Smallsats

A Technology Primer

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TYPE Space platforms	**CHARACTERISTICS** Vantage/Range, Persistence, Resiliency	**RISK FACTORS** Vulnerable, Dual-Use, Predictive
DOMAIN Space	**COUNTRY** United States, China, Russia	

- Small satellites (smallsats) are miniaturized artificial satellites with a mass less than 500 kg used for communication, imaging, and other space applications.
- These relatively low-cost "disposable" space assets can be deployed in a constellation, providing increased redundancy and resiliency against counterspace threats.
- Smallsats can enhance situational awareness (SA) by providing advanced, low-cost sensing of in-orbit space objects, and by delivering persistent broad-coverage Earth imaging for a variety of conventional and nuclear missions.
- Overall, smallsats can provide significant enhancements to situational awareness missions, however, their vulnerability to detection and even disruption means that their impressive SA capabilities could potentially undermine stability in some contexts.

Introduction

Small satellites (smallsats) are miniaturized artificial satellites with a mass less than 500 kg used for communication, imaging, and other space applications.[1] Recent advances in microtechnology have facilitated

[1] Smallsats are further classified by mass, where microsatellites are between 10 and 100 kg, nanosatellites are between 1 and 10 kg, and picosatellites have a mass between below 1 kg. Femtosatellites are an emerging smallsat class with a mass between 10 and 100 g, but current designs require a larger "mother satellite" for communications or launching and docking. See for example Timo Wekerle et al., "Status and Trends of Smallsats and Their Launch Vehicles—An Up-to-date Review," *Journal of Aerospace Technology and Management* 9, no. 3, (July/Sept 2017), 269-286, http://www.scielo.br/pdf/jatm/v9n3/2175-9146-jatm-09-03-0269.pdf; Daniel N. Baker and S.Pete Worden, "The Large Benefits of Small-Satellite Missions," *Eos Trans. AGU* 89, no. 33 (2008), 301-312, www8.nationalacademies.org/astro2010/DetailFileDisplay.aspx?id=405; Anil K. Maini and Varsha Agrawal, *Satellite Technology: Principles and Applications* (Chichester: John Wiley & Sons, 2014).

the development of smallsats equipped with compact, low mass, low-power-consumption sensors, which enable high-performance platforms with significant cost reductions compared to traditional satellite systems. The reduced payload of smallsats further decreases vehicle launch costs, which allows for deployment in constellations, where a group of satellites works in concert under shared control to achieve a particular mission.[2] A constellation of satellites improves the resiliency of the overall system to degradation due to natural causes—such as radiation damage—or adversary attacks. They also allow for trade-offs in individual sensor performance (e.g., lower imaging resolution) in return for broader coverage and gap reduction.

Smallsats provide two primary enhancements to observation in space-based situational awareness relevant for both conventional and nuclear intelligence platforms: 1) advanced, low-cost sensing of in-orbit space objects and 2) persistent broad-coverage Earth imaging. The goal of a variety of smallsat systems is to increase the resiliency of satellite-based imaging systems while expanding planetary coverage. Hyperspectral and multispectral imaging modalities may be employed on smallsat platforms to enhance sensing capabilities.[3] The performance of smallsats may be further augmented via high-resolution imaging capabilities and geospatial intelligence analytics.[4] Technological advancements to expand the smallsat mission space through operational autonomy—in the form of intelligent interfaces and sensor tipping and cueing—are currently underway.[5]

State of Play

The U.S. Department of Defense has conducted single smallsat science and technology demonstration missions since the early 1990s. Currently, these systems are employed to test components intended to fly on larger satellites, enhance the dynamic range of existing platforms, and augment capabilities to meet military objectives. For example, SensorSat, a microsatellite system deployed in low-earth orbit (LEO) and used by U.S. Strategic Command, tracks objects in geosynchronous orbit (GEO). The Air Force's Operationally Responsive Space Office (ORS) deployed SensorSat in August 2017 as an inexpensive gap-filler to temporarily replace the Space Based Space Surveillance (SBSS) satellite used to image and track resident space objects.[6] Another example of the use of smallsat systems comes from BlackSky Global. Beyond multi-source imagery, these systems combine geospatial imagery with predictive analytics to deliver an enhanced global intelligence

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[2] The number of satellites in a constellation typically ranges from 10s to 1000s. There is no lower or upper limit for the number of smallsats working in concert.

[3] Hyperspectral imaging refers to a 2D spatial measurement with one spectral dimension, presented in the form of a data cube, or "hypercube." Multispectral imaging refers to the ability to image in multiple bands using the same optical platform. For example, multispectral systems may provide data in the visible, near-infrared, and short-wave infrared spectral domains.

[4] Darrell Etherington, "Satellogic raises $27M for affordable, high-resolution imaging satellites," Tech Crunch, June 23, 2017, https://techcrunch.com/2017/06/23/satellogic-raises-27m-for-affordable-high-resolution-imaging-satellites/; National Research Council, *Future U.S. Workforce for Geospatial Intelligence* (Washington, D.C.: The National Academies Press, 2013), https://doi.org/10.17226/18265.

[5] Becky Cudzilo, K.C. Foley, Chandler Smith, "The Ability of a Small Satellite Constellation to Tip and Cue Other Commercial Assets," 26th Annual AIAA/USU Conference on Small Satellites, SSC12-IV-5, 2012, https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1039&context=smallsat.

[6] Dorothy Ryan, "ORS-5 SensorSat launched to monitor activity in the geosynchronous belt," November 2017, http://news.mit.edu/2017/mit-lincoln-laboratory-sensorsat-will-monitor-activity-in-geosynchronous-belt-1129.

platform that integrates satellite imagery with a variety of data sources including social media, news outlets, and radio communications for customers that include government agencies.[7]

The commercial market for smallsats has grown in recent years, driven in part by the ability to eschew radiation-hardened electronics leading to low-cost production. Smallsats destined for LEO deployment are now being designed with a shorter lifetime compared with traditional satellite systems.[8] This reduces the requirements for radiation hardening of the electronic components and allows the use of commercial off-the-shelf (COTS) technology. Given that radiation-hardened components are expensive and difficult to obtain, smallsats enable a cheap "disposable" satellite economy where inexpensive components at low orbits can be used for a relatively short period before de-orbiting or burning up. For example, Planet produced the Dove CubeSat, a nanosatellite system, using COTS components in an effort to further decrease costs for constellation deployment.[9] While the North American commercial sector currently dominates the market for these systems, launch rates in Asia are expected to eclipse U.S. figures within a decade for both dual-use and military smallsat systems.[10] The Air Force Research Laboratory costs for a single smallsat mission varies from $100,000 to $10 million and constellation deployment costs are expected in excess of $100 million.[11] Costs tend to increase with higher mission assurance requirements.[12] In general, the trade-offs for a state to invest in smallsat infrastructure hinge on opportunity costs associated with bigger payload systems, where the redundancy afforded by smallsat constellations is weighed against the extended lifetime and sensor performance of larger assets.

Effects on Situational Awareness

Advances in smallsats enable two core situational awareness capabilities: 1) advanced sensing of in-orbit space objects using a range of active and passive observation tools and 2) broad-coverage and persistent Earth

[7] "BlackSky awarded $16.4M Contract by Air Force Research Lab for Next-Generation Geospatial Intelligence Brokering Platform," BlackSky press release, August 28, 2017, https://www.blacksky.com/2017/08/28/blacksky-awarded-16-4m-contract-by-air-force-research-lab-for-next-generation-geospatial-intelligence-brokering-platform/.

[8] The radiation dose and dose rate in LEO are relatively low compared to MEO/GEO, so special manufacturing processes for radiation-hardened components is not necessary. See Rahman, Md Mahbubur & Shankar, Divya & Santra, Shreya. "Analysis of Radiation Environment and its Effect on Spacecraft in Different Orbits," International Astronautical Congress, 2017, https://www.researchgate.net/publication/320765337_Analysis_of_Radiation_Environment_and_its_Effect_on_Spacecraft_in_Different_Orbits.

[9] "Dove 1 Satellite Technical Description," Cosmogia, https://apps.fcc.gov/els/GetAtt.html?id=121393.

[10] Adrienne Harebottle, "The Big Power of the Smallsat Revolution," *Via Satellite, Asian Edition,* April 2017, http://interactive.satellitetoday.com/via/asia-edition-2017/the-big-power-of-the-smallsat-revolution/.

[11] Jeff Foust, David Vaccaro, Chad Frappier, and Dustin Kaiser, "If you build it, who will come? Identifying markets for low-cost small satellites," (2008).

[12] David Voss, "DoD Perspective on CubeSats," Air Force Research Laboratory, June 22, 2015, https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_166652.pdf.

imaging using smallsats in constellations.[13] These capabilities impact situational awareness competencies in different ways, and as a result, each is explored in turn below.

Space-based Space Situational Awareness

Smallsats for sensing in-orbit space objects enhance situational awareness via increased *vantage* with the ability to ascertain new information concerning adversary space capabilities across LEO, GEO, and highly elliptical orbit (HEO). Prior to the launch of SensorSat, the U.S. Strategic Command's space surveillance capability was supported by only a limited number of assets. The low cost and ease of launch of these new systems unlock options for resilient observation in a variety of spectral bands and sensing domains to enhance space situational awareness. This capability significantly augments existing ground- and space-based space situational awareness tools by providing more persistent coverage of LEO, GEO, and HEO.

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Earth Observation Constellations

Smallsat constellations expand the *range*[14] over which information can be continuously collected through expanded and redundant *vantage* points, enhancing missile warning capabilities as well as situational awareness across a variety of domains, particularly on land and at sea.[15] Indeed, mobilization in key bases and around intercontinental ballistic missile (ICBM) silos would be visible from these space-based assets.

For the time being, however, *persistent* monitoring may come at the expense of *precision*—due to their size, smallsats have lower resolution than larger satellites. In the future, advances in sensing technology may increase the resolution of smallsats, allowing for high-quality persistent coverage. For the time being, smallsats can capture lower-resolution images and potentially cue larger, exquisite assets to further investigate areas of interest. As with space situational awareness, smallsats augment existing capabilities, providing redundancy and resiliency, thereby increasing the capability of states to monitor the globe.

Across both competencies, the relatively low cost of smallsat systems provides redundancy, increasing *resiliency* in the face of anti-satellite weapons and other threats. While smallsats can be the target of anti-satellite missiles, lasers, jamming, and other counter-satellite tools including cyber-attacks, constellation structures provide a distributed deployment where multiple nodes increase the survivability of the system as a whole.[16] As a result, smallsats offer an appropriate tool for augmenting situational awareness capabilities both in

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[13] Smallsat platforms can also be used for military communications. This primer focuses solely on observation assets and the associated situational awareness enhancements.

[14] To learn how this project defines the italicized terms, please visit the *On the Radar* website glossary, htttp://ontheradar.csis.org/glossary.

[15] They are hitherto not useful for detecting and tracking activity under the ocean or in the air due to the lack of ability to penetrate water and the lack of resolution with regard to moving targets.

[16] While stealth or ghost imaging capabilities have also been investigated to decrease the detectability of space-based assets, such as the US Misty system, which can reflect light so as to be imperceptible from certain vantage points, such

space and on the ground while reducing the vulnerability of existing space assets.[17]

Risk Factors for Strategic Stability

Smallsat technology is neither *intrusive* nor *destructive*. Both smallsat imaging and space situational awareness involve observation from a distance, whereby the phenomena being measured is not perturbed (as is the case with active sensing). Remote detection is less likely to be detected by the target or to interfere with the target's capabilities. Furthermore, overflight from space is allowed under international law and the Outer Space Treaty, as there is no sovereign territory in space.[18] As smallsat technology does not disable adversary capabilities, it provides a more effective approach to intelligence, surveillance, and reconnaissance in terms of risk management. Though non-intrusive and nondestructive, smallsats are detectable via space situational awareness countermeasures and do not operate *secretly*. If the existence of smallsat platforms is revealed, this may promote increased adversarial intent or the use of decoys to obfuscate intelligence. Further, smallsats are *vulnerable*—if in different ways than traditional satellites—to anti-satellite weapons.

Smallsats allow for *predictive* situational awareness when coupled with advanced sensor technology and machine learning algorithms. Automatic identification systems and associated automated surveillance broadcasts provide the potential for early warning and rapid threat assessment. Smallsats are inherently *dual-use* with both military/economic and conventional/nuclear applications. Predictive smallsat capabilities have already been demonstrated in both the industrial and military sectors, such as the startup Descartes Lab aimed at predicting corn crop yields and the aforementioned BlackSky Global for military intelligence applications.[19] As smallsat technology has high economic promise in the civilian sector, it may usher in unconstrained development and thereby increase the risk of technological surprise. The economic incentives posed by this technology may also introduce challenges to governance in this space as private actors lobby against use restrictions.

Concluding Remarks: Risk versus Reward

Smallsats provide two primary enhancements to situational awareness—a new tool for increasing perception in space and a low-cost, resilient platform for achieving situational awareness on Earth. These capabilities represent a key step forward towards persistent observation within the strategic intelligence mission. As adversary actions and forces become increasingly vulnerable to detection through broad coverage observation, smallsat platforms may serve as a deterrent, discouraging unwelcome or risky behavior. With this potential, however, come new risks. Persistent observation may give military planners improved operational intelligence

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solutions are expensive and not currently a focus for smallsat military objectives. See Jeffrey T. Richelson, "Satellite in the shadows." *Bulletin of the Atomic Scientists* 61, no. 3 (2005): 26-33 and Charles P. Vick, "Misty / AFP-731," Global Security, April 26, 2007, https://www.globalsecurity.org/space/systems/afp-731.htm

[17] Given the lack of radiation hardening and technological limitations due to the reduced size, weight, and power of smallsat sensor suites, smallsats are not expected to replace larger satellites in the mission-critical strategic intelligence space.

[18] "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," UN Office for Outer Space Affairs, http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.

[19] Alex Brokaw, "This startup uses machine learning and satellite imagery to predict crop yields," *The Verge*, August 4, 2016, https://www.theverge.com/2016/8/4/12369494/descartes-artificial-intelligence-crop-predictions-usda.

but increased observational capabilities do not necessarily lead to increased confidence in strategic decision-making outcomes. For example, enhanced awareness provided by smallsats of adversary Intelligence Surveillance and Reconnaissance/Command, Control and Communications (ISR/C3) systems (and persistent observation of on-the-ground deployments) may increase the perceived need for and use of anti-satellite capabilities, thereby escalating conflict. The fog of war might also leave the potential for disconnect between the data collected from smallsat platforms and the operationalization of this intelligence, including the long-term military, diplomatic, and economic consequences. How players use, respond to, and seek to abrogate smallsat technology remains poorly understood, and the impact of this technology poses both risks and rewards for nuclear crisis and stability.

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