loss would have any impact on your daily life.

Now imagine a world that suddenly loses network and cable television, accurate weather forecasts, Global Positioning System (GPS) navigation, some cellular phone networks, on-time delivery of food and medical supplies via truck and train to stores and hospitals in virtually every community in America, as well as science useful in monitoring such things as climate change and agricultural sustainability. Add to this the crippling of the US military who now depend upon

L. Johnson, *Sky Alert!: When Satellites Fail*, Springer Praxis Books,
DOI 10.1007/978-1-4614-1830-6_2,

spy satellites, space-based communications systems, and GPS to know where their troops and supplies are located at all times and anywhere in the world. The result is a nightmarish world, one step away from nuclear war, economic disaster, and potential mass starvation. This is the world in which we are now perilously close to living.

Space satellites now touch our lives in many ways. And, unfortunately, these satellites are extremely vulnerable to risks arising from a half-century of carelessness regarding protecting the space environment around the Earth as well as from potential adversaries such as China, North Korea, and Iran.

No government policy has put us at risk. It has not been the result of a conspiracy. No, we are dependent upon them simply because they offer capabilities that are simply unavailable any other way. Individuals, corporations, and governments found ways to use the unique environment of space to provide services, make money, and better defend the country. In fact, only a few space visionaries and futurists could have foreseen where the advent of rocketry and space technology would take us a mere 50 years since those first satellites orbited the Earth. It was the slow progression of capability followed by dependence that puts us at risk.

The exploration and use of space began in 1957 with the launch of Sputnik 1 by the Soviet Union. The United States soon followed with Explorer 1. Since then, the nations of the world have launched over 8,000 spacecraft. Of these, several hundred are still providing information and services to the global economy and the world's governments. Over time, nations, corporations, and individuals have grown accustomed to the services these spacecraft provide and many are dependent upon them. Commercial aviation, shipping, emergency services, vehicle fleet tracking, financial transactions, and agriculture are areas of the economy that are increasingly reliant on space.

Telestar 1, launched into space in the year of my birth, 1962, relayed the world's first live transatlantic news feed and showed that space satellites can be used to relay television signals, telephone calls, and data. The modern telecommunications age was born. We've come a long way since Telstar; most television networks now distribute most, if not all, of their programming via satellite. Cable television signals are received by local providers from satellite relays before being sent to our homes and businesses using cables. With 65% of US households relying on cable television and a growing percentage using satellite dishes to receive signals from direct-to-home satellite television providers, a large number of people would be cut off from vital information in an emergency should these satellites be destroyed. And communications satellites relay more than television signals. They serve as hosts to corporate video conferences and convey business, banking, and other commercial information to and from all areas of the planet.

The first successful weather satellite was TIROS. Launched in 1960, TIROS operated for only 78 days but it served as the precursor for today's much more long-lived weather satellites, which provide continuous monitoring of weather conditions around the world. Without them, providing accurate weather