Military Satellites 2006

International Satellite Innovation and Cooperation

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In the last 20 years, the status of outer space has changed dramatically. During the early years of the space age right through the Cold War era, Russia and the United States were the world's only space powers. Today, according to the Union of Concerned Scientists Satellite Database, there are 41 countries owning or operating satellites, with a total of 813 known working satellites in orbit. Of that total, 35 countries own/operate communications satellites, 13 nations operate imagery satellites, and 14 countries operate dedicated or dual-use military satellites for a total of 292 such satellites (most U.S. owned).[1] About a dozen countries are able to launch their own satellites, with other nations, such as Iran and North Korea, seeking to join the club. In fact, most countries of the world, as well as non-state actors, now use satellite-provided services in some way, shape or form – including through joint projects or sharing agreements with provider nations. The proliferation of satellite technology, however, is not only horizontal, it is also vertical – meaning that more and more nations are becoming more and more capable at developing new and/or improved space technologies, such as very-high resolution, multispectral imagery and low-cost microsatellites. Indeed, in some areas of research and development, the United States is actually behind the power curve.

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[1] Union of Concerned Scientists, "Satellite Data Base," http://www.ucsusa.org/global_security/space_weapons/satellite_database.html.

These facts raise a number of challenges, as well as opportunities, for the United States – both from a commercial and a national security standpoint. We will be talking today both about technology innovations that are beginning to revolutionize space and access to space, as well as the policy/security implications and how the United States should respond. I will concentrate on the technological developments, while my colleague Michael Katz-Hyman will discuss implications and response.

Microsatellites

Of all the recent space technology developments, the trend toward downsizing satellites is perhaps the most potentially revolutionary. Until recently, most working satellites – regardless of their use – were behemoths. A typical telecommunications satellite weighs in at several metric tons. With launch costs still hovering between $11,000 and $22,000 per kilogram, cost has been a significant factor in limiting the number of actors able to afford their own satellites. This is changing with the advent of smaller and smaller satellites. While there isn't any standard definition, the term microsatellite is usually used to describe a satellite under 100 kilograms; those weighing less than 10 kilograms are often termed nanosatellites, and the term picosatellite is sometimes used for those in the less-than-one to five kilogram range. While microsats today are usually launched in multiples on fairly expensive rockets, a number of nations and companies are also working on small, low-cost launchers that would significantly reduce price tags: such as Europe's planned Vega or the U.S.-planned Falcon.

In addition to potentially breaking cost barriers, these small satellites, particularly those with high maneuverability or that can perform autonomous proximity operations, could also provide a host of new space capabilities – some benign, such as the ability to inspect a damaged satellite; some threatening, such as the ability to ram into or jam a targeted satellite. Indeed, Pentagon officials also often cite the emergence of microsatellites and nanosatellites, using lightweight composites and high-speed computer chips, as a key potential threat to U.S. space assets in the future. According to an annex of the Rumsfeld Space Commission report of 2001, "These micro/nanosatellites, when employed as unacknowledged secondary payloads, can covertly rendezvous with other space assets to perform satellite inspection and other missions to disrupt, degrade or destroy space assets."[2]

Current microsatellite programs range from commercial communications to Earth imaging to electronic eavesdropping to satellite inspection to demonstrations primarily aimed at proving the ability of microsatellites to perform autonomous proximity operations around larger satellites and to orbit in formation. While the development of anti-satellite weapons is not the stated goal of any of the ongoing efforts, many of the programs are demonstrating technologies that could enable ASAT development. Companies in the United States, the United Kingdom, the Russian Federation, Israel, Canada and Sweden are involved in maturing microsatellite technology.[3] The United Kingdom is the undisputed leader in microsatellite technology, and technology developed by the University of Surrey has been shared with a number of countries including China, Pakistan, Chile, Thailand and Malaysia, according to the Space Commission report.[4]

I will review a handful of the programs of interest, in no particular order.

TopSat

TopSat is an optical Earth-imaging demonstrator system funded by the British Ministry of Defense and the British National Space Center. TopSat is one of a number of efforts under Britain's Micro Satellite Applications in Collaboration (MOSAIC) program to develop small satellites.[5] In particular, the British military is interested in using low-Earth-orbit microsatellites as part of a mix of assets that would provide persistent

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[2] Wilson, Tom, "Threats to United States Space Capabilities," Prepared for the *Report of the Commission to Assess United States National Security Space Management and Organization*, pursuant to Public Law 106-65, Jan. 11, 2001, p. 5, available at http://www.globalsecurity.org/space/library/report/2001/nssmo/article05.pdf.

[3] *Report of the Commission to Assess United States National Security Space Management and Organization,* (known as the Space Commission), Jan. 11, 2001, p. 21, available at http://www.defenselink.mil/pubs/space2001011.html.

[4] *Ibid*.

[5] "MOSAIC Small Satellite Programme, United Kingdom," *space-technology.com*, http://www.space-technology.com/projects/Mosaic/

intelligence, surveillance, target acquisition and reconnaissance.[6] The purpose of the TopSat experiment is to demonstrate an ability to "provide high resolution images of a specific location… in real time" to "a mobile ground station that can be taken to remote, off-road locations," according to prime contractor QinetiQ Ltd.[7] TopSat is also intended to provide commercially available imagery services. Another feature of the program is to demonstrate the utility of a low-cost microsatellite imagery satellite – with the program costing a total of 14 million British pounds (20.7 million euros).[8] The cost is about 20 percent of that of current satellites with similar imaging capabilities.[9]

TopSat's space segment is a 120 kilogram microsatellite[10] launched onboard a Russian Cosmos-3M commercial booster on Oct. 27, 2005. The satellite is located in a sun-synchronous orbit at a maximum altitude of 708 kilometers.[11] The system's maximum resolution is 2.5 meters in panchromatic (black and white) mode and 5 meters in multispectral (color) mode.[12] An area 15 kilometers wide (swath width) can be imaged in panchromatic mode, 10 kilometers in multispectral mode and five images can be taken per day. The revisit rate is four days.[13] The design also features an "advanced attitude determination and control system capable of accurate pointing, agile maneuvering, and FMC (Forward Motion Compensation) slewing maneuvers."[14] The spacecraft can maneuver to allow the imager to stay on target for longer, so that in effect, the camera is first facing forward toward the target, and at the end, is facing backward toward the target.[15]

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[6] Chuter, Andrew, "TopSat Reflects UK Interest in Small Military Satellites," *C4ISR Journal*, Nov. 29, 2005, http://www.isrjournal.com/story.php?F=1382169.
[7] "TopSat satellite launch successful," QinetiQ Ltd. news release, Oct. 27, 2005, http://www.qinetiq.com/home/commercial/space/space_missions_and/development_projects/topsat.html.
[8] Chuter, Andrew, op cit.
[9] "UK Launches Advanced TopSat Micro-Satellite Experiment," *Defense Industry Daily*, Oct. 31, 2005, http://www.defenseindustrydaily.com/2005/10/uk-launches-advanced-topsat-microsatellite-experiment/index.php.
[10] "TopSat satellite launch successful," QinetiQ Ltd.
[11] McDowell, J., Harvard-Smithsonian Center for Astrophysics, communication with the author, Dec. 2, 2005.
[12] "TopSat satellite launch successful," QinetiQ Ltd.
[13] "Topsat," eoPortal, http://directory.eoportal.org/pres_TopSat.html.
[14] Ibid.
[15] *Ibid.*

The system also includes the RAPIDS system for direct reception of data in the field using a low-cost satellite dish on a small vehicle. Data can be downloaded to other mobile or fixed ground stations within hours.[16]

The demonstration mission is designed to last one year,[17] and the British military is considering a follow-on.[18]

Rapid Eye

Germany's space agency, DLR, is also partially funding a public-private financing Earth observation system largely aimed at the commercial market for agricultural imaging and mapping, but that also will serve the German military (and possibly others). The Rapid Eye constellation of five 380 kilogram minisatellites will be capable of proving wide swath, multispectral imaging in six bands, with daily revisits over Europe.[19] According to a study by The American Society for Photogrammetry and Remote Sensing (ASPRS), originally funded in part by NASA, Rapid Eye will provide a 6.5 meter resolution and a 78 meter swath width.[20] Rapid Eye AG, a Munich-based company created in 1998 (with the help of the European Commission) will launch the project in June 2004 under a complicated plan that includes a consortium of banks, DLR, and the German state of Brandenburg among others.[21] The constellation, designed by Surry Satellite Technology Ltd., Surrey, U.K., is expected to be launched in 2007 on a DNEPR rocket under a

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[16] *Defense Industry Daily*, op cit.
[17] *Ibid.*
[18] Chuter, Andrew, "TopSat Reflects UK Interest in Small Military Satellites," *C4ISR Journal*, Nov. 29, 2005, http://www.isrjournal.com/story.php?F=1382169.
[19] Sun, Wei; Stephens, J. Paul; and Sweeting, Martin, "Micro- Mini-satellites for Affordable EO Constellations: Rapid-Eye & DMC," presentation to the 5th IAA Symposium on Small Satellites for Earth Observation, Berlin, April 4-8, 2005, p.3, http://www.dlr.de/iaa.symp/archive_3/pdf/0603.pdf.
[20] Stoney, W.E., "Guide to Land Imaging Satellites,' The American Society for Photogrammetry and Remote Sensing, Updated Feb. 2, 2006, http://www.sani-ita.com/pdf/Guide%20to%20Land%20Imaging%20Satellites.pdf
[21] "Financing Successfully Concluded!," Rapid Eye AG press release, June 21, 2004, http://www.rapideye.de/News/Financing_21-06-2004.htm.

contract with Russian company ISK Kosmotras, Moscow.[22] The total program budget is set at 160 million euros, including satellites, launch and ground station.[23]

Essaim

France is the only European country currently operating an electronic intelligence (ELINT) system, known as Essaim, and that program is a demonstration program rather than an actual full-up network. Paris is hoping its demonstration program, along with a planned follow-on, will convince other European governments of the value of an independent European ELINT system.[24]

Essaim (meaning "swarm" in French) is a network of four 120 kilogram microsatellites operating in formation, launched in December 2004 and operational since May 2005.[25] Built by EADS Astrium on behalf of the French defense procurement agency DGA, Essaim "analyze[s] the electromagnetic environment on the ground in a number of frequency bands used exclusively for military communications."[26] I couldn't find any specific specifications for the payload, so I'm assuming it is classified. The constellation, Essaim 1-4, is in a sun-synchronous LEO at approximately 600 kilometers.[27] One ground-based tracking antenna currently receives data from an Essaim spacecraft during its two 10-minute orbital passes per day. The program includes the deployment of two more antennas to allow three satellites to deliver their data at each pass; the fourth satellite is a spare.[28] The program was budgeted at 80 million euros including launch and ground facilities.[29]

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[22] "Surrey Satellite Technology Ltd. Sign RapidEye Launch Agreement with ICS Kosmotras," Surrey Satellite Technology Ltd. press release, April 6, 2005, http://www.rapideye.de/PDF/2005/Rapideye%20Press%20Release%206_4_05.pdf.
[23] *Ibid.*
[24] De Selding, Peter B., "CNES, DGA to Fund Demonstration Satellite," *C4ISR Journal*, May 11, 2005, http://www.isrjournal.com/story.php?F=842558.
[25] Malik, Tariq, "Ariane 5 successfully orbits France's Helios 2A satellite," *Space.com*, Dec. 18, 2004, http://space.com/missionlaunches/ariane5_helios_launch_041218.html.
[26] "ESSAIM, micro-satellites in formation," EADS website, June 13, 2005, http://eads.net/.
[27] Union of Concerned Scientist's Satellite Database, op cit.
[28] De Selding, Peter B., "France Debuts Helios 2A Recon Satellite Images," *C4ISR Journal*, March 29, 2005, http://isr.dnmediagroup.com/story.php?F=750641.
[29] *Ibid.*

In May 2005, DGA, and France's space agency, CNES, signed an agreement to develop a follow-on to Essaim, tentatively named Elint. The project would involve a constellation in LEO of three small satellites to monitor radar signals and radio communications, to be launched in the 2008/2009 timeframe. The budget for the program totals about 150 million euros.[30]

Spirale

France is also pursuing a precursor program that could lead to a space-based missile warning constellation. The project is being funded by the French Defense Ministry, and is designed to demonstrate an initial capability to detect missiles during their boost phase immediately after launch. According to prime contractor EADS Astrium, "The Spirale demonstration program is designed to collect and analyze images in the infrared band against a land background … The Spirale program heralds a future early warning system that will be a strategic component in a ballistic missile defense system."[31] The experimental program involves two 130 kilogram microsatellites, based on CNES's Myriade platform, carrying advanced, high-resolution infrared payloads. Again, I could find no specifics on the payloads. The satellites will operate in a geostationary transfer orbit (a highly elliptical orbit normally used to place satellites in GEO).[32] EADS Astrium was awarded a 124 million euro contract for the project in 2004, and in turn awarded an undisclosed contract to Arianespace for launch of the two satellites simultaneously on an Ariane 5 in 2008.[33]

Tsinghua-1

Tsinghua-1 was born from a collaborative project between Surrey Satellite and Tsinghua University in Beijing, began in 1998, and was launched aboard a Russian Cosmos rocket from Plesetsk in 2000. "The 50 kg microsatellite carried a medium resolution multispectral Earth imaging payload providing 30-meter ground sampling distance (GSD)

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[30] De Selding, Peter B., "CNES, DGA To Fund Demonstration Satellite,"op cit.
[31] "EADS Astrium selects Arianespace to launch Spirale," EADS Astrium press release, Oct. 17, 2005, http://www.space.eads.net/press-center/press-releases/eads-astrium-selects-arianespace-to-launch-spirale.
[32] "French Spirale To Launch Aboard Ariane 5," *Space News*, Oct. 24, 2005, p.8.
[33] *Ibid.*

in four optical bands (NIR, green, blue)," according to Surrey Satellite's website.[34] According to the ASPRS study, the satellite's resolution is 39 meters, with a swath width of 600 kilometers.[35]

The satellite was controlled by Surrey itself, as well as from a Surrey-built ground-station at Tsinghua. Its mission was to serve as the first demonstrator for a five-nation project to orbit a Disaster Monitoring Constellation that I will explain shortly. It also was designed to carry out "research in low Earth orbit using digital store-and-forward communications, a digital signal processing (DSP) experiment, a Surrey-built GPS space receiver and a new three-axis microsatellite attitude control experiment."[36] Sir Martin Sweeting, the head of Surrey Satellite, early last year felt compelled to explain the nature of this project (as well as that of the Disaster Monitoring Constellation), after media reports (primarily in the United States) raised red flags about Surrey-China collaboration providing the Chinese with technologies applicable to ASAT development. According to Sweeting, Tsinghau-1 was built entirely from commercial, off-the-shelf technologies, and the project was designed to provide training in satellite techniques to the Chinese researchers involved. Further, Sweeting said, the satellite contained no on-board propulsion unit and thus is unable to maneuver on orbit.[37] In addition, he stressed, Surrey received all the necessary export approval/licenses required from the U.K. government.[38]

Tsinghau, at the same time, has become one of China's leading microsat developers. In 2000, the university set up Aerospace Tsinghua Satellite Technology Co. Ltd. to develop microsats and market their applications, with financing from the China Aerospace Machinery and Electronics Corporation, the Tsinghua University Enterprise Group, and the Tsinghua Tongfang Co. Ltd.[39]

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[34] "Statement to press from Sir Martin Sweeting regarding PR China," Surrey Satellite Technology Ltd., March 23, 2005, http://www.sstl.co.uk/index.php?loc=27&id=804.
[35] Stoney, W.E., op cit.
[36] Long, Wei, "China's First Microsat Operational," July 11, 2000, *Space Daily*, http://www.spacedaily.com/news/microsat-00k.html.
[37] *Ibid*.
[38] *Ibid*.
[39] Long, Wei, "China Eyes Microsat Market," *Space Daily*, June 28, 2000, http://www.spacedaily.com/news/china-00zi.html.

Disaster Monitoring Constellation

This five-nation effort to develop a constellation of Earth observation microsatellites for mid-resolution, wide-area mapping to monitor and help manage natural and man-made disasters is led by Surrey Satellite. The partners in the collaboration are: Algeria's Centre National des Techniques Spatiales, China's Ministry of Science & Technology, Nigeria's National Space Research & Development Agency, Turkey's Scientific and Technical Research Council TUBITAK-ODTU, the British National Space Centre (the U.K. national space agency), and Surrey Satellite. Vietnam and Thailand are aspiring partners. Surrey Satellite was responsible for the construction of five microsats: Algeria's AISAT-1, Turkey's BILSAT-1, Britain's UK-DMC satellite, NigeriaSat-1[40] and China's Beijing-1.[41]

The members, through their Disaster Monitoring Constellation Consortium established in 2004 to provide data to outside customers, in November 2005 adhered to the International Charter on Space and Major Disasters.[42] Members of the charter pledge to provide, for free, data from their space systems to rescue and other local authorities in the event of a major disaster.[43] For example, it was activated after the Oct. 8, 2005, earthquake in Pakistan and Kashmir.

AISAT-1 was launched Nov. 28, 2002. Weighing 90 kilograms, it has a multispectral camera (blue, green and NIR) with a 32 meter resolution and a 600 kilometer swath

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[40] "SSTL readies first DMC satellite for November launch," Surrey Satellite Technology Ltd., Nov. 12, 2002, http://www.sstil.co.uk/index.php?loc=27&id=195

[41] "DMC (Disaster Monitoring Constellation): AISAT-1, BILSAT-1, NigeriaSat-1, UK-DMC, Beijing-1," eoPortal, http://directory.eoportal.org/pres_DMCDisasterMonitoringConstellationAlSAT1BILSAT1NigeriaSat1UKDMCBeijing1.

[42] "The British National Space Centre and the DMC join the International Charter 'Space and Major Disasters,' European Space Agency website, Nov. 16, 2005, http://www.esa.int/esaEO/SEMS3TTLWFE_environment_0.html.

[43] "Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters," Rev.3 (25/4/2000).2, International Charter Space and Major Disasters website, http://www.disasterscharter.org/charter_e.html.

width.[44] BILSAT-1, NigeriaSat-1 and UK-DMC were launched simultaneously, from a Russian Cosmos rocket, on Sept. 27, 2003. BILSAT-1 weighs 130 kilograms. Its payload consists of a high-resolution panchromatic imager (12 meter ground resolution, 25 kilometer swath width), a four-band medium-resolution (26 meters, 55 kilometers swath width) imager, and a nine-band hyperspectral imager.[45] NigeriaSat-1, weighing 100 kilograms, carries a multispectral imaging payload (green, red and NIR) with a 32 meters resolution and a very wide swath width of more than 640 kilometers (meaning it can image scenes as large as 640 X 560 kilometers with medium-level resolution).[46] UK-DMC, also 100 kilograms, carries the same payload as NigeriaSat-1, but features increased on-board data storage capabilities.[47] Beijing-1 weighs 166 kilograms, and carries a panchromatic imager with a four meter resolution and 24 kilometer swath width, as well as the multispectral imager carried by NigeriaSat-1 and UK-DMC.[48]

The constellation is in a sun-synchronous circular orbit, at an altitude of 668 kilometers, in one orbital plane – the satellites have nominal phase slots of 0 degrees, 90 degrees, 180 degrees and 270 degrees – providing a daily revisit rate to any point on the equator and more often to higher latitudes. The satellites are designed to last for at least five years in orbit, and can operate alone or in tandem. Each of the satellites carries either a pressurized cold gas or liquefied gas system – with thrusters providing 12 meters per second delta-v, with accurate orbit position and velocity data provided by onboard GPS receivers, to allow the satellites to maneuver to stay in synchronization with each other on orbit. They also employ an electric propulsion system (a low-power resistojet).[49] Surrey Satellite also has used the UK-DMC to demonstrate a new steam-powered micro-

[44] Mantell, Katie, "Disaster-monitoring satellite blasts off," *SciDev Net*, Nov. 29, 2002, http://www.scidev.net/News/index.cfm?fuseaction=printarticle&itemid=309&language=1; eoPortal, op cit.
[45] eoPortal, op cit, "Enhanced Microsatellite for Turkey," Surrey Satellite Technology Ltd., http://www.sstl.co.uk/index.php?loc=110&sstl-website=2fb56ca69086b2e750b0c52f0c47002c.
[46] "Remote Sensing Microsatellite for Nigeria," Surrey Satellite Technology Ltd., http://www.sstl.co.uk/index.php?loc=112; Government of Nigeria, Office of Public Communications press release, "The NigeriaSat-1 Project," Nigeriafirst website, Jan. 25, 2004, http://www.nigeriafirst.org/article_1992.shtml.
[47] "British National Space Centre DMC Microsatellite," Surrey Satellite Technology Ltd., http://www.sstl.co.uk/index.php.
[48] "Satellite observing Beijing sent into orbit," *Xinhuanet*, Oct. 10, 2005, http://www.cast.cn/printpage.asp?ArticleID=958; eoPortal, op cit.
[49] eoPortal, op cit.

propulsion unit, a miniature resistojet, that could be used in the future by nanosatellites and so-called Cubesats (very small satellites weighing about 1 kilogram, designed to be deployed on a mother satellite and capable of docking with other satellites[50]) weighing only 13 grams.[51] UK-DMC also carries a commercial, off-the-shelf router designed by Cisco Systems Inc., being tested for mobile Internet protocol applications. Each member of the consortium operates its own satellite and ground facilities, linked by a centralized mission planning system to coordinate imaging opportunities.[52]

The fact that each of the DMC satellites includes a propulsion unit, and thus are capable of maneuvering, again raised eyebrows amongst "China hawks" in the United States – concerned that the Surrey-Chinese collaboration would enable Chinese ASAT development. Sweeting, however, defended the program, explaining that the Beijing-1 satellite was a turn-key project and that the satellite would never enter China. In addition, he said, "no propulsion technology or know-how has been provided by SSTL to China and therefore the satellites supplied by SSTL are not able to be used either as ASAT anti-satellite devices nor as a basis to develop such devices as claimed by some press reports. Futher, no nanosatellite designs or know-how have been supplied to China by SSTL."[53]

Other Chinese Efforts

China is very interested in small and microsatellite technology, and a number of institutions and universities have been undertaking research. According to one report, the Chinese Academy of Sciences (CAS) in 2005 set up the Shanghai Engineering Center for Microsatellite Engineering and a unified lab for microsat studies. CSA launched a microsatellite (exact weight unknown, exact purpose unknown) called Chuangxin-1, or CX-1, in October 2003 (along with the second China-Brazil Earth Resource Satellite that

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[50] Hoey, Matthew, "Military Space Systems: The Road Ahead," Presentation at the Symposium on Non-proliferation and Disarmament – The Way Forward, co-sponsored by MIT and the Institute for Defense and Disarmament Studies, Oct. 25, 2005, available at http://www.cdi.org/program/document.cfm?DocumentID=3332&StartRow=1&ListRows=10&appendURL=&Orderby=D.DateLastUpdated&ProgramID=68&from_page=index.cfm.

[51] "Surrey successfully demonstrate steam micro-propulsion in-orbit," *Innovations Report*, March 17, 2003, http://www.innovations-report.com/html/reports/energy_engineering/report-27046.html.

[52] "Disaster Monitoring Constellation – the facts… and enhanced technologies," Surrey Space Newsletter, September 2003, http/www.sstl.co.uk/documents/SNews4.pdf.

[53] "Statement to the Press….," Surrey Satellite Technology Ltd., op cit.

I will discuss later).[54] According to a report in *People's Daily*, "the satellite, which has adopted a series of advanced telecommunication technologies, can play a big role in data transmission to help traffic control, environmental protection, oil and gas transportation, flood prevention and earthquake monitoring."[55]

As noted, Tsinghua – as well as Harbin Polytechnic University – long have been involved in research and development. In April 2004, the two groups launched two new small satellites from Xichang Satellite Launch Center on a Long March 2C rocket. The first, called "Experimental Satellite," also known as Shiyan-1, and weighing in at 204 kilograms, is touted as "China's first transmission-type small satellite capable of stereo mapping" and will be used for "photographic surveys of China's land resources" and other mapping experiments.[56] It was launched into a sun-synchronous orbit of about 600 kilometers.[57] It was jointly designed by the Harbin Polytechnic University, Chinese Research Institute of Space Technology, Changchun Photomechanical Institute of the Chinese Academy of Sciences (CAS) and Xi'an Surveys and Designs Institute.[58] The second satellite, "Nano-satellite 1," was developed by Tsinghua and Aerospace Tsinghua Satellite Technologies Co. Ltd. "for high-tech experiments", and weighed 25 kilograms.[59] The nanosat, also known as Naxing, was launched into an orbit of about 600 kilometers.[60] I could find no solid data about the capabilities of either satellite in English, and I don't read Chinese. I will also caveat that English translations of Chinese often use different spellings and different translations for various institutions, making research in this area for non-China specialists extremely confusing.

A second Shiyan satellite, Shiyan-2, was launched on Nov. 18, 2004, also a remote sensing payload and weighing 300 kilograms. It is in a 694-711 kilometer sun

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[54] "China Eyes Small Satellites," Chinanews, May 20, 2005, http://www.china.org.cn/english/scitech/129402.htm.
[55] "China puts two satellites in orbit," People's Daily, Oct. 21, 2003, http://english.people.com.cn/200310/21/eng20031021_126502.shtml.
[56] "China launches two new satellites," Xinhuanet, http://news.xinhuanet.com/english/2004-04/19/content_1426357.htm.
[57] "Shiyan-1, Naxing-1," *Space Newsfeed*, http://www.spacenewsfeed.co.uk/2004/25April2004_19.html
[58] "China launches two …," Xinhuanet, op cit.
[59] *Ibid.*
[60] "Spacewarn Bulletin," National Space Science Data Center/World Center for Satellite Information, May 1, 2004, http://nssdc.gsfc.nasa.gov/spacewarn/spx606.html.

synchronous orbit at an inclination of 98.2 degrees. It was developed by Dongfanghong Satellite Co.[61] NASA dubbed this satellite Tansuo 2, and it is also known as Experimental Satellite-2, and stated that it would "test some technology developments and also survey and monitor the geographical environment."[62]

SSETI

In 2000, ESA started a program called Student Space Exploration and Technology Initiative to involve European students in space sciences. On Oct. 27, 2005, the group launched the SSETI Express microsatellite mission – designed and built in 18 months by more than 400 students at 23 universities in 12 countries who communicated largely via Internet. The microsat weighed 62 kilograms, and was designed to take Earth imagery, test a cold-gas attitude control system, and function as a radio transponder for amateur operators.[63] Even more interestingly, the microsat also carried three picosats, called CubeSat XI-V, Ncube 2, and UWE-1, each weighing about 1 kilogram and shaped like a tiny, 10 centimeter cube. The three picosats were released from SSETI Express into separate orbits. CubeSat XI-V, built by students at ISSL in Tokyo, demonstrated innovative solar cells, plus was designed to take digital photos of the Earth. Ncube 2, developed by a Norwegian consortium, contained a GPS receiver. UWE-1, developed by students at University of Würzburg, was designed to conduct "telecommunications related to the optimization of an Internet-related infrastructure for space applications."[64] My point is that SSETI Express shows just how disseminated microsatellite technology and capabilities have already become.

Imaging Capabilities

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[61] McDowell, Jonathan, "Jonathan's Space Report," No. 539, Nov. 28, 2004, http://host.planet4589.0rg/space/jsr/back/news.539.
[62] "Space Warn Bulletin No. 16," National Space Science Data Center/World Data Center for Satellite Information, NASA, Dec. 1, 2004, http://nssdc.gsfc.nasa.gov/spacewarn/spx613.html.
[63] Malik, Tariq, "Students Prepare to Launch Homemade Satellite," space.com, Sept. 21, 2005, http://www.space.com/businesstechnology/050921_techwed_sseti.html.
[64] European Space Agency fact sheet, "About SSETI Express," Sept. 5, 2005, http://www.esa.int/SPECIALS/sseti_express/SEMN9Z708BE_0.html.

You may have noticed that many of the ongoing microsatellite efforts outside the United States are aimed at Earth observation, remote sensing and even high-resolution imaging. Earth observation satellite systems are used by militaries to make detailed maps, monitor troops in the field (both friendly and enemy), look for suspicious activities (such as the construction of nuclear facilities), provide geographic data to missiles and other weapon systems for use in targeting, etc. To be useful during a conflict or crisis, images must be taken repeatedly at the shortest time intervals possible and data relayed and analyzed as quickly as possible. The website of the French Space Agency, CNES, website offers the following primer:

- The 'recency[sic]' of the information in the image is just as important as the information itself.

- The lead times required for acquisition and operational processing must be compatible with the decision-making or utilization time, and vary according to the level of use:

    - the strategic level requires the **continuous** acquisition of image data over the entire world, using specific detection capabilities, in order to prevent crises and conflicts and monitor the application of treaties,

    - during the different phases of a projection operation, the operative level implies the collection and analysis of essential information for acquiring or completing the areas of engagement. This results in the production of mapping data and the composition of databases of targets required for the preparation of missions and weapons systems. It is therefore essential to update these databases, often with **very short deadlines**, which implies a high revisit capability,

- the tactical level, which corresponds to the engagement of troops, requires the **regular and frequent** assessment of the situation and assessments of the operations theatre. At this level, **the date of the information** is fundamental, and coverage of the operations theatre must be as comprehensive as possible. All available sensors are used to assess the adverse situation, implement the appropriate weapons systems, engage the missions and determine the results of strikes.[65]

Satellite systems with these capabilities are proliferating rapidly. The United States, Russia, France, Israel, Japan, and China all own and operate very capable imaging satellites; Germany and Italy have plans to launch their first imaging satellites for military use; and India, Pakistan, Malaysia and Korea have announced intentions to orbit high resolution dual-use remote sensing systems. According to the ASPRS study, some 13 countries had civil or dual-use mid- to high-resolution satellites in orbit as of February 2006, and by the end of the decade that number will jump to 20.[66] And that doesn't count dedicated military reconnaissance satellites owned by the United States, Russia, France, China, and Israel and being planned by a handful of other nations. Resolutions are also improving – down to the submeter level. With 20 meter resolution, a user would have a limited capability to identify large ships; while a one meter resolution is good enough to identify types of ships, aircraft and tanks – although submeter resolution would be required for detecting specific design parameters. In addition, the type of sensor also matters to the usefulness of imagery satellites for military purposes. Radar, for example, can image through cloud cover whereas optical cameras using visible light cannot.[67]

European states, furthermore, have recognized that their capabilities for reconnaissance – both for civil and military purposes – could be vastly improved through cooperation. While space cooperation, particularly amongst Europe's militaries, is progressing slowly and faces both political and economic obstacles, it is clear that the desire to become

[65] "Pleiades/Key Applications," Centre National D'Etudes Spatiales (CNES) website, http://smsc.cnes.fr/PLEIADES/lien7_app.htm.
[66] Stoney, W.E., op cit.
[67] Lewis, James, "China as a Military Space Competitor," January 2004, available at http://www.gwu.edu/~spi/spaceforum/China.pdf.

independent from the United States in the security arena is a strong driver for European states to obtain their own intelligence gathering capabilities. “Europe can no longer assume a fortuitous coincidence of interest with the USA,” found a March 2005 report to the European Commission by a panel of space experts.[68]

On the civil side, Europe has launched the ambitious, and highly complex, *Global Monitoring for Environment and Security (GMES)* Earth observation effort, intended to enhance European abilities to monitor borders, study climate change, and provide natural disaster warnings. Sponsored by the European Union and the 17-member European Space Agency (ESA), it also has direct security and defense applications, as the program is being specifically designed to support the EU Common Foreign and Security Policy, and the European Security and Defense Policy that governs joint European military operations such as peacekeeping. According to a February 2004 joint EU/ESA report, GMES will be used “in support of conflict prevention and crisis management: monitoring of international treaty [sic] for preventing the proliferation of nuclear, chemical and biological weapons; monitoring population (settlements, movements, density, etc.); assessment of sensitive areas for early warning; [and] rapid mapping during crisis management.”[69] GMES also is slated as a European contribution to the Global Earth Observation System of Systems, launched by the United States in 2003 at the Earth Observation Summit and intended to improve sharing of Earth imaging and data for both climate research applications and for monitoring and responding to natural disasters.

European officials, however, make clear that, like the Galileo satellite navigation and positioning system, GMES is about providing Europe with an independent capability for Earth observation – a capability that could provide significantly improved European militaries abilities to independently generate mapping, weather prediction and targeting data. “The idea at the basis of the GMES is the same which justifies the Galileo global system of satellite navigation. It is the independence of a Europe that must be able to

[68] ‘Report of the Panel of Experts on Space Security’ to the Commission of the European Communities, March 2005, p. 38, URL < http://europa.eu.int/comm/space/news/article_2262.pdf>
[69] “Global Monitoring for Environment and Security,” Final Report for the GMES Initial Period (2001-2003), European Space Agency and European Union, Feb. 10, 2004, p.18.

count on its own global information source," said Volker Liebig, head of ESA's Earth Observation programs, in a February 2005 interview.[70]

GMES is only partially a space program; it is more importantly a data control and integration effort, although Earth observation satellites obviously are the critical sensor node, as imaging from space can cover vast swathes of ground and provide different spectral views (i.e. electro-optic, infrared, radar) to enable many different types of scientific analyses. The GMES space-based network will involve the use of existing satellites, both national and multinational, as well as the development of new infrastructure including new satellites to be built collectively by ESA and the European Commission. GMES will comprise four segments: services providing data and analysis to users (users consisting largely of public institutions such as fisheries administrations); space observations; in-situ observations from air, ground and sea monitoring facilities; and data integration and information management capacity.

GMES will include two major new satellite efforts. The first is the **Sentinel** program. Five specific new space missions, dubbed "Sentinels," are being planned. According to ESA, "Sentinel-1 is to be a C-band interferometric radar mission; Sentinel-2, a multispectral optical imaging mission; Sentinel-3, a mission with an altimeter and wide swath low/medium resolution optical and infrared radiometers; Sentinel-4 and -5, two families of atmospheric chemistry monitoring missions," with Sentinel-4 on geostationary and Sentinel-5 on Low Earth orbit (LEO).[71] Under current plans, each mission will be conducted by a family of small satellites networked together and each group aimed at replacing specific satellite systems on orbit today. Sentinel-1 will involve a family of Synthetic Aperture Radar (SAR) satellites, eventually replacing the current ERS and Envisat radar satellites that conduct ocean and atmospheric monitoring. The first Sentinel-1 satellite is expected to be operational in the 2007-2008 timeframe.[72] Sentinel-2 will involve a number of optical satellites for Earth imaging, eventually to

[70] "Earth and Space – Europe sets its sights on GMES," *RTDinfo – Magazine on European Research*, No. 44 – February 2005, http://europa.eu.int/comm/research/rtdinfo/44/01/print_article_2027_en.html.
[71] *Ibid.*
[72] "Earth and Space – Europe sets its sights on GMES."

replace today's SPOT and Vegetation satellites.[73] Sentinel-3 will involve a group of oceanographic satellites, designed to eventually replace the U.S.-French Jason satellite that last December became the first ever satellite to observe and measure a tsunami in the open ocean.[74] Sentinel-4 would involve improved versions of ESA's current Meteosat Second Generation satellites to monitor atmospheric components and pollution migration; Sentinel-5 would be achieved by a group of LEO satellites that will monitor the chemical make-up of the atmosphere.[75] However, the exact requirements for these latter two satellites and their relationship to other GMES-related systems such as Meteosat and the new Metop network remain undecided.[76]

EPS/Metop. The EUMETSAT Polar System (EPS) will be the European Meteorological Satellite agency's polar-orbiting system, complementing the existing geostationary Meteosat constellation and operating in conjunction with a polar-orbiting system managed by the U.S. National Oceanic and Atmospheric Administration (NOAA). EPS will consist of a series of three satellites, labeled Metop-A through Metop-C, each of which will operate in sun-synchronous orbit at an altitude around 800 kilometers.[77] Metop will be the first European meteorology satellite system in polar orbit – a form of Low Earth Orbit – which allows the satellites to cover a smaller geographic area at any one time than the Meteosat system, but in greater detail.[78]

The Metop series will carry 12 instruments – some provided by NOAA and the U.S. National Aeronautics and Space Administration (NASA) as well as European developed instruments – designed to provide enhanced accuracy in measuring temperature, humidity,

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[73] *Ibid.*
[74] *Ibid*; "NASA/French Satellite Data Reveal New Details of Tsunami," NASA news release, Jan. 11, 2005, http://www.nasa.gov/centers/jpl/news/jason-011105.html.
[75] "Earth and Space – Europe sets its sights on GMES."
[76] Ginati, A., "Das GMES-Weltraumsegment & Relevante Earth Explorer Missionen," presented at the DLR & DWD Nationaler Nutzerworkshop, "Operationelle Satellitensysteme der Erdüberwachung," Nov. 7-9, 2004, Walberberg, Germany, http://www.dlr.de/rd/fachprog/eo/bmvbw-aufgaben/opse/vortraege/V04-GMES-Earth-Explorer.pdf.
[77] "EUMETSAT Polar System (EPS)," EUMETSAT website, Sept. 30, 2005, http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&nodeId=47&l=en.
[78] "Orbits," EUMETSAT website, Nov. 29, 2005, http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&nodeId=505&l=en.

over-ocean wind speed and direction, and ozone distribution in the atmosphere.[79] The satellites will undertake operational meteorology activities, which are related to analyzing and predicting changes in weather, including all-weather monitoring, imagery of clouds and land/ocean surfaces and air-sea interactions amongst others. The Metop series also will provide climate monitoring data related to the atmosphere, land surface and oceans, which will be used for such things as predicting crop yields, creating maps of snow and ice covers used by the transportation and tourism industries, and ozone layer monitoring.[80]

Metop-A is scheduled to be launched in June 2006. The other two craft are to follow in 2011 and 2015, with each launch scheduled to coincide with the end of the previous craft's planned lifetime.[81] As if to highlight European concerns about dependency on the United States in space, the two sides of the Atlantic argued for months about the controversial issue of when weather data from the Metop satellites might be denied to users in times of conflict and crises. The issue was made more acute by the fact that NOAA and the U.S. Department of Defense are now in the process of merging meteorological satellite systems.[82] An agreement was finally announced on Feb. 22, 2006, that "provides the necessary steps for data denial if NOAA makes the request."[83]

European cooperation in military space has been more complicated, and slow. Nonetheless, in the area of Earth observation, there is a widespread recognition that more interconnectivity and interoperability is needed. In 2002, Belgium, France, Germany, Italy and Spain signed onto a document called the "Common Operational Requirements for a European Global System of Observation by Satellite," usually known by its French

[79] "Russian space agency to launch European meteorological satellite," ESA website, May 5, 2005, http://www.esa.int/esaME/SEMV7Y2IU7E_index_0.html.
[80] "EUMETSAT Polar System Objectives," EUMETSAT website, Nov. 10, 2005, http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&ssDocName=SP_1117025675266&l=en&ssTargetNodeId=452.
[81] "Satellites," EUMETSAT website, Nov. 24, 2005, http://www.eumetsat.int/idcplg?IdcService=SS_GET_PAGE&nodeId=42&l=en.
[82] "U.S., Europe Wrestle With Weather Data-Denial Plan," *Space News*, Dec. 5, 2005, p.20.
[83] National Oceanic and Atmospheric Administration, press release NOAA 2006-R301, "U.S., Europe Take Steps To Advance Polar Satellite Cooperation," Feb. 22, 2006, http://www.publicaffairs.noaa.gov/releases2006/feb06/noaa06-r301.html.

acronym, BOC (for *Besoins Operationnels Communs).* Greece signed on in 2003. The document seeks to define what is needed to build an independent European military satellite Earth observation system to support future peacekeeping missions and other European joint operations. It was designed to also bring together contributions from the signatory states to form a collaborative program building on their national military and dual-use systems. The agreement further stipulates that the European Union will be granted access to the eventual network.[84] A key obstacle, however, has been developing ground systems that allow participating governments to link into each other's satellite networks, and protocols for what data would be available for exchange.[85]

There are several national military and dual-use space reconnaissance programs in Europe that are of note.

The first is France's **Helios.** Helios is an optical imaging system intended primarily for military reconnaissance. The Helios program is funded primarily by the French military procurement agency and is managed by CNES. Spain, Italy and Belgium are also involved in different phases of the program, and a bilateral information exchange agreement exists between France and Germany.[86]

The Helios program is divided into two phases, Helios I and Helios II, each consisting of two satellites. Satellites Helios IA and IB were respectively launched on July 7, 1995, and Dec. 3, 1999.[87] These first two satellites had about a one meter optical imaging resolution, and no infrared capability – and thus were not capable of obtaining images at night or in cloudy weather.[88] Helios IA remains operational. Italy has a 14 percent stake in Helios I and Spain has a 7 percent stake, and both thus can receive data at an amount proportional to their funding.

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[84] De Selding, Peter B, "Europe Pools Space Spy Efforts," *Defense News*, July 1-7, 2002, p.18.
[85] "Report of the Panel of Experts on Space and Security," p.33.
[86] "HELIOS," CNES website, January 2005, http://www.cnes.fr/; and "Helios II: Further enhancing Europe's reconnaissance capability," EADS Space press release, http://www.space.eads.net/families/a-safer-world/recon/helios-2.
[87] "HELIOS," CNES website.
[88] De Selding, Peter B., "France Debuts Helios 2A Recon Satellite Images," *C4ISR Journal,* March 29, 2005, http://www.isrjournal.com/story.php?F=750641.

Helios IIA was launched on Dec.18, 2004, and Helios IIB is expected to be launched in late 2008.[89] In addition to the reconnaissance functions performed by its predecessor, Helios II is intended to "support targeting, guidance, mission planning and battle damage assessment," according to CNES.[90] The two-satellite network will be used for, among other missions, surveillance of nuclear facilities of interest and mapping targets for missiles.[91] Helios IIA is located in sun-synchronous, polar, orbit at an altitude of approximately 680 kilometers. The craft weighs 4,200 kilograms and carries two optical instruments, a high-resolution camera and a wide-field camera, each operating in both the visible and near-infrared spectra.[92] The system is designed to provide all day/night capability, and although its resolution is classified, it is estimated at about 0.5 meters for the high-resolution camera.[93] Belgium and Spain each have a 2.5 percent share in the Helios II program, currently budgeted to cost a total of 2 billion euros.[94] The program should be able to provide imagery through 2013, with each satellite expected to have a minimum of a five-year lifetime on orbit.[95]

Germany, for the first time, is moving out with its own spy satellite, **SAR-Lupe.** SAR-Lupe is a German synthetic-aperture radar (SAR) constellation intended for military reconnaissance.[96] The planned system will consist of five satellites, each weighing 770 kilograms, distributed over three polar orbits at an altitude of 500 kilometers.[97] The X-band radar will have two modes: Stripmap, providing extended time imaging; and Spotlight, which will provide a higher resolution image. Further, when two satellites are

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[89] "The Helios II satellites," EADS Space press release, June 6, 2005, http://www.space.eads.net/press-center/press-documents/464-en.
[90] "HELIOS," CNES website.
[91] Fiorenza, Nicholas, "Helios 2 Boosts French Satellite Intelligence," *C4ISR Journal*, Jan. 13, 2005, http://isr.dnmediagroup.com/story.php?F=589309.
[92] "Helios IIA Key Figures," CNES website, http://www.cnes.fr/html/_455_461_2744_2745_.php; Malik, T, "Ariane 5 successfully orbits France's Helios 2A satellite," *Space.com*, Dec. 18, 2004, http://www.space.com/missionlaunches/ariane5_helios_launch_041218.html.
[93] De Selding, Peter B., "France Debuts Helios 2A Recon Satellite Images," *C4ISR Journal*, March 29, 2005, http://www.isrjournal.com/story.php?F=750641.
[94] Fiorenza, Nicholas, "Helios 2 Boosts French Satellite Intelligence."
[95] "Helios IIA Key Figures," CNES website.
[96] "SAR-Lupe," OHB-System AG website, http://www.ohb-system.de/Security/sarlupe.html.
[97] "SAR-Lupe: The innovative program for satellite-based radar reconnaissance," OHB-System AG website, http://www.ohb-system.de/pdf/sar-lupe-broschure.pdf.

used in Spotlight mode, a very high resolution can be obtained – this mode is what is referred to by the word *Lupe*, which means magnifying glass. The system is expected to provide a best resolution of 0.5 meters, coverage of the Earth between 80 degrees north and 80 degrees south latitude, and more than 30 images a day; users also expect that the network will be able to begin imaging no more than 36 hours after being tasked and that images will arrive at a ground station in no more than 12 hours time after it has been taken.[98]

The satellites are expected to be launched between 2006 and 2008,[99] after delays in development of the system pushed back an original 2004 planned launch.[100] Data collected by SAR-Lupe will be provided to the French government in exchange for data from Helios.[101] Under the Franco-German agreement, receivers for each system will include the capability to receive the other's data. Total program cost is expected to be about 300 million euros.[102]

Finally, there is the Franco-Italian effort, launched under a January 2001 bilateral agreement, to orbit a dual-use system of optical and radar imaging satellites, called ORFEO (Optical and Radar Federated Earth Observation) program.[103]

Pleiades will be the French contribution, a two-satellite optical military reconnaissance system that is billed as the dual-use successor to France's SPOT Earth-observation system. Other partners include Austria (1 percent), Belgium (4 percent), Spain (3 percent) and Sweden (3 percent), which are sharing the costs of the Pleiades system in exchange

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[98] De Selding, Peter B., "German Military Prepares for 2005 SAR-Lupe Deployment," *C4ISR Journal*, June 1, 2004, http://isr.dnmediagroup.com/story.php?F=327973.

[99] Sell, D., OHB-System AG Communications & Public Relations, communication with the author, Nov. 28, 2005.

[100] "Fifth Franco-German Council of Ministers – Statement by the Franco-German Defence and Security Council," Embassy of France in the United States, April 26, 2005, http://www.ambafrance-us.org/news/statmnts/2005/franco_germany_defense042605.asp.

[101] "Helios II: Further enhancing Europe's reconnaissance capability," EADS Space press release, http://www.space.eads.net/families/a-safer-world/recon/helios-2.

[102] De Selding, Peter B., "German Military Prepares for 2005 SAR-Lupe Deployment."

[103] The two nations signed a memorandum of understanding in January 2001, under which each nation would pay for its own space system but the costs of ground systems to utilize the satellites would be shared. See: "Pleiades (Optical Imaging Constellation of CNES)," *eoPortal*, http://directory.eoportal.org/pres_PleiadesOpticalImagingConstellationofCNES.html.

for access to data.[104] EADS-Astrium was awarded in October 2003 a contract for 314 million euros to produce the two satellites.

Pleiades will consist of two small (approximately 1,000 kilogram) satellites in sun-synchronous orbits at an altitude of 694 kilometers. The high-resolution system will offer both a panchromatic and a multispectral (blue, green, red and near infrared) mode – with a field of view of 20 kilometers; a resolution of 0.7 meters in panchromatic, and 2.8 meters in multispectral modes; and daily full-Earth coverage.[105] The system will allow fast and detailed mapping of urban environments – in large part because it can take many images during one orbital pass – thus making its capabilities directly applicable to ongoing military operations. Indeed, access to Pleiades data will be prioritized to military users, and during times of crisis the imaging of certain priority areas could be established.[106]

According to CNES, Pleiades features several key technological innovations:

> In terms of technologies, the two Pleiades satellites feature several major innovations designed to enhance system performance. These include new measuring instruments, onboard memory, compact electronics and faster data transmission rates. The satellite architecture is built around the telescope to give the spacecraft more agility. In particular, an all-new guidance and control system uses extremely high-performance equipment. This increased agility is achieved by tilting the satellite along and off its orbital ground track. As a result, it can cover a wider swath by imaging several contiguous ground strips on the same pass.[107]

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[104] "Pleiades: a multi-missions concept and a partnership program," CNES website, March 24, 2005, http://smsc.cnes.fr/PLEIADES/; "Organisation of the ORFERO Programme," CNES website, http://smsc.cnes.fr/PLEIADES/GP_organisation.htm.
[105] "Pleiades: a multi-missions concept and a partnership program," CNES website.
[106] "Pleiades/Key Applications," CNES website, http://smsc.cnes.fr/PLEIADES/lien7_app.htm; "Pleiades/Mission/Needs Analysis," CNES website, http://smsc.cnes.fr/PLEIADES/GP_mission.htm.
[107] "CNES Programs/Science and technology challenges," CNES website, http://www.cnes.fr/html/_455_461_3236_3238_.php.

Pleiades-HR 1 is due to be launched in late 2008 and Pleiades-HR 2 in 2009 or early 2010.[108]

COSMO-SkyMed, the Constellation of Small Satellites for Mediterranean Basin Observation, is the Italian contribution to the ORFEO program. COSMO-SkyMed will be Italy's first Earth imaging satellite and will be used by both the military and civilian authorities. It will consist primarily of a constellation of four X-band (9.6 GHz) synthetic-aperture radar (SAR) Earth observation satellites.[109] The Italian Ministry of Defense is one of several sponsoring agencies of the dual-use system,[110] which overall is expected to cost about 900 million euros. Cosmo-Skymed satellites will provide high resolution metric and sub-metric imagery through clouds, at night, with a revisit time of few hours, providing worldwide coverage.[111] The use of SAR enables more defined imaging capabilities than optical sensors, with higher contrast and more accurate definition of topography, even under cloud cover. The data and imagery provided will support "defense missions such as surveillance, intelligence, mapping, damage assessment, vulnerability assessment, target detection/localization."[112]

The COSMO-SkyMed satellites will use a dawn/dusk sun-synchronous orbit at roughly 600 kilometers, with an inclination of 97.86 degrees; the configuration will allow a revisit time of a few hours anywhere on the globe (revisit rate meaning the time it takes for another satellite to pass the same geographic location and provide images).[113] Project prime contractor Alenia Spazio describes the resolution of the system as "in the order of

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[108] "Pleiades: a multi-missions concept and a partnership program," CNES website; "Arianespace to launch Pleiades satellites," Arianespace website, Jan. 4, 2005, http://arianespace.com/.
[109] "COSMO-SkyMed 1, 2,3,4," *Gunter's Space Page*, http://www.skyrocket.de/space/doc_sdat/cosmo-skymed-1.htm.
[110] "COSMO-SKYMED: A system looking to the future of our planet," Alenia Spazio website, http://www.alespazio.it/earth_observation_page.aspx?IdProg=23.
[111] "COSMO-SkyMed," *deagel.com*, http://www.deagel.com/pandora/cosmo-skymed_pm00353001.aspx.
[112] "Constellation of 4 SAR Satellites," COSMO-SkyMed, *eoPortal*, http://directory.eoportal.org/pres_COSMOSkyMedConstellationof4SARSatellites.html.
[113] *Ibid.*

one meter."[114] Although the program's name emphasizes its use for observing the Mediterranean region, the satellites' ground coverage will be global.

The SAR sensor can work in four modes. Using the Spotlight mode, the SAR scans with a resolution of less than one meter covering an area of 10 square kilometers. The HIMAGE (Stripmap) acquisition mode provides 3-15 meter resolution, with a swath width (width of the image) about 40 kilometers. The WideRegion (ScanSAR) mode provides a resolution of about 30 meters, with a swath width of 100 kilometers. Finally, the HugeRegion mode has a resolution of about 100 metres but a swath width of 200 kilometers. Users also can choose to use two modes at a time, called Ping Pong, with a resolution of 15 meters and a swath width of 30 kilometers.[115]
The COSMO-SkyMed satellites will be launched over a period beginning in late 2006, and the system is expected to be operational by the end of 2008.[116] The program is expected to cost about 900 million euros.[117]

Another interesting collaborative effort is the **China-Brazil Earth Resource Satellite network (CBERS).** The program between the Chinese Academy of Space Technology and Brazil's Space Agency, INPE (Instituto de Pesquisas Espaciais) was agreed in 1998 and the first satellite, CBERS-1 (also known as ZiYuan or ZY-1) launched in 1999 on a Chinese Long March 4B, into a 773 kilometer orbit.[118]

A second satellite was launched in October 2003, following the failure of the first (after exceeding its planned two-year lifespan). The CBERS-2 was built with the same specifications as the first, and operates in a sun-synchronous circular orbit at 778 kilometer altitude, an inclination of 98 degrees and a revisit period of 26 days.[119] The

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[114] "COSMO-SKYMED: A system looking to the future of our planet," Alenia Spazio website, http://www.alespazio.it/earth_observation_page.aspx?IdProg=23.
[115] "Constellation of 4 SAR Satellites," COSMO-SkyMed, *eoPortal.*
[116] "Alenia Spazio signs COSMO-Skymed contract - Galileo receives go-ahead," Alenia Spazio website, Dec. 22, 2004, http://www.alespazio.it/news.aspx.
[117] "COSMO-Skymed," *deagel.com*, http://www.deagel.com/pandora/cosmo-skymed_pm00353001.aspx.
[118] McDowell, Jonathan, *Jonathan's Space Report*, Sept. 7, 2000, http://www.planet4589.org/space/jsr/back/news.434.
[119] "CBERS Satellite Series," eoPortal, http://directory.eoportal.org/pres_CBERS1234ChinaBrazilEarthResourceSatellite.html.

satellite carries three imaging payloads. The first, the High Resolution CCD camera (HRCC) designed and built in China, operates in five spectral bands (visible to near-infrared[120] with capabilities nearly equal to Landsat channels 1 to 4), with a 20 meter resolution and 113 kilometer swath width.[121] The second Chinese-built payload is the IRMSS (Infrared MultiSpectral Scanner), which operates in four spectral bands, with an 80 meter resolution in panchromatic and shortwave infrared, a 160 meter resolution in thermal infrared, and a swath width of 120 meters. Finally, the WFI (Wide Field Imager) operates in two spectral bands, red and near-infrared bands with a resolution of 260 meters, and a huge 910 kilometer swath width.[122] In addition, the satellite carries a Space Environment Monitor for detecting high-energy radiation.[123]

In November 2002, Brazil and China agreed to jointly produce two more capable follow-ons, CBERS-3 in 2008 and CBERS-4 in 2010.[124] These two planned satellites will operate at the same orbit as the first two, but will carry much-improved sensors. The first will be a panchromatic camera (PAN) to provide mapping imagery, with a 5 meter resolution and a 60 meter swath width. Also, "an instrument cross-pointing capability is provided to extend the Field of Regard."[125] They also will carry a multispectral camera (MUX) in four of the same bands as the HDCC (leaving out the panchromatic), with a 20 meter resolution and a 120 kilometer swath width; an "Infrared System" (IRS), with four spectral bands, a resolution of 40 meters in infrared and 80 meters in thermal infrared, and a swath width of 120 meters; and a Brazilian developed WFI, with four spectral bands, a 73 meter resolution and a swath width of 866 kilometers.[126]

In October 2004, China's National Space Agency announced that the two nations would orbit another CBERS in the interim, dubbed CBERS-2B and to be launched in June

[120] "Earth-observation Technology in China," National Remote Sensing Center of China, http://www.nrscc.gov.cn/english/about-mj1.asp.
[121] "CBERS-1/2/3/4 (China-Brazil Earth Resource Satellite)," eoPortal, http://directory.eoportal.org/info_CBERS1234ChinaBrazilEarthResourceSatellite.html.
[122] "CBERS Satellite Series," eoPortal, op cit.
[123] *Ibid.*
[124] "CBERS-1/2/3/4 …," eoPortal, op cit.
[125] "CBRES Satellite Series," eoPortal, op cit.
[126] *Ibid.*

2006[127] to replace CBERS-2, which like the first satellite has a two-year planned lifecycle.[128] The satellite is to be a replica of CBERS-2,[129] but with a new High Resolution Camera, with a resolution of 2.5 meters, replacing the IRMSS.[130] The agreement on the interim satellite was signed during a visit of Chinese President Hu Jiantao to Brazil in November 2004.[131] At the same time, the two countries decided to begin jointly marketing CBERS data under a new protocol, the CBERS Data Policy, between the space agencies. According to the policy, "CBERS images will be made available to any country or organization through a network of licensed representatives operating an application system which can receiver[sic] and process the CBERS data."[132] According to a Chinese space official, Iran, Egypt, Malaysia, Canada and Nigeria have expressed interest.[133]

Confusingly, China launched a satellite also dubbed ZiYuan-2 on Sept. 1, 2000, in a sun-synchronous orbit of about 474-493 kilometers with a 97.4 degree inclination[134] – that, according to satellite launch expert Jonathan McDowell, "appears to be a purely Chinese mission." The lower orbit of the satellite, he noted, "may indicate a heavier payload."[135] China did not release the parameters of this satellite, although the state-run Chinese media reported that it's to be used primarily for land surveying, city planning, crop yield assessment and disaster monitoring. It was reported by the media, however, to have a military code name as well, JianBing-3 (JB-3) – although even more confusingly the JB designation is often used for China's recoverable observation satellites. In any event, U.S. and Taiwanese intelligence sources speculate that this is a military reconnaissance

[127] Stoney, W.E., op cit.
[128] "China, Brazil To Launch 3 Earth Resources Satellites In Coming Years," *Xinhua News Agency*, Oct. 15, 2004, http://www.spacedaily.com/news/eo-04zzzzzg.html.
[129] "Brazil and China to build third satellite," *Agence France Press*, Oct. 22, 2004, http://www.spacedaily.com/2004/041022202645.frww1262.html.
[130] Filho, José Monserrat, "Brazilian-Chinese Cooperation on Earth Resource Observation," 2nd Asian Space Conference, Hanoi, Vietnam, Nov. 8-11, 2005.
[131] Lula, Edla, "Brazil Delighted to be First Stop on Chinese Leaders Tour," Brazzil Magazine, Nov. 11, 2004, http://www.brazzilmag.com/content/view/705/41/.
[132] Filho, op cit.
[133] "China, Brazil…," *Xinhua News Agency*, op cit.
[134] McDowell, Jonathan, "Jonathan's Space Report," No. 434, Sept. 7, 2000, http://www.planet4589.org/space/jsr/back/news.434.
[135] *Ibid.*

satellite with a higher resolution – 2m or less – and capable of real-time data return.[136] A second satellite was launched Oct. 27, 2002, into a 470-483 kilometer orbit at a 97.4 degree inclination.[137] The Union of Concerned Scientists (UCS) Satellite Database, which calls this satellite ZY-2B, labels it a military remote sensing satellite, with a mass of 1,500 kilograms and an expected lifetime of three to five years.[138] A third satellite in this series, labeled ZY-2C by UCS, was launched Nov. 6, 2004, and is in a sun-synchronous orbit of 479-503 kilometers, with a 97.3 degree inclination.[139] According to UCS, this is a military reconnaissance satellite, although there is little data available about it.[140] China officially dubbed the satellite a land resources satellite for civil purposes.[141]

Other Planned Programs

India has seven remote sensing satellites in orbit: IRS-1C, 1D, and P3, Oceansat-1, Resourcesat-1, Cartosat-1 and Technology Experiment Satellite (TES).[142] New Delhi also plans this year to launch two new imaging satellites with better resolutions: Cartosat-2 is planned to have a "better than 1 m" resolution using a single panchromatic camera.[143] ResourceSat-2, with three multispectral sensors with 6 meter, 23 meter and 56 meter resolution, and one panchromatic camera with a 6 meter resolution.[144] Even more interestingly, India plans to launch its first radar imaging satellite, Radar Imaging Satellite (RISAT), in early 2007. According to the Indian Space Research Organization, "The satellite will involve the development of a multi-mode, multi polarisation, agile Synthetic Aperture Radar (SAR) operating in C-band and providing 3-50 metre spatial

[136] "ZY," *Encylopedia Astronautica*, astronautix.com, http://www.astronautix.com/craft/zy.htm; "China Launches Remote Sensing Satellite as Taiwan Expresses Concern," *Space Daily*, Sept. 4, 2000, http://www.spacedaily.com/news/china-00zz.html.
[137] McDowell, Jonathan, "Jonathan's Space Report," No. 489, Oct. 31, 2002, available at http://www.spaceref.com/news/viewsr.html?pid=6957..
[138] Union of Concerned Scientists, "Satellite Data Base," http://www.ucsusa.org/assets/documents/global_security/UCSSatelliteDatabase_3-17-06.xls.
[139] McDowell, Jonathan, "Jonathan's Space Report," No. 538, Nov. 18, 2004, http://host.planet4589.org/space/jsr/back/news.538.
[140] UCS Satellite Database, op cit.
[141] "China's Satellite Launch Centers," china.org.cn, http://www.china.org.cn/english/features/cslc/139838.htm.
[142] UCS Satellite Data Base, op cit.
[143] Indian Space Research Organization (ISRO), "Earth Observation System," ISRO website, http://www.isro.org/rep2004/Earth%20Observation.htm.
[144] Stoney, W.E., op cit.

resolution. Various modes of operations such as ScanSAR, strip and spot will provide images with coarse, fine and high spatial resolutions."[145] While the Indian government touts the civilian nature of its space program, the capabilities provided by its remote sensing suite – in particular the TES satellite with its one-meter resolution and the planned RISAT – are militarily useful and no doubt used for both military purposes and for spying on Pakistan and China. In addition, Indian Defense Minister Pranab Mukherjee told Parliament in August 2005 that India is assembling a military surveillance and reconnaissance system that is planned to be operational by 2007 – although he did not give specifics and it is unknown if India is planning a dedicated military satellite.[146] Interestingly, India's military has complained that Google Earth, which uses months-old satellite images obtained from commercial providers as well as aerial imagery, "compromises" India's security.[147]

Vietnam, Thailand, South Africa, Malaysia and Korea also plan new imaging satellites over the next couple of years. In particular, Korea's KOMPSAT-2 is being designed to provide 1 meter resolution in panchromatic, and 4 meter resolution in multispectral mode – certainly good enough for military usage.[148]

Space Surveillance

I'm going to touch briefly on this, because it is an area where the U.S. lead in space technology is being diminished as other nations seek to build capacity. Space surveillance, via radar or optical sensors, is used to track space debris as well as to monitor operational satellites. Japan, China, Canada and India all have ongoing efforts to build their space-surveillance capabilities, from actual space observation facilities to data-crunching computers to improved debris/tracking models.

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[145] Indian Space Research Center, op cit.
[146] "India Building a Military Satellite Reconnaissance System," *Defense Industry Daily*, Aug. 10, 2005, http://www.defenseindustrydaily.com/2005/08/india-building-a-military-satellite-reconnaissance-system/index.php.
[147] "India army boss slams Google Earth," *Associated Press*, April 4, 2006, available at http://edition.cnn.com/2006/TECH/internet/04/04/india.google.ap/index.html.
[148] Stoney, W.E., op cit; "KOMPSAT-2 (Korea Multi Purpose Satellite 2), eoPortal, http://directory.eoportal.org/pres_KOMPSAT2KoreaMultiPurposeSatellite2.html.

In addition, European nations, many of which operate sensor facilities and debris tracking projects, are for the first time considering bolstering their capabilities by pooling their current resources and building some new sensor facilities. Again, this is partially driven by a political desire to break dependency on the United States in space. The European Commission's Panel of Experts on Space and Security in March 2005 asserted in its final report:

> [T]he security of [space] systems become (sic) a true challenge taking into account the increasing security issue of the space debris proliferation.
>
> While Europe is able to detect and catalogue some space debris using European facilities implemented by some European Union Member States, most of the data are still provided for free by the United States of America. This situation could change in the near future and the data already provided are not exhaustive or (sic) not be made available at the needed time.
>
> The lack of a European Space Surveillance Capability is identified as a serious capability gap that must be one of the priority (sic) of the future European Space Program. Beyond the security of the European space assets, this system must contribute to the control of the application of International Space Treaties and to the evaluation of the activities of the space faring nations or organizations.[149]

The European Space Operations Center in 2002 specified a design study for an independent European Space Surveillance System and later awarded a contract[150] to a team led by France's Office National d'Études et des Recherches Aérospatiales (ONERA) to provide options for achieving such a system. The study was to establish requirements, define the system architecture, analyze performance and assess the costs for a network that could autonomously detect and track objects down to 10 centimeters in diameter in

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[149] "Report of the Panel of Experts on Space and Security," to the Commission of the European Communities, March 2005, p. 36, http://europa.eu.int/comm/space/news/article_2262.pdfp.
[150] ESOC Contract no 16407/02/D/HK(SC).

LEO and 1 meter in GEO.[151] A final report was presented to ESA on May 25, 2004, although not made public until Oct. 12, 2004. The report found that a network that could provide about 99 percent of U.S. detection and tracking capabilities in LEO and 95 percent in GEO would cost around 330 million euros to develop by the 2015 timeframe.[152] Gerhard Brauer, head of ESA's security policy office, during a March 30-31, 2006, meeting sponsored by the United Nations Institute for Disarmament Research, said that ESA intends to have a draft plan for establishing such a network ready for ministerial review in 2008.[153]

Although it would require several new sensors, this network could be implemented largely by linking current European assets – such as the Space Debris Telescope at the Teide Observatory in Tenerife, the Canary Islands, which currently monitors part of GEO.[154] ESA operates the 1-meter-aperature telescope on Mt. Teide, which is capable of detecting and following (initial orbits can be derived accurately enough to allow re-observation) small objects (down to 15 centimeters in diameter) in a 120 degree arc of GEO.[155] The telescope, with its 0.7 degree field of view, can be used both for optical communications applications or space debris observation,[156] and has been undertaking debris observations since 1999. Indeed, the Teide observations have confirmed the existence of cloud of unknown objects with sizes down to about 15 centimeter diameter in GEO.[157] The telescope can produce three images per minute, and can see objects down to a magnitude (a measurement of brightness whereby a smaller number equals a

[151] Donath, Therese, et al, "European Space Surveillance System Study – Final Report," Document No. DPRS/N/158/04/CC, Oct. 12, 2004, p.6.
[152] *Ibid*, pp.2, 18, 23.
[153] Author was in attendance at the meeting, "Building the Architecture for Sustainable Space Security," March 30-31, 2006, Geneva, Switzerland.
[154] Hitchens, Theresa, "Future Security in Space: Charting a Cooperative Course," Center for Defense Information, Washington, D.C., September 2004, p.58.
[155] Flury, Dr. Walter, "European Space Agency (ESA) Agenda Item 8: Space Debris," presented to the 41st Session of the Science and Technical Committee of the United Nations Committee on the Peaceful Uses of Outer Space, Vienna, Austria, Feb. 16-27, 2004, http://www.oosa.unvienna.org/COPUOS/stsc/2004/presentations/flury2.ppt#271,7,Slide 7.
[156] Klinkrad, Heiner, "Monitoring Space – Effort Made by European Countries," presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France, Nov. 27-28, 2002.
[157] Flury, Dr. Walter, "European Space Agency (ESA) Agenda Item 8: Space Debris."

brighter object, with the brightest object being the Sun, at -27 magnitude) of between +19 to +21.[158]

The linchpin in such a network, however, would be the French Defense Ministry's Grand Réssau Adapté à la Veille Spatial (GRAVES), which has been working on an experimental basis since 2001.[159] Operated by ONERA, GRAVES is able to autonomously detect – that is with no input from U.S. supplied orbital tracking data – objects of about 1 m at altitudes up to 1,000 kilometers.[160] The GRAVES system is a so-called radar "fence" – based on a continuous wave (VHF), bi-static radar, meaning that its transmission and receiver stations are located at different sites. The system consists of a transmitting station at Broyes-de-Pesmes (near Dijon) and a receiver station at Revest-du-Bion – about 400 kilometers apart. The radar is used to determine direction angles (azimuth and elevation), Doppler and Doppler rates for objects as they pass through the radar beams, which form a kind of electronic fence.[161] The system is optimized to detect and track spacecraft at inclinations of 45 degrees to 90 degrees, although in a test in October 2001 GRAVES was able to detect some objects with inclinations as low as about 28 degrees and as high as about 140 degrees.[162]

The system is able to generate an autonomous catalog of space objects by generating the basic orbital data required to track an object (called orbital element sets) from its radar returns with enough accuracy to then task other sensors to correlate subsequent detections of the same targets. A one-month experiment in 2001 produced a catalog of 2,200 objects.[163] GRAVES is able to re-detect the same satellite at least once every 24 hours,

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[158] Klinkrad, Heiner, "Monitoring Space – Effort Made by European Countries."
[159] "Imminent delivery of the French space surveillance system," *French Science & Technology Fortnightly*, No. 9, Aug. 24, 2005, Ambassade de France en Australie, www.fitscience.org/media/upload/FranceST_075.pdf.
[160] *Ibid.*
[161] Klinkrad, Heiner, "Monitoring Space – Effort Made by European Countries," presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France, Nov. 27-28, 2002.
[162] Michal, Thierry, "Les perspectives d'avenir pour les equipments au sol," presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France, Nov. 27-28, 2002, p. 4.
[163] Klinkrad, Heiner, "Monitoring Space – Effort Made by European Countries."

and can produce new orbital data every 12 hours for about 70 percent of the objects being tracked.[164]

Although there is strong support for the development of such a network at ESA, the European Commission and in France, as of now, no funding or implementation plan has yet been proposed. European officials say the effort remains controversial politically, in large part because Britain, Norway and Denmark all operate facilities that are tied to the U.S. Air Force's Space Surveillance Network.

Conclusion

My presentation today has essentially been a very long-winded effort to point out that critical space capabilities are evolving rapidly throughout the world. The age of microsatellites and low-cost launch will dramatically lower the threshold for nations desiring space capabilities, likely producing a space-faring boom. The dissemination of imagery capabilities useful for military operations as well as space surveillance capabilities will continue – meaning that there will soon be "no place to hide' either on Earth or in space. These three factors have both short- and long-term implications for U.S. security – about which you will hear more from my colleague Michael. But it is imperative for everyone to understand that space is increasingly globalized, and that no single country is likely to ever again be able to establish a de facto monopoly in space technology or in the use of space for national security and military purposes. With that, I hand the floor over to Michael.

[164] "Imminent delivery of French space surveillance system," *France ST: Science and Technology in France.*