

Chapter 2

The Development of Small Satellite Systems and Technologies

2.1 The Evolution of Small Satellites

The fascinating world of small satellites began when Sputnik launched the Space Age in October 1957 and surprised the world with the knowledge that humans could lift artificial satellites into Earth orbit. But that was nearly 60 years ago. Soon the rockets that were developed in the U.S.S.R. and the United States were capable of launching payloads that were not tens of kilograms or tens of watts in size and power but represented thousands of kilograms and thousands of watts. The drive to launch larger and larger civil spacecraft was accelerated by several factors. These included higher power (solar cell arrays), large aperture and high-gain antenna systems, and, in time, the building of space habitats to house astronauts and large scientific instruments such as the Hubble Space Telescope.

As noted in Chap. 1, there are a number of economies of scale and scope that help the cost efficiencies of a large remote sensing or large telecommunications satellites to become much greater than small ones. These include proportionally lower costs of design, engineering, testing, and verification as well as launch. In the case of a telecommunications satellite, one large parabolic reflector can be used by a small multi-beam feed system to create dozens or even hundreds of spot beams to support intensive frequency re-use. Since the electronics are small, the driver of the mass and size of the satellite is the aperture of the communications satellite antenna.

Thus, for many years the predominant trend in commercial satellites was bigger, more capable, and more cost-efficient satellites. The larger launchers also tended to be more cost efficient in terms of cost of lift as measured in dollars per kilogram of payload. As a result of these efficiencies, the cost of a satellite telecommunications circuit since the start of service in 1965 has plummeted from \$64,000 (in U. S. dollars) per month to about a dollar per month.

In light of the tremendous increase in lift capacity of today's launch vehicles, such as the increase from Atlas 1 to Atlas V or from Ariane 1 to Ariane 5, and the economies of scale and scope, one might jump to the conclusion that there is no longer a need or even a true market for small satellites. This is clearly not the case.

Today there are many more small, micro, cube, and nano satellites being launched than ever before. As noted in Chap. 1, the reasons why so many of these small satellites are being launched are numerous. We believe that one of the more useful ways to explain this ongoing interest in designing, building, launching, and operating small satellites is to break the market down by categories of users. Let's begin with military applications.

2.2 Small Military and Defense-Related Satellites

Small satellites for military applications can actually cover a number of needs. In light of the wide range of purposes now delivered by military space systems, only the citation of specific examples can provide a useful understanding of why small satellites might be appropriate or even best for certain strategic needs. One should start, however, by noting that the military has many ongoing requirements that depend on quite large satellites. Surveillance satellites and telecommunications satellites, for instance, can be the size of a small house. Thus, military satellites can be very large, large, medium, small, and micro-sized spacecraft, depending on the specific need. The various types include:

2.2.1 Rapid Deployment Small Satellites for a Specific and Newly Emergent Theater of Combat or Other Exigent Need

In the case of commercial or civil governmental services the demand for a particular service such as telecommunications, remote sensing, meteorological, navigational, geodetics, etc., is well established, and the transition from an existing satellite to the next generation with enhanced capability or capacity can be easily planned and executed. In the case of military systems, the outbreak of hostilities or an emergency situation prompted by a terrorist attack can occur with little or no warning. The military has adapted to such needs by having small and dedicated satellites that can be launched with little advanced warning. The military has also promoted the idea among satellite suppliers to have components of small satellites (i.e., antennas, power supply, processors, stabilization systems, and thrusters) that could be quickly assembled and launched on short-term notice. These innovations have helped others be able to order small satellites with much quicker delivery schedules.

2.2.2 Constellations for Mobile Communications or Machine-to-Machine Data Relay

The ability to communicate by voice, data, and even image to the “edge” of networks where combat soldiers or emergency relief operations are located is critical

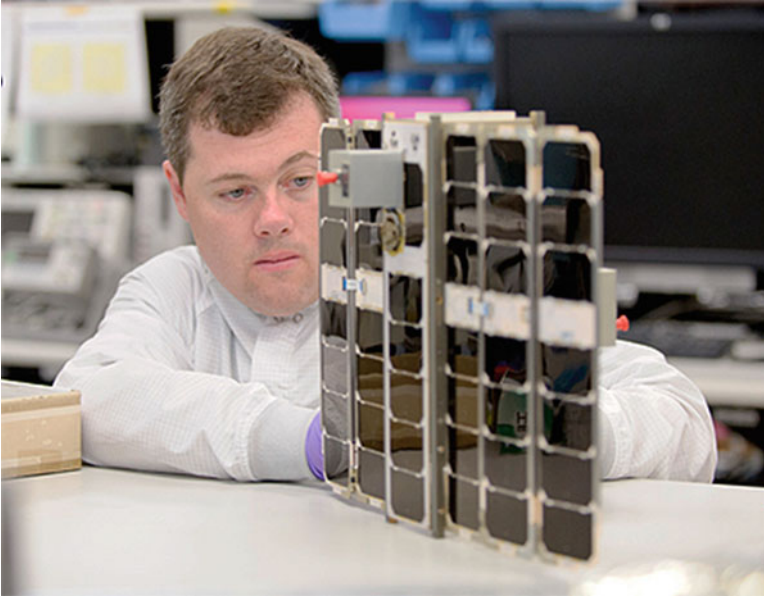


Fig. 2.1 One of the OR-3 nano sat units built by Boeing for the U. S. Air Force (Graphic provided by the Boeing Corporation)

to modern military activities. Several military operations are now relying extensively on the Iridium and Globalstar small satellite constellation for mobile communications services. The U. S. military is now deploying its so-called MUOS small satellite LEO constellation to support remote mobile communications on a global basis. There are negotiations underway with regard to the next generation of the Iridium small satellite network to place “hosted payloads” on this network to support specialized military services.

2.2.3 Small Satellites for Collection of Data from Ground, Sea, or Other Distributed Sensors

Many types of military services require broadband (i.e., television or videoconference type) service and large commercial or defense satellites meet these needs. There are other applications, however, that involve only the collection of very short data bursts from remote buoys or ground-based sensors to detect and monitor sea, snow, or other meteorological conditions. The U. S. Air Force under their so-called SENSE program is deploying and testing two 3U cube-sats ($30 \times 10 \times 10$ cm and weighing 4 kg) to evaluate whether the meteorological nano sats might be able to provide reliable weather data from around the world (Fig. 2.1).¹

¹ Boeing [NYSE: BA] has delivered two *Space Environmental Nano-sat Experiment* (SENSE) satellites to the US Air Force Satnews Daily December 21, 2012; available online at: <http://www.satnews.com/cgi-bin/story.cgi?number=789943063>.

2.2.4 Experimental Packages to Test New Technology or Service Delivery Systems

Beyond the OR-3 program the U. S. Air Force has a Space Test Program (STP) that seeks to develop new technology to advance space capabilities in such areas as meteorology, surveillance, remote sensing or communications. The Advanced Research and Global Observation Satellite (ARGOS) was designed and launched by the Air Force Space Command in 1999. This is just one such test program. Although this system with multiple experiments might be considered too large to be a small satellite, earlier phases of the Space Test Program included smaller missions designed to test smaller experimental packages.

2.3 Commercial Constellations

The evolution of the satellite industry has unfolded in various phases. Initially, in the late 1950s, satellites were launched into low Earth orbit as the first limited rockets and launcher systems were barely capable of achieving very rudimentary orbital speeds, and stabilization systems were almost non-existent. By the early 1960s it was demonstrated that satellites could be successfully launched into geosynchronous orbit and operated there for extended periods of time. Geosynchronous satellites of greater and greater capacity with higher gain antennas and more capable sensors were deployed. By the 1980s, however, there was interest in deploying satellites for mobile communications, but special constraints emerged in the development of these services. These constraints involved the need to have low-gain transceivers for users on the ground, and also a desire to minimize transmission delay prompted thoughts of using a large constellation of small satellites to provide global coverage rather than having a few satellites in geosynchronous orbit. The Iridium, Globalstar, and Orbcomm systems were designed on this premise, and all envisioned dual-use applications to meet commercial, governmental, and defense communications requirements.

Today the U. S. defense network for mobile communications known as MUOS is also being deployed. This network to support mobile communications for the U. S. Navy, however, is a large-scale geosynchronous satellite. This design that features a very high gain deployable antenna represents a move away from using a low Earth orbit small satellite constellation to support defense-related communications. In the commercial mobile satellite industry, this same strategy has also been employed by Inmarsat with its high-gain geosynchronous satellite Inmarsat 4 and by the Thuraya system that has also deployed very high-gain geosynchronous satellites instead of using a small satellite constellation.

Similar low Earth orbit constellations may also be used to support meteorological, surveillance, and other applications, but their prime use is for mobile telecommunications. The satellites that constitute commercial constellations can be in different orbital constellations with different masses. For instance, Iridium satellites

have a mass of 680 kg and are in 780-km high polar orbits within a constellation of 66 satellites plus spares. Globalstar satellites have a mass of 550 kg and are in a 1,400-km high orbit that are inclined up to 52° of latitude above and below the equator within a constellation of 40 satellites plus spares. The Orbcomm constellation that is used for machine-to-machine messaging includes a variety of satellites with masses that have ranged from 42 kg up to 115 kg. The original constellation had 36 satellites in it, and the current generation has 18 satellites.

2.4 Small Satellites for Educational and Scientific Applications

Perhaps the predominant application of small satellites is for educational projects and scientific experimentation. This can be for the most basic of nano satellite experiments that students at elementary or secondary schools might undertake under a structured competition sponsored in the United States by the National Center for Earth and Space Science Education (NCESS), with these experiments flying up to the International Space Station as part of the NanoRacks LLC enterprise. On the other end of spectrum, there can be quite small but sophisticated experimental satellites designed by the world's leading universities or space agencies. In short, the range of sophistication, size, and mass in this type of satellite is enormous. A nanorack experiment designed by 12-year-old fifth-graders that seeks to measure radiation effects on yeast under the NCESS program that flies on the International Space Station rather than as a free-flyer in space is one such extreme example.² Another example is the New Millennium Space Technology 5 project (See Fig. 2.2). This project consists of three micro-satellites (each 25 kg in mass) that have been measuring Earth's magnetic field since their launch on March 22, 2006.³

In the case of commercial applications where there are specific services being provided and an established market, it is clear that larger satellites that offer economies of scale with satellite manufacturing costs, launch costs, and operating expenses make very good sense. But in the case of student projects, scientific experiments and projects where only one small sensor in space is required, small craft make good sense – particularly if the small satellite can be launched as a very small and/or ancillary part of a larger launch mission. In the case of a Nanorack LLC experiment that flies as a part of an International Space Station resupply mission, the launch cost effectively becomes zero since NASA considers this as a part of its support to the Science Technology, Engineering and Math (STEM) initiative. However, some university-based small satellites, such as those designed by Utah State, Surrey Space Technology, Ltd., or the University of Texas, Austin, can be fairly sophisticated (See Fig. 2.3).

²National Center for Earth and Space Science Education, Student Spaceflight Experiments Program; available online at: <http://ssep.ncesse.org/>.

³NASA New Millennium Program, the Space Technology 5 project; available online at: http://www.nasa.gov/mission_pages/st-5/main/index.html.

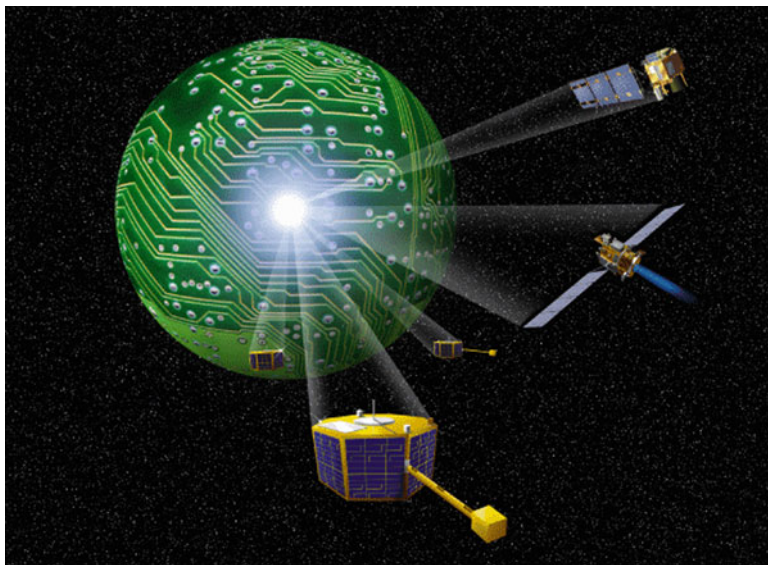
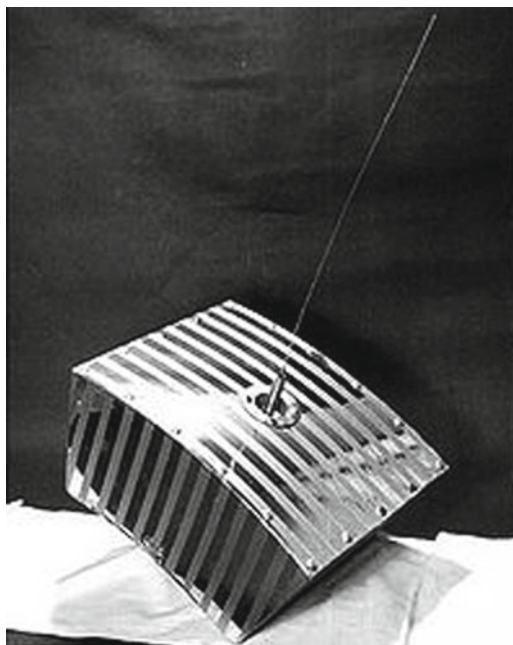


Fig. 2.2 NASA's small satellite new millennium program to measure Earth's magnetosphere (Courtesy of NASA)



Fig. 2.3 Frastac-A small satellite constructed at the University of Texas (Graphic Courtesy of the University of Texas, Austin)

Fig. 2.4 OSCAR 1, the first of seventy such small satellites launched into low Earth orbit (Courtesy of Amateur Satellite)



2.5 Small Satellites for Amateur Radio, Emergency, Disaster Relief and Other Social Applications

The other important application of small satellites can be to support emergency services, disaster relief, or medical or health services in very rural and remote areas where conventional communications or other services are not present. Livesat operated a two-satellite low Earth orbit messaging service to provide medical information as data relay on demand service. Small machine-to-machine data relay satellites that support everything from amateur radio to emergency or health services are within the resources of many organizations, particularly if volunteers can design and build the spacecraft and arrange for a low-cost launch.

Since the first amateur radio satellite known as OSCAR 1 (Orbiting Satellite Carrying Amateur Radio) was launched many decades ago, there have been over 70 of these satellites placed into low Earth orbit (See Fig. 2.4). These small satellites that have been designed and built by a number of countries around the world operate within the FM range of radio frequencies and is available to all “hams” worldwide.

2.6 Start-Up Programs in Various Countries with Fledgling Space Programs

Many countries that are just beginning a space program – or embarking on scientific measurement programs where a spacecraft is the optimal approach to take – typically embark on a small satellite program. In such cases, the satellite might be for

various applications such as telecommunications, remote sensing, meteorological or navigational purposes. Alternatively, the small satellite may be for various types of space experiments. These small satellites may be built at universities or governmental research institutes. In a number of cases, there may be a partnership formed with one of the various groups that specialize in designing and building small state-of-the-art satellites. In Europe, the leading organization is Surrey Satellite Technology Ltd., which was associated spin-off company from the University of Surrey in the United Kingdom in 1985 as a commercial venture and is, in fact, now majority-owned by the European aerospace giant Astrium. The University of Surrey Space Centre continues with academic research into small satellite techniques.

When the Republic of Korea, for instance, started to design and build satellites they formed a cooperative relationship between KAIST (Korean Advanced Institute for Science and Technology) and Surrey Satellite Technology Ltd and the Surrey Space Centre to design remote sensing, telecommunications, and experimental satellites based on the very efficient Surrey small satellite platform. To date, scientists and engineers from Surrey Satellite Technology, Ltd., have been involved in over 40 small satellite missions involving Earth observation, imaging and space situational awareness, navigation, telecommunications, meteorology, military technical demonstration, technical verification and demonstration, and scientific experimentation. In 2003, SSTL formed the international Disaster Monitoring Constellation (DMC) of microsatellites. These projects have involved cooperative arrangements with Algeria, the Chilean Air Force, China, the European Space Agency, France, Korea, Malaysia, Nigeria, Portugal, Thailand, Turkey, Kazakhstan and even the U. S. Air Force.⁴ In addition to other projects, SSTL are now building the 22 satellites in the European Galileo navigation constellation with its partner OHB in Germany. Another major small satellite center is at Utah State University. This university has the experience and ability to design and build small satellites. Other centers are evolving at the University of Texas, Austin, the University of Colorado, Boulder, and other universities around the world.

Countries that are starting up space programs and are not only designing and building spacecraft but also launching satellites have a wide range of options open to them. There is a growing range of alternatives, including dedicated small launch vehicles, ancillary payloads within a large-scale launch operation, or even by insertion into orbit from the International Space Station or other large space system. Finally, there is the option of becoming a “hosted payload” within another spacecraft program. In most cases, this would be in the case of riding onboard a constellation in low Earth orbit satellites.

⁴Surrey Space Centre and Surrey Space Technology Ltd. Historical Missions; available online at: www.sstl.co.uk/Missions/SSTL-Missions.

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