

## If You Build It, Who Will Come? Identifying Markets for Low-Cost Small Satellites

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### ABSTRACT

Technological advances in small satellites have opened up new markets beyond their traditional role of technology demonstration applications, but which markets would be most receptive to smallsats, and how large those markets might be, are critical unanswered questions. To determine the potential market for a notional low-cost smallsat, Futron Corporation performed a market definition study. The first step of this process was to identify all the potential markets that could be served by a notional low-cost smallsat. Through a process of secondary research and interviews with smallsat manufacturers, Futron identified over 30 potential markets in the military, civil/commercial communications, civil/commercial remote sensing, and miscellaneous market sectors.

Futron researched these potential markets by conducting secondary research and performing interviews with prospective customers to gauge their interest in low-cost smallsat systems. From that list six markets emerged that are the most promising in the near term: military science and technology; intelligence, surveillance, and reconnaissance; remote site communications; polling of unattended sensors; high-resolution Earth observations; and Landsat-class environmental monitoring. Combined, these markets could generate an estimated demand for up to 40 to 75 smallsats a year, with resulting revenue potentially in excess of a half-billion dollars per year.

### INTRODUCTION

In the past decade, technological miniaturization, improved hardware design, and advances in computing power and sophistication have fostered the development of small satellites, or smallsats, that can perform many of the same functions of larger satellites for a significantly lower cost. These smallsats represent both an emerging sector of the satellite manufacturing industry and a potential enabler of new capabilities for military, Earth observation, communications, and other sectors. Moreover, because smallsat design, production, and marketing are still in their nascent stages of development, government and industry have a unique opportunity to critically assess potential uses and markets for smallsats in order to direct research and development efforts towards those smallsat technologies that offer the greatest potential utility or return on investment.

To obtain this assessment, the Air Force Research Laboratory's (AFRL) Phillips Technology Institute (PTI) Kirtland Air Force Base, N.M., through Science Applications International Corporation (SAIC), contracted with Futron Corporation to perform a study analyzing potential markets enabled by low-cost small satellite missions. The prototypical smallsat referenced for this study was defined by the following key characteristics:

- Total satellite weight of no more than 100–200 kilograms;
- Payload mass fraction in excess of 50 percent;
- Orbit-averaged power of 200 watts, peak power of 500 watts;
- Life expectancy of one to two years; and
- Total cost of \$5–10 million, with low-cost launch options available

Specifications for this reference model were determined via discussions among AFRL, SAIC, and Futron, combined with research into smallsats currently under development.

### MARKET IDENTIFICATION

The first challenge in assessing the potential markets for smallsats is to develop a comprehensive list of possible markets that could utilize such spacecraft. While there has been no shortage of efforts to propose potential civil, commercial, and military applications for smallsats, there is no single accepted list of potential markets. Moreover, as smallsats become more technologically sophisticated, and as more people become cognizant of smallsat capabilities, the list of potential markets grows.

Thus, the first step of this study was to develop a list of potential smallsat markets that is as complete and up-to-date as possible. This process—incorporating both secondary research and interviews with smallsat manufacturers—and its results are described below.

In addition, the interviews with executives of several smallsat manufacturers yielded further insights into the industry that go beyond simply an assessment of potential markets. Those issues are also discussed in this section.

Creation of a comprehensive list of potential addressable markets started with a list included in the original statement of work for this project. The potential markets were divided into four broad sectors: military, civil/commercial remote sensing, civil/commercial communications, and other. Futron then expanded this list to include additional markets that could be served by smallsats that met the technical requirements provided in the statement of work, as described in the Introduction.

Futron expanded the list of potentially addressable markets by two means. First, a secondary research effort identified additional markets that have been discussed by smallsat developers, customers, or other parties. Resources used in this effort include company web sites, media reports, and conference papers, most notably the annual Conference on Small Satellites organized by the American Institute of Aeronautics and Astronautics (AIAA) and Utah State University, and the annual AIAA Responsive Space conference.

As a next step, Futron performed primary research by interviewing executives with six smallsat manufacturers in September 2006: AeroAstro, Instarsat, MicroSat Systems Inc. (MSI), SpaceDev, Surrey Satellite Technology Ltd. (SSTL), and Swales Aerospace.

The complete list of potential addressable smallsat markets, incorporating the original markets from the statement of work and the markets added through Futron research, is provided in Table 1. The list identifies a total of 33 markets, which are investigated in further detail in this paper.

**Table 1: Potential Addressable Smallsat Markets**

Market Areas	Market
Military	Blue Force Tracking
	Communications
	Intelligence, Surveillance, and Reconnaissance (ISR)
	Meteorology
	Missile Defense and Early Warning
	Ocean Condition Monitoring
	On-Orbit Servicing
	Positioning, Navigation, and Timing (PNT)
	Precision Targeting
	Science and Technology
Civil/Commercial Communications	Space Asset Defense
	Space Surveillance and Situational Awareness
	System Augmentation or Gap-fillers
	Asset Tracking
	Gap-filler Communications for Disaster Relief
	Remote Site Communications and Data
	Polling of Unattended Sensors
	Store-and-Forward Communications
	Wide Area Broadcast
	Civil/Commercial Earth Observation
Disaster Assessment	
Earth Observation	
Environmental Monitoring	
Meteorology	
Natural Resource Surveying	
Other	Assist Astronaut EVA
	Biotech
	Entertainment
	Microgravity Research
	Moon-Mars Scout, Communications, Sensing, and Navigation Networks
	On-Orbit Inspection and Servicing of Space Systems
	Scientific Research
	Technology Demonstration

## MARKET ASSESSMENTS

While there are a large number of potential markets for low-cost smallsats, not all markets are created equal. Some of the 33 markets identified in this study are already utilizing smallsats to some degree, while others are much more speculative, with many possible customers not even aware of the utility smallsats could provide them. The potential sizes of these markets, and the obstacles smallsats face to adoption within them, also vary greatly.

To determine which of these markets appear to be the most promising in the near term, Futron assessed all 33 markets listed in Table 1. (In some cases, markets with similar characteristics have been combined for the purpose of the assessments in this paper.) The goal of these assessments was to evaluate the viability of these markets and determine which ones appear to be the most promising markets for low-cost smallsats in the near future (i.e., within the next five years.)

Futron developed this analysis on the basis of a combination of secondary research and interviews. The secondary research included reviews of news accounts, research papers, company web sites, and other material. This research was supplemented by 30 interviews Futron performed with representatives of potential customers in the academic, civil, commercial, and military communities. The interviews gauged individuals' awareness of smallsat capabilities, their potential interest in a smallsat solution with the costs and technical requirements given in the statement of work, their use of competing technologies (such as cellular telephony, aerial imagery, etc.), and what issues might prevent their adoption of low-cost smallsats.

### *Military*

Futron's research and interviews with smallsat manufacturers concluded that, in terms of overall interest and available resources, the military market is clearly the biggest. Futron's research also concluded that the military smallsat market will remain strong, due to the broad utility of smallsats; the Operationally Responsive Space (ORS) effort within the Department of Defense (DoD), which requires flexible and quick-to-orbit capabilities; and emerging smallsat launch options scheduled to go online in the next few years.

Futron analyzed 13 different potential military markets for smallsat applications. Interviews conducted with smallsat manufacturers indicated that, of these, intelligence, surveillance, and reconnaissance (ISR); technology demonstration; and communications are perceived as being the most promising military markets. Additional secondary research and interviews with potential customers indicated that, of these, communications may not yet be a fully-developed military smallsat market.

Smallsat manufacturers and potential military customers were in consensus that providing various capabilities to theater commanders would be the most ideal military applications for smallsats, but that these applications would require the development of a proven smallsat system. This observation regarding the need to develop proven technologies and the current demand to fly technology demonstration and experimentation flights made it clear that smallsat science and technology missions would be the largest military smallsat market, as it enables the successful development of technologies necessary in other military smallsat markets. Stemming from its analysis Futron identified the top two military smallsat markets as science and technology and ISR. These two applications, along with possible other applications that develop later in the future, provide a solid market for low-cost smallsats for use by the military.

**Blue-force tracking (BFT)** is the identification and communication of friendly forces' location on the battlefield. This role is implemented using integrated technologies, currently including L-band satellite communications. A BFT payload is planned for the TacSat-4 satellite, providing experimentation for BFT use from highly elliptical orbits (HEO) as an augmentation and a test for use of similar payloads linked to the Global Positioning System (GPS).

This is currently an undeveloped application for the military and could become a future market for smallsat use, but at this time there is no indication of the exact technologies that will be utilized. Blue-force tracking is an application to monitor as a potential future smallsat use.

**Communications** services are provided primarily by large military and commercial satellites in geosynchronous orbit (GEO). The demand for military bandwidth has been increasing with the implementation of network-centric warfare principles, but the demand has been filled through further use of large GEO satellite systems, whether dedicated military satellites or more general commercial satellites that lease capacity to the government. While some military communications needs are met by smaller low earth orbit (LEO) systems such as Iridium, these are of a larger size and cost than the smallsats considered in this study.

While there will be testing of smallsat communications capabilities through the TacSat-4 satellite, and there is an interest in such capabilities to provide the flexibility needed for ORS programs, the market for military communications smallsats has not yet developed. Responsive communications satellites could be used for surge capacity and to augment large space and terrestrial systems in a future conflict zone, but sustained demand will be limited and not likely to emerge until the medium to longer term.

The **ISR** market encompasses many different sensors and platforms for multiple collection disciplines: imagery, signals, and measurements and signatures collection. Satellites, both military and commercial, play a role in overhead ISR combined with terrestrial-based systems and, increasingly, unmanned aerial vehicles (UAVs). The military satellites used for ISR are of large mass and high capacity, and generally part of large programs. The commercial satellites in this market, used primarily for imagery and remote sensing applications, supplement those military systems.

This study has indicated that smallsats will likely find a positive market in the military ISR sector, largely as a result of the goals of reducing the cost and turnaround time for ISR systems. Key contributors here are the TacSat projects and the concept of ORS. TacSat projects are using smaller, less capable sensors with lower mass and power requirements that will still be operationally relevant, and provide a potentially good market for smallsats.

**Military meteorological monitoring** requires continuous information to support weather forecasting, severe storm tracking, and meteorological research. These requirements are currently met from space using the Defense Meteorological Satellite Program (DMSP) system of LEO satellites. Future requirements will be met using the National Polar-orbiting Operational Environmental Satellite System (NPOESS) that is currently planned to begin operations around 2010.

The eventual contracting schedule and level of technological successes of the NPOESS project will determine whether other meteorological satellite systems will be required for military use. While low-cost smallsats could fulfill the role of gap-filler between such systems, those of the very low-cost and low-mass variety are not a likely fit for meteorological requirements in the foreseeable future. There is no significant push to use small satellites in this capacity as an alternative to the primary systems being developed.

**Space-based missile defense and early warning** satellite programs generally involve the use of a satellite or satellite system to detect missile launches and track missiles through space. The satellites then relay tracking information to ground stations. This capability is especially useful in specific active theater operations. The use of smallsats in this role is still awaiting technology maturity. In an effort to play a role within ORS, missile defense and early warning smallsats are now being designed as modular system components. This approach is expected to save time and money in system deployment while reducing the risk of failure.

**Monitoring ocean conditions** by satellite is a niche application proposed by SSTL to remotely sense the reflection of global navigation satellite signals—currently GPS and potentially Galileo in the future—as they reflect off the Earth’s surface to gather information about characteristics of the ocean. Maritime forces could use this information to provide increased safety by distinguishing passable from dangerous sea conditions. This application is analyzed in more detail in the Dangerous Sea Monitoring market discussion in the Civil/Commercial Remote Sensing section of this paper.

Experimental technology for this application is being tested on the UK’s Disaster Monitoring Constellation satellite built by SSTL. This is an interesting application for low-cost smallsats, but it is a limited one that will likely not produce significant demand for additional satellites. In addition, there are concerns regarding cost of providing this service by means of satellite data. Competing low-cost systems could be placed on other platforms, avoiding launch and satellite operations costs. Despite these issues, there continue to be a number of weather-related maritime accidents every year, so there will likely continue to be innovation in this market.

**On-orbit servicing** refers to the use of a satellite to maintain and repair another satellite in orbit to extend its operational life. This generally involves autonomous tracking, guiding, and docking capabilities. The only economically sensible option for continuing or improving a satellite-based service that has existed for satellite operators has been to replace an older or defunct satellite with a new one. On-orbit servicing would provide another option to operators that might make more economic sense. As the relevant technologies have improved, been miniaturized, and become more efficient, the integration of these technologies onto a smallsat system has become more realistic.

Like most of the smallsat markets, the technologies that will enable autonomy and thus enable on-orbit servicing are still being developed and tested. While it is still too early to say how viable on-orbit servicing market will be, based on the current development costs and physical size of demonstration missions like Orbital Express, it is probably safe to assume that the use of 100-kilogram smallsats in this market will not occur in the near term, thus limiting the attractiveness of this market within the parameters of this study.

Current **positioning, navigation, and timing (PNT)** capability is based on GPS, which uses a constellation of satellites with masses in the 2,000-kilogram range. The GPS infrastructure has become a global utility whose multi-use services are integral to U.S. national security, economic growth, transportation safety, and homeland security, and are

an essential element of the worldwide economic infrastructure. Europe's Galileo system will also potentially provide PNT to U.S. forces when it becomes available. With these two major systems operational and in development, there will not be a great future need for alternative PNT constellations.

There are projects ongoing, though, to develop alternative geolocation capabilities in case these major systems are unavailable, and to create an integrated PNT capability. These projects are in conceptual phases and could contribute to the science and technology development market as design and development takes these projects in the direction of new satellite systems. It is thus too early to determine what platforms, including smallsats, any new PNT systems would use.

**Precision targeting** is a technology application used to geolocate a particular object of significance. A range of sensors can be applied to this application, including imagery, signals, and measurements and signatures. GPS signal-based weapons targeting and signals direction finding are examples of this application. The concept often involves the integration of multiple inputs, such as a synthetic aperture radar (SAR) or ground moving target indicator (GMTI) sensor with GPS signals.

There are government programs to improve military precision targeting, but there do not seem to be any particular efforts to develop new smallsat capabilities for this purpose. Therefore, the opportunities for this application will not likely create significant demand for new smallsat development.

**Technology demonstration** is the solution to the market's chicken-and-egg problem. Secondary research and interview respondents indicated that the absence of proven capabilities of smallsat technologies was an obstacle to their acceptance in other applications. Before military customers (or commercial or civil government customers) will adopt smallsat applications, the smallsat industry must convince them that the smallsats are capable of performing real missions and serving their needs. Smallsat technology demonstration missions are the enablers of other satellite markets because they provide a relatively inexpensive means of proving hardware and software that will eventually fly on actual satellite missions.

While science and technology smallsats are relatively inexpensive, the smallsat market has been plagued by the difficulty of finding cost-efficient launch opportunities. Many satellites are currently in storage due to lack of launch options. It is not uncommon for launch costs to easily double the total smallsat mission cost. Emerging smallsat launch opportunities, if successfully developed, will change this paradigm, with science and technology smallsat missions

probably benefiting the most in the near term. Over half of the manufacturers surveyed identified technology demonstration as a top smallsat market, especially for the 100-kilogram-class smallsats.

**Space asset defense** is an issue that has received a lot of attention in recent years, mostly because a growing number of countries are developing space capabilities and existing space powers are becoming concerned over control of space. Space asset defense is simply the protection of large satellites that are important to the country's economic and national security. Often, this is achieved passively by methods such as radiation hardening to prevent damage from electromagnetic pulses. Active methods for defense of space assets might include the use of smallsats as a companion to the larger systems.

Active space asset defense would require capabilities (i.e., rapid orbit maneuvers, autonomous rendezvous, etc.) similar to those still being developed and tested for smallsat space surveillance and situational awareness missions. While it is safe to assume that the smallsat market for space asset defense is not going to be a high priority, smallsats will continue to be ideal for testing advanced technologies and capabilities.

**Space surveillance and situational awareness (SSSA)** applications are intended to provide complete awareness of existing natural and man-made objects of all sizes that can pose a threat to space operations. SSSA is closely related to space defense activities, and is especially important in terms of "space control." Increased SSSA capabilities may be necessary for distinguishing between natural threats and intentional attacks on a space asset. Smallsats can play a role in this market by serving as in-space inspectors, a role that is important because existing ground-based capabilities are limited by factors such as object size, object characteristics, weather interference, daylight interference, and non-continuous coverage.

The existing capabilities for identifying and tracking space debris are effective at present, given the degree to which space is currently being used, and while SSSA is already a top priority for the Air Force, smallsats will only play a limited role in these applications the near-term. However, as space becomes more crowded with a variety of military, civil government, and commercial space vehicles, it will be necessary to maintain a more accurate catalog of all existing debris. Thus over time, this smallsat market may mature as technologies for on-orbit maneuvering and servicing evolve.

**System augmentation** is the use of a smallsat to enhance the capabilities of an existing satellite system. The role of smallsats as gap-fillers involves their use to tentatively replace a large satellite that

has become inoperable or is about to become inoperable, or to fill in during delays in deployment of new or replacement spacecraft. In this case, the smallsat capabilities will not be as good as those of the larger satellite, but it will avoid loss of service until a large replacement satellite can be built and launched.

This market will be dependent on the successful emergence of low-cost, small satellite launch options and maturity of smallsat technologies. Smallsat serving as system augmenters or gap-fillers for remote sensing and space surveillance are more likely to see a market in the near-term than smallsat serving as system augmenters or gap-fillers for communication satellites mostly because of technology maturity. As a military smallsat market, system augmentation and gap-filler missions are likely to grow only after low-cost smallsat technologies have proven their capability and utility.

### *Civil/Commercial Communications*

This study examined six potential communications markets: asset tracking, gap-filler communications for disaster relief, polling of unattended sensors, remote site communications, store-and-forward communications, and wide area broadcast. Research and interview results revealed that no substantial market opportunities appear to exist in the commercial sector of any of these six markets. However, opportunities appear more promising for smallsat communications services targeting civil government customers in two main market areas: polling of unattended sensors and remote site communications. If smallsat can demonstrate either a cost or functionality advantage in providing these two types of services, government interviewees expressed a willingness to consider smallsat-enabled solutions. However, because several of the government institutions interviewed currently obtain these two types of communications services from larger government agencies, communication and coordination with those agencies will be an important step in making these markets viable.

**Asset tracking** monitors the movement and location of items such as post mail, small packages, cargo containers, trucks and other freight vehicles, and shipping vessels. Commercial clients use asset tracking services to make supply-chains, business operations, and customer delivery more efficient, reliable, and secure. Government customers use asset tracking for the same functions, but with a particular emphasis on security in the aftermath of September 11, 2001.

The asset tracking market appears to hold few near-term prospects for smallsat applications due to the same three factors that pose obstacles for smallsat in other communications markets: a preference for

proven satellite communications systems, a reluctance to assume responsibility for managing a dedicated smallsat system, and price.

The most likely customers of asset tracking services would be government agencies such as the Department of Homeland Security (DHS), which is seeking technologies to monitor international cargo vessels for weapons of mass destruction. While respondents indicated that DHS is working with the U.S. Coast Guard to implement a satellite-based passive ship monitoring program—known as the Long-Range Vessel Identification and Tracking (LRIT) system—the initiative is still several years from fruition. Instead, DHS is placing more emphasis on monitoring shipments through sensors located in ports and other areas of transit.

**Gap-filler communications** satellites for disaster relief would provide additional voice, data, and Internet telecommunications for regions afflicted by humanitarian crises. The most likely potential clients are government and intergovernmental organizations, along with the non-governmental organizations that support them in their humanitarian relief roles. The common perspective among these organizations was that small satellites represented an intriguing new possibility, but one far beyond even the combined annual communications budgets of the disaster relief community, who rely on longstanding partners who provide telecommunications at a discount as a form of corporate social responsibility, including Inmarsat, Thuraya Communications, and a host of terrestrial providers.

**Polling of unattended sensors** (including Supervisory Control And Data Acquisition or SCADA) allows satellites to link to terrestrial devices in order to remotely monitor conditions in areas where people are not, or cannot safely be, present. Satellites poll unattended sensors in support of scientific, security, or general surveillance missions. Manufacturers of remote sensors or utility companies that use such sensors to monitor pipeline flows, water throughput, and similar measurements constitute the main potential commercial markets for polling of unattended sensors. Government scientific institutes and security agencies are the primary civil market for such smallsat-enabled services.

The private firms interviewed indicated little interest in smallsat-enabled polling of unattended sensors. Energy companies and other users believed that using dedicated smallsat to monitor sensors that were already being monitored via terrestrial communications was not cost-effective. Government respondents, on the other hand, expressed interest, contingent upon the ability of small satellites to facilitate new functionality for sensor networks. Small satellites might cut government costs and provide incentives to replace aging sensor arrays in

streambeds and watersheds throughout North America if smallsats can allow unattended sensors to be reprogrammed remotely. Currently, when such devices malfunction—or merely need to be reprogrammed or recalibrated to focus on different data variables—experts must drive or fly out to isolated areas, transporting equipment with them, to replace or reconfigure the sensors. If smallsats could enable two-way reprogrammable communications between unattended sensors and their support teams, their \$5–10 million price tag might compare favorably with transportation and labor cost savings.

**Remote site communications and data services** enable researchers, explorers, and travelers in geographically isolated areas to communicate with supporting institutions, agencies, or companies. Potential commercial users for such services include energy companies who deploy scientists to unpopulated areas to perform exploratory drilling, as well as tourism and adventure travel companies who sponsor excursions to rugged or secluded locales. Likely civil consumers of such services include government agencies that fund research expeditions to largely inaccessible places of scientific interest.

There was little commercial interest in smallsat-enabled remote site communications services. Energy companies, whose need for remote communications support varies considerably based on unpredictable patterns of exploratory and drilling activities, expressed concern about maintaining a dedicated satellite system that might frequently go unused. They prefer their current arrangements with subscriber satellite data and phone services, which allow users to pay per use on an as-needed basis. The same dynamic applied for adventure travel companies, regardless of the country in which they were based.

However, government interviewees responded more favorably. For example, the federally-funded National Snow and Ice Data Center (NSIDC) at the University of Colorado currently facilitates communications with remote researchers through National Oceanic and Atmospheric Administration (NOAA) satellites, the French Centre National d'Études Spatiales (CNES) Argos satellites, and Iridium satellite phones. The NSIDC did express interest, though, in the potential of smallsat communications to support research teams in Antarctica whose voice and data relay needs are difficult to meet using the current system. Also, while the store-and-forward communications market did not attract government respondents as a stand-alone market, when conceptually linked with remote site communications, the remote site communications and data market as a whole drew more interest.

**Store-and-forward communications** enable the transmission of large files, such as sophisticated maps

and data models, from areas where Internet and other data services are not available. Likely clients include government agencies charged with performing remote-site surveying or in-depth scientific research, as well as mining and energy companies pursuing similar projects for commercial ends.

Although government and industry interviewees expressed some interest in smallsat-enabled store-and-forward communications, they described their current systems as sufficient, and showed no interest in switching to smallsats if doing so meant managing the smallsats themselves. Respondents were also unwilling to entertain the price point of \$5–10 million for dedicated store-and-forward services, largely because they perceived store-and-forward communications as part of the larger service of remote-site communications, rather than a distinct market. Therefore, no specific market currently exists for smallsat-enabled store-and-forward communications service. However, store-and-forward service could add appeal to the smallsat-enabled remote-site communications market if defined as part of that broader market.

**Wide area broadcast** allows the dissemination of voice and data services over large geographic expanses. Companies with far-flung offices or facilities use wide area broadcast as a one-way communications tool to inform and direct their employees and (as applicable) the public. Civil clients use such services to notify both government personnel and the general public of important news, instructions, emergency bulletins, or security measures.

After interviewing a range of potential commercial and civil customers for smallsat-enabled wide area broadcast services, Futron determined that this market currently holds little promise for small satellites. The most likely consumers of smallsat-enabled wide area broadcast services are government, not commercial, clients. Although large commercial clients with global reach, such as shipping and energy companies, have a natural interest in dedicated capacity to broadcast over wide areas, they consistently expressed reluctance in interviews to own and operate their own satellites for this purpose.

Government clients of similar scope, such as DHS, are more willing to assume responsibility for managing a dedicated small satellite constellation for wide area broadcast. However, government respondents indicated that current commercial satellite constellations, combined with terrestrial radio, telephony, and Internet alternatives, have so far proven effective in meeting government wide area broadcast needs, even during emergencies. In comparison with these currently available and proven alternatives, which can be scaled up or down depending on need, maintaining a dedicated smallsat

constellation for wide area broadcasting does not currently appear cost-effective for potential government clients.

### ***Civil/Commercial Remote Sensing***

Research into the civil/commercial remote sensing field revealed some strong opportunities for sales of smallsats. In this sector, six potential markets were examined, including dangerous sea monitoring, disaster assessment, Earth observation, environmental monitoring, meteorology, and natural resource surveying. In many of these markets, smallsat missions have already been conducted to prove the basic utility of the smallsat platform, but most of these markets are being served by proven terrestrial and space-based alternatives. Although cost savings may draw some investment in smallsats, the overall market will be limited until smallsats match or exceed the capability and reliability of their competitors. Based on interviews with industry representatives and secondary research, high-resolution Earth observation imagery and Landsat-class data for environmental monitoring represent two of the strongest market segments for smallsats.

**Dangerous sea monitoring** uses bistatic remote sensing, where the reflection of navigation satellite signals off the Earth's surface can be utilized to sense surface features. This method eliminates the need to carry a transmitter on the spacecraft. A smallsat network utilizing space-based GPS bistatic remote sensing could provide ocean vessels with vital data on hazardous ocean conditions such as dangerous waves or icebergs. Potential customers include ocean transport companies, yacht clubs, the International Maritime Organization, and national coast guards or navies (see the Ocean Condition Monitoring discussion in the Military section of this paper.)

Potential customers have shown skepticism that a satellite-based system could provide a useful service at a reasonable fee. Currently high-value large ships utilize X-band radar to provide situational awareness of ocean conditions within a limited range of the ship. This market is not strong in the short term, but may improve once smallsat technology becomes proven and less expensive.

In **disaster assessment**, commercial and government customers are interested in purchasing high spatial resolution Earth observation data following a disaster. For example, following Hurricane Katrina, satellite imagery was utilized to assess the storm damage to critical infrastructure along the Gulf Coast. Customers of satellite data for disaster assessment include FEMA, other federal agencies, and state and local responders.

Smallsat constellations conducting Earth observation missions could be re-tasked to image disaster

locations; however, the sporadic nature of the market does not support the development of dedicated disaster assessment smallsats. This market segment will also face strong competition from aerial platforms capable of rapidly deploying sensors over a disaster area.

**High spatial (<2 meter) and temporal resolution imagery** is useful for applications such as mapping, urban planning, resource management, homeland defense, national security, and emergency preparedness. Three basic customer types exist for high resolution data: the military, civil government, and commercial Geographic Information Systems (GIS) providers. High-resolution Earth observation data is supplied to customers by remote sensing satellites and aerial-based sensors.

Interview participants representing the civil government and commercial GIS companies agree that they would be interested in purchasing data provided by smallsats if it were cheaper than data supplied by large satellites or aerial sources. Purchasers of high-resolution Earth observation data are hesitant to invest in the development of smallsats given the availability of high-resolution data on the open market. Increased temporal resolution provided by multiple smallsats could be a strong selling point in this market, however.

**Medium spatial resolution (30–90 meter) and multi-spectral Earth observation imagery** data is often used to monitor the characteristics of ecosystems including ocean conditions, de/forestation, and pollution levels. The primary customers of environmental data are civil agencies such as the USGS and the Environmental Protection Agency (EPA).

Historically, medium spatial resolution and multi-spectral imagery has been collected by the USGS through the NASA-built Landsat series of spacecraft. The Land Remote Sensing Policy Act of 1992 directs NASA and USGS to assess various system development and management options for a satellite system to succeed Landsat 7. Current plans call for a single large satellite for the Landsat Data Continuity Mission. However, there may be an opportunity to utilize smallsats for future Landsat missions, especially if smallsats cost substantially less than other options.

**Meteorological monitoring** requires a continuous and reliable stream of environmental information to support weather forecasting, severe storm tracking, and meteorological research. A constellation of smallsats could provide weather imagery and atmospheric sounding data. The primary customer for this data would be NOAA; however, a constellation of meteorological smallsats could include commercial smallsats that serve niche markets such as

commercial weather modification. Next generation architectures for NPOESS could also include a constellation of smallsats.

Earth atmospheric monitoring is conducted primarily by NOAA through the use of the NASA-constructed Geostationary Operational Environmental Satellite (GOES) series spacecraft. NOAA's NESDIS (National Environmental, Satellite, Data, and Information Service) advanced system planning division believes that it would be possible to use a smallsat architecture to fulfill the GOES mission, but cannot allocate funding to support smallsat technology development. Therefore, in the short term, meteorology is not a strong market, but has potential if NOAA could be given the authority to allocate funding for satellite research and development. Development of the latest NPOESS spacecraft have suffered from cost overruns and increased scrutiny from Congress. Pressure has been placed on the program to produce results within a fixed budget. Therefore, it is unlikely that planners will invest in unproven smallsat technology. However, a market may open in the future once smallsats have become a proven, low-cost solution.

**Natural resource surveying** is the process of identifying, cataloging, and tracking natural resources such as forests, animals, and mineral deposits. Natural resource surveying is conducted through utilization of satellite imagery, airborne sensors, and terrestrial sensors, including people equipped with handheld computers that they download periodically into larger databases. Customers of this application include civil agencies and commercial companies conducting natural resource exploration and exploitation.

Flexible and relatively inexpensive aerial and terrestrial-based natural resource surveying systems are currently more cost effective, limiting the willingness of surveyors to invest in their own smallsats. However, surveyors may be interested in purchasing useful imagery from smallsat operators who are collecting data for other purposes.

#### **Other Markets**

Six loosely-defined markets were identified, including biotech and microgravity research; entertainment; Moon-Mars scout, communications, sensing, and navigation networks; on-orbit inspection, servicing, and assisting astronauts on extravehicular activities (EVA); scientific research, and technology demonstration. For most of these markets, the unproven market demand and unproven smallsat technology severely limit interest in purchasing smallsats. Once federally-funded programs prove the utility of smallsats in these market segments we may see further investment by the private sector, however, large scale investment

will not happen until market demand exists. Based on the interviews and secondary research none of these markets show a significant opportunity in the short term.

Conducting **biotech research in space** requires the ability to expose biological organisms to the unique space environment, monitor the reaction, and return the results and possibly samples to the ground. The majority of biotech research conducted in space is conducted by or subsidized by the federal government and is conducted on laboratories on the Space Shuttle and International Space Station (ISS).

GeneSat-1 is leading the way for the effort to utilize smallsats for biotech research. GeneSat-1 is a technology demonstration spacecraft that validated the use of research quality instrumentation for in situ biological research and processing. The spacecraft and mission was developed by NASA Ames Research Center's Astrobiology group. GeneSat-1 launched as a secondary payload on a Minotaur launch vehicle in December 2006. When asked about the future outlook for the use of smallsats for biotech missions, a representative from the mission was very positive.

Others, though, warned of past biotech research efforts that produced low return on investment, which makes it difficult for commercial organizations to justify biotech research in space regardless of the platform. Biotech research that does not require microgravity also faces strong competition from terrestrial-based laboratories that can simulate the space environment.

The success of GeneSat-1 has helped validate the technical capability of smallsats to conduct biotech research. However, a larger commercial market will not be created until the value of biotech research in space can be proven. As NASA's need for microgravity research increases in the future, pressure to more effectively utilize the ISS may negatively impact the market for biotech research on smallsats. However, microgravity research on smallsats could be a promising market. The microgravity environment on large orbital facilities such as the ISS is of relatively low quality given the vibrations that run throughout the large facility. Smallsats in the vicinity of the station or in separate orbits could provide a pure microgravity environment for research.

Very low cost smallsats could fill an **entertainment** role. One such concept proposed by SpaceDev utilized a smallsat carrying a high-resolution camera that would orbit the Moon providing imagery of the Earth-Moon system that could be sold for scientific and or entertainment value. A similar mission has been proposed by TransOrbital. The TransOrbital Trailblazer spacecraft is a conceptual smallsat

mission that would carry a high-resolution camera and provide a ride for mementos. At this point, the market is simply a concept. A limited market for smallsats providing entertainment may be enabled by the availability of reliable low-cost smallsats; however, investment in manufacture of satellites for this sector will not occur until market demand can also be proven.

Smallsats could be effectively utilized to fill a variety of **exploration** roles including navigation networks, remote sensing, communications, and reconnaissance. Smallsats are becoming more attractive to NASA planners who have been asked to utilize current NASA appropriations to conduct ambitious exploration objectives. Smallsats offer the potential to decrease development and launch costs for a variety of exploration missions.

NASA Ames Research Center has taken a strong position advocating the use of smallsats for the exploration role. An Ames representative indicated that NASA would sponsor the development of several smallsats per year for exploration-related missions. As smallsat technology develops and the utility of the smallsat platform is realized, the size of this market may increase further.

**On-orbit inspection, servicing, and assisting astronauts** on EVA are examples of areas where smallsats could serve a useful purpose if they were capable of completing complex tasks in close proximity to sensitive space systems. Efforts to develop smallsats for on-orbit inspection are underway at the Jet Propulsion Laboratory (JPL) with funding from NASA's Exploration Systems Mission Directorate (ESMD). The team at JPL has developed a small Micro-Inspector spacecraft capable of visually inspecting a host spacecraft. The Micro-Inspector spacecraft is envisioned to have a mass of less than five kilograms and have minimal impact on the host with respect to mass, size, cost, interface, and integration. Once tested, it is envisioned that a host spacecraft such as Orion will carry multiple inspector spacecraft that can be deployed as necessary during a mission.

Similar to the on-orbit inspection capability, smallsats could serve as an added set of eyes and hands for assisting astronauts with EVAs. Control of such smallsats could be conducted through automated systems or teleoperation. Smallsats of larger mass could also be utilized to ferry supplies, provide orbital reboost capability, and service space systems. A market for smallsats in this role, though, will not develop until smallsats have been proven to operate reliably.

**Scientific research** has been performed with smallsats in the past and there may be a market for proven smallsat technology in the future. Most

organizations funding scientific missions build a satellite around the characteristics of scientific payload as defined by the principal investigator and/or science team. With this management model, science spacecraft design requirements tend to creep towards larger, more complex spacecraft as the science team piles more scientific capability onto the spacecraft.

Given this paradigm, it is often difficult to limit the size of scientific spacecraft especially given the perceived failure of "faster, better, cheaper." Although this market may be limited in the short-term, once smallsat missions can demonstrate reliability and decreased mission costs, they will become more attractive to the scientific community.

**Technology demonstration** will be an important enabler of other smallsat markets. Historically, the DoD and NASA fund the bulk of technology demonstration. NASA's Space Technology demonstration satellite series is an example. Various universities and commercial organizations also conduct smallsat technology demonstration missions. For more information on technology demonstration, see the related discussion in the Military section.

Selling smallsats to organizations conducting technology demonstration outside of the military is an uncertain market. Most universities cannot afford to conduct smallsat technology demonstration missions without support from the government. Commercial entities conducting technology demonstrations usually want to build the whole satellite in order to preserve their trade secrets. However, as smallsat technology becomes more advanced, demand may be created for generic proven smallsat platforms that could be utilized to test new sensors and similar technologies.

## **MOST PROMISING MARKETS**

### **Introduction**

As the previous section demonstrates, some of the 33 markets studied in this report appear more viable in the near term than others. Futron performed a qualitative assessment of the markets and found that six of them appeared to be the most promising markets to adopt the use of low-cost smallsats. Those six markets are:

- Military Science and Technology
- Intelligence, Surveillance, and Reconnaissance
- Remote Site Communications
- Polling of Unattended Sensors
- High-Resolution Earth Observation
- Landsat-Class Data for Environmental Monitoring

(The last two markets are modifications of the Earth Observation and Environmental Monitoring markets from the original list of 33 markets in Table 1, reflecting the specific imagery resolutions of interest for the two markets.) The list above is a subset of the near-term markets identified in the previous section, since not all near-term markets will generate significant demand for smallsats. Futron performed a more detailed study of each of these six markets, utilizing interview results and additional research. This additional analysis focused on the nature of potential customers for low-cost smallsats, the technologies such smallsats have to compete against in those markets, and a rough estimate of the overall size of the market.

### ***Military Science and Technology***

While science and technology smallsat missions have been identified as the largest in the military smallsat market, demand for them should not be expected to increase dramatically in the next couple of years. This is because military demand is dictated by the defense budget, which in turn is dictated by existing programs, existing launch opportunities, and the existence of space contractors who do not focus on smallsat technologies but who also must be supported by defense dollars. Once the emerging smallsat launch opportunities become available and develop this niche market, it is reasonable to expect more smallsat science and technology missions to be included in long-term strategic planning. One manufacturer anticipates that there will be a larger role for smallsats in terms of risk reduction activities as part of spiral development, the development strategy of feedback and performance parameter-based improvements beginning at early stages between customers and contractors.

In the space industry, reliability is a large factor in the monetary equation. People want low-cost access, reliability, and availability. According to a few interviewees, the reliability should be at least between 90 and 95 percent before a market for a particular smallsat application, particularly military ones, can exist. These respondents also stated that one of the best ways to prove a technology is by demonstrating it on relatively inexpensive smallsat missions. There is no better way to acquire flight heritage for technology that will eventually be flown on larger and more expensive programs like the Space-Based Infrared System (SBIRS). So smallsat science and technology demonstration missions will not only play an important role in enabling other smallsat markets, but they will also continue to play an important role in proving technologies, such as newly-developed sensors, to be flown on large satellite systems.

As the smallsat market as a whole matures, and the industry begins to experience true economies of scale, defense budgets might be more inclined to increase

their use of smallsat technology demonstration missions. Cheaper access to space and inexpensive smallsat development will almost necessarily translate into support for using funding to test and prove technologies for later missions. This type of market will allow the Space Experiments Review Board (SERB) to select a greater number of technologies on its list each year. Currently, about one-third of all SERB experiments can fly on a smallsat.

There really is no existing terrestrial competitor to technology demonstration missions. The best way to test how a technology will perform in space is to fly it in space. The desired AFRL smallsat system will, however, face competition from larger smallsats. Many respondents were pessimistic about the small size and low cost of the specified AFRL smallsat system, noting that even the Air Force's Standard Interface Vehicle (SIV) concept is almost twice as large and is still too small to carry desired cameras. The SIV is being developed for the Air Force by Ball Aerospace and AeroAstro. The design of the SIV is based on the STPSat-1 that AeroAstro built for the Air Force and will be able to accommodate a variety of small payloads and hitch a ride into orbit on a secondary payload adapter, such as the ESPA ring. The two companies have an indefinite demand, indefinite quantity (IDIQ) contract that has a potential value of up to \$110 million for the delivery of up to six SIVs. Another potential U.S. competitor is the DOD's own TacSat program, which is developing 200–400 kilogram smallsats specifically for the responsive space program. Finally, SpaceDev's line of microsats would also pose a threat to the AFRL notional smallsat system. The company's microsats generally weigh less than 250 kilograms and rely on the company's comprehensive "plug and play" hardware and software.

There are a range of factors that need to be taken into consideration regarding the use of smallsats for technology demonstration. One important factor is the availability of low-cost launch options. As smallsats become more mainstream, their use as technology demonstrators will likely be limited by minimal launch opportunities in the near term. While potential military customers such as AFRL, DARPA, and NRL will be interested in acquiring smallsats for technology demonstration, other military offices said they would not be interested in acquiring the AFRL notional smallsat.

Ultimately, in the short term, the number of smallsats requested for technology demonstration will not witness a drastic spike in demand. As mentioned earlier, this is influenced by budgetary and reliability factors. While ESPA rings will help increase the number of smallsats launched, EELV launch demands will not be driven by the smallsats. The use of the ESPA ring will be limited to the EELV launch

demands. Falcon 1 launch prices start at around \$7 million and will need to launch 20 times per year to reach a price of \$5 million per year, a price that might be more suited for the notional AFRL smallsat. However, given that most respondents and an abundance of secondary research supported the idea that the desired smallsats will serve the technology demonstration market, one could expect 10–20 smallsat technology demonstration missions to be launched per year within a couple of years of successful employment of smallsat launch opportunities.

### *Intelligence, Surveillance, and Reconnaissance*

The ISR application is promising for low-cost smallsats. This technology provides overhead data collection as well as other important areas of interest. There are certain characteristics that make the use of smallsats beneficial for ISR, though competing systems do exist that can be used instead of, or in conjunction with, this technology.

Competing systems include large military satellites, commercial satellites, near-space vehicles, and airborne assets. Manned aircraft, unmanned aircraft, and near-space assets provide high quality, the most responsive coverage of areas of importance, and long loiter capability, but are limited by airspace restrictions, which satellites are not. Large military and commercial satellites provide extremely high quality collection, better than what a low-cost smallsat could provide, but have limited coverage and return times. Smallsats can provide timely ISR over a large swath of the theater, if not the whole theater, as compared to aircraft, which have a more limited view of the battlespace. Smallsats will be used in conjunction with these other ISR platforms. In this position, some likely roles that smallsats can fulfill are as a system augmentation, targeting asset, or surge-capacity asset. Using a constellation in LEO, increased temporal resolution of a large geographical space can be achieved with low-cost smallsats to supplement other systems, with sensors for multiple intelligence collection disciplines.

Smallsats should not necessarily be considered in direct operational competition with these technologies, but would compete for funding opportunities. Smallsats, large satellites, and terrestrial technologies, if used strategically, can increase each others' operational effectiveness by utilizing the advantages of each platform. One use of the low-cost ISR smallsat system could be to cue a more capable system, such as larger satellites or aircraft with advanced spectral or signals sensors that require greater mass or power usage, on targets of importance. In this way, smallsats can augment other assets.

One method to reduce costs and production timelines is to leverage current reconnaissance systems developed for other platforms, such as manned aircraft or UAVs. This is a method promoted by some companies and military projects vying to supply responsive space electro-optical reconnaissance systems that are compatible with the Joint Warfighting Space demonstrations and the ORS Modular Bus.

Market size is dependant on multiple factors. One determinant is whether the concept of responsive space is adopted in a strategic manner, beyond a single program office producing one type of satellite. If so, and if there are conflicts necessitating responsive overhead ISR, then smallsats providing theater-tasked ISR will have a greater demand. When this capability is developed, the market will likely remain in the single digits of spacecraft per year, as long as trends in large satellites and terrestrial capabilities do not greatly change. The operations tempo and level of global instability will have an effect on the quantity that theater commanders require, but there is always a baseline need for overhead ISR for strategic and tactical considerations. Though low-cost launch options are a constraint to delivering a responsive ISR smallsat capability and keeping total mission costs between \$5–10 million, this market demand will not by itself drive the development for increased launch capabilities.

### *Polling of Unattended Sensors*

Polling of unattended sensors on behalf of U.S. government civil agencies currently represents the most promising communications market for smallsats. If smallsats can enable two-way communications between scientific facilities and unattended sensors in the field in a way that makes those sensors remotely reprogrammable, smallsats may not only serve an important need, but also produce enough cost savings to justify their expense to government consumers like the USGS. Additionally, smallsats may be able to improve polling of unattended sensors in Southern Hemisphere locations including New Zealand and Antarctica, which respondents identified as underserved.

Finally, DHS, with its emphasis on monitoring ports for the radiological and biochemical signatures of WMD, may find incentives to use smallsats to assist in that effort in the event that terrestrial communications are compromised. While this third potential use is too preliminary to be considered a viable market, interviews with DHS officials indicate that it is a possible area of interest if smallsats can become cost-effective in this regard.

For now, though, the two main possibilities for smallsat polling of unattended sensors involve

smallsats as an enabler of two-way reprogrammable communications with sensors in the field, and as an enabler or unattended sensor polling in Southern Hemisphere regions currently underserved. One important step in making these possibilities viable is communication and coordination with NOAA.

The most likely space-based competitor to smallsat-enabled polling of unattended sensors is other smallsat communications systems, primarily ORBCOMM. ORBCOMM operates approximately 30 satellites, each weighing approximately 50 kilograms in six orbital planes to offer worldwide communications coverage. Although polling of unattended sensors is not the main function of these satellites, future replacement satellites in ORBCOMM constellation may place greater emphasis on such a service. One way other smallsats may obtain an advantage over ORBCOMM satellites is by optimizing the two-way reprogrammable aspect of their services. This functionality might ultimately be the factor that would differentiate competing smallsats from ORBCOMM smallsats.

Radio is the primary competing terrestrial technology to smallsats in polling remote sensors. However, according to respondents, many of the sensors are in unusual environments, such as streambeds and snowpacks, where radio cannot necessarily offer reliable coverage. A smallsat communications system may provide a better solution. The price competitiveness of small satellites against radio, though, would depend on how many smallsats were needed to cover a given area.

Taking this information into account, it is reasonable to say that if NOAA found use for smallsats, 20 to 30 smallsats might be needed every two years to constantly replace old satellites in order provide truly reliable continuous worldwide coverage. Without adoption by NOAA, however, little realistic demand for this number of smallsats is foreseen in the polling of unattended sensors market space. Interested research institutes are not authorized to procure smallsats independently, and also lack the budgets to easily do so.

### ***Remote Site Communications***

Interest on the part of civil government agencies in smallsats to facilitate remote site communications makes this market worth examining in greater detail. However, while this market holds promise due to expressed government interest, it also suffers from the classic chicken-and-egg dilemma: smallsats will not be considered truly viable in the remote site communications marketplace unless they can demonstrate reliability over time, yet they cannot show this reliability until a client chooses smallsats to meet remote site communications needs over competing space and terrestrial technologies.

Remote site communications represent a potential market for smallsats insofar as they are price-competitive with existing satellite and terrestrial alternatives. The most important step in making this market viable is to effectively demonstrate their ability to facilitate communications in remote areas. Without such a demonstration, government research teams will remain skeptical and continue to rely on Inmarsat and other operators. However, if smallsats can demonstrate reliability while simultaneously offering added functionality in the form of high-bandwidth video and data communications, then government research institutes may agree to share the cost burden in order to secure such services for scientists in isolated regions.

As with polling of unattended sensors, a key factor in market viability will be coordination with NOAA. Just as many government agencies depend on NOAA GOES satellites for polling of sensors, they also use NOAA satellites to communicate with remote site research teams. NOAA may see utility in offloading some of its remote site communications functions from its current satellites in a controlled manner, and conversations with NOAA officials along those lines are advisable.

In the space segment, ORBCOMM is again the most likely competitor to alternative smallsats, and enjoys a first-mover advantage in the remote site communications market space. This advantage might be offset if alternative smallsats provide functionality not found in current or planned ORCOMM satellites, such as higher bandwidth, more real-time, or more interactive video and data communications.

Ground-based communications represent the more obvious competitor to smallsats in providing remote site communications. Nonetheless, radio signals require infrastructure that may not be cost-competitive with dedicated communications smallsats. Here again, price competitiveness will be a function of how economically the cost of the 20 to 30 satellites needed to provide truly continuous worldwide coverage can be shared among designated users in various coverage areas.

As with polling of unattended sensors, if NOAA is enticed to use small satellites to create a dedicated capability in support of remote research teams in the field, then 20 to 30 smallsats may be needed every two years to replace old models to ensure uninterrupted global coverage. Without NOAA sponsorship, though, it is unlikely small satellites will find a niche in the remote site communications market near-term. Indeed, the only way to create a true market is to establish a track record of consistently reliable communications service—and absent a market, smallsats can only hope to establish this track record through continued DoD-sponsored demonstration flights.

### ***High-Resolution Earth Observation***

Three basic customer types exist for high resolution data including the military, civil government, and commercial GIS providers. A survey sponsored by the American Society for Photogrammetry and Remote Sensing (ASPRS) revealed that roughly half of their members work with imagery of spatial resolution below two meters. A forecast conducted by ASPRS and sponsored by NOAA and NASA estimated the total sales of satellite imagery of around \$1 billion in 2005 with steady growth of sales to \$2 billion in 2010. These studies show that sales of high-resolution satellite imagery totaled approximately \$500 million in 2005 and will increase to \$1 billion in 2010.

Internet distribution of GIS by companies such as Google, Microsoft, and Yahoo are exposing Internet users to the powerful capabilities of GIS and, in turn, increasing demand for satellite imagery. At a recent GIS workshop, an EPA official commented that the EPA had recently taken their web-based Enviromapper GIS database offline and were subsequently flooded by messages from realtors around the country who had utilized their software to identify environmental hazards around property. The EPA was mostly unaware of the strong public demand for this data and has since increased efforts to develop improved web distribution capabilities. Other government agencies have also taken note of the usefulness of Internet distribution of GIS data and have begun efforts to share their data with the public through the web.

Interviews indicated that companies desire increased temporal resolution. Increasing temporal resolution will require more satellite imaging capabilities that will, in turn, also increase demand. A constellation of smallsats collecting high resolution imagery would be ideally suited for increasing the temporal resolution as opposed to a single large satellite. Smallasats offering increased temporal resolution and approximately one meter spatial resolution at prices lower than currently offered will be able to capture a significant share of the market. Reliable smallasats, in combination with low-cost launch, have the potential to severely undercut current imagery providers.

The majority of remote sensing data is currently gathered by satellites larger than smallasats. These larger satellites offer higher spatial resolution, the capability to carry large multispectral imagers, perform on-orbit data processing, and have long on-orbit lifespans. This technology is proven to be reliable, which makes it easier for companies to justify investing large amounts of capital in construction, launch, and operations. For these reasons, it will be difficult for companies to switch to the use of smallasats until the technology is preliminarily proven.

According to the ASPRS forecast, sales of aerial high-resolution Earth observation data is roughly double that of satellite data and will maintain that margin through 2010. Advancements in unmanned aerial vehicle (UAV) technology and imaging sensors driven by defense needs have substantially increased the capabilities of aerial imaging. If airspace challenges for civil UAVs can be overcome, then the efficiency and flexibility of aerial imagery may pose a real threat to satellite-based imagery.

The current approximately \$500-million market, increasing in size to \$1 billion by 2010, will support strong growth in high-resolution satellite imaging. Smallasats may begin as a niche in the market, but have the potential to increase their market share substantially as the platforms and sensors become proven and increased investment funding can be gathered. With the assumption that one large satellite will need to be replaced by three smallasats it is conceivable to see a market for at least 10–20 smallasats on orbit collecting imagery by 2010. If the value of increased temporal resolution can be proven by the market, then the number of smallasats could increase beyond 2010.

### ***Landsat-Class Data for Environmental Monitoring***

Medium spatial resolution (30–90 meter) and multi-spectral Earth observation imagery data is often used to monitor the characteristics of ecosystems including ocean conditions, de/reforestation, and pollution levels. The primary customers of environmental data are civil agencies such as USGS and the EPA. An ASPRS member survey indicated that roughly 25 percent of its membership works with medium resolution imagery. The forecast conducted by ASPRS found that sales of medium-resolution satellite imagery totaled approximately \$250 million in 2005 and will increase to \$500 million in 2010. However, the ASPRS survey also indicated that demand exists for at least a 50 percent increase in the supply of medium resolution imagery. These statistics show that a strong market exists for medium-resolution satellite imagery.

Historically, medium spatial resolution and multi-spectral imagery has been collected by the USGS through the NASA-built Landsat series of spacecraft. Although emphasis was taken off of the Landsat program for a time in favor of commercially supplied imagery sources, the push to develop a replacement for the Landsat 7 spacecraft has intensified recently. The effort to create this replacement is called the Landsat Data Continuity Mission (LDCM). While that mission will use a single large satellite, there remains the opportunity to utilize smallasats for future Landsat missions.

Large imaging satellites pose substantial competition for smallasats in this market. NASA-built

government-funded spacecraft strive to be as large as possible in order to attract the largest amount of dollars to the project. Furthermore, the Landsat satellites are seen as a national asset and therefore an argument can be made for utilizing proven satellite technology.

Satellites gathering medium-resolution multi-spectral imagery for other nations may also become competitors in this market. Programs such as the Global Earth Observation System of Systems establish data-sharing protocols that facilitate sharing of data. Therefore, the requirement for a substantial national system may be diminished.

Aerial imagery collection is not as big of a concern in this market given the relative ease with which satellites can gather large swaths of medium-resolution imagery with greater efficiency than aerial platforms. However, this area of competition should not be ignored as high-altitude airships and long-endurance aerial platforms become available.

The ASPRS survey indicated that demand exists for at least a 50 percent increase in the supply of medium-resolution imagery. Assuming that a constellation of six smallsats could be utilized to replace a medium resolution multi-spectral large satellite, a market exists for approximately 6-12 smallsats on orbit by 2010. Growth beyond a dozen smallsats may be enabled by development of new remote sensing sensors that could be spun into the constellation as they are developed.

**MARKET SIZE**

The analysis of over 30 markets performed in this study showed that six markets in the military, civil/commercial communications, and civil/commercial remote sensing sectors are the most promising initial markets for a smallsat system with the cost, size, and capabilities proposed at the beginning of this study. The potential sizes of these markets, as measured by the estimated number of satellites per year at the end of the decade and resulting revenue (based on an average price per satellite of \$7.5 million), are summarized in Table 2.

**Table 2: Potential Addressable Smallsat Markets**

Market	Satellites/ Yr	Revenue/ Yr (\$M)
Military Science and Technology	10-20	75-150
Intelligence, Surveillance, and Reconnaissance	1-10	7.5-75
Remote Site Communications	10-15	75-112.5
Polling of Unattended Sensors	10-15	75-112.5
High-Resolution Earth Observation	5-10	37.5-75
Landsat-class Environmental Monitoring	3-6	22.5-45
<b>TOTAL</b>	<b>39-76</b>	<b>292.5-570</b>

Over time, the demand for such spacecraft may grow as additional markets utilize them. This study found a number of additional markets that may be receptive to low-cost small satellites, but are not considered prime initial markets due to their limited size or customer concerns about the viability of smallsats to meet their requirements. Should these smallsats be successful in one or more of the initial most promising markets, it is likely that other markets will become more interested in them, growing the overall demand for smallsats. These additional markets include space surveillance and missile defense, missile defense and early warning, civil/commercial meteorology, and non-military technology demonstration.

**INSIGHTS AND RECOMMENDATIONS**

While the market results above may be promising for low-cost smallsats, there are a number of issues uncovered during this analysis that may hinder the adoption of such spacecraft in some or all markets. These potential obstacles, discussed below, will have to be addressed by AFRL/SAIC or another organization for low-cost small satellites to be successful in the overall market.

*Lack of Awareness*

A number of interviewees, particularly in the commercial communications and remote sensing markets, were simply not familiar with smallsats in general, regardless of cost or capabilities. This is particularly true for people who do not typically deal with space systems, but also extends to people who are more familiar only with larger satellites. (Adding to the confusion is that, in the commercial communications market in particular, “small satellite” is a term usually assigned to GEO spacecraft weighing approximately two tonnes or more, as opposed to the much smaller spacecraft studied here.) That lack of familiarity makes it much more difficult to convince companies and organizations to select a smallsat-based solution for their requirements.

To address this, Futron suggests that satellite manufacturers and/or other organizations conduct outreach to the community of potential smallsat users. This outreach, which could take the form of conferences, workshops, white papers, or even advertising targeted at specific markets, would be designed to raise awareness of smallsats in general and the applicability to various markets. Over time, as low-cost smallsats demonstrate their effectiveness in their initial markets, such outreach activities will be less necessary, but may be required in the near term to achieve success in those first markets.

*Concerns about Smallsat Utility*

An issue related to the one discussed above is the skepticism raised by some interviewees regarding how useful low-cost smallsats could be. This issue

was raised by respondents in all market categories (military, civil, and commercial), and focused on whether any sort of useful payload could be flown given their \$5–10 million cost limitation and 100–200 kilogram mass limitation. Some thought that these low-cost, small spacecraft could only carry out “university-class” demonstration missions, and that operational, “real” missions required larger, more expensive spacecraft.

This concern can be partially addressed by looking at some recent smallsat projects: the SSTL-built Disaster Monitoring Constellation (DMC) satellites and the Orbital-built ORBCOMM satellites carry out “real” missions today with sizes, and in some cases per-spacecraft costs, similar to what has been proposed for smallsats in this study. Convincing people that smallsats can perform such missions may require additional “existence proofs” in the form of more successful low-cost smallsat missions. The payload issue can also be addressed through studies of available and planned payload technologies that could be utilized by smallsats, as described in the following section.

#### *Avoiding Satellite Operations*

Some interviewees, while intrigued by the potential capabilities of low-cost smallsats, expressed concerns about the overhead involved in operating and maintaining such spacecraft. Many commercial customers in both the communications and remote sensing markets were not interested in having to own and operate their own networks (including all the requirements needed to ensure continuous operations of the satellite system), preferring instead to lease services as needed from dedicated satellite operators. Potential civil government users who expressed an interest in smallsats noted that they are in many cases currently restricted from procuring and operating space systems, with those responsibilities assigned to specific organizations like DHS and NOAA.

For many users procuring satellite services, rather than the satellites themselves, makes sense, just as many companies rely on utility companies for telephone communications and electrical power rather than building their own communications networks and power plants. Some of these concerns can be assuaged by demonstrating that such spacecraft can provide required levels of reliability with a minimum of operational overhead and maintenance. Satellite manufacturers or other organizations could also reach out to satellite operators (who were not addressed in this study), demonstrating to them that a market exists for the kinds of communications, remote sensing, and other services that could be provided by low-cost smallsat constellations. Satellite operators are already beginning to revisit the LEO satellite communications market—based both on plans by Globalstar and

ORBCOMM to replenish their systems, as well as proposals by companies like LeoTerra to establish new systems—and the existence of suitable low-cost smallsats could be of great interest to them.

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