SPACE SECURITY 2006

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Library and Archives Canada Cataloguing in Publications Data

Space Security 2006

ISBN 13: 978-1-895722-53-6

ISBN 10: 1-895722-53-5

Design and layout by Graphics, University of Waterloo, Waterloo, Ontario, Canada

Cover image: ESA-J.Huart

Printed in Canada

First published July 2006

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ACRONYMS

ABM	Anti-Ballistic Missile
ANGELS	Autonomous Nanosatellite Guardian for Evaluating Local Space
ASEAN	Association of Southeast Asian Nations
ASAT	Anti-Satellite Weapon
ASLV	Augmented Satellite Launch Vehicle
ATV	Automated Transfer Vehicle
AWS	Advanced Wideband System
BMD	Ballistic Missile Defense
CBM	Confidence-Building Measures
CD	Conference on Disarmament
CEV	Crew Exploration Vehicle
CNES	Centre National d'Études Spatiales
CNSA	Chinese National Space Administration
CONUS	Continental United States
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
COSPAR-SARSAT	Committee On Space Research – Search and Rescue Satellite-Aided Tracking
CSA	Canadian Space Agency
CX-OLEV	ConeXpress Orbital Life Extension Vehicle
DARPA	Defense Advanced Research Projects Agency
DART	Demonstration of Autonomous Rendezvous Technology
DBS	Direct Broadcasting by Satellite
DGA	Délégation Générale pour l'Armement
DOD	United States Department of Defense
DSCS	Defense Satellite Communications System
DSP	Defense Support Program
DTRA	Defense Threat Reduction Agency
EADS	European Aeronautics Defence and Space Company
EC	European Commission
EELV	Evolved Expendable Launch Vehicle
EHF	Advanced Extremely High Frequency
EKV	Exoatmospheric Kill Vehicle
ELINT	Electronic Intelligence
ESA	European Space Agency
EU	European Union
FALCON	Force Application and Launch from the Continental United States
FAA	Federal Aviation Administration (US)
FCC	Federal Communications Commission (US)
FMCT	Fissile Material Cut-off Treaty
FOBS	Fractional Orbital Bombardment System
GAGAN	GPS and GEO Augmented Navigation
GEO	Geostationary Orbit
GEOSS	Global Earth Observation System of Systems
GLONASS	Global Navigation Satellite System
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigator Satellite System
GPS	Global Positioning System
HAND	High Altitude Nuclear Detonation
HEL	High Energy Laser
HELSTF	High Energy Laser Systems Test Facility
HEO	Highly Elliptical Orbit
IADC	Inter-Agency Debris Coordinating Committee
ICBM	Intercontinental Ballistic Missile
ILS	International Launch Services
INMARSAT	International Maritime Satellite Organization
INTELSAT	International Telecommunications Satellite Consortium
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
ISS	International Space Station
ITAR	International Traffic in Arms Regulation
ITU	International Telecommunications Union
JAXA	Japan Aerospace Exploration Agency
JHPSSL	Joint High-Power Solid-State Laser
LEO	Low Earth Orbit
MDA	Missile Defense Agency
MEO	Medium Earth Orbit
MIRACL	Mid-Infrared Advanced Chemical Laser
MKV	Miniature Kill Vehicle
MOD	Ministry of Defence (UK)
MOST	Microvariability and Oscillations of Stars
MPX	Micro-satellite Propulsion Experiment
MSV	Mobile Satellite Ventures
MTCR	Missile Technology Control Regime
NASA	National Aeronautics and Space Administration (US)
NEO	Near-Earth Object
NFIRE	Near-Field Infrared Experiment
NGA	National Geospatial-Intelligence Agency (US)
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration (US)
NORAD	North American Aerospace Defense command
NSTAC	National Security Telecommunications Advisory Committee
NTM	National Technical Means

ORS	Operationally Responsive Spacelift
OST	Outer Space Treaty
PAROS	Prevention of an Arms Race in Outer Space
PEIS	Programmatic Environmental Impact Statement
QZSS	Quazi-Zenith Satellite System
RAIDRS	Rapid Attack Identification Detections Reporting System
RAMOS	Russian-American Observation Satellite program
RASCAL	Responsive Access, Small Cargo, Affordable Launch program
RFTWARS	Radio Frequency, Threat Warning, and Attack Reporting
ROKVISS	Robotic Components Verification on the International Space Station
RSSS	Remote Sensing Satellite System
SAINT	Satellite Interceptor
SALT	Strategic Arms Limitations Talks
SAR	Search and Rescue (Satellite-based)
SBI	Space-Based Interceptors
SBIRS	Space-Based Infrared System
SBL	Space-Based Laser
SBSS	Space-Based Surveillance System
SBSW	Space-Based Strike Weapon
SDI	Strategic Defense Initiative
SHF	Super High Frequency
SIGINT	Signals Intelligence
SMV	Space Maneuver Vehicle
SOI	Silicon-On-Insulator
SSL	Solid State Laser
SSN	Space Surveillance Network
SSS	Space Surveillance System
STSS	Space Tracking and Surveillance System
SUPARCO	Space and Upper Atmospheric Research Commission
TECSAS	Technology Satellite for Demonstration and Verification of Space Systems
TSat	Transformational Satellite Communications system
UHF	Ultra High Frequency
UN	United Nations
UNGA	United Nations General Assembly
UNITRACE	United Nations International Trajectography Centre
USAF	United States Air Force
USML	United States Munitions List
VLF	Very Low Frequency
XSS	Experimental Spacecraft System

INTRODUCTION

The strategic environment of outer space is evolving rapidly. A growing number and diversity of actors are accessing and using space; revenues from its commercial exploitation are growing; satellite services affect daily life all over the world; and military space applications are continually expanding. While demonstrating the vital importance of this environment, intensifying space use creates governance challenges including management of space traffic, orbital debris, and the distribution of scarce resources such as orbital slots and radio frequency. It has become clear that technological and political developments are outstripping the existing governance framework for outer space. These governance challenges will become increasingly salient as states' dependence on space for national security grows.

Space Security 2006 aims to provide a comprehensive and integrated assessment of the state of space security. It is the third such annual evaluation of space security, which for these purposes is defined as the secure and sustainable access to and use of space, and freedom from space-based threats. The report examines international developments in space security according to eight indicators, providing a comprehensive overview of the concerns of military, civilian, and commercial space stakeholders from around the world.

This project accepts the position that space is a global commons, as enshrined in the 1967 Outer Space Treaty, bordering every community on Earth. There is no doubt that national and international security dynamics on Earth and space security are interlinked: space systems can enhance national security by providing transparency and by supporting military operations and international security concerns on Earth risk spilling over into the space environment. However, our approach posits that there are policies that can enhance the security of all actors in space. Space security need not be a zero-sum game but instead can be a path to prosperity and a path to peace.

The pursuit of space security is plagued by certain contradictions. For example, the acquisition of independent space access by more actors could aggravate environmental concerns in space. Technologies that enable more effective use of space for some often have the inherent potential to negate the secure use of space for others. Indeed, the same assets used for space surveillance and collision avoidance could provide precision targeting of space assets. These contradictions are commonly interpreted from the national security vantage points of individual space actors. However, these concerns need to be explored and collectively managed, and, by their very nature, require a common understanding of space security. We expect this report will provide food for thought in this regard.

It is our hope that *Space Security 2006* will improve the transparency of activity in outer space. As with all security matters, perceptions and *misperceptions* are tremendously important. The vulnerability of space assets, the high degree of secrecy in the activities of space actors, as well as the often limited awareness of the space environment tend to generate mistrust among space actors. Because *Space Security 2006* is based entirely on open source information, it is inevitably challenged by the limitations of secrecy. However, great effort was made to ensure a complete, neutral, and accurate description of developments based on a critical appraisal of the available information and consultation with international experts.

Space Security 2006 follows *Space Security 2003* and *Space Security 2004* as the third iteration of the Space Security Index annual report. Although the date was changed this year to reflect the year of publication, there exists no gap in the annual research. *Space Security 2006* references developments from 1 January 2005 to 31 December 2005.

We would like to express our gratitude to the many advisors and expert participants who have supported this project since its inception. For research and writing in *Space Security 2003* and *Space Security 2004*, from which much was drawn for this year's edition, we would like to thank Mr. Phillip Baines, Mr. Michel Bourbonnière, Mr. Simon Collard-Wexler, Ms. Jessy Cowan-Sharp, Ms. Sarah Estabrooks, Dr. Nicole Evans, Ms. Theresa Hitchens, Mr. Maciek Hawrylak, Dr. Andrew Latham, Dr. Robert Lawson, Mr. Robert McDougall, Dr. David Mutimer, Mr. Robert Schingler, Mr. Gabriel Stern, Dr. Lucy Stojak, and Mr. George Whitesides.

Research for *Space Security 2006* was carried out by Mr. Richard Bruneau, Ms. Jasmin Cheung-Gertler, Ms. Jennifer Erickson, Mr. Scott Lofquist-Morgan, and Ms. Toby Schwartz. For copyediting and layout, we would like to thank Ms. Wendy Stocker and Graphics at the University of Waterloo. For comments on early drafts we would like to thank Mr. Phil Baines, Dr. S. Chandrashekar, Mr. Simon Collard-Wexler, Mr. Phil Coyle, Mr. Richard DalBello, Mr. Niklas Hedman, Mr. Bertrand de Montluc, Ms. Sarah Estabrooks, Air Marshall Lord Garden, Dr. Tom Gillon, Ms. Theresa Hitchens, Dr. John Logsdon, Dr. Lucy Stojak, and Dr. S. Pete Worden (Brig. Gen., USAF ret.). We would also like to thank all those who participated in the on-line Space Security Survey and provided valuable input through the Space Security Working Group meeting in Montreal (See Annex 2).

For organizing the Space Security Working Group meeting on 1-2 May 2006, we would like to express our gratitude to the McGill University Institute of Air and Space Law, and in particular to Mr. Raja Bhattacharya, Dr. Maria Buzdugan, Ms. Maria D'Amico, and Dr. Paul Dempsey.

This project would not be possible without generous support from our partners. For financial and in-kind support, we would like to thank the Ford Foundation, The Simons Foundation, the International Security Research and Outreach Programme at the Department of Foreign Affairs and International Trade Canada, the Secure World Foundation, and the Nicolas Mateesco Matte Fund for Space Law of the McGill University Institute of Air and Space Law.

While we have benefited greatly from the input of many experts in the development of *Space Security 2006*, responsibility for any errors or omissions in this volume remains our own. The views expressed in this volume represent those of the experts engaged throughout this process. They do not necessarily reflect the views of the Spacesecurity.org partners – the McGill University Institute of Air and Space Law, Project Ploughshares, the Simons Centre for Disarmament and Non-proliferation Research, and the Space Generation Foundation – or the Government of Canada or the Department of Foreign Affairs and International Trade.

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EXECUTIVE SUMMARY

The Space Environment

Growing debris threats to spacecraft, but annual rate of new debris production decreasing

The number of objects in Earth orbit has increased steadily and there are an estimated 35 million pieces of space debris in orbit today. Approximately 13,000 orbiting objects large enough to seriously damage or destroy a spacecraft – over 90 percent of which are space debris – are being tracked. However, the annual growth rate of tracked orbital debris has been decreasing since the early 1990s, due in large part to national space agency debris mitigation efforts.

In 2005, the space debris population grew by 2.1 percent, a modest rate increase compared with those of recent years. The new space debris was partially attributable to five incidents of satellite fragmentation and two accidental collisions in orbit over the past year. New research in 2005 indicated that global warming, and the consequent contraction in the thermosphere, could cause space debris to be more persistent and space collisions more common.

Increasing awareness of space debris threats and continuing efforts to develop international guidelines for debris mitigation

There is widespread recognition, in light of tracking efforts and recorded on-orbit collisions, that space debris is a growing threat. Since the mid-1990s, many space-faring states, including China, Japan, Russia, and the US, and the European Space Agency have developed national debris mitigation standards. In 2001, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) mandated the Inter-Agency Debris Coordination Committee (IADC) to develop a set of voluntary international debris mitigation guidelines.

In 2005, the Space Debris Working Group of the Scientific and Technical Subcommittee of COPUOS reached agreement that the intentional destruction of any orbiting object that could generate "long-lived" orbital debris should be avoided. In the US, the Federal Communications Commission (FCC) enacted rules which require orbital debris mitigation plans to be submitted by any entity requesting FCC space station authorization.

Growing demand for radio frequencies

Expanding satellite applications are driving growing demand for radio frequencies. The number of satellites operating in the 7-8 gigahertz band commonly used by GEO satellites has been increasing. Satellite operators now spend about five percent of their time addressing frequency interference issues, including the US and European Union (EU) disagreement over frequency allocation for the proposed EU Galileo navigational system. The growth in military consumption of bandwidth has also been dramatic: the US military used some 700 megabytes per second of bandwidth during Operation Enduring Freedom in 2003, compared to just 99 megabytes per second during Operation Desert Storm in 1991.

Demand for radio frequencies continued to increase in 2005. To respond to these challenges, regional organizations such as the Association of Southeast Asian Nations (ASEAN) and the EU worked on common regional radio frequency allocation policies. The US conducted a review of its policies to enhance efficient and effective management and use of the radio frequency spectrum. Radio frequency interference and piracy are of growing concern to commercial space actors. One thousand, three hundred and seventy-four incidents of satellite radio frequency interference were reported in 2005, although only one percent of these incidents were intentional.

Growing demand for orbital slot allocations

There are more than 620 operational satellites in orbit today: about 46 percent in LEO, 6 percent in MEO, and slightly more than 47 percent in GEO. Increased competition for orbital slot assignments, with greatest demand for GEO orbital slots where most communications satellites operate, has caused occasional disputes between satellite operators. The International Telecommunications Union (ITU) has been pursuing internal reforms designed to address slot allocation backlogs and related financial challenges.

Demand on orbital slots continued to increase in 2005, leading certain COPUOS delegates to express the view that GEO orbital slot positions should be shared equitably among states. Iran became the 45th state to acquire indirect access to space, launching a satellite using Russian launch services. In 2005, cooperation and competition over scarce orbital slots in GEO continued to mark relations among commercial space operators.

Space surveillance capabilities to support collision avoidance slowly improving

The US Space Surveillance Network uses 31 sensors worldwide to monitor over 9,000 space objects in all orbits, supporting collision avoidance and debris re-entry. Since 2004, the US has moderated public access to the two-line elements to registered users out of concern for national security. Russia maintains its Space Surveillance System with 14 sensors, and monitors some 5,000 objects (mostly in LEO), but does not widely disseminate data. The EU, Canada, China, France, Germany, and Japan are all developing new space surveillance capabilities.

In 2005, the US expanded its space surveillance and space situational awareness capabilities by modernizing its Michigan Orbital Debris Survey Telescope and Ground-Based Electro-Optical Deep Space Surveillance system, continuing to pursue a Space-Based Surveillance System, and announcing plans for a space situational awareness nanosatellite in GEO. China established its first Target and Debris Observation and Research Center, while actors in Europe explored the possibility of setting up a space surveillance network by pooling existing ground-based radars and optical telescopes with new capabilities.

Laws, Policies, and Doctrines

Progressive development of legal framework for outer space activities

Since the signing of the Outer Space Treaty (OST) in 1967, the international legal framework related to space has grown to include the Astronaut Rescue Agreement (1968), the Liability Convention (1972), the Registration Convention (1979), and the Moon Agreement (1979), as well as a range of other international and bilateral agreements and relevant customary international law. This legal framework establishes the principle, primarily through the OST, that space should be used for ‘peaceful purposes’ and is not subject to claims of national sovereignty. The OST prohibits the stationing of nuclear weapons or any other weapons of mass destruction anywhere in space. The abrogation of the Anti-Ballistic Missile Treaty in 2002 eliminated a longstanding US/USSR-Russia prohibition on space-based conventional weapons, stimulating renewed concerns about the potential for space weaponization.

In 1981, the UN General Assembly (UNGA) adopted a resolution that states refrain from actions contrary to the peaceful use of outer space, calling for negotiations within the Conference on Disarmament (CD) on a multilateral agreement on the Prevention of an Arms Race in Outer Space (PAROS). Voting patterns have demonstrated nearly unanimous support for the PAROS resolution, suggesting a consistent and widespread desire on the part of states to expand international law to include prohibitions on weapons in space.

In 2005 there was a noteworthy shift in the PAROS debate, when Israel and the US voted against the PAROS resolution – the first opposition votes in the resolution’s history. Also, Russia tabled a new resolution, inviting states to provide input on measures to promote transparency and confidence building in outer space. Continuing efforts to stimulate discussion on PAROS, China and Russia submitted a non-paper to the CD on Definition Issues Regarding Legal Instruments on the Prevention of Weaponization of Outer Space.

COPUOS remains active, but the CD deadlocked since 1998

A range of international institutions, such as UNGA, COPUOS, ITU, and CD, have been mandated to address space security issues. However, the CD has been deadlocked since 1998 and unable to address the PAROS mandate to develop an instrument relating to space security and the weaponization of space.

The CD deadlock persisted in 2005, without any formal work on PAROS. However, two informal sessions on PAROS were organized for CD delegates, as well as a number of international conferences on space security. At COPUOS debate emerged on the possible introduction of topics pertaining to the militarization of space. An aborted effort was also made to create four open-ended ad hoc committees under UNGA First Committee auspices to address PAROS and other priority issues.

Space-faring states’ national space policies consistently emphasize international cooperation and the peaceful uses of outer space

All space-faring states emphasize the importance of cooperation and the peaceful uses of space, including the promotion of national commercial, scientific, and technological progress. The US has recently announced plans for peaceful space exploration of the Moon and Mars, while there is growing interest in manned space programs. Brazil and India tend to focus on the utility of space cooperation for social and economic development.

New space policies were adopted in China, Europe, Japan, Kazakhstan, Russia, and the US in 2005. The European Commission (EC) unveiled a plan to spend more than $5-billion on “Security and Space” programs for 2006-2013 and to double its budget for space-related research programs. Russia approved a new Federal Space Program with the stated objective of retaining status as a leading space power. Japan’s 20-year space plan outlined manned flights to the moon by 2025 as a first step to explore the solar system. Stated objectives of China’s new space plan include launching four space flights, the first of which will feature China’s first spacewalk in 2007. Finally, China released a White Paper in 2005, which reiterated its position that effective preventative measures, including international legal instruments, are needed to prohibit the deployment of weapons in outer space and the threat or use of force against objects in outer space, and ensure that outer space is used purely for peaceful purposes.

Growing focus within national military doctrine on the security uses of outer space

A growing number of states, led by China, Russia, the US, and key European states, increasingly emphasize the use of space systems to support national security. Dependence on these systems has led several states to view space assets as critical national security infrastructure. US military space doctrine has also begun to focus on the need for “counterspace operations” to prevent adversaries from accessing space.

Building on existing trends, in 2005 actors that included the EU, India, Israel, and Japan placed more emphasis on the national security applications of space. Israel and Japan introduced plans to boost surveillance capabilities from space. India's Air Force urged the government to set up a Strategic Aerospace Command to better develop military space capabilities. A European Panel of Experts on Space and Security urged the development of a security-related space strategy as well as a balance between the civil and military uses of space. The US was expected to release a new military space directive that, according to certain media reports, would depart from current policy by explicitly calling for development of certain space systems negation capabilities to ensure that space systems or services cannot be used for purposes hostile to US national interests.

Civil Space Programs and Global Utilities

Growth in the number of actors gaining access to space

By 2004, 10 actors had demonstrated an independent orbital launch capacity. Forty-four states have accessed space independently or with the launch services of others. In the 1990s, the rate of increase doubled from just less than one new actor to just less than two per year, mostly for civil space programs. In the last 12 years Surrey Satellite Technology Ltd. of the UK has enabled seven countries to build their first civil satellites. Iran and South Korea have announced plans for civil space programs. China recently joined Russia and the US as the only space powers with demonstrated manned spaceflight capabilities.

In 2005 China, Russia, and the US launched 24 civil spacecraft, of which nine were manned. Europe and Japan fielded new launch vehicles and Iran became the 45th state to launch a satellite. There were also a number of qualitative advances in space propulsion with the testing of "double layer thrusters" by the European Space Agency (ESA) and continued work on nuclear electric power and propulsion technologies by NASA.

Changing priorities and funding levels within civil space programs

The general trend in recent years has seen civil space expenditures increase in India and China and decrease in the EU, Japan, Russia, and the US. The budget of the Indian Space Research Organisation (ISRO) grew over 60 percent in real terms between 1990 and 2000, while the US NASA and European ESA budgets dropped by 25 percent and nine percent respectively between 1992 and 2001. The annual number of civil space missions has generally held steady for the past decade, with a decreasing number of manned missions, and an increasing number of missions involving small satellites and microsatellites. Civil space programs increasingly include security and development applications. India has designed 19 telecommunications and remote sensing satellites for development applications; and Algeria, Brazil, Chile, Egypt, Malaysia, Nigeria, South Africa, and Thailand are all placing a priority on satellites to support social and economic development.

In 2005 most space-faring states, except Japan, experienced modest increases in civil space budgets. With a budget of $16.5-billion, NASA continues to be the world's dominant civil space investor. China, Japan, Russia, and the US announced plans to develop manned spacecraft in the coming decades. The asteroid interception missions completed by civil space agencies in Japan and the US represent a significant achievement in engineering, although the results of the Japanese mission remain uncertain and the technologies could have dual-use functions.

Steady growth in international cooperation in civil space programs

International civil space cooperation efforts over the past decades have included the US-USSR Apollo-Soyuz docking of manned modules, Soviet flights to the MIR space station with foreign representatives, the Hubble Space Telescope, and joint NASA-ESA projects such as Skylab. The most prominent current example of international cooperation is the International Space Station (ISS), involving 16 partner states, 44 launches, and an estimated cost of over $100-billion. International civil space cooperation has played a key role in the proliferation of technical capabilities for states to access space.

Continuing the trend of international civil space cooperation, Russia reached agreements with Brazil, Canada, China, Egypt, ESA, India, Indonesia, Iran, Kazakhstan, and South Korea in 2005. The US established agreements with India, Japan, Russia, and Sweden. ESA, a regional space agency that embodies the benefits of international cooperation, signed agreements with China, India, Morocco, Russia, and Ukraine. Eight regional partners – Bangladesh, China, Indonesia, Iran, Mongolia, Pakistan, Peru, and Thailand – signed an agreement to form the Asia Pacific Space Cooperation Organization.

Dramatic growth in global utilities as states acknowledge strategic importance of satellite-based navigation systems

The use of space-based global utilities, including navigation, weather, and search-and-rescue systems, has grown substantially over the last decade. For example, GPS unit consumption grew by approximately 25 percent per year between 1996 and 1999, generating sales revenue of $6.2-billion in 1999. These systems have spawned space applications that are almost indispensable to the civil, commercial, and military sectors, as well as most modern economies. The number of actors developing satellite-based navigation capabilities has grown, from two (Russia and the US) in 1990, to five in 2004 with the addition of China, the EU, and Japan. Currently, there are 88 navigation satellites in orbit, of which between 60 and 80 are operational. The strategic value of satellite navigation was underscored by the conflict over frequencies for Galileo and GPS, which was resolved in 2004.

The expansion of global utilities, particularly in the area of satellite navigation, continued in 2005. The EU launched the first of its constellation of Galileo navigation satellites, while India, Israel, Morocco, Saudi Arabia, and Ukraine announced their participation in the project. In a significant reversal of policy, Russia required the fitting of GLONASS satellite navigation systems on a wide range of Russian space, air, land, and sea vehicles. It also made plans to cooperate with China and India on GLONASS. India also started development of its own separate civilian satellite navigation system called GAGAN.

Commercial Space

Continued overall growth in the global commercial space industry

The commercial space sector, including manufacturing, launch services, space products, and operating insurance, accounted for an estimated $2.1-billion in revenues in 1980 and exceeded $100-billion by 2004. This growth is being driven by the satellite services industry, including telecommunications, which accounted for 60 percent of 2003 commercial space revenues in spite of some decline within the manufacturing and launch sectors. Major commercial satellite telecommunications companies today include PanAmSat, Loral, SES Americom, Intelsat, and News Corporation.

In 2005 there were 17 commercial launches, an increase over 2004. Commercial space revenues for the year were expected to reach $115-billion. Twenty new commercial satellites were launched. Providers of commercial space services had a watershed year; some satellite radio companies doubled subscriptions. The general trend to privatize government-owned telecommunications agencies continued in 2005 with the first initial public stock offerings of New Skies Satellites and Inmarsat. There was ongoing consolidation in the commercial space industry with Intelsat purchasing PanAmSat, SES Global purchasing New Skies, the European Aeronautics Defence and Space Company (EADS) acquiring Dutch Space BV, Alcatel Alenia merging with Telespazio, and SpaceDev merging with Starsys Research Corporation.

Declining commercial launch costs support increased commercial access to space

Commercial space launches now account for about one-third of the 60 to 70 annual space launches. The costs to launch a satellite into GEO have declined from an average of about $40,000/kilogram in 1990 to $26,000/kilogram in 2000, with prices still falling. In 2000, payloads could be placed into LEO for as little as $5,000/kilogram. The European and Russian space agencies are the most active space launch providers. Today's top commercial launch providers include Lockheed Martin and Boeing Launch Services in the US, Arianespace in Europe, Energia in Russia, and two international consortia – Sea Launch and International Launch Service. With the launch of Mojave Aerospace Ventures' SpaceShipOne in 2004, the private sector entered the suborbital manned spaceflight sector. Cheaper space access has also been key to the growth of high-resolution commercial satellite imagery.

Demand for commercial launchers stayed flat in 2005 and the US continued to lose market share to Europe and Russia. European and multinational commercial space launchers saw strong growth in 2005, with the European Ariane 5G vehicles experiencing a record year. Japan successfully tested a new launcher in 2005 and China announced its imminent return to commercial space launch. The embryonic space tourism sector advanced in 2005. More than 20 companies are developing a suborbital, reusable launch vehicle for space tourism. Scaled Composites and Virgin Galactic announced a joint venture, The Spaceship Company, which plans to build a fleet of commercial suborbital spacecraft and equipment to be deployed in commercial space flights by the end of 2008. Despite these promising developments, the space tourism industry continued to face the twin challenges of supply constraint and uncertain liability regulation in 2005.

Government subsidies and national security concerns continue to play an important role in the commercial space sector

The 1998 US Space Launch Cost Reduction Act and the 2003 European Guaranteed Access to Space program provide for significant government subsidization of the space launch and manufacturing markets, including insurance costs. The US and European space industries also receive important space contracts from government funds. The 1987 Missile Technology Control Regime (MTCR), designed to restrict the proliferation of missile technology, has encouraged actors outside the regime to develop space systems using components that are restricted by the regime itself. In 1999, the US placed satellite export licensing on the State Department's US Munitions List, bringing satellite product export licensing under the International Traffic in Arms Regulations (ITAR) regime and significantly complicating the way US companies participate in international collaborative satellite launch and manufacturing ventures.

Government continued to play a central role in commercial space in 2005. The US Department of Defense remained the single largest commercial space client. At the same time, commercial space actors such as the International Space Business Council cited ITAR as the "industry's most serious issue." High insurance premiums also continued to represent a barrier to growth in the industry. As a result, a number of commercial space actors have stopped insuring their in-orbit assets and/or purchased spare satellites.

Space Support for Terrestrial Military Operations

The US and Russia lead in developing military space systems

By the end of the Cold War, the US and USSR had developed extensive military space systems to provide military attack warning, communications, reconnaissance, surveillance, intelligence, navigation and weapons guidance. By the end of 2003, the US and USSR/Russia had together launched more than 4,800 military satellites, while the rest of the world had launched only 70 to 80.

The US has dominated the military space arena since the end of the Cold War. It currently spends roughly 95 percent of all the money spent on global military space expenditures and has approximately 135 operational, military-related satellites – over half of all the military satellites in orbit. Russia is believed to have some 85 dedicated military and 18 multi-purpose satellites in orbit. The US is, by all major indicators, the actor most dependent on its space capabilities. The 2001 Report of the Commission to Assess United States National Security Space Management and Organization warned that US dependence on space systems made it uniquely vulnerable to a "space Pearl Harbor" and recommended that the US develop enhanced space control (protection and negation) capabilities.

Nineteen dedicated military space satellites were launched in 2005. The US launched seven military satellites: two signals intelligence satellites, two reconnaissance satellites, two technology satellites, and one navigation satellite. However, 2005 also saw significant cutbacks to a number of US military space programs. The Future Imagery Architecture, the SBIRS-High program, the TSAT system, and the Space Radar were all plagued by delays and cost overruns and saw funding cutbacks.

With a budget currently 30 times less than that of the US, Russia continued to face setbacks in its military space programs. In 2005, Russia launched six military satellites: four navigation satellites, one communication satellite, and one reconnaissance satellite. However, it also saw three failed launches and the loss of two military satellites. Russia announced future funding and growth for a military space program that includes the launch of six military satellites in 2006 and the future orbiting of an entire constellation of high-resolution space radars.

More states developing military space capabilities

Declining costs for space access and the proliferation of space technology are enabling more states to develop and deploy their own military satellites using the launch capabilities and manufacturing services of others, including the commercial sector.

China provides military communications through its DFH series satellite, and has deployed a pair of Beidou navigation satellites to ensure its navigational capability. China also maintains three ZY series satellites in LEO for tactical reconnaissance and surveillance functions, has deployed three military reconnaissance satellites, and is believed to be purchasing additional commercial satellite imagery from Russia to meet its intelligence needs.

EU states have developed a range of military space systems. France, Germany, Italy, and Spain jointly fund the Helios 1 military observation satellite system in LEO, which provides images with a one-meter resolution. France, Germany, and Italy are planning to launch six low-orbit imagery intelligence systems to replace the Helios series by 2008. The UK maintains a constellation of three dual-use Skynet 4 communications satellites in GEO. France operates four signal intelligence satellites. The EU Galileo satellite navigation program, initiated in 1999, is intended to operate for civil and commercial purposes, but will have an inherent dual-use capability.

Israel operates a dual-use Eros-A imagery system as well as the military reconnaissance and surveillance Ofeq-5 system. India maintains its Technology Experimental Satellite and a naval satellite, both of which provide military reconnaissance capabilities. Japan operates the commercial Superbird satellite, which also provides military communications and has two reconnaissance satellites – one optical and one radar. In cooperation with a French company, Thailand will soon produce its first intelligence and defense satellite.

International military space programs were active in 2005. Ongoing regional tensions drove military space development in Asia. China launched the Beijing-1 (Tsingshua-1) Earth observation microsatellite amid speculation that China's continued participation in the Galileo navigation system might eventually be used to improve the accuracy of its missiles. Taiwan announced plans to launch a $300-million Follow-On RSS reconnaissance satellite. In an effort to improve satellite images of North Korea's nuclear and missile facilities, Japan began research in 2005 on scaling down the size of reconnaissance satellites to enhance their maneuverability. Pakistan began construction of a remote sensing satellite.

In 2005, France continued development of the most advanced and diversified independent military space capabilities in Europe with the launch of the Syracuse 3A military communications satellite and ongoing work on the Spirale early-warning and Melchior military communications satellites. Spain launched the XTAR-EUR communications satellite, and the UK launched a dual-use imagery microsatellite called TopSat.

The Middle East saw a proliferation of military space capabilities with the launch of Iran's Sina-1 satellite, which, although officially civil, has been claimed to have dual-use remote sensing functions. Israel, for its part, announced its intention to launch the Ofeq-7 and TechSAR surveillance and reconnaissance satellites. In North Amrica, Canada announced its intention to launch a radar surveillance satellite called RADARSAT-2 as part of Project Polar Epsilon.

Space Systems Protection

The US and Russia lead in general capabilities to detect rocket launches, while the US leads in the development of advanced technologies to detect direct attacks on satellites

US Defense Support Program satellites provide early warning of conventional or nuclear ballistic missile-based attacks. The US is also developing capabilities to detect in-orbit attacks on satellites through its Rapid Attack Identification, Detection, and Reporting System (RAIDRS) program. Russia began rebuilding its aging missile launch warning system in 2001 by replacing its Oko series satellites with three early-warning satellites. France is due to launch two missile-launch early-warning satellites, Spirale-1 and 2, in 2008. Most actors have a basic capability to detect a ground-based electronic attack, such as jamming, by sensing an interference signal or by noticing a loss of communications. Directed energy attacks move at the speed of light, making advance warning very difficult to obtain.

The US maintained its lead in space situational awareness capabilities in 2005 with developments in a number of new programs. The Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) program is intended to provide the continuous monitoring of areas in the immediate proximity to assets in GEO. The Space Surveillance Telescope (SST) is designed to complement existing space surveillance systems with advanced ground-based optical searching and tracking of objects in GEO. The Deep View radar is supposed to provide high-resolution images for objects in deep space as well as critical monitoring of activities in GEO. And the Large Millimeter Telescope is expected to be the world's largest and most sensitive single-aperture telescope when it is completed in 2008.

Protection of satellite ground stations is a concern, while protection of satellite communications links is poor but improving

Many space systems lack protection from attacks on ground stations and communications links. Typically with only one operations center and one ground station each, most commercial space systems are vulnerable to negation efforts. While many actors employ passive electronic protection capabilities, such as shielding and directional antennas, more advanced measures, such as burst transmissions, are generally exclusive to the military systems of more technically advanced states. China and the US have been aggressively pursuing a variety of jamming protection capabilities.

In 2005, the US successfully tested the GPX airborne pseudo-satellite, employing an unmanned aerial vehicle to boost power of GPS satellite signals and overcome jammers. In addition, researchers at the University of Surrey in the UK, the Turkish research the Tubitak-Bilten institute in Turkey, Pennsylvania State University, and the US Naval Research Laboratory have each been conducting research on more robust encryption of satellite communications.

Protection of satellites against some direct threats is improving, largely through radiation hardening, system redundancy, and greater use of higher orbits

Both the range of actors employing satellite protection capabilities and the depth of these capabilities are increasing. China and Japan are developing navigation satellites that will increase the global redundancy of such critical systems. The EU and the US have agreed to make their navigation systems interoperable. Increasingly, states are placing military satellites into higher orbits, where they are less vulnerable to attacks than in LEO, due to greater warning times and difficulty of access. Most key US, European, and Russian military satellites are already hardened against the effects of a high-altitude nuclear detonation. The US is reportedly developing a stealth satellite with the ability to evade detection by the terrestrial space surveillance systems of other actors. Reflecting concerns about the protection of commercial satellites, in 2002, the US General Accounting Office recommended that "commercial satellites be identified as critical infrastructure."

To reduce the vulnerability of satellites to natural and manmade threats in orbit, the US improved radiation hardening in 2005. The US Defense Threat Reduction Agency, the Air Force Research Laboratory, and Honeywell have been working to mainstream radiation-hardened semiconductors that will improve resistance to various types of radiation. To facilitate the use of MEO, the Air Force Research Laboratory, the Defense Advanced Research Projects Agency (DARPA), and NASA were developing a Demonstration and Science Experiments satellite to characterize the radiation environment in MEO.

Russia and the US lead in capabilities to rapidly rebuild space systems following a direct attack on satellites

Russia and the US are able to responsively re-constitute satellite systems. The US is supporting two responsive initiatives: the Force Application and Launch from CONUS (CONtinental US) or FALCON program seeks to develop a rocket capable of placing 100-1,000 kilograms into LEO within 24 hours; and the RASCAL program seeks to deliver 50-130 kilograms into LEO on short notice. The US is also supporting the High Frequency Active Auroral Research Program that looks at measures to mitigate the environmental impact of a nuclear attack in space, and could help facilitate recovery.

The US and Russia conducted research on responsive lift technologies in 2005. SpaceX Corporation continued research on several low-cost launch vehicles of small, medium, and high capacity while Lockheed Martin completed a successful test-firing of a hybrid motor as part of the Small Lift Vehicle program. Russia continued research on air launch capacbilities with a potential Ishim rocket system to be launched from a MiG-31 fighter jet and the Polyot vehicle to be launched from an Antonov carrier.

Space Systems Negation

Proliferation of capabilities to attack ground stations and communications links

Ground segments and communications links remain the most vulnerable components of space systems, susceptible to attack by conventional military means, computer hacking, and electronic jamming. A number of intentional jamming incidents targeting communications satellites have been reported in recent years and Iraq's acquisition of GPS-jamming equipment for use against US GPS-guided munitions during Operation Iraqi Freedom in 2003 suggests that jamming capabilities are proliferating. The US leads in developing doctrines and advanced technologies to temporarily negate space systems by disrupting or denying access to satellite communications, and has deployed a mobile system to disrupt satellite communications without inflicting permanent damage to the satellite.

In 2005 Libya and Iran carried out state-sponsored jamming of satellite communications. China continued to be a major target of satellite jamming. Significantly, the APSTAR VI communications satellite, designated "jam-proof" by China, was jammed in 2005, allegedly by the Falun Gong.

The US leads in the development of space situational awareness capabilities that could support space negation

Several space actors are increasing investments in space surveillance capabilities for debris monitoring, satellite tracking, and near-Earth object detection. The US and Russia maintain the most extensive space surveillance capabilities. China and India also have satellite tracking, telemetry, and control assets essential to their civil space programs. Canada, France, Germany, and Japan are all actively expanding their ground-based space surveillance capabilities. While this technology enhances transparency and enables space collision avoidance, it can also provide capabilities for targeting satellites and space negation. For example, the US has explicitly linked its development of enhanced space surveillance systems to efforts to enable offensive counterspace operations.

The US increased its lead in space situational awareness technologies in 2005 with research and development into ANGELS and the Deep View radar. These dual-use systems could facilitate targeting for space systems negation. Some actors in Europe have begun discussions on the option of pooling existing space surveillance capabilities as well as developing additional independent capabilities of their own, to be less reliant on US data.

Ongoing proliferation of ground-based capabilities to attack satellites

A variety of US and USSR/Russian programs during the Cold War and into the 1990s sought to develop ground-based ASAT weapons employing conventional, nuclear, and directed energy capabilities. The capability to launch a payload into space to coincide with the passage of a satellite in orbit is a basic requirement for conventional satellite negation systems. Twenty-eight states have demonstrated suborbital launch capability; of those, 10 have orbital launch capability. As many as 30 states may already have the capability to use low-power lasers to degrade unhardened satellite sensors. The US leads in the development of more advanced ground-based kinetic-kill systems with the capability to directly attack satellites. It has deployed components for a ground-based ballistic missile defense system and is developing an airborne laser system, both of which have inherent LEO satellite negation capabilities.

In 2005, the US and China continued to work on directed energy technologies. The US is pursuing lighter, smaller, and more durable solid state laser designs, which have not yet been able to generate the same level of continuous power as other types. The existing American Starfire laser range was fitted with a sodium-beacon laser with possible ASAT applications. Northrop Grumman and Raytheon continued development of the advanced high-power chemical oxygen-iodine laser for the MDA Airborne Laser project. Research in China continued on laser frequencies and adaptive optics, which can help to maintain laser beam quality over long distances. Though not a dedicated program, this basic research could eventually support ground-based and airborne ASATs.

In 2005, more advanced work on ground-based kinetic kill weapons was conducted in China, Russia, the UK, and the US. The US conventional kinetic-energy ASAT program was awarded a contract to develop three advanced kill vehicles. The US continued to research and develop its Ground-based Midcourse Defense system and Russia upgraded the A-135 anti-ballistic missile system. China, EADS, and the UK conducted basic research into kinetic kill vehicles for missile defense. Such kinetic kill interceptors could serve as ASATs.

Proliferation of space-based negation enabling capabilities

Space-based negation efforts require sophisticated capabilities, such as precision in-orbit maneuverability and space tracking. Many of these capabilities have dual-use potential. For example, microsatellites, which provide an inexpensive option for many space applications, could be modified to serve as kinetic-kill vehicles. The US leads in the development of most of these enabling capabilities, though none appear to be integrated into dedicated space-based negation systems.

Enabling capabilities for space-based negation continued to proliferate in 2005. In the US, the XSS-11 and DART microsatellites demonstrated dual-use rendezvous and surveillance capabilities. Indeed, the DART satellite unexpectedly collided with its target satellite, sending it several kilometers off orbit. Both Japan and the US conducted asteroid interception missions in 2005 which used key negation-enabling capabilities such as tracking, firing, and monitoring. Robotic technologies for on-orbit servicing such as the Robotic Components Verification on ISS (ROKVISS) system were demonstrated on the International Space Station. DARPA expressed interest in developing capacity for in-orbit servicing, repair, and orbit manipulation using space robotics. China, Europe, and the US conducted research, development, and testing of homing sensors which could be used for a range of space systems negation applications.

Space-Based Strike Weapons

While no space-based strike weapons (SBSW) have yet been tested or deployed in space, the US continues to develop a space-based interceptor for its missile defense system

Although the US and USSR developed and tested ground-based and airborne ASAT systems between the 1960s and 1990s, there has not yet been any deployment of space-to-Earth or space-to-missile SBSW systems. Under the Strategic Defense Initiative in the 1980s, the US invested several billion dollars in the development of a space-based interceptor (SBI) concept called Brilliant Pebbles, and tested targeting and propulsion components for such a system. The US and USSR were both developing directed energy SBSW systems in the 1980s, although today these programs have largely been halted.

US research and development efforts associated with the SBI program declined in the 1990s, but were revived in 2000. The Near-Field Infrared Experiment (NFIRE), originally due for launch in 2006, was planned to be the first fully integrated SBSW spacecraft with a sensor platform and kinetic-kill vehicle. Further MDA plans include the deployment of a test-bed of three to six integrated SBIs by 2011-2012. The annual SBI budget is estimated to be only about $100-million of the $10-billion MDA budget However, even at these funding levels, the timeline for developing the technical capabilities for SBI appears to be decreasing. While such a system would have limited strategic utility, deploying weapons in space would represent a significant departure from current practice.

In 2005, no space-based weapons were tested or deployed. In the US, the question of whether the MDA should deploy and test a “kill vehicle” for NFIRE once again came under Congressional scrutiny. Despite the recommendation made by the US Senate Appropriations Committee, the MDA has removed the kill vehicle portion of the planned test, saying it posed a risk of technical failure.

A growing number of actors are developing SBSW precursor technologies outside of SBSW programs

The majority of SBSW prerequisite technologies are dual-use. They are not related to dedicated SBSW programs, but are sought through other civil, commercial, or military space programs. While there is no evidence to suggest that states pursuing these enabling technologies intend to use them for SBSW systems, their development does bring these actors technologically closer to such a capability.

Both the number of such technologies being pursued in non-SBSW programs and the number of actors doing so are increasing. For example, China, India, and Israel are developing precision attitude control and large deployable optics for civil space telescope missions. Thirty-two states have developed or are involved in developing independent high-precision satellite navigation capabilities. In the last 12 years, nine states have deployed a first small or microsatellite – a key SBI precursor technology. China and the EU are developing re-entry technologies which are also required for the delivery of mass-to-target weapons from space to Earth.

In 2005, the US, Russia, China, and Europe maintained research and development on re-entry technologies relevant to potential orbital bombardment systems. Russia announced that its military had tested a hypersonic missile system capable of precision re-entry to evade missile defenses. The US Air Force Space Command sought to apply similar principles to make US missiles maneuvrable. The US also continued work on the Common Aerothermodynamic Vehicle. The EU has begun work on the aerothermodynamic research program called European Experimental Re-entry Testbed. Researchers in Chinese academic institutions continued research on re-entry techniques for “space-based ground attack weapons systems.” However, the scope, funding, and political support for such basic research remain unclear.

Upgrades were made in 2005 to the US and Russian global missile tracking and warning systems – foundational technologies for any future space-based missile interceptor. The US Air Force is seeking Congressional approval to begin work on a new space-based missile warning satellite to capitalize on new sensor technologies. As part of the modernization of its missile attack warning system, Russia plans to test a new early-warning radar station near St. Petersburg. While lagging far behind Russia and the US on missile tracking, China conducted basic research on how to obtain greater missile-tracking precision and real-time accuracy. China, the EU, India, Russia, and the US continued research and development on global positioning systems, a precursor technology of use in certain SBSW systems.

CHAPTER ONE

The Space Environment

This chapter assesses trends and developments related to the space environment with an emphasis upon space debris and space resource issues such as the registration of orbital slots and the allocation of radio frequencies.

Space debris, both naturally generated and manmade, represents a growing threat to spacecraft. The impact of space debris upon space security is related to a number of key issues examined by this chapter, including the amount of space debris at various orbits; space surveillance capabilities which track space debris to enable collision avoidance; and efforts to reduce existing space debris populations.

All space missions inevitably create space debris – rocket booster stages are expended and released to drift in space and exhaust products are created. The testing of anti-satellite (ASAT) weapons has also created hundreds of pieces of space debris, some 500 of which were reportedly still in orbit in 1994 from USSR ASAT tests in the 1960s, 1970s, and 1980s.[1]

A growing awareness of the impact of space debris upon the security of space assets has encouraged space actors to take steps to mitigate the production of new debris through the development and implementation of national and international debris mitigation guidelines, also examined by this chapter. This chapter does not address natural phenomena such as solar flares and near-Earth asteroids, except in cases where technologies and techniques are developed to mitigate their impact.

Actors who wish to place a satellite in orbit must obtain an 'orbital slot' in which to do so and secure a portion of the radio spectrum to carry their satellite communications. Both radio spectrum and orbital slot assignments are coordinated through the International Telecommunication Union (ITU) and recognized by the ITU Constitution as "limited natural resources," given their finite number.

Because under the Outer Space Treaty space is considered open to everyone and not subject to sovereign claims, the distribution and use of these two scarce resources has to be negotiated among space-faring states. This chapter assesses the trends and developments related to the demand for orbital slots and radio frequencies, as well as the conflict and cooperation associated with the distribution and use of these key space environment resources. This includes compliance with existing norms and procedures to manage the distribution of orbital slots and radio frequencies developed by the ITU.

Space Security Impacts

Space is a harsh environment and orbital debris represents a growing threat to the security of access to, and use of, space. Due to very high orbital velocities of 36,000 kilometers per hour in Low Earth Orbit (LEO), debris as small as 10 centimeters in diameter carries the energy of a 35,000-kilogram truck moving at 190 kilometers per hour. While objects have lower relative velocities in Geostationary Orbit (GEO), debris at the speed of about 1,800 kilometers per hour is still moving as fast as a bullet. No satellite can be reliably protected against this kind of destructive force.

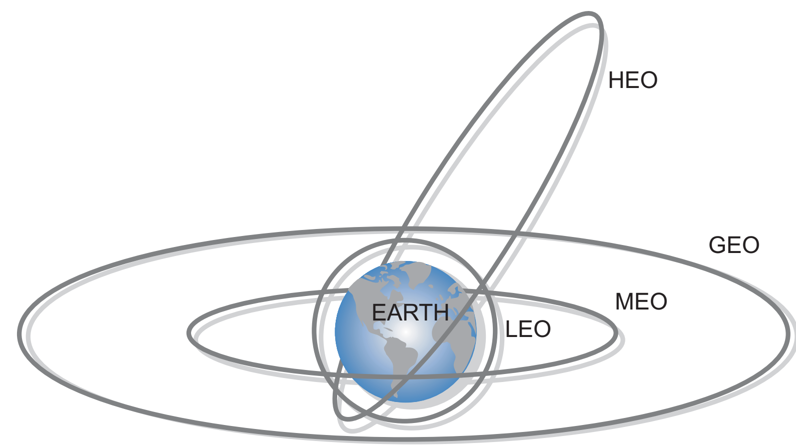
The total amount of space debris in orbit is growing each year, although the annual amount of new debris created each year is declining. LEO is the most highly contaminated orbit. Some debris in LEO will fall back to Earth and burn up in the atmosphere, but debris in orbits above 600 kilometers will remain a threat for decades and even centuries. There have already been a number of highly destructive and costly incidents involving space debris collisions with civil, commercial, and military spacecraft. Although a rare occurrence, the re-entry of very large debris can also cause considerable damage to Earth-based objects.

The development of surveillance capabilities to track space debris and enable collision avoidance clearly provides significant space security advantages. Efforts to mitigate the production of new debris through compliance with national and international regulations can also have a positive impact on space security. Other space environment threats include radiation surges caused by solar flares which damage on-board satellite microchips, interrupt short-wave radio transmissions, and cause errors in navigation systems.

Resource distribution, including the assignment of orbital slots and radio frequencies to space actors, has a direct impact on the abilities of actors to access and use space. Growing numbers of space actors, particularly in the communications sector, have led to more competition and sometimes friction over distribution.

New measures to increase the number of available orbital slots and frequency bands, such as technology to reduce interference between radio signals, can reduce competition pressures and increase the availability of these scarce resources. There are strong incentives for space actors to cooperate in the registration and use of spectrum and orbital slots – namely confidence in the sustainability of their use. Cooperation in this area can also strengthen support for the application of the rule of law to broader space security issues.

FIGURE 1.1: Types of Earth orbits



Key Trends

TREND 1.1: Growing debris threats to spacecraft, but rate of new debris production decreasing

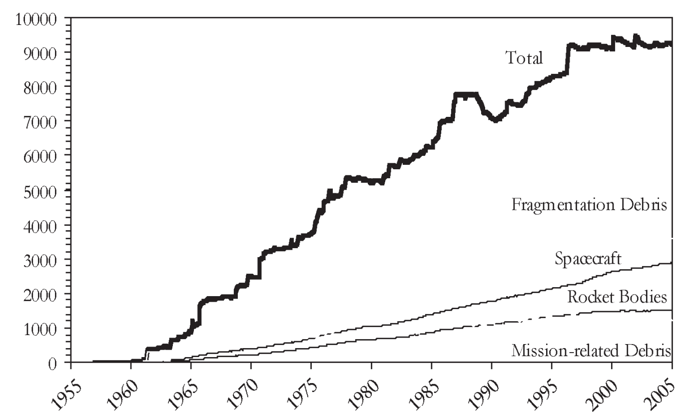
The US Space Surveillance Network (SSN) is the only system that comprehensively tracks and catalogues space debris. Since 1957, the US has registered more than 27,000 large and medium-sized objects orbiting Earth; of the approximately 13,000 *known* objects in orbit today, six to seven percent are operational satellites.[2] At the beginning of January 2005, 9,233 of these known objects had been catalogued. The total number of catalogued objects had increased in 2003, when the US Cobra Dane collateral sensor radar that had been taken offline in 1994 was reinstated in the SSN.[3] Figure 1.2 provides an overview of the number of catalogued objects in orbit.

Two key factors affecting debris production are the number of objects in orbit and the number of new satellites being launched each year. Growth in the debris population increases the probability of interdebris collisions that have the potential to create even more debris. Space debris in LEO could be created by ground- and space-based midcourse missile defense systems currently under development or other weapons testing in space.[4] Between 1961 and 1996, an average of approximately 240 new pieces of debris were catalogued each year, due in large part to fragmentation and the presence of new satellites. Between 8 October 1997 and 30 June 2004, only 603 new pieces of debris were catalogued, representing a noteworthy decrease from the previous rate of debris generation.

While the total debris population continues to increase, a decrease in the annual amount of new debris production appears to be related in large part to international debris mitigation efforts, which increased significantly in the early 1990s. A global decline in the absolute number of launches per year has also contributed to the decreased rate of debris production. However, debris mitigation techniques associated with specific launches, rather than the short-term decrease in the number of launches, are what need to be examined as an indicator of sustainable debris mitigation.

The highest concentration of space debris is found in LEO, where more debris-producing activities take place. The overwhelming majority of debris in LEO is smaller than 10 centimeters, too small to be reliably tracked and catalogued. Space scientists estimate that there are tens of millions of objects between one and 10 centimeters in size (i.e., larger than a marble), and an even greater number under one centimeter. Space debris can remain in orbit for very long periods of time, depending on the altitude and mass of the object. While debris in parts of LEO will fall back to Earth over periods of days to months due to atmospheric drag, at altitudes greater than 600 kilometers debris can remain in orbit for "tens, hundreds, or even thousands of years."[5]

FIGURE 1.2: Number of catalogued objects in Earth orbit by object type[6]



Hypervelocity space debris particles one to two millimeters or larger constitute a serious hazard to the security of spacecraft, threatening unprotected fuel lines and other sensitive components.[7] Protection against particles one to 10 millimeters in size can be achieved by shielding spacecraft bodies, while protection against larger debris can only really be achieved through collision avoidance procedures. Debris fragments between one to 10 centimeters "will penetrate and damage most spacecraft," according to the Center for Orbital Re-entry and Debris Studies. Moreover, "if the spacecraft bus is impacted, satellite function will be terminated and, at the same time, a significant amount of small debris will be created.[8]

Today, collisions between space assets like the International Space Station and very small pieces of debris are a daily but manageable problem, and occur in LEO.[9] A 1995 US National Research Council study found that within the orbital altitude most congested with debris (900-1,000 kilometers), the chance of a typical spacecraft colliding with a large fragment was only about one in 1,000 over the spacecraft's 10-year functional lifetime, with even larger odds against impact in higher orbits.[10]

However, the same study noted that "although the current hazard to most space activities from debris is low, growth in the amount of debris threatens to make some valuable orbital regions increasingly inhospitable to space operations over the next few decades."[11] According to NASA models, without further implementation of orbital debris mitigation measures, the number of objects 10 centimeters and greater in orbit – which can be fatal to an average-sized satellite – could grow rapidly in the second half of this century.[12] Indeed, some experts at NASA believe that collisions between space assets and larger pieces of debris will remain rare only for the next decade, although there is ongoing discussion about this assessment.[13] However, it is clear that the consequences of collisions between space debris and spacecraft can be disastrous. While major collisions have so far been rare, as noted in Figure 1.3 below, there have been several incidents of varying severity.

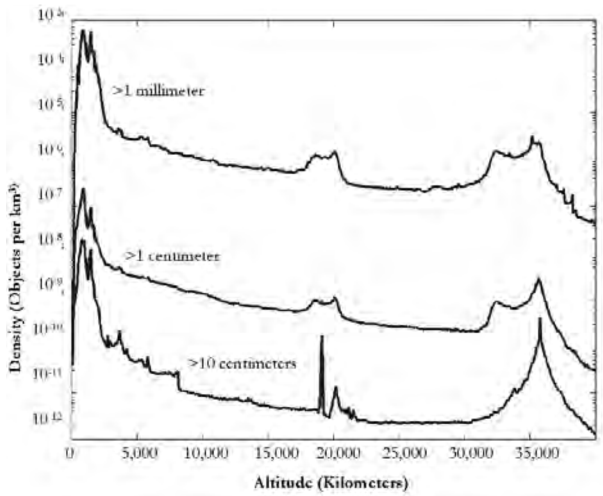
FIGURE 1.3: Space debris incidents[14]

Space Debris Incidents
The French military satellite Cerise had its stabilization arm severed in 1996 by a briefcase-sized portion of an Ariane rocket, and was temporarily put out of commission.
The Space Shuttle has been hit several times by particles bigger than one millimeter, and the first 33 Shuttle flights sustained debris damage to some of the tiles on the Shuttles' undersides.
The 10-year-old Hubble Space Telescope, which orbits in LEO, has a three-quarter-inch hole in its antenna that is believed to have been created by debris.
The Russian Kosmos 1275 military navigation satellite experienced an unexpected breakup in July 1981, generally thought to have been a result of space debris.
In 1985, a US kinetic energy ASAT test produced over 250 pieces of catalogued debris, some of which came within 1.3 kilometers of the International Space Station. The last piece of debris generated from this test de-orbited almost 20 years later in 2002.
The Long Duration Exposure Facility, a school bus-sized satellite, recorded more than 30,000 impacts by debris or meteoroids during six years in orbit.

TREND 1.2: Increasing awareness of space debris threats and continued efforts to develop international guidelines for debris mitigation

Growing awareness of space debris threats has led to the development of a number of international and national debris mitigation guidelines. The Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) began discussions of space debris issues in 1994 and published its Technical Report on Space Debris in 1999. In 2001, COPUOS asked the Inter-Agency Space Debris Coordination Committee (IADC) to develop a set of international debris mitigation guidelines. The IADC brings together representatives of the space agencies of China, Europe (ESA), France, Germany, India, Italy, Japan, Russia, Ukraine, the UK, and the US.

FIGURE 1.4: Density of space objects by altitude[15]

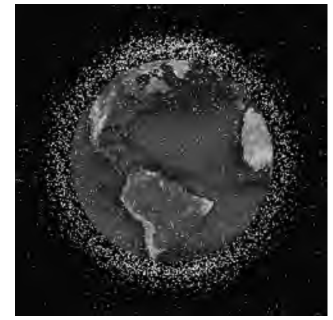


At the national level, NASA issued guidelines on limiting orbital debris in the August 1995 *NASA Safety Standard 1740*. The 1996 US National Space Policy makes it the policy of the US to "seek to minimize the creation of space debris."[16] In December 2000, the US Government issued formal orbital debris mitigation standards for space operators developed by the Department of Defense (DOD) and NASA. In 2004, the FCC initiated requirements of satellite operators to move geostationary satellites at the end of their operating life into "graveyard orbits" some 200 to 300 kilometers above GEO.[17] ESA first introduced a space debris mitigation effort in 1998. The *ESA Space Debris Mitigation Handbook* was published in 1999 and revised in 2002.[18] Also in 2002, ESA issued the European Space Debris Safety and Mitigation Standard[19] and in 2003, it announced new debris mitigation guidelines.

Japan and Russia also appear to strongly support the mitigation of space debris production. While there are some differences among national debris mitigation guidelines, they are broadly consistent. For example, all national guidelines address issues related to the minimization of debris released during normal operations. Most states require residual propellants, batteries, flywheels, pressure vessels, and other instruments to be depleted or made passive at the end of their operational lifetime.[20] All major national debris mitigation guidelines address the disposal of GEO satellites, typically in graveyard orbits some 235 kilometers above the GEO orbit, and most seek the removal of dead spacecraft from LEO within 25 years.[21]

China, although a member of the IADC, has not formally adopted debris mitigation guidelines, but is reportedly working to adopt national guidelines in line with those recommended by the IADC. At the 2003 COPUOS annual meeting, China committed to "undertake the study and development of Chinese design norms to mitigate space debris, in conformity with the principles appearing in the space debris mitigation guidelines developed by the Coordination Committee."[22]

FIGURE 1.5: Space debris in LEO[23]



In April 2004, the IADC released a revised debris "Protection Manual" describing design measures for spacecraft survivability against debris.[24] In addition, a subcommittee of the International Organization for Standardization started working on a set of standards incorporating elements of the IADC guidelines.[25] In 2004, space situational awareness topped the list of EU security research, in recognition of the importance of environmental awareness in collision avoidance.[26]

The progressive development of international and national debris mitigation guidelines has been complemented by research into practical debris mitigation technologies. For example, progress is being made in the development of electro-magnetic "tethers" that could help safely de-orbit non-operational satellites and small ion-propelled spacecraft that could fuel spacecraft to extend their operational life.[27]

TREND 1.3: Growing demand for radio frequency spectrum

The radio frequency spectrum – the part of the electromagnetic spectrum that allows the transmission of radio signals – is divided into portions known as frequency bands, measured in hertz. Higher frequencies are capable of transmitting more information. Communications satellites tend to use the L-band (one to two gigahertz) and S-band (two to four gigahertz) for mobile phones, ship communications, and messaging. The C-band (four to eight gigahertz) is widely used by commercial satellite operators to provide services such as roving telephone services, and the Ku-band (12-18 gigahertz) is used to provide connections between satellite users. The Ka-band (27-40 gigahertz) is now being used for broadband communications. It is US policy to reserve the Ultra-High Frequency, X-, and K-bands (240-340 megahertz, eight to 12 gigahertz, and 18-27 gigahertz, respectively) for the US military.[28]

For technical reasons, most satellite communication falls below 60 gigahertz, meaning actors are competing for a relatively small portion of the radio spectrum, with competition particularly intense for spectrum below three gigahertz.[29] Additionally, the number of satellites operating in the seven-to- eight gigahertz band, commonly used by GEO satellites, has grown rapidly over the past two decades.[30] Since many satellites vie for this advantageous orbit, there is increased risk of incidents of jamming.

Growth in the number of operational satellites in space at any given time has led to a corresponding increase in the demand for bandwidth with which to communicate. For example, during Operation Enduring Freedom in 2001, the US military used some 700 megabytes per second of bandwidth, compared to about 99 megabytes per second during Operation Desert Storm in 1991.[31] It is reported that during Operation Desert Storm certain air tasking orders and time-sensitive intelligence information were delivered by hand, due to a lack of available bandwidth.[32] The Wideband Gapfiller Satellite system is being designed to provide transmission capacity of up to 2.4 gigabits per second per satellite, more than 10 times the capacity of the most advanced Defense Satellite Communications System satellite.[33]

While crowded orbits can result in signal interference between satellites, new technologies are being developed to address the need for greater frequency usage, allowing more satellites to operate more closely together without interference. Frequency hopping, lower power output, laser technology, digital signal processing, frequency-agile transceivers, and software-managed spectrum have the potential to significantly improve bandwidth use and, it is hoped, alleviate certain existing and potential conflicts over bandwidth allocation. Present-day receivers are also being produced with higher tolerance for interference than those created decades ago, reflecting the need for increased frequency usage and sharing.[34]

There is also significant research being conducted on the use of lasers for communications, particularly by the US military. Lasers transmit information on precise frequencies as opposed to less focused radio waves, allowing higher bit rates and tighter placement of satellites to alleviate some of the current congestion and concern about interference. The main proposed system to make use of such technology is the US military Transformational Satellite Communications System; however, it is not expected to be fielded before 2012. The planned US NeXt Generation Communications Program would allow several users to share one band of frequency, with their respective devices intelligently searching through the allocated band for unused portions for transmission.[35]

Today, issues of interference arise primarily when spacecraft either require the same frequencies or when their fields of view overlap. While interference is not currently at epidemic proportions, it is a daily fact of life for satellite operators. For example, AsiaSat's general manager of engineering has noted that "frequency coordination is a full-time occupation for about five percent of our staff, and that's about right for most other satellite companies."[36]

An official at New Skies Satellites noted, however, that while interference is common, "satellite operators monitor their systems around the clock and can pinpoint interference and its source fairly easily in most cases."[37] The simplest way to reduce such interference is to ensure that all actors have access to reasonable and sufficient bandwidth. To this end, in July 2002, the US agreed to release a portion of the military-reserved spectrum from 1,710-1,755 megahertz to the commercial sector by 2008, to free up space for commercial third-generation (3G) wireless communications.[38] Significantly, in 2004, the US and EU reached a long sought agreement over frequency allocation and interoperability between the US GPS and the EU's proposed Galileo navigational system.[39]

Originally adopted in 1994, the current version of the ITU Constitution[40] governs international sharing of the finite radio spectrum and orbital slots used to communicate with and house satellites in orbit. Article 45 of the Constitution stipulates that "all stations (…) must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other members."[41] Military communications are exempt from the Constitution, though they must nonetheless observe measures to prevent harmful interference.

International negotiations over radio frequency allocations have become politicized, involving bargaining over systems and capabilities which can take years.[42] There is growing concern within the US that the open discussion of certain system characteristics and positioning information necessary to identify and resolve frequency and interference disputes among systems could compromise the security of the systems in question. The Aerospace Corporation noted in 2002 that "the spectrum-management community is moving toward more confidentiality, including the use of generic or non-identifying names instead of actual program names for registration submissions."[43]

TREND 1.4: Growing demand for orbital slots

Prime GEO slots are located above or close to the equator to maximize the communications footprint, since satellites inclined too far north of the equator may not be able to communicate with parts of the southern hemisphere. The orbital arc of interest to the United States lies between 60 and 135 degrees west longitude because satellites in this area can serve the entire continental US;[45] these desirable slots are also optimal for Canada, Mexico, and parts of Latin America. Similar limitations are true for all geographic regions.

The ITU Constitution states that radio frequencies and GEO "must be used efficiently and economically so that countries or groups of countries may have equitable access to both."[46] In the case of the GEO orbital slots registered by the ITU, the principle has been interpreted as meaning that such positions should be made available on a first-come, first-served basis. In order to avoid radio frequency interference, GEO satellites are required to maintain at leasttwo degrees of orbital separation, depending on the band they are using to transmit and receive signals and the field of view of their ground antennas.[47] This means that no more than approximately 180 satellites could occupy the prime equator (0 degree inclination) orbital path. In the most desired equatorial arc around the continental US, there is room for only 38 satellites.

GEO satellites must generate high-power transmissions to deliver a strong signal to Earth, due to distance and the use of high bandwidth signals for television or broadband applications.[48] According to an AsiaSat official, true spacing to avoid interference should be five degrees, as the two-degree stipulation is based on restrictions on the size of the satellite's antenna and the power of the transmission. Current US FCC policies require US direct broadcast satellites to be spaced nine degrees apart.[49]

There are measures which can help reduce the problem of competition for orbital slots and mitigate signal interference. First, the US FCC's two-degree spacing requirement only applies to satellites that wish to use the same frequency. Satellites with different frequencies can be spaced as little as one-tenth of a degree away from one another.[50] Second, some satellite operators – primarily direct-to-home video suppliers – have begun stacking satellites in the same orbital slot (often known as "hot bird" slots) to be able to provide more service.[51] For example, the 91-92 degrees West slot in GEO houses a Brazilsat, two Galaxy satellites, and a Canadian Nimiq satellite.[52] Lastly, satellite operators have begun swapping or sharing orbital slots with other space actors in order to better respond to their operational needs.

Increased demand has resulted in greater competition, motivating some actors to file requests for orbital slots prematurely and/or in greater quantity than necessary, creating a backlog of work at the ITU and long delays for those with legitimate requests. For example, Pakistan orbited a Paksat-1 satellite in 2002 essentially to reserve the orbital slot for a future satellite.[53]

Compounding these issues to some extent have been ITU revenue shortfalls and disputes over satellite network filing fees. In 2002, the ITU predicted a $16-million shortfall for 2004-2007. Since 1999, it has been implementing a cost recovery scheme for processing satellite network filings, charging members a filing fee. While these fees were intended to quell "paper satellite" filings, a growing percentage of the cost recovery revenues have been moving into the ITU's general operating budget. Average cost recovery fees have grown from about $1,126 in 2000, to $13,146 in 2002, and $31,277 in 2003, and member states are increasingly skeptical that the high fees actually represent the cost of processing the filings. The result has been patterns of non-payment, causing tensions between satellite operators and the ITU. In 2002, an Ad Hoc Group on Cost Recovery for Satellite Network Filings was formed to consider the methodology behind satellite network filing charges, and to make recommendations to the ITU Council.[54]

TREND 1.5: Space surveillance capabilities to support collision avoidance slowly improving

Space surveillance capabilities are vital to the mitigation of environmental hazards. The American SSN is the only network that systematically tracks and catalogues orbital debris. The system is comprised of radars and optical sensors at 31 sites worldwide, as well as one dedicated on-orbit satellite.[55] The SSN can track objects in LEO with a radar cross-section of five centimeters in diameter or greater. The US system uses a tasked sensor approach, which means that not all of orbital space is searched at all times, and thus objects may be observed and then lost again. The system makes up to 80,000 observations daily. Objects one to five centimeters in size, which cannot be dealt with by protective shielding on satellites, are not detectable by the system. Since 2004, the US has begun restricting access to its SSN, citing concerns that the information could be used for adversarial purposes.[56]

The broader category of space situational awareness, within which space surveillance is a primary capability, remains one of the "most urgent space security shortcomings" of the US according to leading experts.[57] Therefore, it has been bolstering such capabilities. The US Deep View program plans to develop a high-resolution radar-imaging capability to characterize smaller objects in Earth orbit.[58] The US Space Surveillance Telescope program will "demonstrate an advanced ground-based optical system to enable detection and tracking of faint objects in space, while providing rapid, wide-area search capability."[59] Also under development are the SBSS, set for launch in 2007, and the Orbital Deep Space Imager. Both surveillance systems are expected to have inherent capabilities for identifying and tracking orbital debris in GEO, but are being developed as part of the broader US space control mission (see Space Systems Negation).[60] The Naval Fence was transferred to Air Force control in 2004 when it was renamed the Air Force Space Surveillance System. The oldest US space surveillance system, it consists of three transmitters and six receivers capable of making some 5-million detections each month of objects larger than a basketball.[61]

Russia also has a Space Surveillance System (SSS), which functions using Russia's early warning radars in space and more than 20 optical and electro-optical facilities at 14 locations on Earth.[62] The main optical observation system, Okno, allows detection of objects to an altitude of 40,000 kilometers,[63] although its capacity to detect smaller objects is unclear. The Russian Academy of Sciences also participates in the SSS.[64] The system cannot track satellites at very low inclinations and the operation of Russian surveillance sensors is reportedly erratic.[65] The network as a whole carries out some 50,000 observations daily, contributing to a catalogue of approximately 5,000 objects, mostly in LEO.[66] While information from the system is not classified, Russia does not have a formal structure to widely disseminate information about observations.

Other states, France and Germany in particular, have emphasized surveillance for debris monitoring. Since 1999, France has operated the Graves radar, which tracks satellites over French territory below 1,000 kilometers. The development of this system was reportedly motivated by a desire for independence from US and Russian space surveillance capabilities.[67] The German Defense Research Organization also operates the FGAN Tracking and Imaging Radar (TIRA). The 34-meter-diameter antenna carries out observations in the L- and Ku-bands and can see objects as small as two centimeters in diameter at altitudes of 1,000 kilometers.[68]

The EU maintains information from the SSN its own Database and Information System, DISCOS, which also takes inputs from Germany's FGAN Radar and ESA's Space Debris Telescope in Tenerife, Spain. The Space Debris Telescope, a one-meter Zeiss optical telescope, focuses on observations in GEO and can detect objects down to approximately 15 centimeters in diameter in that orbit.[69] Other optical sensors, including three Passive Imaging Metric Sensor Telescopes operated by the UK Ministry of Defence, the Zimmerwald one-meter telescope at the Astronomical Institute of the University of Berne in Switzerland, and the French SPOC system and ROSACE telescope, contribute to debris surveillance in GEO.[70] ESA's Space Operations Centre in Germany has begun to provide a Space Debris Avoidance Service using data from DISCOS for satellite operators.[71]

China, since joining the IADC in 1995, also maintains its own catalogue of space objects, using data from the SSN to perform avoidance maneuver calculations and debris modeling.[72] Space surveillance is an area of growth for China, which announced new investments in optical telescopes for debris monitoring in 2003. Prior to the launch of the Shenzou V in 2003, it was revealed that the spacecraft had a debris 'alarm system' warning of potential collisions.[73] In 2005, the Chinese Academy of Sciences established a Space Object and Debris Monitoring and Research Center at Purple Mountain Observatory that employs researchers to develop a debris warning system for China's space assets.[74] In support of its growing space program, China has established a tracking, telemetry and control (tt&c) system consisting of six ground stations in China and two on foreign soil, in Namibia and Pakistan, as well as a fleet of four Yuan Wang satellite tracking ships.[75] These assets provide the foundation for space surveillance but have limited capacity to track uncooperative space objects.

Since 2004, Japan has operated a radar station in Okayama prefecture dedicated to the observation of space debris to support manned space missions. The Kamisaibara Spaceguard Center radar can detect objects as small as one meter in diameter to a distance of 600 kilometers, and track up to 10 objects at once.[76] Two optical telescopes at the Bisei Astronomical Observatory – a 0.5 meter tracking telescope and a 1.01 meter reflecting telescope capable of viewing objects to 30 cm[77] – are dedicated to space debris surveillance in GEO.

Canada's Microvariability and Oscillations of STars (MOST) micro-satellite hosts a space telescope and was a technology demonstrator for future space surveillance efforts.[78] Canada is also developing the SAPPHIRE system, which will feature a space-based sensor that will provide observations of objects to high Earth orbits (6,000 to 40,000 kilometers). It is anticipated that the data will be included in the US space catalogue, maintained by the North American Aerospace Defense Command (NORAD), to contribute to space situational awareness.[79] Canada's planned Near Earth Orbit Surveillance Satellite asteroid discovery and tracking mission also has space surveillance capabilities.

2005 DEVELOPMENTS

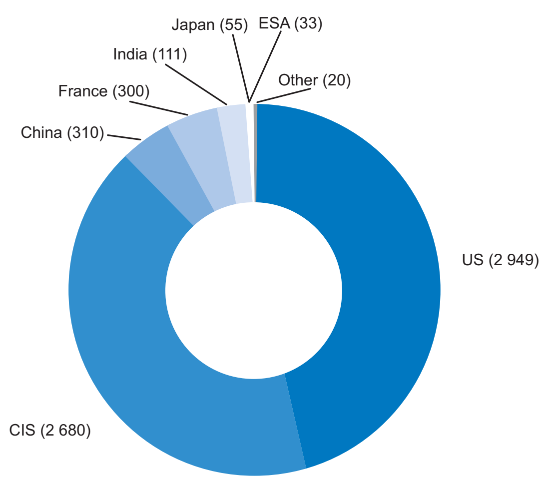
TREND 1.1: Growing debris threatens spacecrafts as rate of new production increases

2005: Space debris population increases by 2.1 percent

By the end of 2005 the number of large and medium-sized objects in orbit tracked by the US SSN stood at 9,428.[80] This number represents an increase of 195 objects or 2.1 percent when compared with yearend data for 2004.[81] The 2005 increase is also slightly larger than that of the previous year in which 176 pieces of debris representing a 1.9 percent increase were catalogued.[82] Of the total increase in space debris from 2004 to 2005, US space activity accounted for almost 45 percent, Commonwealth of Independent States countries accounted for approximately 25 percent, and France accounted for almost 10 percent (see Figure 1.6).[83] Most space debris orbits within 2,000 kilometers of the Earth's surface, with areas of concentration found near 800, 1,000, and 1,500 kilometers of altitude. Smaller amounts of debris orbit in both MEO and GEO (see Figure 1.4).

International efforts to mitigate debris production in the mid-1990s succeeded in reducing the rate of debris production. However, recent data suggests the rate of debris production is increasing once again. This trend could be the result of a possible increase in interdebris collision, but could also be related to increasing occurrences of satellite fragmentation and space launches.

FIGURE 1.6 Debris creation by launching state in 2005[84]



Several satellite fragmentation and debris collision events took place in 2005. By October, five cases of satellite fragmentation had been recorded and two new accidental collisions identified. On 17 January, a US rocket body collided with a fragment from a Chinese launch vehicle that exploded in 2000. Two Russian motors also broke-up in 2005 – the first, on 23 April, was a Russian Proton launch vehicle launched as part of the Kosmos 2224 Mission in 1992. The second breakup occurred on 1 June and was associated with the Russian Kosmos 2392 mission launched in mid-2002. As many as 40 objects were initially detected from the second fragmentation, five of which were catalogued by the SSN. On 30 June, that same motor experienced another fragmentation and 50 fragments were initially catalogued. On 21 June, a Russian meteorological observation system generated one small piece of debris. And on 22 June, a Russian Kosmos 3M rocket body released a single piece of debris. The event is believed to have been caused by a collision between the rocket body and a small piece of orbital debris or a meteoroid.[85]

2005: Pursuit of debris mitigation technologies continues

Advances were made in 2005 in the development of electromagnetic tethers that could be deployed after a satellite becomes non-operational. Space tethers are essentially cables made of conductive material and attached to a satellite while passing through the Earth's magnetic field. The motion generates electric current along the tether, providing propulsion for orbital objects, like satellites. This propulsion can be used to alter the object's orbit. When a satellite reaches the end of its operational lifetime a tether could be released to de-orbit the satellite, eventually causing it to burn up in the atmosphere.[86] The NASA orbital debris program office has been conducting analyses and testing of different tether designs at various altitudes with possible use for debris removal. These tests are ongoing and progress has been made in determining survival probabilities of the various designs.[87]

The ConeXpress Orbital Life Extension Vehicule (CX-OLEV) project headed by the Dutch Space Agency continued in 2005. The project is developing a space tug, expected to be launched by 2008, capable of prolonging the life of satellites for up to 10 years by propelling them to remain in their orbital positions. The CX-OLEV will attach to an orbiting satellite, using its thrusters to provide the necessary orbital control to maintain correct position. This technology will prevent satellite drift, prolong satellite operational lifespan, and prevent collisions with other spacecraft. Therefore, this technology may help prevent certain satellites from becoming effective space debris. The space tug could also be used for rescue missions, to store a satellite near the geostationary orbit for contingency purposes, or even to remove an inactive spacecraft, propelling it to a graveyard orbit where it would not pose a threat to operational satellites in GEO.[88]

Lastly, on 27 October 2005 the US DOD hosted the official meeting for the Large Area Debris Collector (LAD-C). Presently under development, the LAD-C will characterize and collect micro-meteoroids and orbital debris using a rigid low-density foam called aerogel on the International Space Station (ISS). The LAD-C is currently scheduled for launch in mid-2007, and is expected to be deployed for a one-year period, after which it will be returned to Earth.[89]

2005: New research finds carbon dioxide emissions could increase space collisions

In 2004, scientists at the US Naval Research Laboratory found that greenhouse gasses are causing the cooling and contraction of the thermosphere over 80 kilometers in altitude above the Earth. While this thermospheric cooling may allow operational satellites to remain in orbit for longer periods of time by reducing atmospheric drag, it appears that rising carbon dioxide levels will also make space debris more persistent.[90] In 2005, scientists at the University of Southampton found that rising carbon dioxide levels, and the resulting decreases in atmospheric density, could cause an increase in space collisions. In addition, if satellites are launched and destroyed at the existing rate, the researchers predicted a 17 percent increase in the number of collisions and a 30 percent increase in the number of objects more than one centimeter in diameter by the end of the 21st century.[91]

Net assessment:

Developments in space debris had a mixed impact on space security during 2005. On the one hand, developments in debris mitigation technology such as space tethers and CX-OLEV could potentially have a positive effect on space security by reducing the amount of space debris, ensuring that satellites remain in their allocated positions, and limiting the number of inactive satellites in orbit that could pose threats to operational spacecraft. On the other hand, these mitigation technologies have yet to be proven, let alone in any cost effective way. In the case of space tugs, these technologies could have dual-use potential for space systems negation. Furthermore, the continued increase in space debris, rebounding increase of the rate of debris production, and the cooling of the thermosphere represent more deeply rooted and persistent concerns for space security.

TREND 1.2: Increasing awareness of space debris threats and continued efforts to develop international guidelines for debris mitigation

2005: Space debris mitigation guidelines drafted at UN COPUOS meeting

During the meeting of the Space Debris Working Group of the Scientific and Technical Subcommittee of COPUOS, delegates from several member states discussed drafting a set of space debris mitigation guidelines, based on those of the IADC. Brazil, Canada, China, Japan, India, Russia, the US, and EU member states provided suggestions for developing the guidelines. The Committee achieved consensus on the adoption of Guideline 4: "Avoid intentional destruction and other harmful activities." Submitted by Canada, this guideline stipulates that the intentional destruction of any orbiting object that could generate "long-lived" orbital debris is to be avoided. Although the guidelines were originally supposed to be approved in 2004, concerns raised by a number of delegations, most notably India and Russia, slowed progress on the issue, and the 2005 version has been cited as a less technically specific version of IADC guidelines.[92] The committee hopes to adopt finalized space debris mitigation guidelines by 2007, and is expected to discuss the issue further during the working group meeting in February 2006.[93]

2005: NASA and FCC introduce debris mitigation measures

In February 2005, NASA revealed plans to implement the ISS Continuous Improvement actions. In a report entitled "NASA's Implementation Plan for International Space Station Continuing Flight," the Agency introduced plans to increase inspections of the orbital outpost as well as install more protective shielding to prevent damage from space debris. The report also discussed plans to prevent debris buildup in the orbital path of the ISS, including tests of a space tether launched on an expendable rocket to ensure that if the tether broke the resulting debris would not threaten the space station. NASA is also engaged in assessing the "potential risks to the ISS from future planned Missile Defense Systems managed by the U.S. Department of Defense" and stated its intentions to provide comments on the Missile Defense Agency's draft Environmental Impact Statement.[94]

Media reports about a forthcoming NASA study reveal that the risk posed by orbital debris to spacecraft may be higher than previously thought. Leaked information from the study suggests that shuttles now face a 1-in-54 to 1-in-113 chance of being destroyed by space debris. This is much greater than the stated NASA program goals of a 1-in-200 chance.[95] In addition, NASA found that space debris accounts for half of the risk associated with spaceflights and collisions with space debris account for 11 of the 20 problems that could be most fatal to a shuttle and its crew.[96] Because there is disagreement within NASA as to the likelihood of a fatal collision between space debris and the shuttle, NASA officials plan to conduct further study to provide more clarity.[97]

On 19 October 2005, the US Federal Communications Commission (FCC) orbital debris mitigation rules went into effect. These new rules require that any satellite system operator requesting FCC space station authorization, or any entity requesting a Commission ruling for access to a non-US-licensed space station under the Commission's satellite market access procedures submit an orbital debris mitigation plan to the Commission regarding spacecraft design and operation.[98]

Net assessment:

The adoption of debris mitigation guidelines by COPUOS bodes well for space security although at present these guidelines remain voluntary and do not encompass any implementation, verification, or compliance measures. The development of new measures by NASA and the FCC may also help to reduce the production and risk of debris.

TREND 1.3: Growing demand for radio frequency spectrum

2005: Over one thousand cases of radio frequency interference reported

Radio frequency interference and piracy are becoming a growing concern to commercial space actors. According to the Satellite Users Interference Reduction Group, there were 1,374 satellite radio frequency interference incidents reported in 2005, more than one-third caused by equipment malfunction, another 15 percent by human error, while the causes of more than 20 percent of incidents were unknown. Adjacent satellites were responsible for less than 7 percent of the incidents and 10 interferences were caused deliberately, representing less than 1 percent of the total number. Less than 1 percent of the interference occurrences were caused by terrestrial services and another 13 percent occurred during cross-polarization – when satellite dishes are being aligned to receive signals from the satellite (see Figure 1.7). Most incidents were reported over the continental US.[99]

2005: Regional efforts to harmonize radio frequency utilization in Europe and Southeast Asia

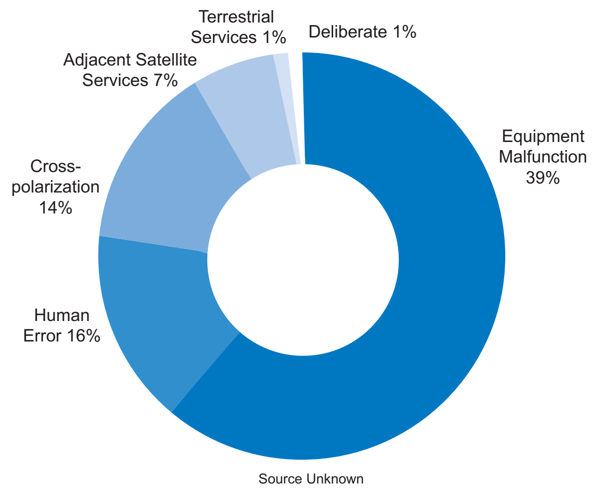
In response to greater utilization of space assets and demand for radio frequencies, regional political bodies have sought to harmonize regulation and use of this global common. In September 2005, the Association of Southeast Asian Nations (ASEAN) agreed to begin work on establishing a common radio frequency allocation, expected to be completed by 2006.[100] The move would allow for the deployment of radio frequency identification, an automatic identification system that receives and responds to radio frequency communication, within the 860-960 megahertz band. At the ASEAN Telecommunication Regulators Council meeting in Vietnam, ASEAN representatives agreed on allocating two frequencies within the 100-megahertz range.[101]

Building on the 2002 EU Radio Spectrum Decision, the European Commission (EC) released its second annual report to the European Council and European Parliament on the EU's radio spectrum policy. The report, entitled "A Forward Looking Radio Spectrum Policy for the European Union," also advocated the establishment of a coordinated spectrum policy for the EU in accordance with the Commission's 2010 initiative, which seeks to encourage the development of a digital economy in the EU. The report emphasized the need for a reform in policy and regulatory approaches to spectrum access and management, to allow for greater efficiency, flexibility, and responsiveness.[102] The March 2005 Panel of Experts Report on Space and Security also recommended that the EC undertake to coordinate frequency allocations and requirements between various parts of the security sector in Europe.[103]

2005: GAO completes review of FCC commercial spectrum license policy

In accordance with the Commercial Spectrum Enhancement Act, the US Government Accountability Office conducted a review of the FCC commercial spectrum license policy from March to August 2005, reporting its results on 10 November. Specifically, the review sought to address concerns that spectrum allocation is dominated by a "command-and-control" process whereby the government in effect dictates spectrum use. Industry stakeholders and expert panelists offered a number of suggestions for improving spectrum management. Notable suggestions included re-examining the distribution of spectrum bands to enhance efficient and effective use, ensuring clearly defined rights and flexibility in commercially licensed spectrum bands, and extending and modifying the FCC's auction authority.[104]

FIGURE 1.7: Causes of radio frequency interference in 2005[105]



Net assessment:

While growing demand for radio frequency allocation continued to challenge the sustainability of broader access to and use of space, regional efforts to harmonize the allocation of radio frequencies promised to help manage the demand on this limited resource. Radio frequency competition and interference, whether accidental or deliberate, also continued to represent a serious challenge to space security in 2005. Efforts by the private sector to coordinate their response to interference could play some role in helping to mitigate conflicts in the use of this global common.

TREND 1.4: Growing demand for orbital slot allocations

2005: Increasing number of states acquiring satellites

The year 2005 saw more states access space. Iran's first satellite was launched with the help of Russia in October, making Iran the 45th space-faring state.[106] The same launch put the NCUBE-2, Norway's first domestically developed satellite, into orbit, to be used to track reindeer and ship movements.[107] Kazakhstan had planned the launch of its first satellite for 25 December 2005, but the launch was delayed until 2006 by unspecified technical difficulties.[108] Reports in February 2005 announced that Sudan planned to have its first satellite launched before the end of 2005, but the launch did not take place.[109] In December 2005 the New Zealand government approved plans to have the country's first satellite launched in 2010.[110] In addition, the Prime Minister of Vietnam formally requested that authorities consider allowing the country to have its own satellite by 2008. Vietnam Posts and Telecommunications Corp was asked to begin bidding for the "Vinasat" satellite, which would occupy the 132 degrees East GEO orbital slot. Vietnam has until the second quarter of 2008 to put a satellite into GEO before it loses rights to the orbital slot it reserved several years ago with the ITU.[111]

2005: Competition and cooperation in the allocation and use of orbital slots

Some delegates attending the 2005 COPUOS meetings expressed the view that, owing to limited space resources, geostationary orbital slot positions should be shared equitably among states.[112] In August 2005, US-based PanAmSat and Japan-based JSAT agreed on a joint venture to launch the Horizons-2 Satellite in the 74 degrees West longitude orbital slot over the US. PanAmSat also signed an agreement with France-based Alcatel to acquire multiple European orbital slots and a satellite with coverage over Africa, Asia, Europe, and the Middle East. According to the terms of the agreement, PanAmSat will acquire both the 45 and 47.5 degrees East longitude orbital positions.[113] However, competition for orbital slots also continued in 2005 with both US-based EchoStar and Mobile Satellite Ventures (MSV) seeking the 101 degrees West longitude orbital slot. While MSV is first in line for the position, which overlooks the central US, EchoStar has also applied for extended Ku-band frequencies in that slot. In May, the US FCC authorized MSV to operate a second generation Mobile Satellite Service satellite in that location and in July, it denied EchoStar's second-in-line application for extended Ku-band frequencies at the slot. EchoStar has since petitioned the FCC to reconsider its denial order.[114]

2005: ITU's Ad Hoc Group on Cost Recovery for Satellite Network Filings implements changes to resolve cost recovery issue

In order to recover administrative costs and to deter the filing of "paper satellite" applications, the ITU has been charging its members filing fees. At the ITU Council meetings in July 2005, delegates agreed to modifications of the cost recovery methodology, including new fees effective 1 January 2006. As per Decision 482 (modified 2005), the 2005 ITU Council implemented a new fee schedule, recommending that the 2006 ITU Council meetings revisit the issue and possibly revise it further. The revised text also encourages member states to implement policies that will minimize occurrence of non-payment and resulting revenue loss on the part of the ITU.[115]

Net assessment:

Developments in 2005, including competition for GEO slots, demonstrated the governance challenges associated with secure and sustainable access to and use of space. It also illustrated one of the central dilemmas of space security. While the increasing number of states seeking to acquire satellites is may allow greater access and use of space for some, the corresponding strain on the availability of orbital slots may reduce the sustainability of space use.

TREND 1.5: Space surveillance capabilities to support collision avoidance slowly improving

2005: Expansion of US space surveillance and space situational awareness capabilities

The US continued to pursue the world's most robust space surveillance system in 2005. The US Air Force Research Laboratory announced plans to develop an experimental Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) and released a solicitation notice for innovative technology solutions for the project in December 2005.[116] Along with a host satellite, ANGELS is scheduled to be launched in 2009 to monitor the host's surrounding space environment by orbiting in close proximity. It is expected to be capable of monitoring space weather conditions, detecting anti-satellite weapons, and diagnosing technical problems with the host spacecraft. The Air Force Research Laboratory also announced plans to develop an experimental space-based optical telescope, to be mounted on a larger satellite, capable of monitoring distant objects in space.[117]

The US continued efforts throughout 2005 to update space situational awareness systems for monitoring orbital objects including space debris. The Michigan Orbital Debris Survey Telescope, used to produce statistical observations of the GEO debris environment, was completely modernized in March 2005.[118] In addition, the Ground-Based Electro-Optical Deep Space Surveillance system, a set of ground-based telescopes that form part of the Space Surveillance Network, is being upgraded with a new "Deep Stare" telescope to enhance image resolution.[119]

Progress on the development of the Space-Based Surveillance System (SBSS) continued throughout 2005, with the completion of the preliminary design review for the SBSS Pathfinder satellite; critical design review is slated to reach completion by FY2007, with Pathfinder ready for launch by FY2009. The Pathfinder satellite will be equipped with a non-imaging sensor to track manmade objects in space, and will be used primarily to monitor communications, intelligence, surveillance, and reconnaissance technology in space, but will also be employed by the US DOD to detect and track orbital debris.[120]

Growing concerns about the potentially adversarial use of US satellite and space debris tracking data led US authorities to place new restrictions on the public availability of such information, as mandated in the 2004 Defense Authorization Act.[121] A review found that available data could be employed to damage or jam satellites or to strategically move space assets to avoid detection. In accordance with stipulations in the US Defense Authorization Act, as of 3 January 2005 such information is only available on a new site requiring access permissions, and users are prohibited from sharing any information without prior approval by appropriate DOD authorities.[122] For approved users, and in some cases at a fee, more precise data on satellite coordinates is available. Questions and concerns regarding the implementation and effectiveness of the new restrictions on tracking data continue to be raised, particularly by scientists and astronomers whose research depends on unrestricted access to data.

FIGURE 1.8: Ground-based space surveillance sites

Canada continued development of its SAPPHIRE system in 2005. The surveillance system is expected to feed into the activities of North American Aerospace Defense Command (NORAD) and provide an additional data source for the US Space Surveillance Network.[123] The SAPPHIRE system is currently in a nine-month design phase and, if the design is accepted, will proceed for full implementation and delivery by 2009 or 2010.[124]

In March 2005, the Space Target and Debris Observation and Research Center of the Chinese Academy of Sciences was established to monitor and research space debris. The Center plans to develop a database of micro-space debris, as well as capabilities that allow personnel to trace space debris in real time, identify undiscovered space debris, and establish a risk assessment system. The Center is also expected to erect an advanced near celestial body telescope capable of tracking most space debris passing above Chinese territory.[125]

2005: European actors consider developing independent space surveillance network

In 2005, members of a Panel of Experts on Space and Security submitted a report to the EC recommending, among other things, that Europe develop an independent space surveillance network.[126] Other sources indicated that the Panel members, whose views do not reflect official EC or EU member state policy, had recommended a single network linking existing ground radars and optical telescopes with other European systems already in place or under development. Such a network could integrate France's GRAVES and Monge systems with Germany's FGAN Tracking and Image Radar system, and would require the European Automated Transfer Vehicle, an unmanned spacecraft used to transfer equipment, food, air, and water to the ISS, to be fitted with technology for space-based surveillance.[127] While the report garnered support from all EU member states, many officials pointed out that the network could be construed as a means of facilitating a missile defense system, which some EU members currently oppose.[128] To examine a scenario for a European civil network for space surveillance, ESA ordered a pre-feasibility study to be conducted by the French aerospace research institute ONERA.

France was expecting its GRAVES space surveillance radar to be fully operational before 2006, capable of monitoring space objects, including orbital debris. This radar will also be able to observe satellites up to 1,000 kilometers in altitude and follow more than a quarter of total satellites, particularly those that France considers "the most threatening."[129] France has also cited the necessity of developing this system to decrease reliance on US surveillance information, and to ensure the availability of data in the event of a data distribution blackout.[130] The Belgian Federal Parliament also indicated the importance it places on space surveillance by adopting a law on the activities of launching, flight operations, and guidance of space objects on 28 June 2005. The law establishes a National Register of Space Objects and a system of liability-sharing for damage caused by space debris.[131]

Net assessment:

The international improvement of space surveillance and space situational awareness capabilities in 2005 may have a positive effect on space security by providing improved and redundant tracking of space objects. However, the development of space situational awareness and the drive for *independent* space tracking systems indicate broader mistrust, and the technology holds dual-use potential for space negation purposes.

CHAPTER TWO

Space Security Laws, Policies, and Doctrines

This chapter assesses trends and developments related to space security-relevant national and international laws, multilateral institutions, national space security policies, and military space doctrines.

Space security-relevant international law has become progressively more extensive and now includes, among other agreements discussed below, the 1967 Outer Space Treaty, the 1968 Astronaut Rescue Agreement, the 1972 Liability Convention, the 1975 Registration Convention, and the 1979 Moon Agreement. These treaties establish the fundamental right of access to space, as well as state responsibility to use space for peaceful purposes. They also restrict space from national appropriation and prohibit certain military space activities, such as placing in outer space objects carrying nuclear weapons or any other kinds of weapons of mass destruction.

This chapter also assesses trends and developments related to space security-relevant multilateral institutions mandated to address the international uses of space, such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS), the UN Conference on Disarmament (CD), and the UN General Assembly (UNGA). While COPUOS tends to focus exclusively on commercial and civil space issues, the CD has attempted to address military space challenges through its work on the Prevention of an Arms Race in Outer Space (PAROS). The International Telecommunication Union (ITU) and the Inter-Agency Space Debris Coordination Committee (IADC) also address space issues regarding radio frequency spectrum, orbital slots, and space debris. These institutions are examined in the Space Environment chapter.

National space security policies include authoritative national policy statements regarding the principles and objectives of space actors with respect to the access to, and use of, space. Such policies provide the context within which national civil, commercial, and military space actors operate. For the most part, states continue to emphasize international cooperation and the peaceful uses of space in their national space policies. National civil and commercial space developments are examined in the Civil Space Programs and Global Utilities and Commercial Space chapters.

This chapter also examines national military space policies and doctrines through which national space policies are translated into military space programs and capabilities. Reflecting the fact that space is increasingly being used to support military operations, some space actors also have designated national military space doctrines that support the development of military space applications such as navigation, communications, intelligence, surveillance, reconnaissance, or meteorological capabilities.

Space Security Impacts

National and international law directly impact space security since this legal framework establishes key space security parameters, such as the common access to space, prohibitions regarding the placement of certain weapons in orbit, and the obligation to ensure that space is used for peaceful – meaning non-aggressive – purposes. International law can improve space security by restricting activities that infringe upon actors' secure and sustainable access to, and use of, space, or that directly or indirectly result in space-based threats. International law, when applied, promotes predictability and transparency among space actors and helps overcome collective action problems. National legislation and international space law also play an important role in establishing a framework necessary for the sustainable commercial uses of space.

Multilateral institutions play an essential role in space security, providing a venue to discuss issues of collective concern, mediate potential disagreements over the allocation of scarce space resources in a peaceful manner, and develop new international law as necessary. Ongoing discussion and negotiation within these institutions also help build a degree of transparency, and therefore confidence, among space-faring states.

National space policies and doctrines both reflect and inform space actors' use of space, as well as their broad civil, commercial, and military priorities. As such, the relationship of policies and doctrines to space security varies, depending whether or not a specific policy or doctrine promotes the secure and sustainable use of space by all space actors. Some space actors maintain explicit policies on international cooperation in space with the potential to enhance transparency and exert a related positive influence upon space security considerations. Such international cooperation frequently supports the diffusion of capabilities to access and use space, increasing the number of space actors with space assets and thus an interest in maintaining peaceful and equitable use of space.

National space policies and military doctrines may have adverse effects on space security if they promote policies and practices designed to constrain the secure use of space by other actors or advocate space-based weapons. Policies and doctrines that remain ambiguous on these counts may nonetheless have a negative impact on space security if they are misperceived by peer competitors as threatening, and stimulate the development of policies, doctrines, and capabilities to counterbalance these assumed threats. Furthermore, military doctrines that rely heavily on space can have mixed impacts on space security by both underscoring the need for the secure and sustainable use of space, and pushing states to develop protection and negation capabilities to protect valuable space systems.

Key Trends

TREND 2.1: Progressive development of legal framework for outer space activities

The web of national and international laws, regulations, and treaties that govern the use of space has become progressively more extensive. The international legal framework that governs the use of outer space includes space-specific UN treaties, customary international law, bilateral treaties, and other space-related international agreements.

The UN Charter establishes the fundamental objective of peaceful relations between states, including their interactions in space. Article 2(4) of the Charter prohibits the threat or use of force in international relations, while Article 51 codifies the right of self-defense in cases of aggression involving the illegal use of force by another state(s).[1]

Outer Space Treaty - Often referred to as the Magna Carta of outer space, the Outer Space Treaty (OST) represents the primary basis for legal order in the space environment (see Figure 2.1). However, the OST has several gaps. It contains no verification or enforcement provisions, does not expressly prohibit conventional weapons in outer space, nor does it prohibit ground-based anti-satellite weapons (ASATs). Article IV of the OST has been cited by some to argue that all military activities in outer space are permissible, unless specifically prohibited by another treaty or customary international law.[2]

The lack of definitional clarity in the OST presents several challenges. Although the prevailing view holds that space begins at 100 kilometers above the Earth, the definition of outer space remains unclear in the OST. This issue has been on the agenda of both the Legal and the Scientific and Technical Subcommittees of COPUOS since 1959, and remains unresolved.[3] There has also been debate regarding the expression "peaceful purposes." The position maintained by the US is that the OST's references to "peaceful purposes" mean "non-aggressive."[4] The interpretation initially favored by Soviet officials equated "peaceful purposes" with wholly non-military ones.[5]

State practice over the past 40 years has generally supported the view that "peaceful purposes" does mean "non-aggressive" purposes. Thus, while space assets have been used extensively to support terrestrial military operations, actors have stopped short of actually deploying weapons in space. This said, it is also noteworthy that there is no widely accepted definition of the term "space weapon." Various definitions have been advanced around the nature, place of deployment, location of targets, and scientific principle of weapons, as well as debates about whether ASATs and anti-ballistic missile weapons constitute space weapons.[6]

FIGURE 2.1: Key provisions of the Outer Space Treaty[7]

Article	Key provisions
Preamble	Mankind has an interest in maintaining the exploration of space for peaceful purposes.
Article I	Outer space, including the Moon and other celestial bodies, is "the province of all mankind" and "shall be free for the exploration and use by all states without discrimination of any kind, on a basis of equality."
Article II	Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty.
Article III	General principles of terrestrial international law are applicable to outer space.
Article IV	It is prohibited to place in outer space objects carrying nuclear weapons or any other kinds of weapons of mass destruction. The Moon and other celestial bodies are to be used exclusively for peaceful purposes. Military fortifications and the testing of any other kind of weapons on the Moon are prohibited. However, the use of military personnel and hardware are permitted, but for scientific purposes only.
Article VI	States are internationally responsible for national activities in outer space, including activities carried on by non-governmental entities.
Article IX	Parties to the Treaty shall be guided by the principles of cooperation and mutual assistance in the exploration and use of outer space. State parties are to undertake international consultations before proceeding with any activity that would cause potentially harmful interference with the peaceful exploration and use of outer space.

Liability Convention

This Convention establishes a liability system for activities in outer space, which is instrumental in addressing threats from space debris and other spacecraft. The Convention specifies that any damages to a state's surface, air, or space assets as a result of another state's space activities are to be compensated by the state that launched the offending object. The Convention reiterates that state parties remain responsible for the activities of their nationals and non-governmental entities. The commercialization and growing military uses of space are challenging the structure of the Liability Convention. For example, the growing number of private and international actors undertaking space launches is confusing the definition of the term "launching state."

Registration Convention

This Convention establishes a mandatory system of registration of objects launched into space. Mandatory reporting to the Secretary-General of the UN on several data points is required, such as the date and location of the launch, changes in orbital parameters after the launch, and the recovery date of the spacecraft. This central registry's purported benefits are, in theory, effective management of space traffic, enforcement of safety standards, and attribution of liability for damage. Furthermore, the Convention acts as a space security confidence-building measure (CBM) by promoting transparency.

Lack of compliance remains a problem for the Registration Convention. While information is to be provided "as soon as practicable," it might not be provided for weeks or months, if at all. For example, by 2001, the US had failed to register 141 of its over 2,000 satellite payloads. The compliance of other signatories is equally poor.[8] To date, not one of the satellites registered has ever been described as having a military function. Nor does the Convention require a launching state to provide appropriate identification markings for its spacecraft and its component parts. Various proposals have been advanced at the CD to resolve the enumerated shortcomings of the Registration Convention.

Moon Agreement

This Agreement generally echoes the space security language and spirit of the OST in terms of the prohibitions on aggressive behavior on and around the Moon, including the installation of weapons and military bases, as well as other non-peaceful activities.[9] The Moon Agreement is not widely ratified and lacks support from major space powers.[10] Objections to its provisions regarding an international regime to govern the exploitation of the Moon's natural resources; differences over the interpretation of the Moon's natural resources as the "common heritage of mankind"; and the right to inspect all space vehicles, equipment, facilities, stations, and installations belonging to any other party appear to have kept most states from ratifying this Agreement. These issues of contention could be magnified by renewed interest in lunar missions.

FIGURE 2.2: Key UN space principles

Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (1963)
Space exploration should be carried out for the benefit of all countries. Outer space and celestial bodies are free for exploration and use by all states and are not subject to national appropriation by claim of sovereignty. States are liable for damage caused by spacecraft and bear international responsibility for national and non-governmental activities in outer space.
Principles on Direct Broadcasting by Satellite (1982)
All states have the right to carry out direct television broadcasting and to access its technology, but states must take responsibility for the signals broadcasted by them or actors under their jurisdiction.
Principles on Remote Sensing (1986)
Remote sensing should be carried out for the benefit of all states, and remote sensing data should not be used against the legitimate rights and interests of the sensed state.
Principles on Nuclear Power Sources (1992)
Nuclear power may be necessary for certain space missions, but safety and liability guide lines apply to its use.
Declaration on Outer Space Benefits (1996)
International cooperation in space should be carried out for the benefit and in the interest of all states, with particular attention to the needs of developing states.

Astronaut Rescue Agreement

This Agreement accords astronauts a form of diplomatic immunity and requires that assistance be rendered to astronauts in distress, whether on sovereign or foreign territory. The Agreement requires that astronauts and their spacecraft are to be returned promptly to the launching authority should they land within the jurisdiction of another state party.

UN space principles

In addition to treaties, five UN resolutions known as UN principles have been adopted by the General Assembly for the regulation of special categories of space activities (see Figure 2.2). Though these principles are not legally binding instruments, they retain a certain legal significance by establishing a code of conduct recommended by the members of the UNGA, and reflecting the conviction of the international community on these issues.

PAROS resolution

Since 1981, the UNGA has passed an annual resolution asking all states to refrain from actions contrary to the peaceful use of outer space and calling for negotiations in the CD on a multilateral agreement to support the Prevention of an Arms Race in Outer Space (PAROS).[11] PAROS resolutions have generally passed unanimously in the UNGA, with only four abstentions on average, demonstrating a widespread desire on the part of the international community to expand international law to include prohibitions against weapons in space.[12] However, the US is one state that has consistently abstained from voting on the resolution since 1995, along with Israel and a few others.

FIGURE 2.3: Signature and ratification of major space treaties

Treaty	Date	Ratifications	Signatures
Outer Space Treaty	1967	98	27
Rescue Agreement	1968	88	25
Liability Convention	1972	83	25
Registration Convention	1975	46	4
Moon Agreement	1979	12	4

Multilateral and bilateral arms control and outer space agreements

Since space issues have long been a topic of concern, there are a range of other legal space security-relevant agreements that have attempted to provide predictability and transparency in the peacetime deployment or testing of weapons that either travel through space or can be used in space. For example, one of the key provisions of some arms control treaties, beginning with the 1972 Strategic Arms Limitation Treaty I (SALT I) agreement, has been a recognition of the legitimacy of space-based reconnaissance – or National Technical Means (NTMs) – as a mechanism of treaty verification, and a related prohibition of interference with these space assets.[13] A claim can be made, therefore, that a norm of non-interference with NTMs, early warning satellites, and certain military communications satellites has been accepted as conforming to the OST's spirit of populating space with systems "in the interest of maintaining peace and international security."[14] A summary of the key space security-relevant provisions of these agreements is provided below in Figure 2.4.

FIGURE 2.4: Multilateral and bilateral arms control and outer space agreements

Agreement	Space security provisions
Limited Test Ban Treaty (1963)	Prohibition of nuclear weapons tests or any other nuclear explosion in outer space[15]
Strategic Arms Limitation Treaty I (1972)*	Acceptance of, and prohibition of interference with, national technical means of verification Freezes the number of intercontinental ballistic missile launchers[16]
Hotline Modernization Agreement (1973)*	Sets up direct satellite communication between the US/USSR[17]
Anti-Ballistic Missile Treaty (1972)*†	Prohibition of space-based anti-ballistic missile systems[18]
Environmental Modification Convention (1977)	Bans, for use as a weapon, modification techniques having widespread, long-lasting, or severe effects on space[19]
Strategic Arms Limitation Treaty II (1979)*	Acceptance of, and prohibition of interference with, national technical means of verification Prohibits fractional orbital bombardment systems (FOBS)[20]
Launch Notification Agreement (1988)*	Notification and sharing of parameters in advance of any launch of a strategic ballistic missile[21]
Conventional Armed Forces in Europe Treaty (1990)	Acceptance of, and prohibition of interference with, national and multinational technical means of verification[22]
Strategic Arms Reduction Treaty I (1991)*	Acceptance of, and prohibition of interference with, national technical means of verification[23]
Intermediate-Range Nuclear Forces Treaty (1997)	Acceptance of, and prohibition of interference with, national technical means of verification[24]
Memorandum of Understanding establishing a Joint Data Exchange Center (2000)*	Exchange of information obtained from respective early warning systems[25]
Memorandum of Understanding establishing a Pre- and Post-Missile Launch Notification System (2000)*	Exchange of information on missile launches

* Indicates a bilateral treaty between US and USSR/Russia
† Abrogated in 2002

Other laws and regimes

Coordination among participating states in the Missile Technology Control Regime (MTCR) adds another layer to the international space law framework.[26] The MTCR is not a treaty but rather a voluntary arrangement between 34 states to apply common export control policy on an agreed list of technologies, such as launch vehicles which could also be used for missile deployment (see Commercial Space).[27] Another related effort is the International Code of Conduct against Ballistic Missile Proliferation – also referred to as the Hague Code of Conduct – which calls for greater restraint in developing, testing, using, and proliferating ballistic missiles.[28] To increase transparency and reduce mistrust among subscribing states, it introduces CBMs such as the obligation to announce missile launches in advance.

Finally, the treaties which have an impact on space security during times of armed conflict include the body of international humanitarian law composed primarily of the Hague and Geneva Conventions – also known as the laws of armed conflict (LOAC). Through the concepts of proportionality and distinction, they restrict the application of military force to legitimate military targets and establish that the harm to civilian populations and objects resulting from specific weapons and means of warfare should not be greater than that required to achieve legitimate military objectives.[29] Therefore, attacks on satellites, it could be argued, may violate LOAC through direct or collateral damage on civilian satellites and/or the satellites of neutral parties.

The emergence of space commerce and the potential for space tourism has led at least 20 states to develop national laws to regulate space activities.[30] While the proliferation of national legislation may increase compliance with international obligations and reinforce responsible use of space, in practice it has occasionally led to divergent interpretations of treaties.[31]

Lastly, the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in 1999, adopted the Vienna Declaration on Space and Human Development. The Vienna Declaration established an action plan calling for the use of space applications for environmental protection, resource management, human security, and development and welfare. The Vienna Declaration also called for increasing space access for developing countries and the promotion of international space cooperation.

Space Security Proposals

The last 25 years have seen a number of proposals to address gaps in the space security regime, primarily within the context of the CD. At the 1981 UN General Assembly, the USSR first proposed a "Draft Treaty on the Prohibition of the Stationing of Weapons of Any Kind in Outer Space." The proposed treaty was to ban the orbiting of objects carrying weapons of any kind and the installation of such weapons on celestial bodies or in outer space in any other manner. States would also undertake not to destroy, damage, or disturb the normal functioning of unarmed space objects of other states. A revised text, the "Draft Treaty on the Prohibition of the Use of Force in Outer Space and From Space Against the Earth." introduced to the CD in 1983 had a broader mandate and included a ban on ASAT testing or deployment, as well as verification measures.[33]

During the 1980s, several states tabled working papers in the CD proposing arms control frameworks for outer space, including the 1985 Chinese proposal to ban all military uses of space. India, Pakistan, and Sri Lanka made proposals to restrict the testing and deployment of ASATs. Canada, France, and Germany contributed to the space security debate in the CD by exploring definitional issues and verification measures.[34] In 1989, France proposed the creation of a shared space surveillance system consisting of radar and optical sensors for the international community to track the trajectory of space objects. The proposal presented in the CD became known as the international trajectography centre (UNITRACE).

In the late 1990s, after the collapse of the PAROS ad hoc committee because of the CD agenda crisis, Canada, China, and Russia contributed several working papers on options to prohibit space weapons. In conjunction with the delegations of Vietnam, Indonesia, Belarus, Zimbabwe, and Syria, Russia and China submitted a joint working paper to the CD in 2002 called "Possible Elements for a Future International Legal Agreement on the Prevention of Deployment of Weapons in Outer Space."[35] The paper proposed that state parties to such an agreement undertake not to place in orbit any object carrying any kind of weapon and not to resort to the threat or use of force against outer space objects. Parties would also declare the locations and scopes of launching sites, the properties and parameters of objects being launched into outer space, and notify others of launching activities. Since then, China and Russia have presented several Non-Papers on verification measures for such a treaty and on existing international legal instruments on the topic of space weapons.

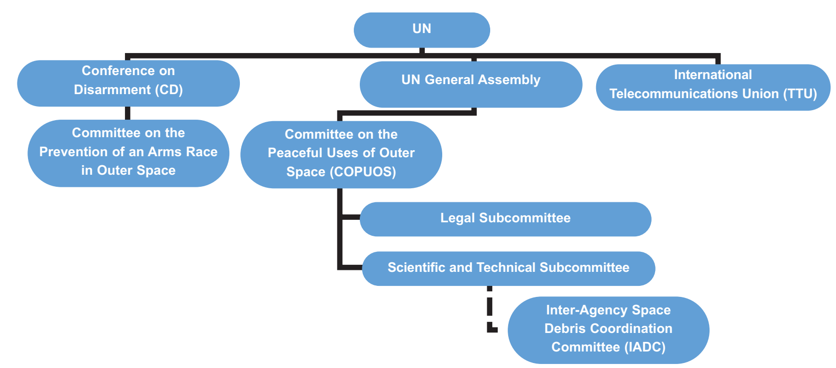
Non-governmental organizations (NGOs) have also contributed to this dialogue on gaps in the international legal framework. For example, the Union of Concerned Scientists drafted a model treaty banning ASATs (1983).[36] More recently, the Henry L. Stimson Center proposed a code of conduct (2003) on dangerous military practices in space.[37] Since 2002, the UN Institute for Disarmament Research has convened expert meetings to examine space security issues and considered a range of options to address them.[38]

TREND 2.2: COPUOS remains active, but the Conference on Disarmament has been deadlocked on space weapons issues since 1998

An overview of the relationships among key space security-relevant institutions is provided in Figure 2.5. The UNGA is the main deliberative organ of the United Nations and issues of space security are often debated within the UNGA First Committee (Disarmament and International Security). While the decisions of the Assembly are not legally binding, they are considered to carry the weight of world opinion. The UNGA has long held that the prevention of an arms race in outer space would make a significant contribution to international peace and security.

The UNGA created COPUOS in 1958 to review the scope of international cooperation in the peaceful uses of outer space, develop UN programs in this area, encourage research and information exchanges on outer space matters, and study legal problems arising from the exploration of outer space.[39] There are currently 67 COPUOS Member States. The IADC was established in 1993 as a stand-alone agency composed of the space agencies of major space actors, and has played a key role in developing and promoting space debris mitigation guidelines. The group submitted recommendations for limiting debris to the COPUOS Scientific and Technical Subcommittee in 2002 (see The Space Environment).[40]

FIGURE 2.5: International space security-relevant institutions



The CD was established in 1979 as the primary multilateral disarmament negotiating forum. The CD presently has 66 Member States plus observers that meet in three sessions on an annual basis and conduct work by consensus under the chair of a rotating Presidency. The CD has repeatedly attempted to address the issue of the weaponization of space. In 1982, The People's Republic of Mongolia put forward a proposal to create a committee to negotiate a treaty to that effect.[41] After three years of deliberation, the CD Committee on PAROS was created and given a mandate not to negotiate but "to examine, as a first step (…) the prevention of an arms race in outer space."[42] From 1985 to 1994, the PAROS committee met, despite wide disparity among the views of key states, and in that time made several recommendations for space-related confidence-building measures.[43]

Extension of the PAROS committee mandate faltered in 1995 over an agenda dispute that linked PAROS with other agenda items. By 1998 the CD agenda negotiations were at a complete standstill and without a plan of work; the CD has been inactive since that time. The US has prioritized the negotiation of a Fissile Material Cut-off Treaty (FMCT) over action on PAROS, while China has prioritized the reverse, with the result being a stalemate on both. In 2000, then President of the CD, Ambassador Amorim of Brazil, attempted to break the deadlock by proposing the creation of four subcommittees, including one to "deal with" PAROS and another to "negotiate" the FMCT.[44] The 2002 Five Ambassadors Initiative again attempted to resolve the blockage, proposing an agenda that decoupled the establishment of an ad hoc PAROS committee from any eventual treaty on the non-weaponization of space. At the end of the third session in 2003, China agreed to support the Five Ambassadors Proposal and concede to discussions on PAROS without a negotiation mandate, leaving only the US to agree to this work plan. In 2004, during an informal closed session on PAROS held by the CD, several states called for the establishment of a CD expert group to discuss the broader technical questions surrounding space weapons, although there is still no consensus on a program of work to proceed with discussions.

TREND 2.3: Space-faring states' national space policies consistently emphasize international cooperation and the peaceful uses of outer space

The national space policies of all space-faring states explicitly support the principles of peaceful and equitable use of space. Similarly, almost all emphasize the goals of using space to promote national commercial, scientific, and technological progress, with countries such as China, Brazil, and India emphasizing economic development. Virtually all space actors underscore the importance of international cooperation in their space policies.

The US has the most to offer to international cooperative space efforts, but at the same time is the least dependent upon such efforts to achieve its national space policy objectives. US national space policy declares an intention to "pursue greater levels of partnership and cooperation in national and international space activities and work with other nations to ensure the continued exploration and use of outer space for peaceful purposes."[45] Such cooperation aims to promote cost-sharing and provide benefits to the US by increasing access to foreign scientific and technological data as well as foreign research and development facilities. It also seeks to enhance relations with US allies and Russia, while supporting initiatives with emerging space-faring states. US national space policy also notes that space cooperation must protect the commercial value of American intellectual property and ensure that technology transfers do not undermine US competitiveness and national security. Overall, it is clear that US space efforts have played a central role in the dissemination of space access and use capabilities to other states.[46]

Russia is deeply engaged in cooperative international space activities, arguing that international cooperation is more efficient in the field of space exploration than breakthroughs by individual states.[47] The International Space Station (ISS) and the Russian-American Observation Satellite Program (RAMOS) for detection of missile launches are examples of this strategy, although RAMOS was cancelled in 2004 (see Space Support for Terrestrial Military Operations).[48] Russia has also undertaken cooperative space ventures with Bulgaria, Canada, China, the EU, France, Germany, Hungary, India, Israel, Pakistan, and Portugal on various occasions.[49] Thus, like the US, Russian space cooperation activities have tended to support broader access and use of space.

China maintains a public commitment to the peaceful use of outer space in the interests of all mankind.[50] While China actively promotes international exchanges and cooperation, it has stated that such efforts must encourage independence and self-reliance in space capabilities. The Chinese White Paper on space also emphasizes that, while due attention will be given to international cooperation and exchanges in the field of space technology, these exchanges must operate on the principles of mutual benefit and reciprocity. China has emphasized Asia-Pacific regional space cooperation, which in 1998 led to the signing of the Memorandum of Understanding on Cooperation in Small Multi-Mission Satellite and Related Activities with Iran, Mongolia, Pakistan, South Korea, and Thailand.[52] China has also pursued space cooperation with at least 12 states, and is collaborating with Brazil on a series of Earth resources satellites.[52]

International cooperation is one key focus of the national space policies of European actors. Another focus is autonomy, as exemplified by the Ariane and Galileo programs. France, Germany, Italy, and the UK all have extensive cooperative ventures with the US. The European Space Agency (ESA) facilitates European space cooperation by providing a platform for discussion and policymaking for the European scientific and industrial community.[53] Many see this cooperation, and the resultant European excellence in space, as one of the most visible achievements of European cooperation in science and technology. The principles of space activity advanced by France have emphasized free access for all peaceful applications, maintenance of the security and integrity of orbital satellites, and consideration for the legitimate defense interests of states. However, it is also clear that Europe currently lacks the resources to meet its stated space policy. For this reason, it continues to pursue cooperation with the larger space powers, specifically the US and Russia.

TREND 2.4: Growing focus within national military doctrine on the security uses of outer space

Fueled by the revolution in military affairs, the military doctrine of a number of states increasingly reflects a growing focus on space-based applications to support military force enhancement functions (see Space Support for Terrestrial Military Operations). Related to this trend is a tendency among China, Russia, the US, European states, and several emerging space powers to view their space assets as an integral element of their national critical infrastructure.

While there is a specific hierarchy in US military space doctrine documents, there is, nonetheless, a growing interest in space control, defined as the "freedom of action in space for friendly forces while, when directed, denying it to an adversary."[54] It also remains US policy, under *Joint Publication 3-14* and Department of Defense (DOD) *Space Control Policy*, to emphasize tactical denial, meaning that denial should have localized, reversible, and temporary effects.[55] Related to concerns about the vulnerability of US space assets, there is a robust debate within the US on how to best assure the security of these assets. Some advocate the development of space control capabilities, including enhanced protection, active defense systems, and space-based counterspace weapons. The 2003 US Air Force (USAF) *Transformation Flight Plan* in particular calls for on-board protection capabilities for space assets, coupled with offensive counterspace systems to ensure space control for US forces.[56] The 2004 USAF *Counterspace Operations* doctrine document, for its part, makes explicit mention of military operations conceived "to deceive, disrupt, deny, degrade, or destroy adversary space capabilities."[57]

Others in this debate advocate enhanced protection measures, but oppose the deployment of weapons in space.[58] Much official US military space doctrine has remained focused primarily on force enhancement, as reflected in the US DOD 1999 *Space Policy*.[59] The authoritative US joint doctrine on such matters, *Joint Publication 3-14*, as well as the *2004 USAF Posture Statement* reflect a continuing emphasis on using space assets for traditional force enhancement or combat support operations, as well as other passive measures such as space systems protection and responsive space access.[60]

Interest in developing an anti-ballistic missile system in the US has also fuelled discussion and plans for space-based interceptors and space-based lasers. Most notable was President Reagan's Strategic Defense Initiative proposed in 1983. While not explicitly mentioning particular land-, sea-, or space-based systems, the 1996 *National Space Policy* calls for the development of national missile defense. In addition, the National Missile Defense Act of 1999 makes it the policy of the US to "deploy as soon as is technologically possible an effective National Missile Defense (…) against limited ballistic missile attack."[61] More recently, the US Missile Defense Agency called for the placement of a test-bed for missile interceptors in outer space by 2012 (see Space-Based Strike Weapons).[62]

In all of its military doctrine documents since 1992, Russia has expressed concern that attacks on its early warning and space surveillance systems would represent a direct threat to its security[63]. Therefore, a basic Russian national security objective is the protection of Russian space systems, including ground stations on its territory.[64] These concerns derive from Russia's assessment that modern warfare is becoming increasingly dependent on space-based force enhancement capabilities.[65] In 2001, Anatoliy Perminov, then Commander-in-Chief of the space corps, stated that the international trend of armed force modernization demonstrates "the continuously rising role of national space means in ensuring the high combat readiness of troops and naval forces."[66] In practical terms, Russian military space policy appears to have two main priorities. The first is transferring to a new generation of space equipment capabilities, including cheaper and more efficient information technology systems.[67] The second priority is the upgrade of the Russian nuclear missile attack warning system. Together, these recent developments are seen as having a critical role in guaranteeing Russia's secure access to space.[68] Russia has expressed concern about the potential weaponization of space and the extension of the arms race to outer space, especially in light of the development of US missile defense systems.[69] Thus, Russia has actively argued for a treaty prohibiting the deployment of weapons in space. In the interim, Russia has pledged not to be the first to deploy any weapons in outer space and has encouraged other space-faring nations to do the same. However, various Russian officials have also threatened retaliatory measures to any country that attempts to deploy weapons in space.[70]

China's military space doctrine, should it exist, is not made public. China's White Paper on Space Activities, released in 2000, identified national security as a key element of China's space program. As part of the modernization of its armed forces, the 2004 National Defense White Paper describes China's plans to develop technologies, including "dual purpose technology" in space, for civil and military use.[71] The official Chinese position is that space security will be undermined rather than enhanced by the weaponization of space, that weaponization will lead to a costly and destabilizing arms race in space, and that this would be detrimental to both Chinese and global security. As a result, China has proposed a multilateral treaty banning all weapons in space and has pressed its case for such a multilateral treaty within the PAROS talks at the CD.[72]

The space policies of EU member states recognize that efforts to assume a larger role in international affairs will require the development of space assets such as global communications, positioning, and observation systems.[73] While most European space capabilities have focused on civil applications, there is an increasing awareness of the need to strengthen dual-use capabilities. According to a European think-tank proposal, creating an intergovernmental agency in the field of defense capacities development, research, acquisition, and armament represents a cornerstone for the development of security technologies, and thus for space activities as well.[74] In 2004, an EU Council meeting took note of a draft proposal advocating progress towards a more interoperable space policy.

The EU *European Space Policy* Green Paper and the subsequent *European Space Policy* White Paper also suggest that the EU will work to strengthen and enforce international space law.[75] At the national level, French military space doctrine recognizes the primordial role of space support for terrestrial military operations. At the national level, French military space doctrine recognizes the primordial role of space support for terrestrial military operations and the Ministry of Defense has emphasized the role of space power in maintaining sovereignty.[76] UK military space doctrine calls for greater satellite use for communications and intelligence. For its part, ESA has traditionally focused on civil uses of space, a role mandated by the reference in its statute to "exclusively peaceful purposes."[77]

Emerging space-faring states have also begun to emphasize the security dimension of outer space. India's army doctrine, released in 2004, noted plans to make extensive use of space-based sensors for what it predicts will be short and intense military operations of the future.[78] Finally, recent Canadian Air Force doctrine documents have highlighted the importance of space systems in support of terrestrial military operations, space situational awareness, and space systems protection.[79]

TREND 2.1: Progressive development of legal framework for outer space activities

2005: Greater stalemate in PAROS debate

The year 2005 saw a noteworthy shift in the PAROS debate. While in the last several years the PAROS resolution in the UNGA has passed with strong international support, no opposition, and the abstention of only a few of states, in 2005 the US and Israel became the first countries ever to oppose the resolution. US officials maintained a long-held position that there is no arms race in space and that the existing multilateral arms control regime adequately deals with the non-weaponization of space. The resolution passed in the First Committee with a vote of 160 in favor to 1 against (US) and with 1 abstention (Israel).[80] In the General Assembly, Israel joined the US in opposing the PAROS resolution.[81] In a speech to the "Conference on Future Security in Outer Space," on 28 May, the US Ambassador to the CD expressed the view that there should be no limitations on the right of sovereign nations to acquire all forms of information from space and hence there is no need for new outer space arms control agreements. The Ambassador also explained that the existing international arms control framework is sufficient in limiting the uses of outer space and protecting states' interests without augmentation.[82]

The UK has also identified several difficulties associated with increasing codification of space-related international law, including the lack of international consensus on the need for further treaties, which would hinder agreement of an instrument and means of verification. Instead, the UK proposed to establish "rules of the road" in space, similar to those that already exist at sea, that could bring immediate security benefits by reducing the risk of accidental collisions and promoting 'safe passage' for satellites.[83]

For its part, China expressed concern that certain warfare concepts, including control over and occupation of space, were becoming codified. At the CD, China warned that as research and development of space weapons continue, the danger of the weaponization of outer space is becoming increasingly imminent. It encouraged CD members to negotiate an appropriate agreement to codify preventative measures with respect to deployment of space weapons to ensure that they cannot be used to wage war or seek military superiority.[84]

2005: New space security proposals tabled

A number of proposals addressing perceived gaps in space security cooperation were put forward in 2005. On 12 October, Russia sponsored a draft resolution in the UNGA First Committee entitled "Measures to promote transparency and confidence-building in outer space" inviting states to inform the UN Secretary-General on transparency and confidence-building measures related to activities in space. The resolution was adopted by the First Committee, with 158 votes in favor, 1 vote against (US), and 1 abstention (Israel).[85] Building on efforts in recent sessions and earlier proposals to advance the PAROS discussion, Russia and China submitted a "food for thought" Non-Paper to the CD entitled "Definition Issues Regarding Legal Instruments on the Prevention of Weaponization of Outer Space."[86] The Non-Paper proposed specific definitions of key space terms and was intended to encourage further discussion on PAROS.

Net assessment:

While the vast majority of states remained committed to expanding space security governance throughout 2005, lack of consensus among key international players on PAROS and eventual treaty implementation could have a negative impact on space security. The UNGA resolution on transparency and confidence-building measures should provide an opportunity for official dialogue on ideas to promote predictability and trust in international space activities.

TREND 2.2: Some progress in COPUOS, but the Conference on Disarmament has been unable to agree on an agenda since 1998

2005: Proposal to expand COPUOS mandate put forward

During the 48th session of COPUOS, debate centered on the possible introduction of additional topics in the space field, namely those pertaining to the militarization of space. Some states were supportive of the Committee's considering all issues affecting the peaceful uses of outer space, including the militarization of space. The US, however, held that the Committee had been created exclusively to promote international cooperation in the peaceful uses of outer space and that non-armament aspects of outer space were more appropriately dealt with in other forums, including the First Committee of the UNGA and the CD. In addition, some delegations expressed support for the establishment of a comprehensive UN convention on space law to ensure that space is used solely for peaceful purposes.[87] One of the most significant developments emerging from COPUOS was the proposal submitted by Dr. Karl Doetsch, former head of the Scientific and Technical Subcommittee, to establish a "Long-Term Planning Working Group." The proposal called for the modification or extension of the COPUOS mandate to properly reflect its desired role in advancing international space activities. While many delegations, including India and China, were very supportive of Dr. Doetsch's proposal, others, while agreeing with the proposal in principle, regarded these efforts as part of a move to change the COPUOS mandate to allow for discussion of space weapons issues. Consensus on this issue was not achieved during the main 2005 COPUOS sessions and this matter is likely to be discussed further during upcoming 2006 meetings.[88]

2005: Continued focus on informal discussion of space security issues in the CD

The CD has been deadlocked since 1998, and remained unable to achieve consensus on an agenda which prevented any formal progress on the PAROS issue in 2005. Language for a draft resolution entitled "Initiating work on priority disarmament and non-proliferation issues," designed to proceed with substantive discussions on CD issues in spite of the current stalemate, was circulated among First Committee delegates. The proposal, jointly sponsored by Canada, Brazil, Kenya, Mexico, New Zealand, and Sweden, called for four open-ended *ad hoc* committees to be convened under UNGA First Committee auspices to address the widely agreed priority issues for the CD, including PAROS.[89] However, this proposal was withdrawn under pressure from, among others, the US, which distributed a memo warning that the proposal would undermine the CD and that the US would boycott any discussions outside the CD.[90]

In spite of the blockage at the CD, informal channels were used to advance discussions on space security themes in a deliberate effort by several states to lay the groundwork for possible future treaty negotiations. In June 2005, the then Norwegian President of the CD announced a series of informal discussions on key issues, including a meeting dealing with PAROS. Twenty-two states addressed the 30 June session.[91] Representatives from Brazil, Canada, Germany, Malaysia, South Africa, and Sri Lanka commended the efforts of China and Russia in submitting thematic Non-Papers on PAROS. Several countries, including Pakistan, Germany, and Canada, applauded efforts to establish single-topic informal plenary discussions to address issues, including PAROS, outside the CD. The Russian delegate's statement reiterated its commitment to not be the first state to deploy any weapons in outer space, a pledge it first announced in 2004 First Committee meetings. He warned, however, that "if someone starts to place weapons in outer space we will have to react accordingly" – reiterating a position made by the Russian Defense Minister on 2 June.[92]

A second informal session on space security themes was held at the invitation of Russia on 16 August. The open-ended meeting considered several documents drafted by Russia and China, including the 2005 Non-Paper on definitions. It concluded with a series of recommendations that the CD adopt a PAROS resolution; the UNGA seek an advisory opinion from the International Court of Justice regarding definition of "peaceful uses;" and the UNGA convene either an open-ended working group or establish an ad hoc committee to discuss a treaty on space security.[93]

In addition, a number of international conferences discussing space security issues took place throughout 2005, demonstrating international engagement on space issues. In March, Russia and China, along with the UN Institute for Disarmament Research and The Simons Foundation, hosted a conference for civil society and government representatives entitled "Safeguarding Space Security: The Prevention of an Arms Race in Outer Space."[94] Also, the first global parliamentary hearing on space security was held on 14 September in Washington, DC. A group of legislators from ten countries – Australia, Brazil, Britain, Denmark, Ghana, Japan, Mexico, Norway, Portugal, and the US – took part in the hearing, facilitated by E-Parliament, which focused on the future of outer space, including the possible deployment of weapons in space.[95]

Net assessment:

International institutions play an important role in facilitating multilateral discussions on space security. The increasing number and frequency of informal multilateral meetings on space security indicate the importance states attach to this issue. The continuing failure to agree on a program of work in the CD, however, could cause this important negotiating forum to lose its relevance.[96] Furthermore, while informal discussions are useful, they have not yet led to tangible outcomes nor to a resolution of the impasse in the CD, and it is unclear how these discussions might feed into any eventual negotiations. The withdrawal of the UNGA First Committee draft resolution calling for the establishment of open-ended ad hoc committees also indicates the lack of political consensus on how to deal with the ongoing deadlock in the CD.

TREND 2.3: Space-faring states' national space policies consistently emphasize international cooperation and the peaceful uses of outer space

2005: New space policies adopted in China, Europe, Japan, Kazakhstan, Russia, and US

In April 2005, the European Commission (EC) unveiled a plan to spend more than $5-billion on "Security and Space" programs for 2006-2013 and to double its budget for space-related research programs.[97] The EC is also working towards approval of a new European Space Policy for 2006-2013. Priorities of the new policy are expected to include space exploration, communication, science, and technological development.[98]

During the ESA Ministerial Meeting on 5-6 December 2005, representatives from ESA's 17 member states, as well as Canada, decided on a plan for European competitiveness in space. Delegates endorsed the continuation of ongoing programs, including the Earth Observation Envelope Program and the International Space Station Exploitation Program, and agreed to undertake new initiatives. The delegates also agreed on a series of new programs, including the Global Monitoring for Environment and Security (GMES) Space Component, the European Space Exploration program Aurora, particularly its first exploration mission to Mars, and subscriptions for the General Support Technology Program to support the development of new space technologies "with a view to non-dependence and security."[99] The delegates agreed to undertake space science missions of strategic and economic value, including earth observation and security-related missions, emphasizing the need for greater European space cooperation to maintain a competitive space sector that would guarantee access to strategic data and services, and consolidate a share of the global commercial market.[100]

In November 2005 the US Senate approved an amendment to the *2000 Iran Nonproliferation Act*, which prohibited the US from purchasing human spaceflight hardware from Russia as long as Russia provides assistance to Iran's nuclear program. As per the amendment, NASA was granted permission to pay Russia for launches and spacecraft to support the ISS, presumably improving space cooperation among the two main space-faring nations.[101]

The Russian government also approved a new Federal Space Program in October 2005, with the stated objective of retaining Russia's status as a leading space power.[102] Under the new program, Russia hopes to construct a reusable spacecraft in cooperation with several European countries, and begin planning for a manned mission to Mars. The plan also stipulates that Russia will increase its orbital group by 18 space vehicles for communications, meteorological observation, remote sensing, and research by 2008.[103] Russia also approved a budget for its 2006-2015 space programs of approximately $11-billion.[104]

In April 2005, the Japan Aerospace Exploration Agency (JAXA) unveiled its new 20-year plan. Entitled "JAXA 2025," it features manned flights to the moon by 2025 as a first step to explore the solar system and requests a budget increase to $2.1-billion from the current $1.6-billion annual budget.[105] JAXA's plan calls for scientists to develop robots and nanotechnology for surveys of the moon and to design a rocket and space vessel capable of transporting cargo and passengers, marking an important policy shift from its previous endeavors involving unmanned scientific probes.[106]

China announced its new space agenda in November 2005. Its main objectives include launching four space flights, the first of which will feature China's first spacewalk in 2007, followed by two more involving an unmanned docking maneuver, and the final a manned docking. Government approval is pending for the construction of a new carrier rocket, necessary for China National Space Agency's plans to develop a space station and lunar probe.[107] Deputy Commander in Chief of China's manned space program, Hu Shixiang, also announced the country's plans to build a space station and achieve a moon space walk within 15 years, noting that China hopes to develop the necessary technology to implement these plans by 2012. Hu stated that the program is not "the competition of the Cold War era."[108] China maintained that all countries share the right and the obligation to ensure the peaceful use of, and prevent an arms race in, outer space and continued to emphasize that its interests in space are solely scientific, economic, and "patriotic." In a White Paper released 1 September 2005, China declared outer space to be the "common wealth of mankind" and reiterated its position that effective preventative measures, including international legal instruments, are needed to prohibit the deployment of weapons in outer space and the threat or use of force against objects in outer space, ensuring it is used purely for peaceful purposes.[109]

In December 2005, Kazakhstan revealed plans to further its Space Industry Development Program for 2005-2007, including the launch of its first two satellites within the next two years. Prime Minister Danail Akhmetov also announced that Kazakhstan will take part in the development of the Russian "Clipper" spacecraft, designed to replace the Soyuz; the development of the Baiterek rocket launching complex; and is considering participation in the development of nuclear propulsion for space vehicles. In addition, Akhmetov noted that the country plans to participate in the ISS in the future.[110]

In 2005, Iran emphasized the importance of the use of space data as part of its Fourth National Development Plan for 2005-2010, coinciding with its first satellite launch on 27 October 2005 (see Civil Space Programs and Global Utilities). Iran is reportedly attaching great urgency to developing its space program because of fears that Western states will seek to impose restrictions similar to those placed on its nuclear program. Iranian space official Mohammad Reza Movaseghinia stated that Iran must "move quickly and achieve our goals in space. Otherwise, we will face political, economic and security threats."[111]

Net assessment:

Developments in 2005 indicate continued growth in bilateral and multilateral cooperation for the peaceful uses of space. Insofar as cooperation promotes transparency and confidence-building among space-faring states, these trends continued to exert a positive influence on space security throughout 2005. In addition, the adoption of new space policies by a variety of space-faring nations emphasizing commercial, communications, and research uses of space indicates the vested interest states maintain in securing outer space for peaceful purposes. Statements by Chinese and Iranian officials, however, highlight underlying international tensions in space exploration.

TREND 2.4: Growing focus within national military doctrine on the security uses of outer space

2005: India, Israel, Japan, China, and the EU placing greater emphasis on national security space applications

The number of states emphasizing the security uses of space in national policies continued to increase in 2005. In January, the Japanese government introduced a plan to deploy a new generation of spy satellites. Japan also continued talks with the US throughout 2005 on furthering missile defense cooperation.[112] The Israeli Air Force unveiled plans in June to launch additional surveillance satellites to boost intelligence capabilities and to manufacture micro-satellites that could provide information on combat zones (see Space Support for Military Operations). In addition, Yuval Steinitz, chairman of Israel's Defense and Foreign Affairs Committee, stated that defense and industry officials should consider future developments of "anti-satellite missiles" and "satellite-attacking lasers."[113] India also continued to pay greater attention to the military uses of space. The Indian Air Force urged the government to set up a Strategic Aerospace Command to purportedly facilitate the development of capabilities to degrade space weapons in preparation for "future star wars."[114] While some reports contend that the government has rejected the proposals, Indian Air Force Chief S. P. Tyagi insists that the recommendations are still under consideration, particularly in light of the Parliamentary Standing Committee's declarations that India needs the ability to counter any threat from space.[115] Media reports throughout 2005 revealed significant speculation about China's space capabilities and military-related space intentions, although Chinese officials maintain that the country's space program is solely for peaceful purposes.

The EU also showed continued focus on both regional cooperation and security in space policy initiatives in 2005 with the release of the "Report of the Panel of Experts on Space and Security." The panel of 150 EU experts concluded that "Europe must establish a new balance between civil and military uses of space" in order to effectively protect its borders in a changing security environment. It is unclear, however, whether there is political support for this recommendation.[116] The panel also recommended that the EU develop a security-related space strategy to protect civil and military satellite systems, including defensive and anti-jamming countermeasures. The report notes that since EU member states possess the industrial capacity needed to develop space systems, member states should coordinate efforts to establish a well developed space security program.[117] In addition, at the third EC Space Council Meeting in November 2005, elements of the space policy, including the GMES initiative, were confirmed as priorities.

2005: US to release new military space policy directive

The US is expected to release a new military space directive to replace the existing policy that was formulated in 1996, although the release has been delayed several times for revisions. Media reports have indicated that the new space directive would provide freer access in space for the USAF and would call for the deployment of capabilities to ensure that space systems or services cannot be used for purposes hostile to US national interests. The new policy directive is widely speculated to build on certain recommendations of the 2001 Rumsfeld Commission report that "explicit national security guidance and defense policy is needed to direct development of doctrine, concepts of operations and capabilities for space, including weapons systems that operate in space."[118] The US reiterated the importance of military uses of space-based assets, conducting its third space war games in February 2005 to test the use of space-based assets in future operations related to the war on terrorism.[119] The "Schriever III" games focused on how the US could maintain space superiority by integrating manned and unmanned space systems to assist terrestrial operations in the event of war. Officials from Canada, Australia, and the UK also participated.

Net assessment:

In 2005 there was a clear continuation of the growing focus on the security uses of space by a growing number of actors. This trend can exert both positive and negative effects on space security. On the one hand, emphasis on security benefits of the sustainable access to and use of space can have a positive effect on space security. On the other hand, space doctrines intended to serve national security objectives by developing defense and negation capabilities may eventually threaten the secure and sustainable access to and use of space. Comments on possible conflicts in space by Israeli and Indian officials, while not reflecting official state policy, are cases in point.

CHAPTER THREE

Civil Space Programs and Global Utilities

This chapter assesses trends and developments associated with civil space programs and global space-based utilities. The civil space sector comprises those organizations engaged in the exploration of space, or scientific research in or related to space, for non-commercial and non-military purposes. This sector includes, in particular, national space agencies such as the US National Aeronautics and Space Administration (NASA), the Russian Space Agency, and the European Space Agency (ESA), and their missions, including Soyuz, Apollo, MIR, the Hubble Space Telescope, and the International Space Station (ISS). Key capabilities associated with launch vehicles, developed by, or in cooperation with, civil programs, that enable actors to access space are also addressed. Finally, the sector includes international collaborations that facilitate space access for countries without launch capability, through the launch capability of other actors.

The chapter examines trends and developments in civil space for each space actor, including the number of actors with either independent access to space or access via the launch capabilities of other actors; the number, scope, and priorities of civil programs, including the number of manned and unmanned civil launches made by each actor; the funding trends of civil programs; and the degree of civil-military cooperation. It also assesses the degree and scope of international civil space collaboration, often seen as the hallmark of civil space programs.

Global utilities are space-based applications provided by civil, military, or commercial providers, which can be freely used by any actor equipped to receive the data they provide, either directly or indirectly. Some global utilities include remote sensing satellites which monitor the Earth's changing environment using various sensors, such as weather satellites; search and rescue satellites that provide emergency communications for people in distress; and some telecommunications satellites with global utility services, such as amateur radio satellites. Finally, the chapter includes satellite navigation systems that provide geographic position (latitude, longitude, altitude) and velocity information to users on the ground, at sea, or in the air, for the purpose of navigation aid. The US Global Positioning System (GPS) is the primary global utility for navigation.

This chapter examines trends and developments in global utilities of all space actors, including the number and types of such programs, their funding, and the number of users. It also assesses trends in conflict and cooperation between actors in the development and use of global utilities.

Space Security Impacts

Civil space programs can effect space security in several positive ways. First, they are one of the primary drivers behind the development of capabilities to access and use space (in particular space launch capabilities), increasing the number of actors with secure access to space. Therefore, the scope and priorities in civil space programs can affect an actor's space capabilities. Second, civil space programs, and their technological spin-offs on Earth, underscore the vast scientific, commercial, and social benefits of secure and sustainable uses of space, thereby increasing global interest in the maintenance of space security. Third, civil space programs develop and shape public interest and awareness of the peaceful uses of space.

Conversely, civil space programs can have a negative impact on space security by enabling the development of dual-use technologies for space systems negation or space-based strike weapons, and by contributing to the overcrowding of certain scarce space resources such as orbital slots and radio frequencies. Civil-military cooperation can have a mixed impact on space security by, on the one hand, helping to advance the capabilities of civil space programs to access and use space while, on the other hand, encouraging adversaries to target dual-use civil-military satellites.

Millions of individuals rely on global utilities on a daily basis for weather, navigation, communications, and search-and-rescue functions. Consequently, global utilities are important for space security because they broaden the community of actors who have an investment in space security and the peaceful uses of space. However, global utilities are also being used for dual-use functions, providing data that can support terrestrial and space military operations (see Space Support for Terrestrial Military Operations, Space Systems Negation, and Space-Based Strike Weapons).

International cooperation remains a key aspect of both civil space programs and global utilities. Such international cooperation can benefit space security by enhancing transparency regarding the nature and purpose of certain civil programs which can have military purposes. Furthermore, international cooperation in civil space programs can assist in the transfer of skills, material, and technology for the access to, and use of, space by emerging space actors. Finally, international cooperation in civil space programs can serve to highlight areas of mutual benefit in achieving space security and reinforce the practice of using space for peaceful purposes.

Key Trends

TREND 3.1: Growth in the number of actors gaining access to space

The number of actors with an independent orbital launch capability continues to grow and now includes 10 states (see Figure 3.1). This total does not include non-state actors such as Sea Launch[1] and International Launch Services (ILS)[2] – two consortia that provide commercial orbital launch services using rockets developed by state actors. Ukraine has not yet conducted an independent launch but it builds the Zenit rockets launched by Sea Launch and has therefore demonstrated an orbital launch capability.

FIGURE 3.1: Independent orbital launch capability and launch sites of states[3]

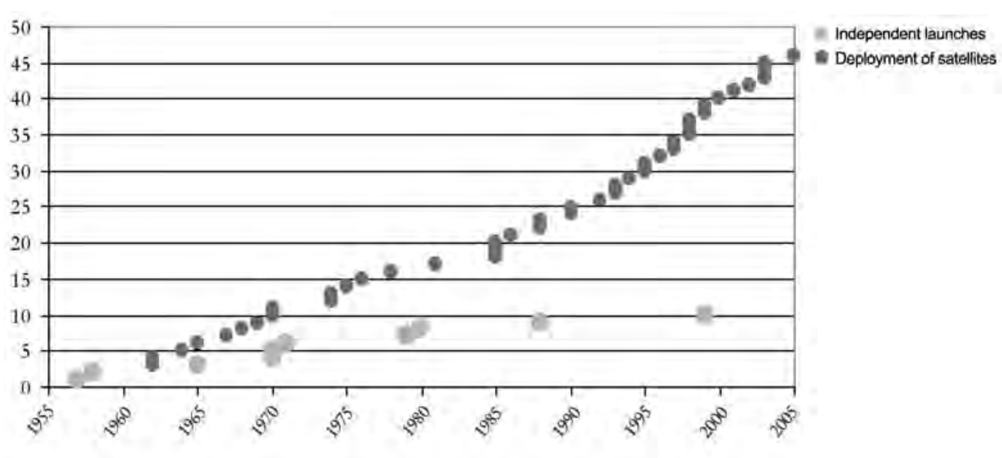
State/Actor	Year of first orbital launch
USSR/Russia	1957
USA	1958
France	1965
Japan	1970
China	1970
UK	1971
ESA[4]	1979
India	1980
Israel	1988
Ukraine[5]	1999

There are a further 18 actors that have sub-orbital capability, which is required for a rocket to enter space in its trajectory, but not achieve an orbit around the Earth. These actors are Argentina, Australia, Brazil, Canada, Germany, Iran, Iraq, Italy, Libya, North Korea, South Korea, Pakistan, South Africa, Spain, Sweden, Switzerland, Saudi Arabia, and Syria.[6] In addition, Iran and North Korea maintain long-range missile programs that could enable them to develop an orbital launch capability.

By the end of 2004, a total of 45 states had accessed space, either with their own launchers or those of other states. This number is expected to continue to grow, largely through the efforts of non-state actors such as the UK's Surrey Satellite Technology Ltd., which specializes in helping countries to develop affordable small satellites. Over the past 12 years, Surrey Satellite has assisted seven states (Algeria, Malaysia, Nigeria, Portugal, South Korea, Thailand, and Turkey) in efforts to build their first civil satellites. Four of these seven states have launched satellites in the last three years.[7]

The USSR was the first space actor to send a man into space in 1961, followed by the US in 1962. With China's first manned launch in 2003, the number of manned launcher states now stands at three. In sum, civil space programs, in collaboration with military space programs, continue to contribute to an increase in the number of space actors (see Figure 3.2). The general proliferation of space technology is also contributing to this trend.

FIGURE 3.2: Growth in the number of states accessing space[8]



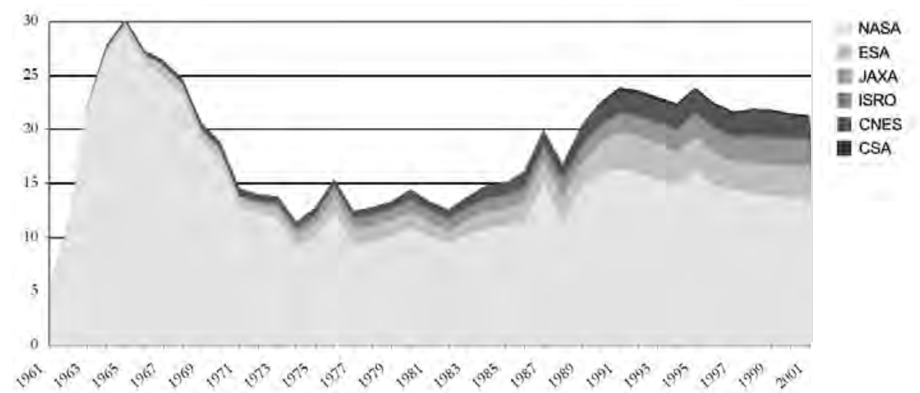
TREND 3.2: Changing priorities and funding levels within civil space programs

Civil expenditures on space continue to increase in India and China, while generally decreasing in the US, the EU, and Russia. There has been a growth of about five percent per annum in real terms in the Indian civil space program over the decade 1990-2000, a total increase of over 60 percent.[9] Due to the growth in civil program activities, in particular the manned program, the Chinese civil space budget has also grown considerably in recent years. Data on China's civil space budget is difficult to ascertain and considered by some to be underestimated.

Although it still dwarfs the civil space budgets of other actors, the NASA budget dropped 25 percent in real terms between 1992 and 2001.[10] The ESA budget dropped nine percent in the same period. This follows a long period of growth for both NASA and ESA from 1970 to 1991, in which the NASA budget grew 60 percent in real terms and the ESA budget grew 165 percent in real terms.[11]

The Russian Space Agency budget saw an even sharper decline in the 1990s, but this may not provide an entirely accurate reflection of the status of Russian civil space capabilities. For example, with a budget less than a tenth of NASA's, Russia launches more civil satellites than any other state. Russia maintains over 160 military, civil, and commercial satellites on a budget of about $400 million per year, which is less than the cost of a single launch of the US Space Shuttle.[12] The USSR/Russia was the most active civil space actor from 1970 to the early 1990s, when funding decreases led to a reduction in the number of its civil missions.

FIGURE 3.3: Annual civil space agency budgets (billion 2001 dollars)[13]



The trend in the 1990s towards miniaturization in electronics helped to reduce the size and weight of civil satellites, which can now perform the same functions as their bulkier predecessors at decreased cost. One of the first satellites to implement this technology was the US Clementine lunar mission in 1994. Thus, despite decreasing funding levels, the number of US missions has held relatively constant as this new technology enabled "smaller, faster, cheaper" space missions.

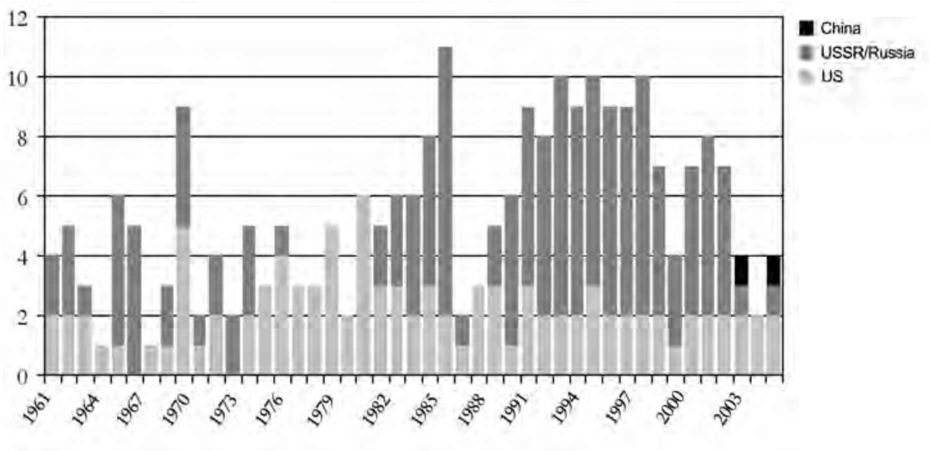
Micro-satellites are now increasingly used for civil missions, including, for example, the multinational Disaster Monitoring Constellation and France's joint military-civil Myriade series of micro-satellites.[14] These developments have enabled European actors, China, and Japan to expand their civil programs to the point where they now together equal the US or Russia's civil efforts. Further, microsatellite technologies and civil-commercial partnerships have allowed an increasing number of states, such as Nigeria, Thailand, and Algeria, to afford satellites for nascent civil programs.

Human spaceflight

On 12 April 1961, Yuri Gagarin became the first human to travel into space on board a Soviet Vostok 1 spacecraft. Human spaceflight was dominated in the early years by the USSR, which succeeded in fielding the first woman in space, the first human spacewalk, the first multiple-person space flights, and the longest duration space flight. Following the Vostok series rockets, the Soyuz became the workhorse of the Soviet and then Russian manned spaceflight program, and has since carried about 100 missions with a capacity of three humans on each flight.

The first US human mission was completed on 5 May 1961 with the sub-orbital flight of the Mercury capsule launched on an Atlas-Mercury rocket. This was followed by the Gemini flight series and then the Apollo flight series, which ultimately took humans to the Moon. The US went on to develop the Skylab manned space laboratories in 1973, and the USSR developed the MIR space station, which operated from 1986 to 2001. The US initiated the Space Shuttle in the 1970s, capable of launching up to seven people to Low Earth Orbit (LEO). The Shuttle was first launched in 1981, has completed about 100 launches, and is currently the only human spaceflight capability for the US. In 2004, the US announced a new NASA plan that includes returning humans to the Moon by 2020 and a human mission to Mars thereafter.[15]

FIGURE 3.4: Number of manned launches[16]



China began developing the Shenzhou human spaceflight system in the late 1990s and completed a successful manned mission in 2003, becoming the third state to develop an independent human spaceflight capability.[17] In 2004 it launched an ambitious plan to develop a manned space station in Earth orbit within 15 years.[18] The 2003 Space Shuttle Columbia disaster, and the subsequent grounding of US Space Shuttle missions, reduced the total annual number of US manned missions. Russia is the only actor performing regular manned missions, with its Soyuz spacecraft providing the only lifeline to the International Space Station (see Figure 3.5).

Space agencies

Different states and regions have varying types of civil space institution. The US maintains two main civil agencies – NASA and the National Oceanic and Atmospheric Administration (NOAA). While much work is fielded out to major contractors such as the Boeing Company and the Lockheed-Martin Corporation, mission design, integration, launch, and operations are undertaken by the space agencies themselves. During the Cold War, Soviet civil space efforts were largely decentralized and led by "design bureaus" –large state-owned companies headed by top scientists. Russian launch capabilities were developed by Strategic Rocket Forces, and cosmonaut training was managed by the Russian Air Force. Formal coordination of efforts came through the Ministry for General Machine Building.[19]

A Russian space agency (Rossyskoe Kosmicheskoe Agenstvo) was established in 1992, and has since been reshaped into the Russian Aviation and Space Agency (Rosaviakosmos). While this new agency has more centralized powers than previous organizations, most work is still completed by design bureaus, now integrated into "Science and Production Associations" (NPOs) such as NPO Energia, NPO Energomash, and NPO Lavochkin. This continued decentralization of civil activities makes it difficult to obtain accurate comprehensive budget figures for Russian civil space programs.[20] It is known that, in 2002, the Russian government contributed about $265-million to the Russian Aviation and Space Agency.[21]

In 1961, France established its national space agency, the Centre National d'Études Spatiales (CNES), which remains the largest of the EU national agencies. Italy established a national space agency in 1989, followed by Germany in 1990. The European Space Research Organisation and the European Launch Development Organisation, both formed in 1962, were merged into ESA in 1975. Most ESA funding is provided by a small group of states with active national space programs. For example, between 1991 and 2000, Germany and France regularly provided between 40 and 50 percent of the ESA budget.[22]

In China, civil space activities began to grow when they were allocated to the China Great Wall Industry Corporation in 1986. The China Aerospace Corporation was established in 1993, followed by the development of the Chinese National Space Administration (CNSA). The CNSA remains the central civilian space agency in China, and reports through the Commission of Science Technology and Industry for National Defense to the State Council. Budget figures for China's civil space program are not public and unofficial estimates range from $175-million to $1.5-billion per year.[23]

In Japan, civil space was initially coordinated by the National Space Activities Council formed in 1960. The Institute of Space and Aeronautical Science of the University of Tokyo, the National Aerospace Laboratory, and, most importantly, the National Space Development Agency undertook most of the work over the years. These efforts were merged into the Japanese Aerospace Exploration Agency (JAXA) in 2003.[24] India's civil space agency, the Indian Space Research Organisation, was founded in 1969. Israel's space agency was formed in 1982, Canada's in 1989, and the Brazilian Agência Espacial Brasileira was formed in 1994.

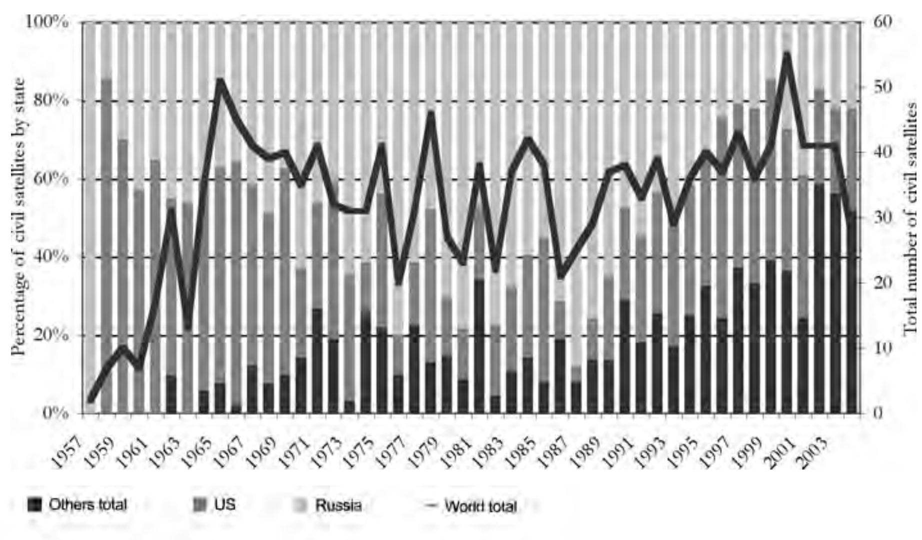
New directions for civil programs

Civil space programs are increasingly being used for national security missions, particularly in the field of meteorology and Earth observation science. For example, the objective of the European Union (EU)/ESA Global Monitoring for Environment and Security (GMES) program is to "support Europe's goals regarding sustainable development and global governance, in support of environmental and security policies, by facilitating and fostering the timely provision of quality data, information, and knowledge."[25]

A growing number of civil space projects are now also explicitly focused on social and economic development objectives. The Indian Space Research Organization has developed 10 communications satellites that provide tele-education and telehealth applications, and nine remote sensing satellites for enhancing agriculture, land, and water resource management, and disaster monitoring.[26] In 2000, Malaysia launched Tiungsat 1, a micro-satellite that included several remote sensing instruments for environmental monitoring. In 1998, Thailand and Chile together launched TMSat, the world's first 50-kilogram micro-satellite to produce high-resolution, full color, multi-spectral images for monitoring the Earth, and FASat-Bravo, a micro-satellite to study depletion of the ozone layer.[27] African states such as Algeria, Egypt, Nigeria, and South Africa have built, or are in the process of building, satellites to support development.

Civil programs also continue to generate significant economic and technological spin-offs. It is estimated that for every dollar the US spends on research and development in its civil space program, it receives seven back in the form of corporate and personal income taxes from more jobs and economic growth.[28] Recent examples of these spin-offs from NASA's programs include scratch resistant lenses, virtual reality equipment, more efficient solar cells, micro-lasers, advanced lubricants, and programmable pacemakers.[29]

FIGURE 3.5: World civil satellites including manned space missions[30]



TREND 3.3: Steady growth in international cooperation in civil space programs

Because of the great costs and technical challenges associated with access to, and use of, space, international cooperation has been a defining feature of civil space programs throughout the space age. One of the first scientific satellites, Ariel-1 launched in 1962, was the world's first international satellite, built by NASA to carry UK experiments. The earliest large international cooperation program was the Apollo-Soyuz Test Project which saw two Cold War rivals working collaboratively on programs that culminated in a joint docking in space of US/USSR manned modules in July 1975.

The 1980s saw a myriad of international collaborative projects involving the USSR and other countries, including the US, Afghanistan, Austria, Bulgaria, Canada, France, Germany, Japan, Slovenia, Syria, and the UK, to enable those states to send astronauts to conduct experiments on board the MIR space station.[31] From 1995 to 1998, there were nine dockings of the US Space Shuttle to the MIR space station, with various crew exchanges.[32] ESA and NASA have collaborated on many scientific missions, including the Hubble Space Telescope, the Galileo Jupiter probe, and the Cassini-Huygens Saturn probe.

The most prominent example of international civil space cooperation is the ISS, the largest international engineering project ever undertaken. The project partners are NASA, the Russian Space Agency, ESA, JAXA, the Canadian Space Agency (CSA), and Agência Espacial Brasileira. The ISS's first module was launched in 1998, and the station is presently still under construction. By the end of 2004, 44 launches had carried components, equipment, and astronauts to the station. The ISS is projected to cost a total of $129-billion.[33] Space-based global utilities, discussed in more detail in Trend 3.4, represent another area of international cooperation. The EU Galileo satellite navigation system currently involves 15 EU states and two non-EU states, while negotiations are ongoing with several other potential partners. Algeria, China, Nigeria, Vietnam, Thailand, Turkey, and the UK are collaborating on the Disaster Monitoring Constellation. The project, initiated by China, foresees the deployment of 10 dedicated micro-satellites, four of which have been deployed to date.

Another recent international civil space initiative is the Global Earth Observation System of Systems, which has the goal of "establishing an international, comprehensive, coordinated and sustained Earth Observation System."[34] The System was initiated in July 2003 at the Earth Observation Summit, which brought together 33 states plus the European Commission and many international organizations. Participants declared their commitment to coordinate data collection and dissemination, and in 2004 agreed on a 10-year implementation framework. This approach will have potential benefits in disaster reduction, resource monitoring and management, sustainable land use and management, better development of energy resources, and adaptation to climate variability and change.[35]

The nature of international space cooperation has changed since the end of the Cold War, as barriers to partnership have been overcome. Examples include the EU-Russia collaboration on launcher development and uses, and EU-China cooperation on Galileo. There are also increasing levels of cooperation among developed and developing countries, and new and unprecedented partnerships such as the Sino-Brazilian Earth observation satellite effort.[36] That being said, increased cooperation with the US has been hindered by export control issues (see Commercial Space).

TREND 3.4: Dramatic growth in global utilities as states acknowledge strategic importance of satellite-based navigation systems

The use of space-based global utilities, including navigation, weather, and search-and-rescue systems, has grown dramatically over the last decade. For example, GPS unit consumption grew by approximately 25 percent per year between 1996 and 1999, generating sales revenue of $6.2-billion in 1999.[37] Key global utilities such as GPS and weather satellites were initially developed by military actors. Today, these systems have grown into space applications that are almost indispensable to the civil, commercial, and military sectors, as well as most modern economies.

Satellite navigation systems

There are currently two large-scale operational satellite navigation systems maintained by states: the US GPS and the Russian GLONASS system. Work on GPS began in 1978, and it was declared operational in 1993, with a minimum of 24 satellites that orbit in six different planes at an altitude of approximately 20,000 kilometers in Medium Earth Orbit (MEO). A GPS receiver must receive signals from four satellites to fix its location, accurate within 20 meters. GPS operates a Standard Positioning Service for civilian use and a Precise Positioning Service that is intended for use by the US Department of Defense and US allies.

Beginning as a military system, GPS diversified and grew to the point that, in 2001, military uses of the GPS accounted for only about two percent of the total market. In 1999 the GPS industry employed 30,000 people. The commercial airplane transportation industry, which carried about 1.6-billion passengers in 2000, relies heavily on the GPS.[38] US companies receive about half of GPS product revenues, but US customers account for only about one-third of the revenue base. The growth rate of GPS units in use continues to increase, particularly outside the US.[39]

The Russian GLONASS system uses similar principles to the GPS. It is designed to be composed of a minimum of 24 satellites in three orbital planes, with eight satellites equally spaced in each plane, in a circular orbit with an altitude of 19,100 kilometers.[40] The first GLONASS satellite was orbited in 1982, and the system became fully operational in 1996, with similar accuracy to that provided by the GPS. While the number of operational GLONASS satellites has fallen below complete operational levels in recent years, it retains some capability and Russia has undertaken to launch replacement satellites to make the system fully operational again.[41] GLONASS operates a High Precision service available exclusively to the military and a Standard Precision service available to all civilian users on a continuous, worldwide basis.[42]

China, Japan, and the EU are all engaged in the research and development of additional satellite navigation systems.[43] The Chinese Beidou system has been under development since the late 1990s and currently has two satellites. It uses a different principle than that of the GPS or GLONASS, and when fully operational, will have two geostationary satellites, one backup satellite, and additional ground stations for operation. Beidou has the capacity to serve some 200,000 users, but can only be used in and around China.[44] Beidou-2, the second generation Chinese satellite navigation system, is scheduled to be operational by 2010. It will be interoperable with Beidou-1 and will consist of four satellites in geosynchronous orbit, 12 inclined geosynchronous-orbit spacecraft and nine satellites in MEO.[45]

Japan began developing the Quazi-Zenith Satellite System (QZSS), to consist of a few satellites interoperable with GPS in Highly Elliptical Orbit, to enhance regional navigation over Japan.[46] In 2004, an internal programmatic dispute continued to deadlock development.[47]

Perhaps most significantly, the EU and ESA are jointly developing the Galileo navigation system, which will consist of 30 satellites in a constellation similar to the GPS. Significant effort on Galileo began in 2002, with the allocation of $577-million in development funds by the European Council of Transport Ministers.[48] In July 2003, ESA announced contracts for two technology demonstration satellites, one with the UK's Surrey Satellite Technology Ltd. and one with Galileo Industries, a multinational consortium.[49] The Galileo project has been opened to international partners. Russia has agreed to launch Galileo satellites, and partnership negotiations have begun with a number of other countries, including Australia, Brazil, India, Mexico, and South Korea, to support the development of the system.[50] China's partnership was clarified in 2004, when it was announced that China would not be granted access to the secure Public Regulated Service government channel.[51]

The EU intention to use a transmission frequency of 1559 and 1591 megahertz for its Galileo navigation signals, similar to one of the GPS military frequencies, was a source of conflict between the EU and the US. However, in February 2004, the US and the EU negotiated an end to the two-year dispute with an agreement ensuring interoperability of the two systems and reserving certain portions of the spectrum for secure military use by the GPS to avoid signal interference.[52] Galileo will offer Open Service, commercial service, safety of life service, search and rescue service, and an encrypted, jam-resistant, public regulated service reserved for public authorities that are responsible for civil protection, national security, and law enforcement.[53]

Earth Observation

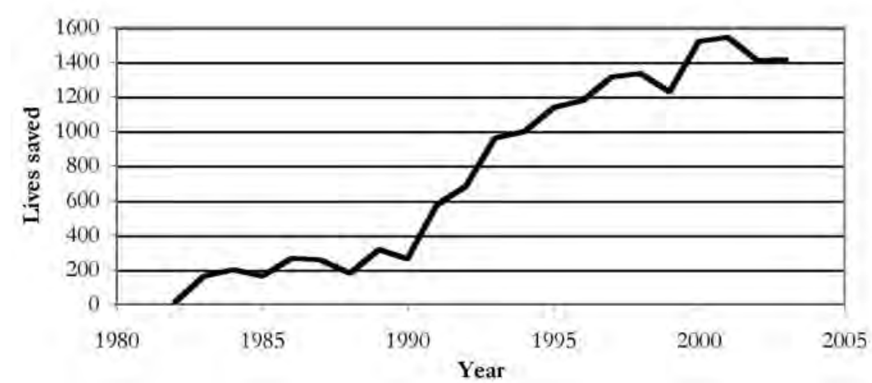
Earth observation satellites are used extensively for a variety of functions, from weather forecasting to disaster warning and emergency response. The European Organization for the Exploitation of Meteorological Satellites has launched eight satellites into GEO since 1972 to provide meteorological data for Europeans. Similarly, the US NOAA, founded in 1970, has launched 34 satellites to provide US meteorological services.[54] Satellite operators from China, Europe, India, Japan, Russia, and the US, together with the World Meteorological Organization, make up the Co-ordination Group for Meteorological Satellites.[55]

Earth observation satellites serve a number of other functions, including surveillance of borders and coastal waters; monitoring crops, fisheries, and forests; as well as monitoring natural disasters such as hurricanes, droughts, floods, volcanic eruptions, earthquakes, tsunamis, and avalanches. Space has become critical for measuring climate change. Several countries, including Algeria, China, Nigeria, Vietnam, Thailand, Turkey, and the UK, are collaborating on the Disaster Monitoring Constellation to deploy 10 micro-satellites dedicated to this use.[56]

Search and rescue

In 1979 COSPAR-SARSAT, the International Satellite System for Search and Rescue Satellites, was founded by Canada, France, the USSR, and the US to coordinate the satellite-based search-and-rescue (SAR) system. Since 2001, SAR has provided emergency communications for people in distress and has been credited with saving the lives of approximately 1,500 people per year (see Figure 3.6).[57] This figure is double that of 1996. Currently COSPAR-SARSAT operates seven satellites.

FIGURE 3.6: Lives saved annually by COSPAR-SARSAT[58]



TREND 3.1: Growth in the number of actors gaining access to space

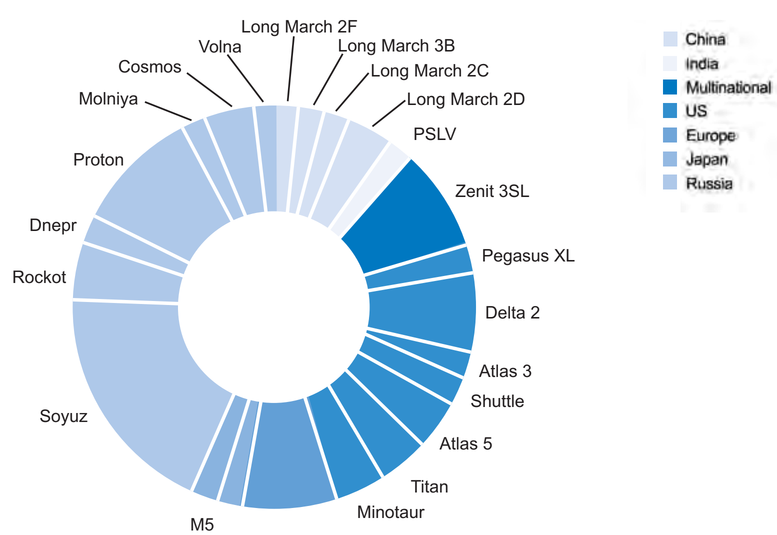
2005: Global progress in space access, launch, and propulsion technologies

The year 2005 saw the launch of 24 civil spacecraft and continued growth in space access. Of these 24 civil spacecraft, nine were human spaceflight missions, nine were science or technology missions, six were communications or navigation missions, five were meteorological or imaging missions, and three were planetary missions (see Figure 3.10). With the Russian launch of Sinah-1[59] on 27 October 2005, Iran became the 45th state to own a satellite. The satellite's telecommunications system and cameras are designed to take pictures of Iran's agriculture and natural resources, and monitor for natural disasters.[60] Other Iranian space plans include launching a second Mesbah reconnaissance and communication satellite,[61] contributing to the development of a small research satellite, building a Zoreh geostationary communications satellite with Russia, and developing indigenous space launch capability using the Shahab-4 missile.[62]

Europe and Japan successfully fielded new launch vehicles in 2005. On 12 February, ESA's heavy-lift Ariane-5 ECA completed its first successful launch.[63] The Ariane-5 ECA is considered crucial to Europe's independent access to higher orbits for Earth observation, meteorology, telecommunications, and navigation.[64] On 26 February, Japan launched the first H-2A rocket since the destruction of an earlier rocket carrying two reconnaissance satellites in November 2003. While the H-2A is costly and has not yet carried a commercial payload, it remains JAXA's primary launcher.[65]

There were also a number of qualitative improvements in space propulsion in 2005. ESA tested a "double layer thruster"; the plasma drive engine will operate longer than a chemical engine, making it more suitable for deep space missions.[66] NASA continued to develop nuclear electric power and propulsion technologies in 2005.[67] Under Project Prometheus, NASA is seeking to reduce interplanetary trip times and increase power available to spacecrafts by employing nuclear propulsion.[68] In Europe, the first spacecraft designed to be propelled by energy captured from sunlight was lost on 21 June 2005 when its Volna launcher failed.[69] The Cosmos-1 project intended to demonstrate the potential of the solar sail as a means for interstellar flight; it would have a great advantage over traditional chemical rockets since no fuel is required and the craft accelerates continuously.[70]

FIGURE 3.7: Space launches in 2005 by state and vehicle[71]



Net assessment:

The widening and deepening of space access capabilities should have a largely positive impact on space security. The development of new space propulsion technology will improve the diversity and efficiency of space access capabilities. The return to flight of civil space launch vehicles and the development of new space propulsion technologies ensure greater access to space and an eventual reduction in space access costs. However, there are concerns that the development of nuclear propulsion in space could serve military applications and potentially generate radioactive debris.[72]

TREND 3.2: Changing priorities and funding levels within civil space programs

2005: Civil space agencies announce new programs, with greater focus on manned space exploration programs

In 2005, NASA successfully completed its first manned mission in two years and further developed manned missions first announced in 2004. The launch of its space shuttle Discovery, the first shuttle flight since the Columbia disaster of February 2003, took place on 26 July 2005. Despite a fuel sensor malfunction that delayed the launch for nearly two weeks, and the loss of at least four pieces of insulating foam from the external fuel tank during liftoff, the mission delivered supplies and carried out maintenance services on the ISS.[73] Despite this successful mission, NASA officials decided to retire the current space shuttle fleet in 2010 and committed to introduce the replacement Crew Exploration Vehicles (CEV) between 2012 and 2014, in accordance with President Bush's January 2004 *Vision for Space Exploration*. Between 2010 and 2012 or 2014, the US expects to have no ability to put humans into space and will rely on Russian Soyuz spacecraft for flights to the ISS.[74] Between 2018 and 2020, NASA intends to launch a manned mission to the Moon and hopes to eventually use the Moon as a staging point for a manned mission to Mars.[75] The CEV and its rocket technology differ from the current reusable shuttles that fly back to Earth and land at an airport; while the CEV itself can be reused up to ten times, most of its launching apparatus will either be abandoned in space, where it could contribute to the space debris problem, or burn up in Earth's atmosphere.[76] In November 2005, NASA released its "architecture" to implement the President's *Vision for Space Exploration*.[77]

China successfully launched its second manned space mission on 12 October 2005 when Shenzhou VI, carrying two astronauts, orbited the Earth for five days.[78] Looking to the future, China announced plans to send the first Chinese woman into space in five or six years, aboard Shenzhou IX.[79] Shenzhou VII, scheduled for 2007, is planned to feature China's first spacewalk; Shenzhou VIII and IX will perform an unmanned docking; and Shenzhou X will feature a manned docking.[80] China also reiterated its intention to build its own space station and put a man on the Moon by 2020.[81] There is some debate about whether the 2005 mission had a military component because publicly available information on the activities of Chinese astronauts is limited. China, however, denies any military purpose.[82]

In July 2005, the Russian Government approved the Russian Space Agency's nine-year 2006-2015 Federal Space Program (see Space Security Laws, Policies, and Doctrines).[83] The Program features the ongoing development of a Clipper spacecraft and completion of the Russian segment of the ISS, as well as a new project designed to collect soil samples from Phobos, a Martian moon.[84] The new reusable, manned Clipper spacecraft is intended to replace Russia's Soyuz vehicle, which is capable of carrying a crew of six. It is expected to be used for both flights to the ISS and the Moon, and for Mars exploration programs.[85] During its December 2005 ministerial meeting, ESA decided against cooperating with Russia on the Clipper.[86]

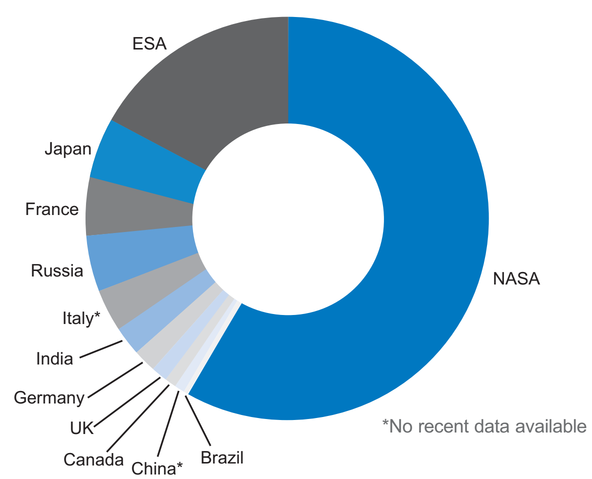
In March 2005, JAXA released its 20-year vision statement, which covers three main areas: manned space flight, solar system and planetary exploration, and aeronautics. JAXA intends to expand its knowledge of manned space activities aboard the ISS as well as develop a manned space shuttle by 2025. The agency also aims to orbit telescopes around the Moon, Venus, and Mercury by 2015. Following the successful launch of the domestically built H2-A rocket on 26 February 2005, JAXA intends to improve the rocket in order to market it commercially and to develop an H2-A Transfer Vehicle to supply the ISS.[87]

In December 2005, ESA members met in Berlin to discuss future European space policy.[88] Key priorities included developing the GMES satellite system, launching a series of Cryosat 2 satellites to monitor the Earth's ice, and starting work to land the ExoMars robotic probe on Mars in 2011 as part of the Aurora program.[89] A "buy European" agreement was also reached, stipulating that ESA nations employ only European launchers for space missions.[90] With human missions to the Moon and Mars on the long-term horizon for NASA and ESA, an October 2005 report by the Royal Astronomical Society recommended that the UK reconsider its reluctance to conduct human space exploration.[91] The Society emphasized that the UK would benefit from participating in such global scientific and technological endeavors.[92]

2005: Modest increases in international civil space budgets

In 2005 there were modest increases in the civil space budgets of most states, except in Japan, where the annual budget has steadily declined from $1.9-billion in 1999 to $1.5-billion in 2005.[93] NASA continues to hold a dominant share of the world's civil space budgets (see Figure 3.9), with $16.5-billion budgeted for FY2006, an increase of $260-million over FY2005. Reversing a steady decline in its civil space budget, Russia approved a 10-year 2006-2015 program with a budget of approximately $11-billion.[94] This budget increase should bring Russian civil space spending closer in line with that of the US as a percentage of GDP. On 6 December 2005, ESA approved a $9.6-billion budget for 2006-2008, $3-million less than the initial request, but more than the 2005 budget.[95] It is predicted that the Indian Space Research Organization will be allocated $697-million for 2005-2006, an increase from the $562.9-million of the previous year.[96] The CSA will receive $292.9-million in 2005-2006, up from $276.8-million in 2004-2005.[97] Lastly, in 2004-2005, the British National Space Centre received $339-million, an increase from its $327.7-million 2003-2004 budget. There is little information on the status of the Chinese civil space budget.[98] Of course, budget figures alone are not adequate measures of a state's civil space efforts. Factors such as existing infrastructure, expertise, and purchasing power can have a dramatic effect on how much a state can achieve within a given budget.

FIGURE 3.9: Civil space budgets in 2005



2005: Civil space agencies develop asteroid interception missions

Consistent with the growing concern of Near Earth Objects (NEOs), a number of asteroid missions were conducted in 2005 by civil space agencies. On 4 July 2005, NASA's Deep Impact spacecraft launched a projectile into the Tempel 1 comet using special autonomous navigation targeting software. This mission, the first to probe the subsurface structure and composition of a comet, could contribute to the preparation of a better response in the event of a NEO collision with the Earth or other objects in orbit, such as satellites.[99] On 26 November, Hayabusa, a space probe launched by JAXA, touched down on the Itokawa asteroid to collect samples from its surface.[100] JAXA is seeking to collect information about the structure of asteroids, which could be useful in averting an asteroid collision with the Earth.[101] Finally, ESA continued work on its Don Quixote mission, which aims to deflect an asteroid-like NEO through impact with a spacecraft.[102]

Net assessment:

The adoption of ambitious space programs should have a positive impact on space security by expanding capabilities for space access. Valid concerns remain, however, as to whether such ambitious goals are achievable within modest budget increases. While representing significant scientific and engineering achievements, recent asteroid interception missions may also be cause for concern for space security by demonstrating the ability to eventually target and strike a satellite or spacecraft.

TREND 3.3: Steady growth in international cooperation in civil space programs

2005: Continuing international civil space cooperation

Fourteen significant bilateral space agreements in 2005 continued the trend of international civil space cooperation. Russia entered into agreements with Brazil, Canada, China, Egypt, ESA, India, Indonesia, Iran, Kazakhstan, and South Korea. Notably, 29 new cooperative projects were agreed to between Russia and China for 2004-2006, as well as cooperation on nuclear space technology.[103] In addition, ESA and the Russian Space Agency signed an accord giving Russia special status in ESA and allowing Soyuz rockets to be launched from the ESA spaceport in French Guyana.

Despite its relatively strict export control laws, the US established agreements with India, Japan, Russia, and Sweden in 2005.[104] In June, India and the US established a Joint Working Group on Civil Space Cooperation and at the Working Group's first meeting plans were established to cooperate on satellite activities, launches, and space exploration with India's Chandrayaan-1 lunar mission, among others.[105] Also in June, the US and Russia discussed the possibility of developing new rocket engines to enable spaceships to fly to the Moon and Mars.[106]

ESA, a regional space agency that embodies the benefits of international cooperation, signed agreements with China, India, Morocco, Russia, and Ukraine in 2005. The agreement with India will allow ESA to place three scientific payloads on the Indian Chandrayaan-1 mission.[107] France and Israel agreed to develop a small hyper-spectral imaging satellite scheduled for launch in 2008.[108] On 28 October, eight space-faring nations – Bangladesh, China, Indonesia, Iran, Mongolia, Pakistan, Peru, and Thailand – signed an agreement to form the Asia Pacific Space Cooperation Organization, with headquarters in Beijing. The countries agreed to promote multilateral cooperation in space science and technology and its application in promoting economic and social development in the Asia-Pacific region.[109] In November, China and ESA signed an agreement on space cooperation for peaceful purposes.[110]

International civil space cooperation through the ISS also continued apace in 2005. During a 26 January 2005 meeting, space agency heads from the US, Russia, Japan, Europe, and Canada pledged to complete the ISS by 2010.[111] To ensure continued US access to the ISS until the completion of its CEV in 2012-2014, the US Congress also amended the *2000 Iran Nonproliferation Act*, which had prohibited "US purchase of Russian human spaceflight hardware as long as Russia continues to help Iran in its pursuit of nuclear know-how and advanced weapons technology."[112]

Net assessment:

Increased space cooperation within Europe and among major space powers, as well as with emerging space actors, should have a positive impact on space security by aiding the diffusion of capabilities to access and use space. This trend can also help to establish a certain degree of transparency and confidence between space-faring nations. However, it should also be noted that international cooperation could facilitate the proliferation of dual-use space technologies such as micro-satellites and nuclear power sources, required for space systems negation and space-based strike weapons.

TREND 3.4: Dramatic growth in global utilities as states acknowledge strategic importance of satellite-based navigation systems

2005: Successful launch of first Galileo satellite despite funding concerns

The European Galileo satellite navigation system saw significant development in 2005. On 1 March, the Galileo Joint Undertaking, which manages operator selection, accepted a joint bid by the iNavsat and Eurely consortia representing companies from five different European countries.[113] Later in March, China announced that China Galileo Industries would develop Galileo's satellite and remote sensing technologies as well as its application systems.[114] India, Israel, Morocco, Saudi Arabia, and Ukraine announced their participation in the Galileo project,[115] while negotiations continued with Argentina, Australia, Brazil, Canada, Chile, Malaysia, Mexico, Norway, and South Korea.[116] The civilian-controlled Galileo satellite navigation system is set to be operational by 2010, with a constellation of 30 satellites.[117] In December, EU members agreed to establish Galileo's administrative headquarters in Toulouse, France, operational headquarters in London, UK, and additional centers in Germany, Italy, and Spain.[118] On 28 December, the first satellite of Galileo's testing phase was launched aboard a Russian Soyuz rocket.[119] Despite these developments, funding for Galileo's In-Orbit Validation phase was blocked due to disputes over the division of responsibilities for the project, particularly for the control center and headquarters.[120]

2005: China and India access Russian GLONASS satellite navigation system

The proliferation of satellite navigation systems continued in 2005. In June, Russia called for GLONASS satellite navigation systems to be fitted on its spacecraft, aircraft, ships, motor vehicles, trains, and equipment employed for land surveys.[121] This represents a reversal of previous restrictions on the use of private satellite navigation devices. Russia also made plans to cooperate with China and India on GLONASS: in November, China began to equip military and civil spacecraft with GLONASS devices, and the Indian Defence Minister announced plans to cooperate with Russia in the field of satellite navigation.[122] In addition, successful bilateral negotiations will bring about the launch of GLONASS satellites on non-Russian boosters from India's near-equatorial launch site.[123]

While India will cooperate with Russia on GLONASS, it is also developing a separate civilian satellite navigation system called GAGAN (GPS and GEO Augmented Navigation) or SBAS (Space-Based Augmentation System).[124] GAGAN will be a low-cost satellite navigation system employing seven geostationary satellites and ground-based systems to provide greater coverage of the Indian sub-continent.[125] The first navigation payload for GAGAN is scheduled for launch in 2006-2007.[126] At the Automation School of Northwestern Polytechnical University, China continues research on how to optimize Beidou's satellite constellation orbital positioning.[127] Chinese researchers are also exploring ways to resolve the regional positioning system's current inability to produce real-time three-dimensional passive positioning.[128]

2005: US Global Positioning System modernization program underway

The first in a series of eight modernized GPS IIR-M satellites was delivered by Lockheed Martin on 8 February 2005 to the US Air Force.[129] The satellite launch, initially scheduled for May, took place on 26 September.[130] The second GPS IIR-M satellite was delivered on 8 November, scheduled for launch in January 2006. The modernized satellites will provide GPS users with increased signal power, two new military signals for improved accuracy, enhanced encryption and anti-jamming capabilities, and a second civilian signal.[131]

2005: Earth observation satellites playing growing role in environmental monitoring and disaster relief

Satellites played a critical role in the relief and reconstruction efforts following the Southeast Asian tsunami of 26 December 2004 by providing up-to-date imagery of affected areas. Unclassified commercial imagery collected from Space Imaging, DigitalGlobe, Orbimage, and Spot Image and imagery from American, Canadian, European, and Indian civil satellites were provided to aid workers, militaries, and non-governmental organizations during the recovery.[132] Satellites are becoming an integral part of many new tsunami early warning systems, to relay information from sensors on the ocean floor to coastal observation stations.[133]

Satellites are also increasingly important for environmental monitoring. The 2005 Earth Observation Summit in Brussels saw agreement by representatives of 61 states, supported by 40 international organizations, on a 10-year implementation plan for the Global Earth Observation System of Systems.[134] The initiative to network Earth observation capabilities is described by the US Environmental Protection Agency as "a large national and international cooperative effort to bring together existing and new hardware and software, making it all compatible in order to supply data and information at no cost."[135] At the same summit, the EU announced a plan to fund a monitoring system to detect fire and water shortages, track refugees, and estimate crop yields in Africa.[136] The year 2005 also saw the closure of the Kyoto Inventory project, which was designed by ESA to assist governments' reporting requirements under the Kyoto Protocol by providing satellite data on forested areas.[137]

Net assessment:

The expansion of multilateral global utilities such as Galileo and GLONASS and the development of new satellite navigation systems such as GAGAN will provide diversity and system redundancy in satellite navigation systems. This in turn should help to ensure uninterrupted access to this global utility. The increasing use of global utilities for disaster relief and environmental monitoring will continue to have a positive effect on space security, by expanding the community of stakeholders who depend on the secure and sustainable use of space. Satellite navigation systems, however, can serve dual-use functions for space systems negation and space-based strike weapons, and for improving the accuracy of missiles and other munitions, all of which may generate distrust among space powers.[138]

FIGURE 3.10: Civil space missions in 2005[139]

State	Mission	Launch Vehicle	Primary Function	Orbit
China	Shenzhou 6	Chang Zheng 2F	Science	LEO
China	Beijing-1	Kosmos 11K65M	Imaging	LEO
ESA	Sloshsat-FLEVO	Ariane 5ECA	Technology	MEO
ESA	Maqsat-B2	Ariane 5ECA	Technology	MEO
ESA	SSETI Express	Kosmos 11K65M	Technology	LEO
	XO-53			
ESA	Venus Express	Soyuz-FG	Planetary	Planetary
ESA	Giove A	Soyuz-FG	Navigation	MEO
EUMETSAT	MSG 2	Ariane 5GS	Meteorological	GEO
India	Cartosat-1	PSLV	Imaging	LEO
India	VO-52 HAMSAT	PSLV	Communications	LEO
India	Insat 4A	Ariane 5GS	Communications	GEO
Iran	Sinah-1	Kosmos 11K65M	Imaging	LEO
Japan	Suzaku	M-V	Science	LEO
Japan	Kirari	Dnepr	Communications	LEO
Japan	Reimei	Dnepr	Technology	LEO
Japan	Cubesat XI-V	Kosmos 11K65M	Communications	LEO
Russia	Universitetskiy	Kosmos 11K65M	Science	LEO
Russia	Progress M-52	Soyuz-U	Space Station	LEO
Russia	TNS-0 Nanosputnik	Soyuz-U	Space Station	LEO
Russia	Soyuz TMA-6	Soyuz-FG	Space Station	LEO
Russia	Foton-M No. 2	Soyuz-U	Science	LEO
Russia	Progress M-53	Soyuz-U	Space Station	LEO
Russia	Progress M-54	Soyuz-U	Space Station	LEO
Russia	Soyuz TMA-7	Soyuz-FG	Space Station	LEO
Russia	Progress M-55	Soyuz-U	Space Station	LEO
Russia	Gonets-D1	Kosmos-11K65M	Communications	LEO
US	Deep Impact	Delta 7925-9.5	Planetary	Planetary
US	DART	Pegasus XL/HAPS	Technology	LEO
US	NOAA 18	Delta 7320-10C	Meteorological	LEO
US	Raffaello	Space Shuttle	Science	LEO
US	Discovery (STS-114)	Space Shuttle	Space Station	LEO
US	Mars Reconnaissance Orbiter	Atlas V 401	Planetary	Planetary

CHAPTER FOUR

Commercial Space

This chapter assesses trends and developments in the commercial space sector, including the builders and users of space hardware such as rockets and satellite components, and space information technologies such as telecommunications, data relay, remote sensing, and imaging. It also examines the space insurance sector, which underwrites the space industry for the inherent risks and liabilities associated with space system operations.

The commercial space sector has experienced dramatic growth over the past decade, largely related to rapidly increasing revenues associated with satellite services. These services are provided by organizations which operate satellites, as well as the ground support centers that control them, process their data, and sell that data to others. The bulk of the revenue in the satellite services sector is generated in the telecommunications sector.[1]

The second largest contribution to the growth of the commercial space sector has been made by satellite and ground equipment manufacturing. This includes both direct contractors which design and build large systems and vehicles, smaller subcontractors responsible for system components, and software providers.

This chapter also assesses trends and developments associated with launch vehicles and launch services developed by commercial sector programs. The companies that operate launch facilities, design and manufacture vehicles intended to place payloads in space, and manufacture launch components and subsystems are examined. Generally, the cost of commercial space launch has decreased, primarily because of overcapacity. More market competition and technological innovations, such as the development of so-called piggyback launches of micro-satellites, also continue to exert a downward pressure on prices and create a corresponding increase in the number of commercial actors accessing space.

Governments play a central role in commercial space activities as users of certain services, by supporting research and development, by subsidizing certain space industries, and by underwriting insurance costs. Indeed, the space launch and manufacturing sectors survive largely on government backing. Conversely, because space technology is often dual-use, governments have also tended to constrain these commercial space capabilities though domestic and international export controls.

Several states have begun to consider commercial space a critical infrastructure for national security. In addition, the military sector has taken advantage of a glut in commercial capacity to acquire military communications and imagery, reinforcing a trend towards greater dependence upon commercial systems for military applications.

Space Security Impacts

The commercial space sector is directly related to space security considerations as it provides several actors with launchers with which to access space, as well as much of the satellite and ground station manufacturing capabilities which enable actors to operate entire space systems.

A healthy space industry will tend to increase commercial competition and can lead to decreasing costs for space access and use. This could have a positive impact on space security by increasing the number of actors who can access and use space or space products, thereby increasing the stakeholders in the maintenance of space security. Increased competition can also lead to the further diversification of capabilities to access and use space.

Commercial space efforts have the potential to increase the level of transnational cooperation and interdependence in the space sector, building a degree of transparency and trust through international projects that engage multiple actors in several different countries. In addition, the development of the space industry could influence international space governance. To thrive, sustainable commercial markets require a framework of laws and regulations on certain issues of property, standards, and liabilities.

Some commercial space actors also note that issues of ownership and property pose an increasing challenge to the growth of the industry. For example, while the non-appropriation clause of the Outer Space Treaty is generally understood to prohibit states from making sovereignty claims in space, this clause also raises questions about the allocation and use of space resources. There is concern that the clause could stifle entrepreneurship and growth in the commercial space industry. As well, future conflicts over the issue could decrease space security if not addressed in a timely manner.

Growth in space commerce could, however, eventually mean greater competition for scarce space resources such as orbital slots and radio frequency allocations. Commercial actors could undercut international regulations if they are not properly regulated by national or international authorities. The dependence of the commercial space sector on military clients or, conversely, the reliance of militaries on commercial space assets could also have an adverse impact on space security by making the industry overly dependent on one client, or by making commercial space assets the potential target of military attacks.

Key Trends

TREND 4.1: Continued overall growth in global commercial space industry

The telecommunications industry has long been a driver of commercial uses of space. The first commercial satellite was the Telstar 1, launched by NASA in July 1962 for the telecommunications giant AT&T.[2] Satellite industry revenues were first reported in 1978, when *US Industrial Outlook* published 1976 Communication Satellite Corporation operating revenues of almost $154-million.[3] By 1980, it is estimated that the worldwide commercial space sector already accounted for $2.1-billion in revenues,[4] and by 2004, the sector collected $97.2-billion.[5] Not yet included in industry totals for revenues is the nascent space tourism industry.

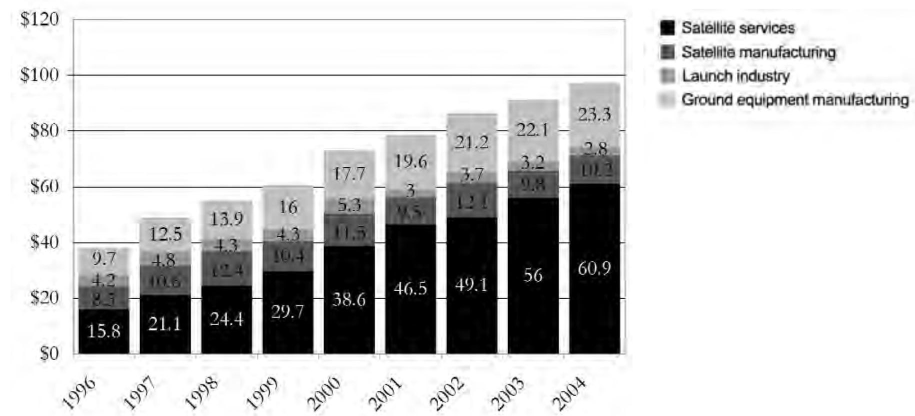
The commercial space sector continues to grow, but at an uneven rate. The years 2003 and 2004 saw the slowest annual growth rates since the mid-1990s. Key recent trends include profits in the manufacturing and launch sectors coupled with significant growth in profits from satellite services. The satellite services sector has tripled in size since 1996, generating $60.9-billion in revenues in 2004, more than 60 percent of the commercial sector's $97.2-billion total revenues (see Figure 4.1).[6]

A number of new companies were founded in the 1980s to take advantage of anticipated growth in the space telecommunications services sector. Telecommunications was deregulated in many countries during this decade, and previously government-operated bodies such as the International Telecommunications Satellite Organization (Intelsat) and the International Maritime Satellite Organization (Inmarsat) were privatized.[7] PanAmSat, New Skies, GE Americom, Loral Skynet, Eutelsat, Iridium, EchoStar, and Globalstar were some of the prominent companies to emerge during this period. Hughes also entered the market with DirecTV, a new satellite television broadcast system.

The 2000 downturn in the technology and communications sectors affected the commercial space sector, reducing market take-up of satellite telephony, which created a related launcher overcapacity problem. For example, there were 21, 220, 21, 12, 20, 13, and 15 commercial launches from 1998-2004 respectively,[8] and yet by comparison the six primary large boosters available today – Ariane 5, Atlas 5, Delta 4, H-2A, Proton, and Zenit 3SL – have a combined capacity of about 40 commercial launches a year (see Trend 4.2). From a record high of $12.4-billion in revenues in 1998, satellite manufacturers worldwide collected only $10.2-billion in 2004, a drop of about 21 percent.

More recently, increased demand has driven significant growth in satellite services such as direct broadcast services. Other factors fueling growth in the satellite services sector include the decreasing cost of communications equipment and decreasing launch costs. Among the current major satellite telecommunications companies are Loral, SES Global, Eutelsat, Intelsat, and News Corporation.

FIGURE 4.1: World satellite industry revenues by sector (billion)[9]



TREND 4.2: Declining commercial launch costs support increased commercial access to space

Space launch

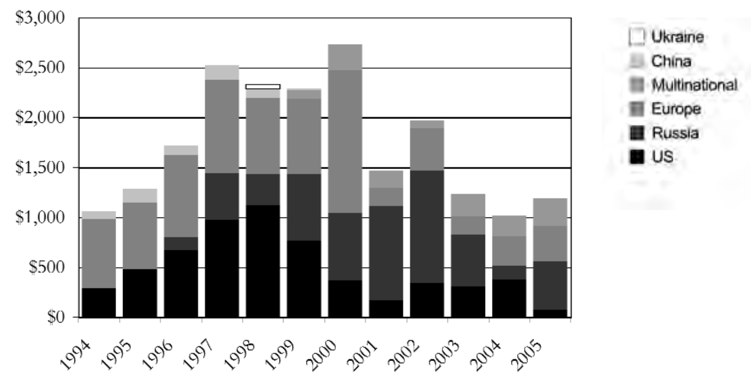
A commercial launch is defined as one in which at least one satellite payload's launch was contracted internationally, such that a launch opportunity was available in principle to any capable launch services provider.[10] Russian, European, and American companies remain world leaders in the commercial launch sector, with Russia launching the most satellites, both commercial and in total in 2005.[11] Generally, launch revenues are attributed to the country in which the primary vehicle manufacturer is based, except in the case of Sea Launch, which is designated as "multinational."[12]

Commercial space launches began to grow significantly in the 1980s. At that time, NASA viewed its provision of commercial launches more as a means to offset operating expenses than a viable commercial venture. European and Russian companies chose to pursue commercial launches via standard rocket technology, which allowed them to undercut US competitors during the period when the US was only offering launches through its Shuttle.

Increasing demand for launch services and the 1986 Challenger Shuttle disaster, which led to a ban of commercial payloads on the Space Shuttle, further encouraged commercial launcher competition. The Ariane launcher, developed under French leadership in the 1980s, captured over 50 percent of the commercial launch market during the period 1988-1997.[13] The

Chinese Long March and the Russian proton rocket provided additional competition in the early and mid-1990s. However, near the end of the decade, the Long March was pressured out of the commercial market due to "reliability and export control issues,"[14] although China has since discussed the possibility of reentering the commercial space flight market by 2020.[15] Today, Ariane, Proton, and Zenit rockets dominate the commercial launch market.

FIGURE 4.2: Commercial space launch revenues (million)[16]



Japanese commercial efforts have suffered from technical difficulties and its H-2 launch vehicle was shelved in 1999 after flight failures.[17] India's Augmented Polar Satellite Launch Vehicle performed the country's first Low Earth Orbit (LEO) commercial launch, placing German and South Korean satellites in orbit in May 1999.[18] Brazil is pursuing an autonomous national launch capability.

Today's top commercial launch providers include Lockheed Martin and Boeing Launch Services in the US, Arianespace in Europe, Energia in Russia, and two international consortia: Sea Launch and International Launch Service (ILS).[19] Sea Launch, comprised of Boeing (US), Aker Kvaerner (Norway), RSC-Energia (Russia), and SDO Yuzhnoye/PO Yuzhmash (Ukraine), launches from a sea-based platform located on the equator in the Pacific Ocean.[20] ILS is a partnership between Khrunichev State Research and Production Space Center (Russia), Lockheed Martin Space Systems (US), and RSC-Energia (Russia). In this global market, new commercial launch vehicle builders such Space Exploration Technologies (SpaceX) are seeking to make inroads by providing cheaper, more efficient launch vehicle designs focusing on reusability.

In addition to a proliferation of rocket designs, the launch sector has also seen innovations in launch techniques. For example, since the early 1990s, companies such as the UK's Surrey Satellite Technology Ltd. have used piggyback launches – where a small satellite is attached to a larger one to avoid paying for a dedicated launch. It is now also common to use dedicated launches to deploy clusters of two to four smaller satellites on small launchers such as the Cosmos rocket. Emerging technologies such as air-launch vehicles capable of being deployed from aircraft, as well as hypersonic "scramjet" engines may in the future further reduce the cost of space launch into LEO.[21]

Launcher competition and new launch techniques have supported a steady decrease in space access costs. In 2000, payloads could be placed into LEO for as little as $5,000 per kilogram.[22] The cost to place payloads in GEO has declined from an average of about $40,000 per kilogram in 1990 to $26,000 per kilogram in 2000,[23] with prices still falling. Nevertheless, the total numbers of commercial launches has declined on average over the last decade, a trend that is expected to continue in the near term.[24]

Greater launcher competition and decreasing launch costs have facilitated steady growth in the number of actors that can access space either through an independent launch capability or via the launch capability of others (see Civil Space Programs and Global Utilities, and Space Support for Terrestrial Military Operations). Forty-five states now have a satellite in orbit; almost all have been enabled in some way by the commercial sector.

FIGURE 4.3: Commercial satellite imagery providers

Company and assets*	Type and resolution	Price per square kilometer
GeoEye, US		
Orbview-3	Panchromatic: 1 meter, multispectral: 4 meter	$10-$24 for panchromatic and multispectral, $34-$48 for stereo
IKONOS	Panchromatic: 1 meter, multispectral: 4 meter	$10-$24 for panchromatic and multispectral, $34-$48 for stereo
OrbView-2	Multispectral: 1.1 kilometer	$10-$24 for multispectral,
OrbView-5	Panchromatic and multispectral: 0.41 meter	N/A
Digital Globe, US		
QuickBird	Panchromatic: 0.6 meter, multispectral: 2.44 meter	$16-$22 for panchromatic, color, and multispectral
WorldView I	Panchromatic: 0.5-meter	$17-$28
WorldView II	Panchromatic: 0.5 meter, multispectral: 1.8 meter	$17-$28
SPOT Image, France		
SPOT 2	Panchromatic: 10 meter	$0.63-$23.27 for panchromatic and multispectral
SPOT 4	Panchromatic: 10 meter	$0.63-$23.27 for panchromatic and multispectral
SPOT 5	Panchromatic: 5 meter, "Supermode": 2.5 meter	$0.63-$23.27 for panchromatic and multispectral
ImageSat, Israel		
EROS A	Panchromatic: 1.9 meter,	$2.55-$15.31
EROS B	Panchromatic: 0.7 meter	$2.55-$15.31
EROS C	Panchromatic: 0.7 meter, multispectral: 2.8 meter	$2.55-$15.31
Sovinformsputnik, Russia		
Resurs-DK1	Panchromatic: 1meter, multispectral: 2-3 meters	N/A
Infoterra, Germany		
TerraSAR-X	Synthetic Aperture Radar: 1 meter	N/A
IAI, Israel		
TecSAR	Synthetic Aperture Radar	N/A
MDA, Canada		
RADARSAT-1	Synthetic Aperture Radar: 8 meter	N/A
RADARSAT-2	Synthetic Aperture Radar: 3 meter	N/A
India Remote Sensing (IRS), India		
IRS 1-C	Panchromatic: 5.8 meter, multispectral: 23.5 meter	N/A
IRS 1-D	Panchromatic: 5.8 meter, multispectral: 23.5 meter	N/A
IRS P-6 (RESOURCESAT-1)	Panchromatic: 5.8 meter, multispectral: 23.5 meter	N/A

* Italics indicate future satellites

Commercial Satellite Imagery

Whereas 40 years ago only a government body would have been able to gain access to satellite imagery, today any individual or organization with the necessary resources can access these services. Companies such as Surrey Satellite Technology Ltd. and SpaceDev have commercialized private research in the area of space technologies, in particular small satellites. There are currently eight companies in Canada, France, Germany, Israel, Russia, and the US providing commercial satellite imagery. In the past decade, the resolution of the imagery has become progressively more refined and affordable with companies such as InfoTerra planning to offer synthetic aperture radar images down to one meter in resolution (see Figure 4.3). However, the increased availability and quality of potentially sensitive commercial satellite imagery have caused some concern for governments (see Trend 4.3).

Space Tourism

An embryonic space tourism industry has recently emerged, seeking to capitalize on advanced, reliable, reusable, and relatively affordable space launch technology. In June 2004, SpaceShipOne, developed by US Mojave Aerospace Ventures, became the first private manned spacecraft.[25] In early December 2004, the US Congress passed into law the "Commercial Space Launch Amendments Act of 2004." Intended to "promote the development of the emerging commercial human space flight industry," the Act establishes the FAA's authority over suborbital space tourism in the US, allowing it to issue permits to private spacecraft operators to send paying customers into space.[26]

TREND 4.3: Government subsidies and national security concerns continue to play an important role in the commercial space sector

Governments have long played a central, if not indispensable, role in the development of the commercial space sector. Most space-faring states consider their space systems an extension of national critical infrastructure, and a growing number view their space systems as critical to national security. Complete state ownership of space systems at the beginning of the space age has given way to a mixed system in which many larger commercial space actors receive significant government contracts and such government subsidies as research and development funds, loan guarantees, insurance coverage, and funding for launch site maintenance. Certain commercial space sectors, such as remote sensing or commercial launch industries, rely more heavily on government customers, while the satellite communications industry is commercially sustainable even without government contracts. However, it is expected that military-commercial interdependence will continue to underwrite growth in the commercial space sector in the near future.[27]

The US Space Launch Cost Reduction Act of 1998 established a low-interest loan program for qualifying private companies to support the development of reusable vehicles.[28] In 2002, the US Air Force requested $1-billion in subsidies from Congress for the period 2004-2009 for Lockheed Martin's Atlas V and Boeing's Delta 4 development as part of the Evolved Expendable Launch vehicle program, which is mandated to ensure the continued existence of the two launch vehicles to provide a degree of redundancy in case of rocket design failure.[29]

In Europe, the Guaranteed Access to Space Program adopted in 2003 has ESA underwriting the development costs of the Ariane 5, ensuring its competitiveness in the international launch market.[30] The program provides both short- and medium-term support for Arianespace during the development and maturation of the Ariane 5 rocket. It explicitly recognizes a competitive European launch industry as a strategic asset, and is intended to ensure sustained government funding for launcher design and development, infrastructure maintenance, and upkeep.[31] Although the program is largely focused on the Ariane 5 program, it also designates money to support a continued relationship with Russia for the use of the Kourou launch site in French Guiana.

Russia's commercial space sector also continues to enjoy a close relationship with its government, which has provided contracts and subsidies for the development of the Angara launcher and launch site maintenance.[32] The Russian space program receives subsidies from the US in the form of contracts related to the International Space Station (ISS). The vulnerability of the Russian commercial space sector was demonstrated in 2002, when Russia's financial struggles and inability to fully meet its subsidy commitments forced the Russian space launch company Energia to default on loan payments. According to the Russian press, the Russian space industry was to receive the equivalent of only $38-million in subsidies in 2003, not enough to cover existing debts or commitments to the ISS.[33]

Insurance

Governments play an equally important role in the insurance sector where rising insurance rates have put pressure on governments to maintain insurance indemnification for commercial launchers. Prior to 1998, the typical insurance rate for a launch plus 12 months of in-orbit coverage could be purchased for about seven percent of the satellite and launch vehicle value. Since 1998, however, a 146 percent rise in the number of in-orbit anomalies has forced a 129 percent increase in insurance premiums.[34] In 2002, the space insurance industry paid out $830-million in claims while it collected just $490-million in premiums.[35] The insurance industry has blamed rising rates on more complex satellites with less manufacturing quality control, while the satellite industry has countered that insurers are simply overreacting. Insurers have begun offering shorter terms, with higher rates and deductibles, and insurance exclusions for events such as terrorism.[36] This has directly increased the cost of space access and use.

In 1988, the US Congress amended the 1984 Commercial Space Launch Act to include an indemnification authority which limited the amount insurance launch providers would be required to pay to $500-million, covering basic damage costs in the event of structure or payload failures. However, the Act also provided for Congress to further appropriate up to an additional $1.5-billion to cover excess liabilities beyond the required insurance.[37] The US Commercial Space Act of 2003 represented the third extension of this provision, to 31 December 2007, in order to give Congress time to re-evaluate proposed changes to the regime.[38] In contrast, the EU offers full indemnification for its launch service providers, while China, Japan, Russia, and Australia offer "better or comparable indemnification regimes" than the US.[39] To date, the provision has cost taxpayers nothing and has helped to support this nascent industry. However, in the event of a failure, public funds would bear the cost.

Export controls

Space launchers and intercontinental ballistic missiles use almost identical rocketry capabilities, and many civil and commercial satellites contain advanced technologies with potential military applications. Dual-use concerns have stimulated states to develop national and international export control regimes aimed at preventing proliferation. The export control regime with the most direct application to commercial space security considerations is the Missile Technology Control Regime (MTCR) (see Space Security Laws, Policies, and Doctrines).

The MTCR was formed in 1987 by a group of states seeking to prevent the further proliferation of capabilities to deliver weapons of mass destruction by working together on a voluntary basis to coordinate the development and implementation of a set of common export policy guidelines.[40] There are 34 members of the MTCR, including Australia, Brazil, Canada, France, Germany, Japan, South Korea, Russia, the UK, and the US, with China formally expressing interest in becoming a member in 2003.[41] Even among members, however, export practices differ. For example, although the American "Iran Nonproliferation Act" of 2000 limited the transfer of ballistic missile technology to Iran, Russia is still willing to provide such technology under its Federal Law on Export Control.[42] Most states control the export of space-related goods through military and weapons of mass destruction export control laws, such as the Export Control List in Canada, the Council Regulations (EC) 2432/2001 in the EU, Regulations of the People's Republic of China on Export Control of Missiles and Missile-related Items and Technologies, and the WMD Act in India.[43]

From the late 1980s to late 1990s, the US had agreements with China, Russia, and Ukraine to enable the launch of US satellites from foreign sites. However, in 1998, a US investigation into several successive Chinese launch failures resulted in allegations about the transfer of sensitive US technology to China by aerospace companies Hughes and Loral. Concerns over the possibility that this could happen again sparked the transfer, in 1999, of jurisdiction over satellite export licensing from the Commerce Department's Commerce Control List to the State Department's US Munitions List (USML).[44] In effect, the new legislation treated satellite sales like weapons sales, making international collaborations more heavily regulated, expensive, and time consuming.

Exports of USML items are licensed under the International Traffic in Arms Regulations regime, which adds several additional reporting and licensing requirements for US satellite manufacturers. A recent US Government report noted that, in total, it now takes "nine to 20 months on average to gain approval for a satellite export and notify Congress."[45] A subsequent study of the market conditions for US satellite manufacturers argued that "nearly every potential international buyer of satellites in 2002 (…) indicated that the US export control system is a competitive disadvantage for US manufacturers."[46]

While some point to export controls as an opportunity that other space companies have leveraged to increase their expertise and profits, others say the controls are necessary to preserve US space technology dominance. Paradoxically, export controls have, at times, stimulated states to develop similar technologies indigenously, undercutting export controls and breaking monopolies. For example, after being denied the sale of cryogenic rocket engine components from Russia in 1993 due to pressure from the US, India subsequently successfully developed its own cryogenic engine technology.[47]

Finally, because certain commercial satellite imagery can serve military purposes, a number of states have implemented regulations on the sector. The 2003 US Commercial Remote Sensing Policy sets up a two-tiered licensing regime, which limits the sale of sensitive imagery.[48] In 2001 the French Ministry of Defense prohibited open sales of commercial Spot Image satellite imagery of Afghanistan.[49] Indian laws require the "scrubbing" of commercial satellite images of sensitive Indian sites.[50] Canada has recently passed Bill C-25, creating a regulatory regime for MDA's RADARSAT-2 that will give the Canadian government "shutter control" – the control exercised by the Executive branch of government over the collection and dissemination of commercial satellite imagery of a particular region due to national security or foreign policy concerns – and priority access in response to possible future major security crises.[51] Analysts note, however, that competition among increasing numbers of commercial satellite imagery providers may eventually make shutter control prohibitively expensive.[52]

Commercial space systems as critical infrastructure

Space systems, including commercial systems, are increasingly viewed as national critical infrastructure and strategic assets. In the 1990s, the US military began to take advantage of the commercial industry's overcapacity by employing commercial satellite systems for non-sensitive communications and imagery applications. During the 1991 Gulf War, 60 percent of the 100 megabytes per second of bandwidth required by US forces was supplied by commercial providers.[53] During Operation Enduring Freedom in 2001, the US military used 700 megabytes per second of bandwidth, 75 percent of which was commercial.[54]

By November 2003, it was estimated that the US military was spending more than $400-million each year on commercial satellite services.[55] This growing dependence upon commercial services prompted a December 2003 US General Accounting Office report to recommend that the US military be more strategic in planning for and acquiring bandwidth, including consolidating bandwidth needs among military actors to capitalize on bulk purchases.[56] A 2004 study of the US National Security Telecommunications Advisory Committee Satellite Task Force noted the great dependence of the national security and homeland security communities on commercial space.[57]

Generally, the US Government makes extensive use of commercial communication satellites. Fixed Satellite Services provide wideband Internet Protocol services, and have provided national security and emergency preparedness services to the Federal Emergency Management Agency and National Communications System. Mobile Satellite Services support civil marine operations, and played a domestic security role in the events following 11 September 2001, as well as during the 2002 Winter Olympics. Furthermore, the US Commercial Remote Sensing Policy specifically calls for reliance on US commercial capabilities to meet government imagery needs.[58]

TREND 4.1: Continued overall growth in global commercial space industry

2005: Unequal growth in commercial space industry

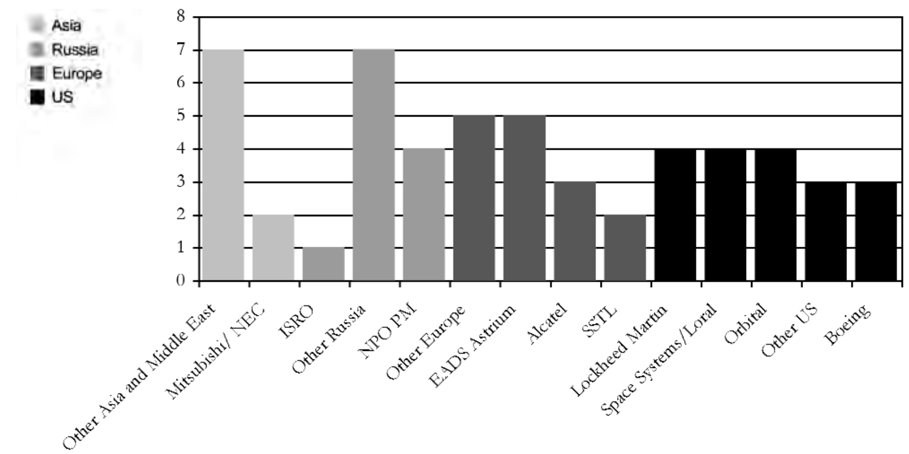
Overall growth in the global commercial space industry continued in 2005. Consolidation, changing ownership trends, and technology innovations were the key developments in the satellite services industry. In 2005 there were 17 commercial launches in which at least one payload procured launch services through an international competition.[59] Satellite manufacturers exceeded industry expectations of 10-15 commercial satellite orders with 20 new commercial satellites, up from a low of 12 in 2004 (see Figure 4.5).[60]

Despite flat revenues in satellite manufacturing and commercial space launch, commercial space revenues are predicted by some to rise to $115-billion in 2005.[61] The satellite services sector continued to be the primary driver in commercial space industry growth and Europe, driven by video broadcasting services, makes up the largest market in terms of revenues for fixed satellite services.[62] At the current growth rate, commercial space revenues are predicted to exceed $158-billion in 2010.[63] This would represent a 53 percent growth in global space industry revenues between 2004 and 2010, most of which is expected to result from increased demand for satellite services including video, voice, internet, and wireless communications.[64] Fiber optics, local area networks, satellite and fixed wireless recorded the highest percentage growth (13 percent) in the number of subscribers of all broadband technologies in the first six months of 2005.[65] Satellite broadband services are expected to grow at a global rate of 8 percent on average in coming years.[66] At this rate, capacity leases for satellite broadband could be worth $1-billion by 2010.[67]

The fixed satellite industry is in a low period of its investment cycle with an average of nine satellites ordered each year over the last three years.[68] The increase in commercial satellite sales and relatively high number of commercial launches in 2005 may be a consequence of irregular delivery schedules more than a significant increase in commercial demand.[69] Increases in the average service life of satellites, satellite transponder capacity, and the carrying capacity of launchers have slowed demand for new satellites and launchers.[70] Although prohibitively high insurance rates in 2005 led some satellite operators to launch more satellites rather than insure ones currently in orbit, this development does not seem to offset depressed demand for launches and satellite manufacturing. Analysts expect the replacement market to sustain commercial space infrastructure development over the next several years.[71] Some predict that the one exception could be commercial satellites for US defense customers as US budget allocations for defense and intelligence space activities continue to grow.[72] From a regional perspective, commentators project that the US will continue to dominate the commercial space services market until 2008. In the long term, US manufacturers may need to widen the commercial base to replace government customers.

Developments and growth predictions indicate that satellite broadband may stimulate the next wave in demand for satellite capacity.[73] Satellite service providers are developing products and services to diversify their customer base and ensure future sustainable growth.[74] For example, 2005 was a watershed year for the nascent satellite radio industry: the number of subscribers to XM Radio nearly doubled from 3.2 million in January 2005 to approximately 5.93 million at year's end[75] and Sirius Radio reported similar growth.[76] The 2005 revenues of XM Radio and Sirius Radio were $558-million and $242-million respectively.[77] Video programming needs have also created greater demand for satellite services and resulted in new products such as advanced compression technologies and Digital Video Broadcasting technologies.[78] Direct and high-definition television has been called the "crucial lifeblood for the industry," and is now beginning to make a breakthrough in Europe.[79] By mid-2005, there were 26,340,706 direct-to-home satellite subscribers in the US alone, a twelvefold increase from 1994.[80] A 2005 survey of commercial satellite executives listed data/internet services and mobile services as the areas of greatest anticipated revenue growth over the next two to three years.[81] Overall, however, analysts do not expect that the growth in demand for bandwidth for satellites services will be matched by corresponding growth in commercial launch and manufacturing sectors.[82]

FIGURE 4.4: Satellite manufacturing in 2005[83]



2005: Privatization and consolidation in commercial sector continues

The general trend towards the privatization of government-owned telecommunications agencies continued in 2005 with the first initial public stock offerings of New Skies Satellites and Inmarsat, with Eutelsat expected to follow soon.[84] While some industry insiders forecast positive results from private ownership, others caution that innovation and reliability may be undermined in favor of cost efficiency.[85] Some argue that private ownership of satellite operators will not fundamentally alter the downward trend in manufacturing. In other words, while the expense of launching and ordering new satellites may mitigate against replacing aging satellite systems among private owners, factors such as the increased transponder capacity of next-generation satellites may alone be sufficient to depress demand for new satellites.[86]

In recent years, overcapacity and subsequent depressed prices have led to a string of mergers and acquisitions; this trend continued in 2005.[87] In the satellite service sector, Intelsat purchased PanAmSat for $3.2-billion and SES Global purchased New Skies for $760-million. In the launch sector, the European Aeronautics Defence and Space Company (EADS) acquired Dutch Space BV. In the manufacturing sector, Alcatel Alenia merged with Telespazio and SpaceDev merged with Starsys Research Corporation. The benefits of economies of scale in satellite fleet procurement and management and of larger capital market access promote consolidation. Further industry consolidation may take the form of integration among providers of different types of services, as satellite operators become content providers and data analysts, and technologies overlap.[88] Demand for new digital applications, networking, and data management will likely push satellite service providers to find new ways of using and combining technologies.[89] Analysts note that this latent "one network" future is driving a "very dynamic, fast moving, and extremely promising worldwide market."[90]

There is wide agreement that the potentially negative implications of industry consolidation for customers of satellite services are offset by the primarily regional organization of the commercial satellite industry.[91] Prices for satellite services will likely remain stable as competition among regional players limits the effects of industry consolidation. Small regional players have and will likely maintain a secure foothold in specific niches to sustain a competitive market and price stability.[92] Opportunities for further consolidation among smaller players will remain as regional operators look to secure places in their respective markets.[93] Formal mergers and acquisitions are not the only vehicles for industry consolidation and satellite operators often enter partnership agreements when outright mergers are not possible.[94]

Net assessment:

Continued growth in the commercial space sector underlined the sector's collective benefit from secure and sustainable access to and use of space. However, it is not yet clear that the sector's growth would be sustainable in the absence of government support. Continued privatization and consolidation in the field may hold promise for space security if efficiency in operations of scale can be translated into a decrease in the cost of space access. Lastly, the increased transponder capacity of commercial satellites, while reducing demand in the space manufacturing sector, could have a positive effect on space security by helping to mitigate demand on orbital slots.

TREND 4.2: Declining commercial launch costs support increased commercial access to space

2005: US continues to lose commercial launch market share to Europe and Russia

Demand for commercial launchers remained relatively flat in 2005, with 17 commercial launches, slightly exceeding the 2004 level.[95] At the same time, US commercial launchers continued to lose market share. Compared to Russia's total of eight commercial launches, there was only one commercial launch using a US vehicle in 2005: the 11 March 2005 launch of Inmarsat 4F1 on an Atlas 5 rocket.[96] In 2004 there were six commercial launches using US vehicles.[97] US share of the worldwide commercial launch market has averaged only 30 to 40 percent and about one-third of total revenues over the past 10 years.[98] Given increasing international competition, strict US export controls, the absence of comparable heavy-lift capabilities, and relatively high prices, it is unlikely that US-manufactured vehicles will regain the market share they once held in the commercial launch sector. US launch companies will be forced to rely upon government and military contracts to sustain production and profits.

In April 2005, the US Air Force announced that it would forgo price-driven competition for launches and instead divide its 23 planned Evolved Expendable Launch Vehicle (EELV) missions, scheduled between 2008 and 2011, between Boeing's Delta 4 and Lockheed Martin's Atlas 5 rockets.[99] This conforms to the new US Space Transportation Policy, which directs the US Department of Defense (DOD) to pay the fixed costs of its EELV program and support both launch companies until the end of the decade.[100] The decision of Boeing and Lockheed Martin to combine their launch operations into a joint venture – the United Launch Alliance (ULA) – has been identified by several experts as indicating the failure of the commercial market to sustain the EELV.[101] While the ULA was ostensibly created to provide cost savings to the government, it is unlikely that both US EELV vehicles would have remained in service without the support of government customers.[102] Competition from China, Europe, and Russia and overcapacity among commercial GEO satellites have depressed demand and lowered prices.[103]

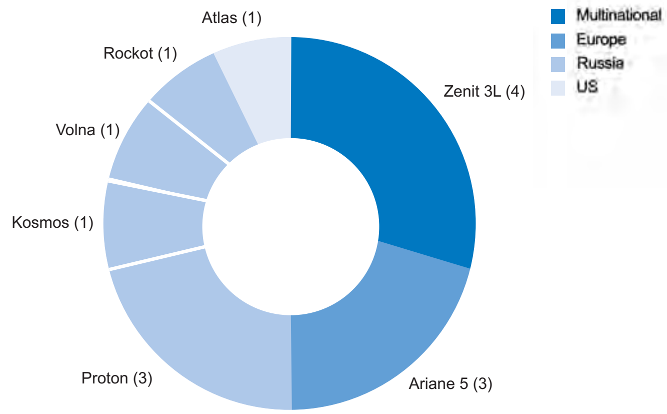
Boeing failed to deliver any launches in the last quarter of 2005 when operations were hampered by a strike of 1,500 employees, beginning in November, which delayed three launches of Delta 2 and Delta 4 vehicles and halted manufacturing work.[104] Until the Delta 4 returns to the commercial market, there is currently no completely US-built commercial launch vehicle available for intermediate-to-heavy lift.[105] US launchers are therefore losing out to foreign launch companies that can carry more than one satellite at once. Boeing continues to rely on government contracts and is contracted to provide launches for the GPS program aboard Delta II vehicles until at least 2007.[106] In November 2005, Boeing was awarded approximately $24-million in new orders from the US National Geospatial Intelligence Agency.[107]

There was continued anticipation in 2005 that the SpaceX Falcon vehicles could provide a competitive American commercial space launcher. However, the inaugural launch of the Falcon 1 was postponed until early 2006 due to structural issues in the first-stage fuel tank.[108] This is just the latest setback in a series of technical problems plaguing the launch of the California-based company's rocket. The Falcon 1 is part of a $100-million program to develop a family of low-cost rockets, including the Falcon 9, a lower-cost alternative to the Delta 4 and Atlas 5 rockets.[109] The company's promise to provide more affordable access to space for US government and commercial actors remains unproven.

Europe's Ariane 5 vehicles had a record year in 2005 with a total of four commercial launches.[110] These include the 11 August launch of Thaicom 4 (IPstar), the 13 October launch of Galaxy 15,[111] and the 16 November dual-launch of Spaceway 2 and Telkom 2, for US and Indonesian customers respectively.[112] On 12 February, the 5 ECA rocket successfully placed Spain's XTAR-EUR military communications satellite and a test payload called the SloshSat, with a combined weight of 8,000 kilograms, into a geostationary transfer orbit.[113] It was the first flight since ECA's unsuccessful 2002 maiden flight.[114] On 11 August, an Ariane 5G rocket launched the Thaicom 4 satellite, the heaviest commercial communications satellite ever to be placed into orbit.[115]

Driven by Sea Launch, the multinational commercial space launch sector also saw a strong year in 2005. Using its Zenit 3SL vehicle, Sea Launch launched the XM3 satellite on 28 February, Spaceway 1 on 26 April, Intelsat Americas 8 on 23 June, and Inmarsat 4F2 on 8 November.[116] In July, Sea Launch announced that it had won a multiple launch contract with PanAmSat, including the first commercial Land Launch mission from Baikonur Cosmodrome, Kazakhstan and several Land Launch options.[117] Finally, it plans to launch the Galaxy 16 and Galaxy 18 satellites – at 4,700 kilograms each – in 2006 and 2007 respectively.[118] The Land Launch contract of 12 July 2005 provides for a Zenit 3SLB vehicle to lift the PAS-11 satellite to GEO by the end of the second quarter of 2007.[119] The new Land Launch program is based on collaboration between the Sea Launch Company and Space International Services and is designed to meet emerging commercial market demand for launching medium weight commercial satellites.[120]

FIGURE 4.5: Commercial space launches in 2005[121]



Despite flat demand and growing competition, emerging competitors are poised to enter the commercial space launch market. Japan's Rocket Systems Corporation, developer of the H2A booster, joined the multinational Launch Services Alliance with Arianespace and Sea Launch in 2005.[122] China's Long March rocket may also enter the commercial launch market to place satellites into GEO using payloads that do not contain American components, in compliance with the US International Traffic in Arms Regulations (ITAR) export restrictions.[123] Alcatel's new-generation, "ITAR-free,"[124] Chinasat 6B communication and broadcast satellite will be launched early in 2007 by the Chinese Long March 3B rocket.[125] India may also enter the commercial launch market with its Geostationary Satellite Launch Vehicle, capable of launching GEO satellites weighing up to several thousand kilograms, to offset the Indian Space Research Organization's (ISRO) costs of development and research.[126] ISRO has launched four satellites commercially and holds contracts to launch three more over the next two years.

2005: Commercial activity continues in space tourism but remains a distant proposition

While still in its infancy, the commercial space tourism sector saw a number of developments in 2005. Currently, Space Adventures Ltd. is the leading space tourism company, and the only one to have successfully launched clients into space.[127] On 30 September, Gregory Olsen became the third space tourist when he took off aboard the Soyuz TMA-6 and spent 11 days at the International Space Station (ISS).[128] On August 10, Space Adventures announced the "DSE-Alpha" mission, the first in a series of lunar missions as part of Space Adventures' Deep Space Expeditions program.[129] A launch, using the Soyuz vehicle, could take place as early as 2008 and is estimated to cost $100-million per client.[130]

Since the successful launch of Scaled Composites' SpaceShipOne in 2004, and the establishment of the Ansari I Prize, there are currently over 20 companies developing a suborbital, reusable launch vehicle for space tourism.[131] In July 2005, Scaled Composites and Virgin Galactic (a new subsidiary of the Virgin Group Ltd.) announced a joint venture, The Spaceship Company, to build a fleet of commercial suborbital spacecraft and equipment to be deployed in commercial space flights by the end of 2008.[132] Scaled Composites is currently developing SpaceShipTwo and its carrier plane White Knight Two.[133] On 14 December, Virgin Galactic and the US State of New Mexico announced a partnership to begin building a $200-million spaceport in the state in 2007.[134] Starchaser has also signaled interest in launching commercial suborbital flights from New Mexico. Hurdles remain, however, including completion of the spaceport's environmental impact statement and the US Federal Aviation Administration (FAA)'s spaceport licensing process.[136] On 16 November, SpaceDev announced that it would develop a new six-passenger human space transport vehicle dubbed the SpaceDev Dream Chaser.[137] The Dream Chaser is marketed both for the emerging commercial suborbital space tourism market as well as for orbital flights as part of NASA's mandate to promote affordable commercial access to the ISS.[138] Space Dev expects to begin suborbital flights in 2008.[139] Lastly, XCOR Aerospace announced it was developing a Xerus suborbital vehicle, designed to meet three different markets, including space tourism.[140]

While there were a number of promising developments in 2005, the space tourism industry continued to face the twin challenges of supply constraint and liability regulation. Market surveys indicate that there is sufficient interest to support commercial space travel, whether orbital or suborbital. However, high prices remain the greatest barrier to the development of the space tourism sector, which also faces rigid supply constraints. At present, the Russian Soyuz launcher is the only vehicle providing public orbital space travel flights, with two to four flights each year.[141] Commercial suborbital tourism is not expected to begin until 2008 at the earliest, supply constraints are not expected to be removed until about 2010, and dedicated commercial orbital flights are not forecast to begin before 2013.[142] At the same time, commercial alternatives to the Soyuz rocket launcher are unrealistic over the short term.

Important space tourism liability questions, presently unregulated under international law, also remain.[143] On 29 December 2005, the FAA released draft rules, which included provisions for "informed consent" whereby safety rules are waived in favor of obtaining written passenger consent.[144] The commercial space tourism sector has not sought government protection from passenger liability.[145] On the contrary, in April 2005, Burt Rutan, designer of SpaceShipOne, accused the FAA of nearly "destroying" his efforts to establish a commercial suborbital tourism industry through its suborbital safety regulations.[146]

Net assessment:

The eventual entry of new commercial launchers into both orbital and suborbital markets may be a positive development for space security, increasing the competition necessary to decrease prices and build more affordable access to space. At this time, liability issues remain a significant barrier for space tourism. However, legislative regimes and common procedures are being developed, at least in the US, to meet the needs of emerging entrepreneurial space travel initiatives.

TREND 4.3: Government subsidies and national security concerns continue to play an important role in the commercial space sector

2005: US DOD remains single largest commercial space client

Military-commercial interdependence continued in 2005 with new contracts between commercial service providers and governments.[147] For example, the US government has contracts with the satellite services sector worth approximately $600-million – 50 percent of which are defense-related.[148] The US government remained the single largest customer for commercial satellite services in 2005.[149] For example, the US DOD accounts for approximately 60 percent of commercial satellite services use provided by New Skies Satellites.[150] This trend is expected to continue, with government and military demand projected to grow by 15-20 percent per year for the next five years.[151] A June 2005 survey of satellite industry professionals projected that the key sectors of growth for commercial space would be US DOD and commercial mobile communications, hardware (including spacecraft), as well as hybrid – mobile and broadband – networks.[152] Seventy percent of respondents stated that, among government agencies, the DOD was the primary source of new business.[153] Significantly, military-commercial interdependence is more important for sustaining US launchers and manufacturers than for satellite services operators, which generally derive most contracts from commercial and civil customers. Growth in the global (non-US) industry is driven primarily by commercial markets for satellite communications services.[154] Overall, the US government accounted for less than 1 percent of total commercial revenues for the global commercial space industry in 2004.[155]

2005: Export controls inhibit commercial space growth

While government contracts were a major contributor to commercial space revenues in 2005, export regulations continued to hamper growth. The International Space Business Council cited the International Traffic in Arms Regulations as the "industry's most serious issue," arguing that "what initially was a nuisance to businesses has evolved into a serious problem for US industry."[156] Many American manufacturers believe that the US export control policy is hampering their commercial competitiveness.[157] Under ITAR, payloads containing US components cannot be transported to China to be launched by Chinese launchers. Analysts described Alcatel's first Chinasat 9 contract as a de facto "non-competed win" since the world's other principal satellite manufacturers in the US and Europe use US components that would be banned from export to China. On the same basis, Alenia Space won another contract to build the ChinaSat 6B in 2005.[158] US regulations have also allegedly prevented growth in the satellite broadband market, causing the US to lag behind countries such as South Korea, Canada, and the Netherlands.[159] At a 20 April 2005 hearing convened by the US House Subcommittee on Space and Aeronautics, testimony focused on the detrimental effect of US government regulations for American launch and satellite companies.[160] Nevertheless, analysts note that US manufacturers continue to dominate the global market.[161]

2005: High space insurance premiums remain a barrier to growth for commercial space, but a new European Liability Regime bodes well for transnational cooperation

According to the Satellite Industry Association, in-orbit claims have risen considerably to a range of two to five percent. The satellite services sector, in particular, faces higher insurance costs.[162] High insurance premiums and stricter policy terms covering satellites with "suspect components" have led certain commercial space actors to build redundant satellites or abandon satellite insurance altogether. In 2005, the satellite service provider Intelsat decided to forgo satellite insurance to lower costs.[163] Beginning in March 2005, Intelsat ceased insuring its in-orbit fleet beyond the first six to 12 months in orbit. This represented a saving of 10-15 million dollars per year in premium payments.[164] On 20 December, Paradigm Secure Communications Ltd., responsible for managing the UK's military satellite communications operations, announced that it would purchase and launch a third Skynet 5 satellite and order components of a fourth instead of continuing insurance on the first two Skynet spacecraft.[165] According to Paradigm, a three-satellite constellation represents "an assurance strategy" that will simultaneously cut insurance costs and deliver "better performance, more efficiency, [and] longer services availability."[166] Currently, up to 30 percent of commercial satellites are not insured.[167] Nevertheless, some analysts note that, after years of historically high insurance premiums, the space insurance market will be dropping rates for "proven satellite and launch hardware on the condition that the sum remains modest."[168] Aon Corporation and other major space insurance brokers may end a common insurance underwriting practice that makes it difficult for owners of large satellites to secure low-price coverage, in favor of crafting specialized coverage on a case-by-case basis.[169]

According to a new agreement reached between France, Russia, and the European Space Agency, France will no longer be the sole state legally responsible for launches from Europe's Guiana Space Center. Under the new regime France will continue to assume full liability for launches using the heavy-lift Ariane 5 rockets; however, France and Russia will share legal liability for launches of Russia's Soyuz rocket from the French Guiana site when they begin in 2008-2009. For the future ESA Vega rockets, France will take on a one-third share of legal liability, with the remaining two-thirds distributed among the ESA nations participating in the Vega project.[170]

Net assessment:

Export controls continue to have a mixed effect on space security. On the one hand they have a negative effect by distorting market competition and restricting the means to access space. On the other hand, these same export control measures can have a positive impact by controlling dual-use goods and technologies that could be used for space negation purposes. The trend for satellite service providers to forgo insurance indicates that it is cheaper to buy new satellites that generate "replacement capacity" than to insure them. This may generate increased demand and revenues for satellite manufacturers, but indicates that insurance premiums continue to hamper general satellite industry growth. Cooperation and partnerships between space insurance brokers and the satellite industry, as well as collective liability agreements between state actors, could bode well for the commercial space sector and space security.

FIGURE 4.6: Commercial satellite launches in 2005[171]

Satellite name	State owner	Owner	Manufacturer	Launch vehicle	Launching organization	Launching state
Anik F1R	Canada	Telesat	Astrium	Proton-M/Briz-M	Krunichev	Russia
Apstar 6	China	APT	Alcatel/Cann	Chang Zheng 3B	CASC	China
Telkom 2	Indonesia	PT Telkom	Orbital	Ariane 5ECA	Arianespace	France
Ekspress AM-2	Russia	GPKS	NPO PM	Proton-K/DM-2M	Krunichev	Russia
Ekspress AM-3	Russia	GPKS	NPO PM	Proton-K/DM-2	Krunichev	Russia
Monitor-E No. 1	Russia	Krunichev	Krunichev	Rokot	KVR	Russia
Rubin-5	Russia	OHB/Polyot	OHB System	Kosmos 11K65M	KVR	Russia
Thaicom 4	Thailand	Shin	Loral	Ariane 5GS	Arianespace	France
Inmarsat 4 F1	UK	INMARSAT	Astrium/Toul	Atlas V 431	ILS/LMA	US
Intelsat Americas 8	UK	Intelsat	Loral	Zenit-3SL	SeaLaunch	US/ Ukraine
Inmarsat 4 F2	UK	INMARSAT	Astrium/Toul	Zenit-3SL	SeaLaunch	US/ Ukraine
AMC 12	US	SES Americom	Alcatel	Proton-M/Briz-M	ILS/K	Russia
XM Radio 3 (Rhythm)	US	XM Radio	Boeing/ES	Zenit-3SL	SeaLaunch	US/ Ukraine
Spaceway 1	US	DirecTV	Boeing/ES	Zenit-3SL	SeaLaunch	US/ Ukraine
DirectTV-8	US	DirecTV	SS/Loral	Proton-M/Briz-M	ILS/K	Russia
Galaxy 14	US	Panamsat	Orbital	Soyuz-FG	Starsem	France
Galaxy 15	US	Panamsat	OSC	Ariane 5GS	Arianespace	France
Spaceway 2	US	DirecTV	Boeing/ES	Ariane 5ECA	Arianespace	France
AMC 23	US	SES Americom	Alcatel	Proton-M/Briz-M	ILS/K	Russia

CHAPTER FIVE

Space Support for Terrestrial Military Operations

This chapter assesses trends and developments in the research, development, testing, and deployment of space systems that provide military attack warning, communications, reconnaissance, surveillance, and intelligence, as well as those with navigation and weapons guidance applications.

Extensive military space systems were developed by the US and USSR during the Cold War. Satellites offered ideal vantage points from which to monitor the Earth to provide strategic warning of signs of nuclear attack, such as the launch plume of a ballistic missile or the light signature of a nuclear detonation. Satellite communications provided extraordinary new capabilities for real-time command and control of military forces deployed throughout the world. The space age also opened a new chapter on the development of reconnaissance, surveillance, and intelligence collection capabilities through the use of satellite imagery and space-based electronic intelligence collection.

By the end of the Cold War, the US and USSR had begun to develop satellite navigation systems that provided increasingly accurate geographical positioning information. Building upon the capabilities of its Global Positioning System (GPS), the US began to expand the role of military space systems, from providing indirect strategic support to military forces, to enabling the application of military force in near-real-time tactical operations through precision weapons guidance. The development of radar satellites offered the potential to detect opposition forces on the ground in all weather at all times.

The US leads in the development of space systems to support military operations, and maintains just over half of all military satellites. Russia maintains the second largest number of military satellites. Together, these two actors dwarf the military space capabilities of all other states. This chapter identifies the development of the military space capabilities of the US and Russia as a distinct space security trend. However, it also examines the efforts of a growing number of other states that have begun to develop national space systems to support military operations, primarily in the areas of surveillance and communications.

This chapter does not examine military programs pertaining to space systems protection or negation, or space-based strike weapons, which are described in their respective chapters. Additional information on the function of satellite navigation systems as global utilities is provided in the Civil Space Programs and Global Utilities chapter.

Space Security Impacts

Over half of all space systems to date have been developed to support terrestrial military operations, making the military space sector the primary driver behind the advancement of capabilities to access and use space. In addition to encouraging an increasing number of actors to access space, military space has played a key role in bringing down the cost of space access. However, increased access to, and use of, space has also led to greater competition for scarce space resources such as orbital slots and, in particular, radio frequency spectrum allocations. While disputes over these scarce resources also affect the civil and commercial space sectors, they become more acute in the military field where they are associated with national security.

Space assets have played a strategic and, increasingly, a tactical role in the terrestrial military operations of certain states. In most cases, space systems have leveraged advanced states' military capabilities through enhanced battlefield awareness, including, as mentioned above, precise navigation and targeting support, early warning of missile launch, and real-time communications. Furthermore, reconnaissance satellites have served as a national technical means of verification of international nonproliferation, arms control, and disarmament regimes. These uses, in addition to the tactical capabilities mentioned above, have driven an increasing dependence on space, particularly by the major space-faring states. It is important to note, however, that the impact of space systems on terrestrial military operations and arms control agreements, while related, is distinct from their impact on space security itself.

An increasing number of state actors are developing military uses for space. This can have a positive effect on space security by increasing the collective vested interest in space security. However, the use of space to support terrestrial military operations can have a negative impact on space security if potential adversaries, viewing space as a new source of military threats and an extension of terrestrial battlefields, develop space system negation capabilities to neutralize the advantages those systems provide.

As actors depend more on space systems to support military operations, they acquire greater incentives to protect their own space systems by developing space system protection and negation capabilities, which can lead to an arms escalation dynamic. Some argue that extensive use of space in support of terrestrial military operations blurs the notion of "peaceful purposes" as enshrined in the Outer Space Treaty (see Space Security Laws, Policies, and Doctrines).

Key Trends

TREND 5.1: US and USSR/Russia lead in developing military space systems

During the Cold War, the US and USSR developed military space capabilities at a fairly equal pace. However, the collapse of the USSR saw a massive drop in Russian military space spending while the US expanded its military space capabilities. There has been a general decrease in the number of military launches of both states in recent years.

Despite this decrease in the number of dedicated military satellites, American and Russian dependence on military space systems appears to be increasing. While new systems are being orbited at a slower rate, they have greater capabilities and longevity and are being used in conjunction with older Cold War systems. Commercial systems are also playing a rapidly growing military support role. Figures 5.1 and 5.3 provide an overview of US and Russian military space satellites.

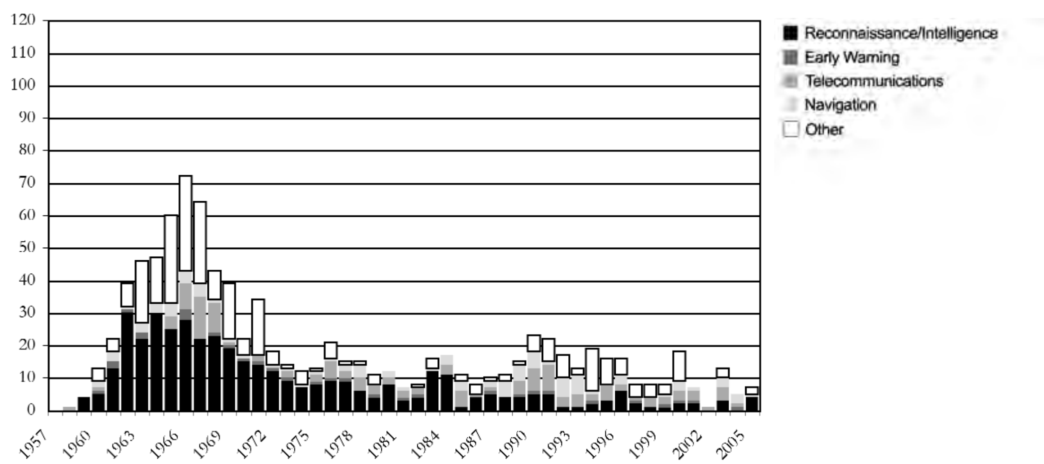
United States

The US has dominated the military space arena since the end of the Cold War. The US currently outspends all other states combined on military space applications, accounting by some measures for 95 percent of total global military space expenditures.[1] At the end of 2004, the US had approximately 135 operational military-related satellites, representing over half of all military satellites in orbit.[2] It continues to place heavy emphasis on upgrading all aspects of its military space capabilities and is, by all major indicators, the actor most dependent on its space capabilities. By comparison, Russia is believed to presently have some 85 operational military satellites in orbit.[3]

The US military relies heavily on satellite communications and operates several systems. The Military Satellite Communication System (Milstar) is currently one of the most important, providing secure, jam-resistant communications for the US Army, Navy, and Air Force, through five satellites in Geostationary Orbit (GEO). There is a plan to replace current Milstar satellites with Advanced Extremely High Frequency satellites, which are designed to provide assured strategic and tactical command and control communications worldwide.[4] By 2012, the US hopes to deploy the Transformation Satellite Communications System to provide high-speed internet-like information availability to the military, using satellite laser communications technology.[5]

The Defense Satellite Communications System (DSCS) – the workhorse of the US military's super-high frequency communications – is a hardened and jam-resistant constellation that transmits high-priority command and control messages to battlefield commanders using five satellites in GEO. A planned follow-on to this system is the Advanced Wideband System (AWS), expected to increase available bandwidth significantly.[6] The Global Broadcast System and Ultra High Frequency (UHF) follow-on satellites provide wideband and secure, anti-jam communications, respectively. The Wideband Gapfiller System is intended to bridge the transition between retirement of the DSCS and full deployment of the AWS constellations. The US military also maintains a polar military satellite communications system to assure communications in those regions. In addition to these dedicated systems, space-based military communications use commercial operators such as Globalstar, Iridium, Intelsat, Inmarsat, and Telstar.[7]

FIGURE 5.1: US military space launches (1957-2005)[8]



Space-based early warning systems provide the US with critical missile warning and tracking capabilities. The first such system, the US Missile Defense Alarm System, was deployed in a polar orbit beginning in 1960, followed by the Vela series early warning satellites. The current US Defense Support Program (DSP) early warning satellites were first deployed in the early 1970s in GEO, providing enhanced coverage of the USSR while reducing the number of necessary satellites to four.[9] The US is planning to replace the DSP system with Space Based Infrared High (SBIRS-High) satellites over the next decade, which will provide advanced surveillance capabilities for missile warning and missile defense.[10] The anticipated US Space Tracking and Surveillance System (formerly known as SBIRS-Low) is intended to work with SBIRS-High to provide early warning and missile tracking to support missile defense responses (see Space Systems Protection).

The first US optical reconnaissance satellites were launched as early as 1959, with the Soviets following suit by 1962.[11] These early imaging satellites had lifetimes of only days and were equipped with film-based cameras. At the end of their operational lifetimes, capsules with the exposed film were ejected from the satellite and collected, usually from the ocean.[12] Gradually, resolution of these cameras was improved from about 10 meters to the current optical resolution of less than a meter. While the precise resolution of today's imaging satellites remains classified, the US is generally thought to have optical satellites with resolutions as low as 10 centimeters.[13] As early as 1976, the US began to fit its imaging satellites with devices which transmit images using electromagnetic communications that provide near-real-time satellite imagery.[14] Open sources information suggests that the US currently maintains in orbit about eight to 10 imagery intelligence satellites, which comprise two optical systems known as Crystal and Misty, and one synthetic aperture radar system known as Lacrosse. The US operates 18 to 24 signals intelligence (SIGINT) satellites in four separate systems known as the Naval Ocean Surveillance System, Trumpet, Advanced Orion, and Vortex (see Figure 5.2).[15]

Anticipated US Space-Based Radar satellites will be designed to provide tactical support capable of tracking "moving ground targets in operational theatres,"[16] and are slated for initial launch in 2012. The US military also uses several commercial imagery services such as DigitalGlobe, Space Imagery, and SPOT Image (see Commercial Space). For example, Landsat is a dual-use imaging satellite used by the US military for tactical planning. The Defense Meteorological Satellite Program provides environmental data in support of military operations. There are also several dual-use civilian-military meteorology spacecraft, including the Geostationary Operational Environmental Satellite and the Polar-orbiting Operational Environmental Satellite.[17]

In 1964 the first navigation system was deployed for military applications by the US Navy, and its position resolution was accurate to greater than 100 meters. This system and others that followed were ultimately replaced by the GPS, which was declared operational in 1993 and uses a minimum constellation of 24 satellites orbiting at an altitude of about 20,000 kilometers. On the battlefield, the navigational system is used at all levels, from navigation of terrestrial equipment and individual soldiers to target-identification and precision weapons guidance (see Civil Space Programs and Global Utilities).

Since 2003, the US Air Force (USAF) has promoted a concept called Operationally Responsive Spacelift (ORS), that aims to reduce satellite costs and deployment times from years or months to days. Such savings are made possible by new launch capabilities, combined with miniaturization technologies that have dramatically increased the "capability per kilogram on orbit" equation for satellites.[18] These ORS efforts seek the capability to replace US satellites on short notice,[19] allowing the US to rapidly recover from space negation attacks and reducing general space system vulnerabilities. ORS would also allow deployments of space systems designed to meet the needs of specific military operations. For example, the US TacSat will be an ORS demonstration imaging satellite, weighing just 110 kilograms and combining existing military and commercial technologies with new commercial launch systems to provide "more rapid and less expensive access to space."[20] The satellite will be controlled directly by deployed US commanders.[21]

FIGURE 5.2: Characteristics of key US military space systems[22]

Current programs	Function	Orbit	Constellation	Future planned systems
Defense Satellite Communications System III	Communications	GEO	5	Advanced Wideband (2009)
Military Satellite Communication System (Milstar)	Communications	GEO	5	Advanced Extremely High Frequency (2006) and Transformational Satellite Communications System (TSAT) (2012)
Polar Military Satellite Communications	Communications	GEO	1	Advanced Polar System (2010)
UHF Follow-on Satellite	Communications	GEO	4	
Global Broadcast System	Communications	GEO	3	Wideband Gapfiller System (2006) and the Mobile User Objective System (MUOS) (2009)
Defense Meteorological Satellite Program	Weather	LEO	2	
Global Positioning System	Navigation	MEO	24	
Defense Support Program	Early Warning	GEO	22	Space Based Infrared High System (2007) and Space Tracking and Surveillance System (2007)
N/A	Tactical Warning			Space Based Radar (2012)
Crystal	Imaging	LEO	3	
Lacrosse	Imaging	LEO	3	
Misty	Imaging	LEO	?	
Naval Ocean Surveillance System (NOSS)	SIGINT	LEO	10	
Advanced Orion (Mentor)	SIGINT	GEO	2	
Vortex (Mercury)	SIGINT	GEO	3	
Trumpet (SB-WASS)	SIGINT	HEO	3	

The Evolved Expendable Launch Vehicle (EELV) program is a $31.8-billion USAF effort that began in 1994, with the objective of reducing launch costs by at least 25 percent by partnering with industry to develop launch capabilities that can be used for both commercial and government purposes.[23] To meet future government requirements, both the Lockheed Martin Corporation and the Boeing Company are also pursuing Heavy Lift launch capability under the EELV program. Boeing tested the Delta 4 Heavy in 2004, which, despite some difficulties, is expected to provide lift capacity for 13,130 kilograms into GEO.[24] Lockheed's Atlas V Heavy is described as "available 30 months from order," but there are no specific plans for its launch.[25]

The growing dependence of the US upon space systems to support military operations has raised concerns about the vulnerability of these assets. The 2001 *Report of the Commission to Assess United States National Security Space Management and Organization* warned that US dependence on space systems made it uniquely vulnerable to a "space Pearl Harbor" and recommended that the US develop enhanced space control (protection and negation) capabilities (see Space Systems Protection, Space Systems Negation, and Space-based Strike Weapons).[26]

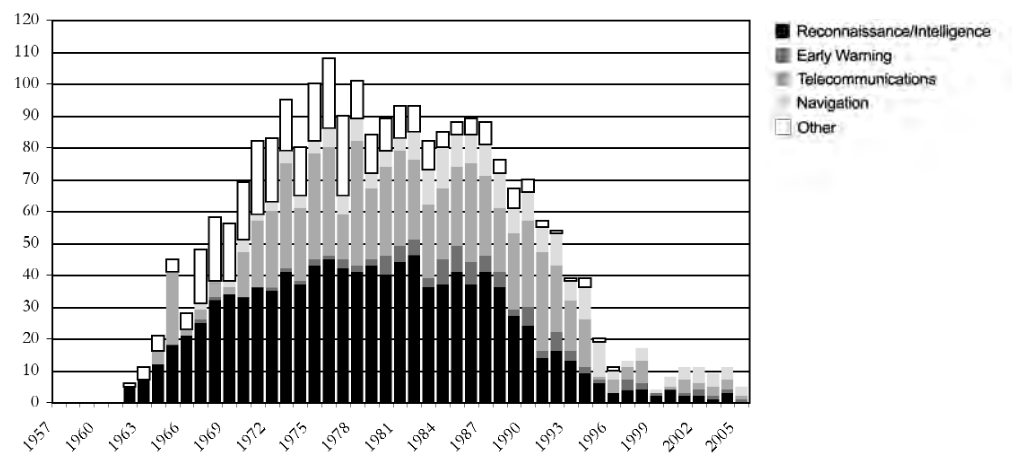
Russia

Russia maintains the second largest fleet of military satellites, but their capabilities remain focused primarily on providing strategic support. Its current early warning, optical reconnaissance, communications, navigation, and SIGINT systems were developed during the Cold War, and between 70 and 80 percent of its spacecraft have now exceeded their designed lifespan.[27] However, some of Russia's more critical systems have received replacement satellites over the years, albeit often from Soviet-era equipment, and several Russian military space systems have managed to survive this transition with some operational capacity.

Russia maintains several communications systems, most of which are dual-use. The Raduga constellation of satellites, promoted as a general purpose system, is reported to have secure military communications channels.[28] The Geizer system is designed to deploy four GEO satellites as a communications relay system for Russian imaging and communications satellites in Low Earth Orbit (LEO), but currently has only one operational satellite in orbit.[29] The Strela-3 military communications system was deployed in the late 1980s and more recently has been paired with civilian Gonets satellites in the same LEO orbits, likely augmenting the military satellite system.[30] The Molniya-1 and -3 satellites are in Highly Elliptical Orbits (HEO) and serve as relay satellites for both military and civilian use. There are indications that maintenance of the Molniya, Strela, and Raduga systems will remain a priority for Russia.[31]

The USSR launched its first early warning Oko satellite in 1972 and by 1982 had deployed a full system of four satellites in HEO to warn of the launch of US land-based ballistic missiles.[32] By the end of the 1990s, this system had been replaced by two satellites in HEO and one in GEO, which provide coverage of US ballistic missile fields with reduced reliability.[33] In 1991, Russia began launching US-KMO, a next generation early warning satellite system, using a mixture of GEO and HEO satellites. While six satellites were in orbit by April 2003, the US-KMO system has been plagued with malfunctions, and none of these satellites is considered operational today (see Space Systems Protection).[34]

FIGURE 5.3: USSR/Russia military space launches (1957-2005)[36]



The USSR began using optical reconnaissance satellites in 1962 and by the 1980s it was electronically transmitting images while still maintaining a film-based system of photoreconnaissance.[36] Russia's optical imaging capabilities have declined since the Cold War, and it does not currently have the capability to maintain continuous coverage of the Earth. The two Russian photo electronic reconnaissance systems in operation today are the Yantar-4KS1 Newman system and the Arkon system, which received new satellites in 2000 and 2002, respectively. Russia maintains two SIGINT satellite systems, neither of which is fully operational. US-PU/EORSAT is dedicated to detecting electronic signals from surface ships, while Tselina is used for more general signals intelligence purposes. There are indications that Russia is developing a new system, but few details are available.[37]

The first Soviet navigational system is thought to have been the Tsyklon system deployed in 1968. Tsyklon was followed by the Parus military navigation system, deployed in 1974 and still operational today, with an accuracy of about 100 meters.[38] Currently, however, this constellation provides more services to the civilian, than the military, sector The USSR began development of its second major navigation system, GLONASS, in 1982. Unlike Tsyklon and Parus, GLONASS can provide altitude as well as longitude and latitude information by using a minimum constellation of 24 satellites at a 19,100 kilometer orbit.[39] With a full constellation, the navigational system is supposed to have resolution comparable to that of the GPS.[40] Russia plans to increase the number of GLONASS satellites in orbit to 17 by 2007 and to 24 by 2010 (see Civil Space Programs and Global Utilities).[41]

As noted in Figure 5.3, Russia has tended to maintain an average annual satellite launch rate slightly higher than that of the US. However, this has not been sufficient to keep its military space systems fully operational since they require more frequent replacements. Forced to prioritize, Russia has focused first on its early warning systems, and more recently has moved to renovate the GLONASS navigation system.[42] In 2004, Russia stated that it would focus on "maintaining and protecting" its fleet of satellites and beginning to develop satellites with post-Soviet era technology.[43]

TREND 5.2: More states developing military space capabilities

By the end of 2004, the US and USSR/Russia had together launched more than 2,000 military satellites, while the rest of the world had only launched between 40 and 50.[44] The UK, NATO, and China were the only other actors to launch dedicated military satellites until 1988, when Israel launched its first. France's Telecom series of satellites, launched in the mid-1980s was reportedly dual-use.[45] In 1995, France and Chile both launched dedicated military satellites.[46] Traditionally, military satellites outside the US and Russia were almost exclusively intended for telecommunications and reconnaissance. Recently, however, states such as Australia, China, France, Germany, Japan, Italy, and Spain have been developing military satellites with a wider range of SIGINT, navigation, and early warning functions.

In the absence of their own dedicated military satellites, some actors rely on dual-use satellites, buy existing satellites from others, or purchase data and services from other satellite operators.[47] In the Cold War, states allied with either the US or the USSR benefited from their ally's capabilities. Today, however, declining costs for space access and the proliferation of space technology enable more states to develop and deploy military satellites, using the launch capabilities and manufacturing services of others, including the commercial sector.

FIGURE 5.4: States' first military satellites and their function[48]

Year	State/Actor	Description
1958	US	Telecommunications experimental satellite
1962	USSR	Reconnaissance
1969	UK	Telecommunications
1970	NATO	Telecommunications
1975	China	Reconnaissance
1988	Israel	Telecommunications
1995	France	Technology development for electronic intelligence
1995	Chile	Telecommunications and remote sensing
1998	Thailand	Telecommunications
2003	Australia	Telecommunications
2003	Japan	Reconnaissance

Europe

European states have developed a range of space systems to support military operations. France, Germany, Italy, and Spain jointly fund the Helios 1 and Helios 2 military observation satellite systems in LEO, which provide images with a one-meter resolution and supply imagery to the European Union (EU). The French Ministry of Defense procurement agency (DGA) runs the program, retains direct control over the management of the ground segment, and delegates the space segment responsibility to the French space agency, the Centre National d'Etudes Spatiales. France, Germany, and Italy are also planning to launch six low-orbit imagery intelligence systems that will exchange data, but not share a common ground segment.[49] France further intends to launch two high-resolution dual-use optical imaging satellites, known as Pleiades, by 2008.[50] By 2007, Germany plans to launch five SAR-Lupe high-resolution radar satellites, which will deliver radar images for the German Armed Forces for at least ten years.[51] Italy is developing a constellation of four dual-use COSMO-Skymed Earth observation satellites that are scheduled for completion in 2007 and will be integrated with Pleiades.[52] In 2004, France launched a constellation of four SIGINT satellites know as Essaim.

The UK maintains a constellation of three dual-use Skynet 4 UHF and Super High Frequency (SHF) communications satellites in GEO.[53] It began work in 1998 to develop four Skynet 5 military communications satellites.[54] France also maintains the dual-use Telecomm-2 communications satellite, in addition to the military Syracuse 2 system.[55] Italy's Sicral military satellite provides secure UHF, SHF, and Extremely High Frequency communications for the Italian military.[56] Spain operates the dual-use Hispasat system, which provides X-band communications to the Spanish military.

The EU has called for a more coherent approach to the development of space systems capable of supporting military operations and has begun to actively develop dual-use systems. The joint EU and European Space Agency (ESA) Global Monitoring for Environment and Security (GMES) project will collate and disseminate data from satellite systems and is anticipated to be operational by 2008. It will support activities prioritized in the European Security and Defense Policy, such as natural disaster early warning, rapid damage assessment, and surveillance and support to combat forces.[57]

The Galileo satellite navigation program, initiated in 1999 and jointly funded by the EU and the ESA, will provide location, navigation, and timing capabilities.[58] Galileo is intended to operate principally for civil and commercial purposes, but will have a dual capability. The fact that ESA, founded with a mandate to launch only peaceful space missions, has recently opened a Space Security Office indicates the changing military space landscape in Europe. EU states spend a total of about $970-million per year on military space activities, largely through the national satellite communications and reconnaissance programs discussed above.[59]

China

China does not maintain the same separation between civil and military space programs that many other states do, and, officially, its space program is dedicated to science and exploration.[60] Leadership of the space program is provided by the Space Leading Group, whose members include three senior officials of government bodies that oversee the defense industry in China.[61] Thus, although the Chinese military's role in the space program is unclear, the space program is certainly governmental.

China began working on space imagery in the mid-1960s, launching its first reconnaissance intelligence satellite in 1975.[62] It successfully launched 15 recoverable film-based satellites, the last of which was reportedly decommissioned in 1996. Several of these satellites were also reported to carry "domestic and foreign commercial microgravity and biomedical experiments."[63] Today, China maintains two ZY series satellites in LEO for tactical reconnaissance and surveillance.[64] It is believed to be purchasing additional commercial satellite imagery from Russia to meet its intelligence needs.[65]

Western experts believe that Chinese military satellite communications are provided by the DFH series satellite, officially known as ChinaSat-22. Officially referred to as a civilian communications satellite, the ChinaSat-22 is thought to enable "theatre commanders to communicate with and share data with all forces under joint command" through C-band and UHF systems.[66] China also operates a pair of Beidou navigational satellites designed to augment the data received from the US GPS system and to enable China to maintain navigational capability in the face of US efforts to deny GPS services in times of conflict (see Civil Space Programs and Global Utilities).[67] Beidou may also improve the accuracy of China's intercontinental ballistic missiles (ICBMs) and cruise missiles.[68]

China experimented with electronic intelligence (ELINT) satellites, called "technical experimental satellites," in the mid-1970s but these programs have since been discontinued. Presently, it uses modern air, sea and land platforms, not satellites, to perform SIGINT missions.[69]

Israel

Israel operates a dual-use Eros-A imagery system, which is capable of providing images with a resolution of about 1.8 meters.[70] Israel also operates the dedicated military Ofeq-5 system, which provides both panchromatic and color imagery at resolutions of less than one meter for reconnaissance and surveillance purposes.[71] The Israeli Ministry of Defense is managing five satellite programs scheduled for completion in 2008: Ofeq-6 and Ofeq-7 are to provide more advanced imaging satellites; TechSAR will be a synthetic aperture radar technology demonstrator; a military version of the Amos-2 commercial communications satellite will be developed;[72] and the Milcom-1 encrypted communications satellite is scheduled for launch in 2007. Israel's programs reflect an interest in exploiting space systems in support of terrestrial military operations, including operational and tactical missions. Recently the Israeli Air Force was renamed the Israeli Air and Space Force.[73]

South Asia

India maintains the Technology Experimental Satellite, which provides images with a resolution of between one and 2.5 meters, and also operates an ocean remote sensing satellite, which was deployed in 1999.[74] Pakistan's space-based capabilities are not believed to be as advanced as those maintained by India, though it operates the Badar 1 multipurpose satellite and is currently developing the Badar 2.[75] While India and Pakistan clearly seem intent on developing space systems capable of supporting military operations, significant progress in this area remains a longer-term objective.

East Asia

The commercial Superbird satellite system provides military communications for Japan, which also has the two reconnaissance satellites – one optical and one radar – that were launched in 2003 following growing concerns over North Korean missile launches.[76] A second launch effort later in 2003 resulted in a high-profile failure of its indigenously developed H-2 rocket.[77] Japan plans to have three intelligence satellites by 2007 and an advanced reconnaissance satellite by 2010.[78] The manufacturer of the optical reconnaissance satellite, Mitsubishi, is also a partner in Space Imaging.[79]

South Korea operates the Kompsat-1 satellite, which provides imagery with a resolution of 6.6 meters, which is "sufficient for [military] mapping although not for military intelligence collection."[80] It also bought 10 Hawker 800 series satellites from the US, and has operated them for signals intelligence since 1999.[81] In December 2003, South Korea announced its intentions to increasingly use space for military purposes.[82]

In July 2004, Thailand signed a deal with the European Aeronautic Defence and Space Company (EADS) Astrium to provide its first Earth observation satellite, which is expected to be used for intelligence and defense purposes.[83]

This growth in the number of new actors that are developing military space capabilities has been facilitated by commercial actors such as the UK's Surrey Satellite Technology Ltd., which has alone enabled nine states in the last 12 years to develop and deploy their first satellite with various communications and remote sensing capabilities, all using foreign launchers (from Russia and Europe in particular).[84] By using commercial off-the-shelf components and limiting satellite functions to specific tasks, certain satellite systems are being made smaller and lighter, thus improving deployment timelines and decreasing total system and launch costs. Not only are the responsive capabilities of existing space powers increased, but so is the ability of less affluent states to exploit space for military support purposes. Moreover, actors can increasingly obtain commercial space products that have significant capabilities to support terrestrial military applications. An example of this is the wide availability of meter-resolution satellite imagery from companies such as Digital Globe, Space Imaging, and Google Earth.

Australia

Until recently, the Australian defense forces used X-band facilities on satellites owned by the US and other allies, but wanted to have its own X-band satellite payload with a footprint covering more of Australia's region.[85] On 12 June 2003, Australia launched the Defence C1 communications satellite. The satellite will be part of a new communications system, the Australian Defence Satellite Communications Capability, which will provide the country's defence with satellite communications across Australia and throughout the Asia Pacific region in the X, Ka and UHF radio frequency bands.[86] Defence C1 is one of the most advanced communications satellites ever built, providing 18 beams across Australia, New Zealand, and the Asia-Pacific region, as well as global beams covering India to Hawaii.[87]

TREND 5.1: The US and Russia lead in developing military space systems

2005: Significant cutbacks to a number of US military space programs

The US remained the dominant military space actor in 2005 in terms of both capabilities and budget, with USAF Space Command alone running programs costing $15-billion.[88] However, the US military space program continued to come under fiscal and political pressure in 2005. Launch delays and significant cost overruns were cited as the major reasons for recommendations by the US Congress to cut the budgets for a number of satellite programs.

Of concern are the Future Imagery Architecture (FIA) program and the highly classified next generation of stealth imagery satellites. The FIA program has been plagued by technical problems that sent costs well beyond the initial projection of $10-billion and delayed the expected launch of new satellites.[89] Cost increases for this program alone are estimated to be more than $25-billion over the next decade. Reports indicate that the classified stealth satellite program has seen its estimated costs double to $9.5-billion.[90] The US Senate Intelligence Committee has moved to cancel the program.[91]

Also in 2005 the USAF announced that the National Polar-orbiting Operational Environmental Satellite System, initially budgeted at $6.8-billion, will likely exceed its estimated cost by 15 percent.[92] The SBIRS-High program continues to experience delays and is expected to exceed its cost projections by more than 25 percent.[93] While the USAF is considering curtailing the number of satellites produced, past reviews of SBIRS-High have failed to find alternatives that meet the system's objectives without increased risk, cost, and delay.[94] General Lance Lord, recently retired head of USAF Space Command, acknowledged the management problems of SBIRS-High, but expressed hope that the program will soon be on track.[95]

The US House of Representatives in 2005 recommended a $525-million cut to the TSAT system and the Space Radar – two programs also plagued by delays and cost overruns.[96] The Senate's bill recommended cutting $250-million from the Pentagon's request for $836-million for TSAT, and $126-million from the $226-million requested for Space Radar.[97] Nevertheless, the initial launch of the five-satellite TSAT constellation is planned for 2013.[98] The Congressional Budget Office estimated that the USAF budget for space programs would grow by 40 percent in 2006 and double by 2011, "mostly to pay for existing programs."[99]

2005: Russia continues to face setbacks in military space programs

The Russian government and its space agency, Roscosmos, continued to struggle to maintain military space capabilities in 2005 in the face of funding shortages, depletion of space assets, and space launch failure. Anatoly Perminov, the head of Roscosmos, had identified growth in its fleet of spacecraft as a priority to retain Russia's status as a leading space power.[100] At present, the Russian fleet comprises 96 military and civil spacecraft, but plans to add 73 new-generation spacecraft by 2015[101] will require significant funding increases to a budget currently 30 times less than the US budget.[102] The military has been launching decommissioned ICBMs on commercial missions, but has not seen significant revenues since the commercial launches started ten years ago.[103]

According to Russia, more than 80 percent of its military satellites have outlived their official service life.[104] Roscosmos reports that it has 18 multipurpose satellites and 40 dedicated military satellites, of which 33 have outlasted their usefulness.[105] Russia currently lacks high resolution space radars; its last radar was lost when the Almaz-1 spacecraft, a former manned military station, stopped operating in 1991.[106] While the US possesses 12 satellites capable of monitoring Russia, according to the deputy head of Russia's space forces, General Oleg

Gromov, only one Russian photoreconnaissance satellite remains. Additionally, he has said that Russian military satellites only cover a third of the Earth's surface at any given time.[107] According to Western intelligence sources, four of the six Oko early warning satellites that detect possible US ICBM launches are non-operational; and of the early warning satellites that are designed to detect ICBM launches from US Trident class submarines, only the one surveying the mid-Atlantic is operational. The two operational Oko satellites observe the US for six hours a day each; the rest of the time Russia is reliant on ground-based radars and would only know of an attack when incoming missiles were detected by these radars.[108]

This situation was compounded by a number of failed launches in 2005. On 21 June, Russia lost its Molnya-3K military satellite when the Molnya-M carrier rocket crashed six minutes into its flight.[109] On 26 August, the Monitor-E surveillance satellite achieved orbit, but the spacecraft went dead soon after.[110] On 28 October, the military satellite Mozhayets-5 failed to separate from its booster rocket Kosmos-3. The satellite is currently rotating in a LEO with the booster's third stage and is sending no signals to Earth.[111]

There were also a number of successful launches in 2005. On 20 January, the Parus-96 navigation satellite was launched into LEO. Normally part of a six-satellite constellation, the military satellite has a service life of two to three years.[112] Since the development of the GLONASS navigation system, data relay is the principal utility of the Parus satellite.[113] On 21 December, Russia successfully fielded the Gonets-D1M and Rodnik military communications satellites into LEO. The Gonets satellite has been added to a multipurpose satellite communications group, which primarily serves Russia's security-related and law enforcement agencies.[114] The new satellite will provide high-speed transmissions of short messages, email, and other communications and will have a service life of seven years. Also sent into orbit on the Kosmos-3M was a military craft known as Sreta-3, which experts believe could be similar to Gonets, but for use by military forces.[115] On 25 December, Russia enlarged its GLONASS constellation with three new satellites (Kosmos 2417, Kosmos 2418, and Kosmos 2419).[116] There are currently 14 satellites in the system, but it is expected to be expanded to 18 satellites by 2007. In November 2005, the Ministry of Defense announced that the military will get six new satellites in 2006.[117]

On 3 March 2005, it was reported that Russia would orbit an entire constellation of high-resolution space radars in the next few years, utilizing Arkon-2 and Kondor-E satellites.[118] The system would possess unique three-band radar that would enable object detection in undergrowth or surface scanning under dry ground.[119] The Arkon-2 satellite will provide high quality photos of areas measuring 10 square kilometers, with a resolution of up to one meter, and panoramic photos in a 450-kilometer sector, with a resolution of up to 50 meters. Also under development is the Kondor-E high-resolution radar satellite, which has a multirole radar that provides high-resolution images along two 500-kilometer sectors left and right of its orbit. The satellite's onboard radar will also provide three-dimensional images for digital terrain models.

Net assessment:

Developments for 2005 could have a mixed impact on space security. The developments in US military communications satellites will increase space security in several ways: as satellite data transmission rates improve, the US will be able to transmit more information with the same amount of bandwidth, thus reducing pressure to claim more of the frequency spectrum. As their transmission protection capability increases (i.e., anti-jamming/anti-interception), the need for other types of protection and negation techniques (such as detecting and targeting Earth stations emitting jamming signals) will decrease. However, as US satellites become harder to jam and intercept with current methods, other countries could feel compelled to develop more advanced satellite negation capabilities. Furthermore, as the US becomes more dependent on space support for their military operations, their space systems may also become more of a target for negation.

If the reduction in Russian launch reliability seen in 2005 becomes a trend, it would have a negative effect on space security: The many different actors who use Russian launch vehicles and facilities face greater risks with less confidence in their ability to access and use space. Strengthening GLONASS, however, could be positive as it would provide redundancy with GPS as well as better accuracy at higher latitudes.[120]

TREND 5.2: More states developing military space capabilities

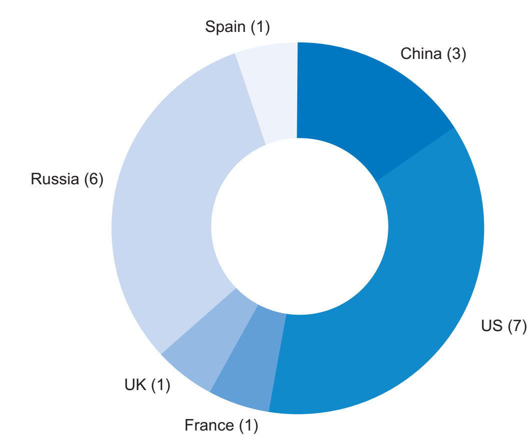
2005: Regional tensions drive military space development in Asia

Existing military space powers in East Asia continued to develop their capabilities in 2005. Taiwan announced plans to launch a $300-million reconnaissance satellite, presumably as a result of continued tensions with China.[121] The planned system, named Follow-On RSS (Remote Surveillance Satellite), would replace Taiwan's Formosa II and be capable of producing images with 50 centimeters resolution.[122] In the meantime, an unnamed Taiwanese official has said that the military and security authorities will have to increase their reliance on images taken from their existing Formosa II "research" satellite, which has 1.8 meter resolution.[123] The Formosa II, for which Chinese officials expressed the concern that it would be used for military purposes, was launched in May 2004; its service life is not expected to last beyond 2008 or 2009.[124]

In an effort to improve satellite images of North Korea's nuclear and missile facilities, Japan began research in 2005 on reducing the size of reconnaissance satellites to enhance their maneuverability.[125] The Japanese government plans to launch its second-generation reconnaissance satellites in FY2005 or FY2006; a third generation in 2009; and a fourth in 2010 or 2011. The Japanese Defense Agency also plans to construct a large-scale image communications system intended to cover East Asia, parts of the Middle East, and Africa.[126]

In Pakistan, President Musharraf approved construction of the Remote Sensing Satellite System (RSSS) on 21 August 2005. Expected to cost $323.8-million, the system is designed "to ensure strategic and unconditional supply of satellite remote sensing data, for any part of the globe over the year." The RSSS will provide high-resolution satellite images in support of the military.[127]

FIGURE 5.5: Dedicated military space mission in 2005



2005: China continues to expand military space program

With a total space budget estimated at $2.2-billion, China continued its ambitious satellite program in 2005.[128] Launched on 27 October, the Beijing-1 (Tsingshua-1) microsatellite is an Earth observation spacecraft that combines a multispectral camera with a high-resolution panchromatic imager.[129] In 2005, China signed agreements with the EU to participate in Galileo, committing $241-million to the project.[130] There is speculation that China's participation in the Galileo navigation system may eventually be used to improve the accuracy of its missiles.[131]

Questions continued to arise in 2005 over China's space programs and whether the civil and commercial activities of a space program that is operated by the People's Liberation Army have concealed military intentions. There have been suggestions that China plans to compete with the US in all areas, including military applications and anti-satellite weapons.[132] Some US officials believe that China will use its space assets to play a major role in the use of force and has shown "significant indications" of developing space weapons, such as satellite-killing missiles, lasers, and satellites.[133] The US Department of Defense supports these assertions in its report, "The Military Power of the People's Republic of China 2005."[134] Other analysts are unconvinced, and suggest that the DOD has no clear evidence to support their contentions.[135] Indeed, the 2005 DOD report dropped previous assertions that China was developing "parasitic micro-satellites," after serious questions emerged regarding the credibility of the intelligence.

Analysts have questioned the purpose of the Shenzhou 6 mission of October 2005. Some analysts support the view that all Shenzhou missions to date have provided the basis for military missions, and that the most recent had at least some image intelligence-gathering capacity.[136] Claims that the Shenzhou 6 carried a single large camera mounted at the "porthole" position has led to speculation that the main mission of China's second manned spaceflight was a continuation of the military imaging reconnaissance conducted by Shenzhou 5.[137] Others analysts contend that the goals of the piloted program are quite specific to the missions and that the equipment being developed for Shenzhou is devoted to accomplishing those goals.[138]

2005: Europe expands navigation, imaging, and communications capabilities

European states launched three military satellites in 2005, contributing to a trend in which an increasing number of states other than Russia and the US are building up military space capabilities. France launched a large communications satellite called Syracuse; Spain launched the communications satellite XTAR-EUR; and the UK launched an imagery microsatellite called TopSat. TopSat, built by Surrey Satellite Technology Ltd. (SSTL), continues the trend in which microsatellites are used for military purposes. A March EU report on security needs in the space sector recommended consolidation and greater interoperability between current European national space systems.[139]

The first two Galileo navigation satellites were developed in 2005. The first satellite arrived at the European Space Agency's European Space Research and Technology Centre in August and was developed by SSTL.[140] A joint initiative of the EU and ESA, Galileo will both compete with and complement the current US GPS system, and also be compatible with the Russian GLONASS network, but is designed strictly for civilian use. The European navigation system will deliver real-time positioning accuracy down to the meter range, unprecedented for a publicly available system.[141] On 29 December 2005, the first Galileo satellite was launched (see Civil Space Programs and Global Utilities).

Spain's XTAR-EUR communications satellite was successfully launched on 12 February 2005. The XTAR-EUR satellite's footprint stretches from Eastern Brazil and the Atlantic Ocean, across all of Europe, Africa, and the Middle East to Singapore, providing X-band services to military clients.[142] The Spanish Ministry of Defense is XTAR's first customer; when its primary national satellite, SPAINSAT, enters service XTAR will provide backup capacity.

2005: France developing satellite communications and early-warning system

In 2005, France continued to develop the most advanced and diversified independent military space capabilities in Europe. On 13 October, France launched into GEO the Syracuse 3A, the first in a new generation of satellites designed to provide ultrasecure communications for the French military. Compatible with Britain's Skynet and Italy's Sicral, the satellite has been described as "the cornerstone in a European military Satcom system" under an arrangement by which NATO allies pool their satellite resources.[143] NATO's 3C agency recently chose the three systems to provide SHF communications for member countries.[144] In December, the Syracuse 3A was accepted by the French procurement agency (DGA) after successful performance tests.[145] It is designed to increase military satellite communications capacity tenfold, ensuring security against surveillance and interference while also providing communications in difficult-to-access areas.[146] The satellite is expected to have a 12-year lifespan.

In October 2005, EADS Astrium chose Arianespace to launch two Spirale early-warning microsatellites for a probative research and technology demonstration program.[147] French defense company Thales, appointed the prime contractor for the Melchior program in 2005, will provide the French armed forces with a high-frequency communication system. Melchior will be vital for military theatre communications and will be interoperable with NATO systems.[148]

2005: UK military expands satellite communications and develops interest in microsatellites

The British Skynet 5 program was delivered a month ahead of schedule in February 2005. The original program consisted of two hardened military communications satellites, the Skynet 5A and 5B, each carrying SHF and UHF communications payloads. In December, Skynet 5C was added.[149] The satellites will feature enhanced survivability, anti-jamming capabilities, and multiple directional spot beams.[150] The system will provide advanced and flexible satellite communications for the UK military, with an expected capacity 2.5 times greater than the current system's.[151] Each new satellite will have sufficient excess capacity to enable Paradigm Secure Communications, a subsidiary of EADS Space Services, to generate further revenue by delivering specialist military and government communications to other customers. Canada, France, Portugal, NATO, and two undisclosed customers have signed on.[152] Skynet 5A, 5B, and 5C will be launched in 2006, 2007, and 2008, respectively.

The high resolution imaging TopSat microsatellite was launched on 27 October 2005. Although not a dedicated military satellite, TopSat – built by a British partnership that includes SSTL (who made the satellite bus) and is led by QinetiQ – is jointly funded by the Ministry of Defence (MOD) and the British National Space Centre. The program is intended is to provide a good commercial standard of imagery at a much lower cost than what is currently available.[153] On 20 December, QinetiQ announced that TopSat had successfully transmitted the first high resolution images.[154] The MOD is already considering a possible follow-on program and increased use of LEO microsatellites as part of a mix of assets to provide persistent intelligence, surveillance, target acquisition, and reconnaissance.[155]

2005: Proliferation of military space capabilities in the Middle East

On 27 October 2005, Iran became the 45th country in the world to own a satellite, the Sina-1, which was launched by a Russian Kosmos-3 launcher. Designed by the Russian firm Polyot, Sina-1 has a resolution precision of about 45 meters and the Iranian government claims that the satellite will be used to collect data on ground and water resources, as well as meteorological conditions.[156] However, less than a month after its launch, the head of Iran's space program said the Sina-1 is capable of spying on Israel and some suggest it is a response to Israel's Ofeq-5 reconnaissance satellite.[157] However, the resolution precision of the Sina-1 clearly limits the effectiveness of any military reconnaissance functions. In cooperation with Italy's Carlo Gavazzi Space, Iran plans to launch a remote sensing Mesbah satellite in the near future and is still pursuing its own Space Launch Vehicle (SLV) – the Shehab-4 missile.[158]

Israel is working to overcome the 6 September 2004 failure of its Shavit-1 SLV and destruction of the Ofeq-6 satellite by developing the Ofeq-7 and the TechSAR surveillance and reconnaissance satellites.[159] TechSAR's launch is scheduled for 2006 at an estimated cost of $15-million.[160] It has become a top priority for the acquisition of strategic image intelligence, intended to have a 14-kilometer-wide imaging swath.[161] Both the Ofeq and TechSAR satellites were developed indigenously as part of Israel's plan to expand its recently created military space command and boost reconnaissance capabilities.[162] Additionally, Israel has signed on to cooperate with the EU's Galileo satellite navigation system and is pursuing air-launched surveillance microsatellites.[163]

Since the failure of the Shavit 1 SLV, Israel has reached an agreement to launch the TechSAR on an Indian Polar SLV.[164] While most reviews have described the TechSAR as a military reconnaissance satellite, Israel claims it has no military capabilities; the statement may speak to the fact that the Indian Space Research Organization (ISRO) is not authorized to launch military space vehicles.[165] The Israeli government has not abandoned SLV self-reliance and plans to send the Ofeq-7 into orbit using an improved version of the rocket.[166] A successful test of the latest Shavit SLV was reported on 14 July 2005, indicating that the rocket was capable of carrying a 700-kilogram payload.[167]

2005: India boosting surveillance and reconnaissance capabilities

The Indian satellite-based Military Surveillance and Reconnaissance System that was to be operational in 2005 is now scheduled for 2007.[168] A joint venture between ISRO and the Defence Research and Development Organization, the remote sensing satellite system would work with extensive ground-based surveillance systems to enable India to keep watch on all areas of concern within the region, including missile silos. India has also entered into discussions with the Israeli MOD and Israel Aircraft Industries Ltd. regarding the possible purchase of a TechSAR reconnaissance satellite.[169] India has not launched any explicitly military satellites to date, though several of its civilian satellites have resolutions that would make them acceptable reconnaissance satellites: Cartosat-1, launched on 7 May 2005, has a resolution of 2.5 meters. The future Cartosat-2 will have better resolution than its predecessor.[170] According to ISRO, Cartosat-2 will provide scene resolution that is better than one meter.[171]

2005: Canada looks to satellite to assert Arctic sovereignty

In June 2005, Canada's Department of National Defence announced the creation of Project Polar Epsilon, a $52.1-million joint space-based wide area surveillance and support capability that will provide all-weather, day/night observation of Canada's Arctic region and its ocean approaches out to 1,850 kilometers.[172] The Polar Epsilon project will develop capabilities for ship detection, environmental sensing, ocean intelligence, and satellite data reception and processing. The project will build ground reception sites on Canada's Atlantic and Pacific coasts that will link information from its new RADARSAT 2 satellite, scheduled for launch in 2006, and other sources to produce high quality imagery for military as well as other applications.[173]

Net assessment:

Space is gaining military importance for a growing number of states. As more actors develop military space capabilities, the perception of space assets as extensions of the terrestrial battlefield, and therefore as military targets, increases. The situation could motivate greater international space security cooperation and the development of independent capabilities for space situational awareness, space system protection, and space system negation. Moreover, continued development of launch vehicle technology as an endeavor towards independent space access could also provide actors with potential space system negation technologies.

FIGURE 5.2: Dedicated military space missions in 2005[174]

State	Satellite name	Launch vehicle	Function	Orbit
China	SJ-7	Chang Zheng 2D	Technology	LEO
China	FSW No. 21	Chang Zheng 2C	Imaging	LEO
China	FSW No 22	Chang Zheng 2D	Imaging	LEO
France	Syracuse 3A	Ariane 5GS	Communications	GEO
Russia	Kosmos-2414	Kosmos 11K65M	Navigation	LEO
Russia	Kosmos-2415	Soyuz-U	Imaging	LEO
Russia	Kosmos-2416	Kosmos-11K65M	Communications	LEO
Russia	Kosmos-2417	Proton-K/DM-2	Navigation	MEO
Russia	Kosmos-2418	Proton-K/DM-2	Navigation	MEO
Russia	Kosmos-2419	Proton-K/DM-2	Navigation	MEO
Spain	XTAR-EUR	Ariane 5ECA	Communications	GEO
UK	Topsat	Kosmos 11K65M	Imaging	LEO
USA	USA 181	Atlas 3B	SIGINT	LEO
US	USA-181 P/L 2	Atlas 3B	SIGINT	LEO
US	XSS-11 (USA 165)	Minotaur	Technology	LEO
US	USA 182	Titan 405B	Imaging	LEO
US	STP-R1	Minotaur	Technology	LEO
US	Navstar GPS IIR-M1	Delta 7925-9.5	Navigation	MEO
US	USA 186	Titan 404B	Imaging	LEO

CHAPTER SIX

Space Systems Protection

This chapter assesses trends and developments related to the research, development, testing, and deployment of capabilities to protect space systems from potential negation efforts. Protection capabilities are designed to mitigate the vulnerabilities of the ground-based components of space systems, launch systems, communications links to and from satellites, and satellites themselves.

Both active and passive means can be used to provide three main types of space systems protection: capabilities to detect space negation attacks; physical and electronic means to withstand attacks on ground stations, communications links, and satellites; and reconstitution and repair mechanisms to recover from space negation attacks. Attacks on the space negation capabilities of others, for example anti-satellite (ASAT) systems, are considered by some as protection measures. These capabilities are addressed by the Space Systems Negation and Space-Based Strike Weapons chapters.

The ability to detect, identify, and locate the source of space negation attacks through surveillance and space situational awareness capabilities is critical to space protection, since it is important to know whether the failure of a space system is being caused by technical or environmental factors or the deliberate actions of an attacker. Detection of an actual attack is often a precondition for effective protection measures such as electronic countermeasures or simply maneuvering a satellite out of the path of an attacker. The ability to detect an attacker is also a prerequisite for deterrence.

Protection of satellite ground stations, communications links, and satellites themselves is dependent upon the nature of the space negation threat that such systems face. Negation capabilities are examined in more detail in the Space Systems Negation chapter, but in general terms they can include: cybernetic attacks against space system computers, electronic attacks on satellite communications links, conventional or nuclear attacks on the ground- or space-based elements of a space system, and directed energy attacks such as dazzling or blinding satellite sensors with lasers.

A critical space systems protection capability is the ability to recover from the space negation attack in a timely manner by reconstituting damaged or destroyed components of the space system. Capabilities to repair or replace ground stations and re-establish satellite communications links are generally available, while capabilities to rebuild space-based systems are much more difficult to develop. Capabilities to protect systems against environmental hazards such as space debris are examined in the Space Environment chapter.

Space Security Impacts

Many space systems remain unprotected from a range of threats, assessed by experts to include, in order of decreasing likelihood, (1) electronic warfare such as jamming communications links, (2) physical attacks on satellite ground stations, (3) dazzling or blinding of satellite sensors, (4) pellet cloud attacks on low-orbit satellites, (5) attacks in space by micro-satellites, (6) hit-to-kill anti-satellite weapons, and (7) high-altitude nuclear detonations (HAND).[1] Other potential threats include radio-frequency weapons, high-powered microwaves and "heat-to-kill" ground-based laser ASATs. Growing awareness of the vulnerabilities of space systems has led actors to develop space systems protection capabilities to detect, withstand, or recover from an attack. With the proliferation of space systems protection techniques and technologies, both the range of actors employing protection systems and the range of protection options are increasing.

These protection capabilities can have a positive impact on space security by increasing the ability of a space system to survive negation efforts, thus helping to assure secure access to, and use of, space. The ability to detect and survive an attack can also help to deter negation attempts. Actors may refrain from attacks on well protected space systems, which could prove to be both futile and costly.

As noted in the Space Systems Negation chapter, the space security dynamics of space negation and protection are closely related. The use of protective measures to address system vulnerabilities could offer a viable alternative to using offensive means to defend space assets. Given concerns surrounding space debris, passive defensive measures may offer more sustainable approaches to space protection challenges.

It is currently difficult to distinguish between satellite failures caused by environmental factors or a deliberate attack. This has led some experts to argue that greater space situational awareness is critical to improvements in space security.[2] There are, however, inherent dual-use concerns; for example, it is largely impossible to distinguish a rocket carrying a satellite from one carrying a nuclear warhead.

Under some conditions, protection systems can have a negative impact on space security. Like many defensive systems, they can stimulate an arms escalation dynamic by motivating adversaries to develop weapons to overcome protection systems. Robust protection capabilities could also reduce an actor's fear of retaliation, reducing the threshold for using space negation capabilities. Finally, protection, which often increases the weight of the space system, can have cost implications that affect space access and use, and can thereby reduce the number of actors with secure use of space.

Key Trends

TREND 6.1: US and Russia lead in general capabilities to detect rocket launches, while US leads in the development of advanced technologies to detect direct attacks on satellites

As noted above, the ability to distinguish space negation attacks from technical failures or environmental attacks is critical to space protection. Mounting effective protection efforts often depends upon effective warning of attack, as well as a clear understanding of the parameters of the attack itself. Detecting attacks on satellite ground stations is not addressed in any detail within this trend assessment since this capability is available to almost all actors with some measure of conventional military capability. A general assessment of the capabilities of key space actors to detect a space negation attack is provided in Figure 6.1.

Detecting rocket launches

During the Cold War, the USSR and the US developed significant space-based early warning systems to detect ballistic missile and space rocket launches. These systems also provided some ability to detect the ground-based launch of an ASAT by monitoring the trajectory of the launch to see if it could place its payload into the same area as an existing satellite. Besides the US and Russia, no other actors currently have such capabilities, although France is due to launch two early warning satellites, Spirale-1 and Spirale-2, in 2008.[3]

The USSR launched its first space-based early warning Oko satellite in 1972 and had fully deployed the system by 1982. To maintain a continuous capability to detect the launch of US land-based ballistic missiles, the system had a minimum of four satellites in Highly Elliptical Orbits (HEO). Over 80 Oko satellite launches allowed the USSR/Russia to maintain this capability until the mid-1990s. By the end of 1999, the Oko system was operating at the minimum possible level of four HEO satellites, which have since been lost and replaced by two satellites in HEO and one Geostationary Orbit (GEO) satellite. The system continues to operate in this configuration, which provides coverage of US intercontinental ballistic missile fields, but with reduced reliability.[4]

In 1991, Russia began launching US-KMO, a next generation early warning satellite system, using a mixture of GEO and HEO satellites. There have been six subsequent launches, but the program has been plagued by satellite malfunctions. Despite setbacks, Russia seems determined to continue its development of US-KMO. In 1998, it completed construction of a new command and control station, which is needed to support the operation of satellites to be deployed over the Pacific.[5]

The US military has always emphasized space protection as one of the key pillars of its space doctrine.[6] First launched in 1970, US Defense Support Program (DSP) early warning satellites have provided the US with the capability to detect missile/rocket launches worldwide. The DSP system consists of four GEO satellites which, since its inception, have been progressively replaced with a total of 22 satellites of increasing capabilities.

The US is now building the Space-Based Infra-Red System (SBIRS)-High, and the Space Tracking and Surveillance Systems (STSS) to replace the DSP satellites. When completed, these systems will be capable of detecting and tracking ballistic missiles, as well as potential ground-based kinetic-kill ASATs. With ground stations, the SBIRS-High project will consist of four GEO satellites, a spare satellite, and additional sensors on two classified HEO satellites.[7] A Lockheed Martin-Northrop Grumman team was awarded a $2.16-billion contract to build SBIRS-High in 1996. By September 2002, this contract was valued at $4.18-billion, not including the cost of three of the five GEO satellites."[8] Continued frustration at the increasing costs of SBIRS-High led Congress to cut $27-million of the $66-million requested for FY2005.[9] The STSS system under development by the US Missile Defense Agency aims to track missiles through all three phases of flight using a system of 20-30 sensor-satellites in Low Earth Orbit (LEO).

Sea-based and terrestrial assets perform ballistic missile launch detection and tracking for China, France, and the UK. China's four Yuan Wang tracking ships are used for satellite tracking as well as missile detection and tracking; as well, China is believed to have one Large Phased Array Radar for missile launch detection near Xuanhua in the west.[10] France employs the Monge tracking ship with ARMOR radars to track ballistic missiles, primarily for its missile testing program. On the Monge ship there are two C-band ARMOR radars with 10-meter receiver dishes, capable of viewing objects to 4,000 kilometers.[11] Royal Air Force Fylingdales in Yorkshire, UK is a major space surveillance site with a Large Phased Array Radar operating in the UHF frequency range. Fylingdales is one of three radars in the Ballistic Missile Early Warning System, which performs missile launch detection for Europe and the US. The radar also acts as a collaborative sensor for the US Space Surveillance Network (SSN) and is currently being updated to play a role in the US ballistic missile defense program.[12]

Detecting ASAT attacks

Most actors have a basic capability to detect a ground-based electronic attack, such as jamming, on their space systems, by sensing the interference signal of the attacker or detecting the loss of communications with the system under attack. It is, however, difficult to provide early warning for such attacks. In the case of jamming, it is reasonable to assume that any satellite operator could detect an interruption of signals from the satellite and most operators could detect the interference signal itself. Many actors also have the capability to use multiple sensors to geo-locate the source of jamming signals, which helps to determine if the interference is intentional. It is also reasonable to assume that all actors operating a satellite have some capability to detect spoofing, since basic electronic error code checking routines are relatively simple to implement.

Directed energy attacks, such as laser dazzling or blinding and microwave attacks, move at the speed of light, so that advance warning is very difficult to obtain. These attacks can be detected either by the loss of a data stream from optical or microwave instrumentation or, in the case of blinding, by detecting the energy beam prior to damage. On-board satellite-specific laser sensors can detect either the key laser frequencies or radiant power. Such capabilities could trigger a variety of protection measures, such as automated mechanical shutters, which may be able to prevent damage, depending on the sophistication of the attacker. Only US satellites are known to have such capabilities, and only Russia, France, and perhaps China have reconnaissance satellites that might employ such capabilities.

Space-based conventional ASATs can be detected through the tracking of satellite maneuvers to monitor whether a satellite is in an orbit that could allow it to intercept or attack another satellite. Both the US and Russia have a limited ability to do this through their space surveillance capabilities (see Space Environment). In 2004, the US began moderating access to satellite orbital information from its SSN because such data can also be used to support negation efforts.[13] However, data from the SSN has been the primary means of collision avoidance for many states. While the ability to constantly monitor all satellites to detect hostile maneuvers would constitute a significant protection capability, no space actor currently has this ability.

Another approach would be to place sensors on every satellite to allow the detection of nearby satellites and negation efforts. While no actor has fully developed these capabilities, the US Radio Frequency Threat Warning and Attack Reporting (RFTWARS) program aims to develop a lightweight, low-power radio frequency sensor suite to attach to individual satellites to provide situational awareness.[14] The US is also developing capabilities for individual spacecraft to detect enemy space negation attempts through its Rapid Attack Identification, Detection and Reporting System (RAIDRS) program. This largely classified program is defined by the US as a Defensive Counterspace System designed to identify, locate, and report attacks on US space systems to enable the timely employment of defensive responses. It is anticipated that RAIDRS will achieve these goals with existing technologies, data, and sensors.[15]

A HAND can be detected by using gamma ray/X-ray/neutron flux detectors in orbit. Only the US and Russia are known to have such capabilities, and no other actors are known to be developing them. The US developed and launched 12 Vela series satellites that would detect nuclear tests to monitor compliance with the 1963 Limited Test Ban Treaty. Subsequently such instruments were integrated with DSP early warning satellites and Global Positioning System (GPS) satellites.[16] Russia integrates nuclear detonation warning sensors onto its GLONASS satellites. Actors in direct line of sight could also detect a HAND.

FIGURE 6.1: Capabilities of key actors to *detect* an attack on a *satellite system*

Category	Attack capability	China	EU/ ESA	France	UK	India	Israel	Japan	Russia	US
Electronic	Jamming	■	■	■	■	■	■	■	■	■
Conventional	Space-based ASAT								■	■
	Ground-based ASAT								■	■
Directed energy	Laser dazzling / blinding	?		■					■	■
Nuclear	HAND								■	■

Key: ■ = Some degree of capability □ = Under development ? = Unclear from open source literature

TREND 6.2: The protection of satellite ground stations is a concern, while the protection of satellite communications links is poor but improving

Satellite ground stations and communications links are the most likely targets for space negation efforts since they are vulnerable to a range of widely available conventional and electronic weapons. Military satellite ground stations and communications links are generally well protected, whereas civil and commercial assets tend to have fewer protection features. A study published by the US President's National Security Telecommunications Advisory Committee (NSTAC) emphasized that the key threats to the commercial satellite fleet are to ground facilities from hacking computers or possibly, but less likely, jamming.[17] However, satellite communications can usually be restored and ground stations rebuilt for a fraction of what it costs to replace a satellite.

The vulnerability of civil and commercial space systems raises concerns, since a number of military space actors are becoming increasingly dependent upon commercial space assets for a variety of applications. Many commercial space systems have a single operations center and ground station,[18] leaving them potentially vulnerable to some of the most basic attacks, such as car bombs. As a notable example, the US GPS was operational for five years before a second primary ground station was completed.[19] Responding to these types of concerns, in 2002, the US General Accounting Office recommended that "commercial satellites be identified as critical infrastructure" (see Commercial Space).[20]

Electronic protection

Most, if not all, space actors are capable of providing effective physical protection for their satellite ground stations within the general boundaries of their relative military capabilities, although they may not elect to do so. Thus, this chapter focuses on the increasingly critical area of the protection of satellite communications links. This is also an area in which space negation efforts have recently been undertaken both during times of peace and of conflict (see Space Systems Negation).

Satellite communications links require specific electronic protection measures to safeguard their utility. Unclassified information on these capabilities is difficult to obtain. However, one can assume that most space actors, by virtue of their technological capabilities to develop and operate space systems, are also able to take advantage of simple but reasonably robust electronic protection measures. These basic protection capabilities include: (1) data encryption; (2) error-protection coding that increases the amount of interference which can be tolerated before communications are disrupted; (3) directional antennas that reduce interception or jamming vulnerabilities, or antennas that utilize natural or manmade barriers as protection from line-of-sight electronic attacks; and (4) shielding and radio emission control measures that reduce the radio energy that can be intercepted for surveillance or jamming purposes.[21]

Sophisticated electronic protection measures are generally unique to the military communications systems of technologically advanced states. These advanced protection capabilities include: (1) narrow band excision techniques that mitigate jamming by using smaller bandwidth; (2) burst transmissions and frequency-hopping (spread-spectrum modulation) methods that communicate data in a short series of signals, or across a range of radio frequencies, to keep adversaries from "locking-on" to signals to jam or intercept them; (3) antenna side-lobe reduction designs that mitigate jamming or interception vulnerabilities by providing more focused main communication beams and reducing interferences from jamming in the side-lobe regions; and (4) nulling antenna systems (adaptive interference cancellation) which monitor interference and combine antenna elements designed to null or cancel the interference.[22] This last technique is considered the most comprehensive anti-jamming technique in existence.[23]

During the Cold War, the US and the USSR led in the development of satellite communications protection systems. The US currently appears to be the leader in developing advanced satellite communications protection, and some of these capabilities are now available to other states with more advanced military communications systems. For example, US/NATO Milstar communications satellites use multiple anti-jamming technologies, employing both spread-spectrum modulation and antenna side-lobe reduction. Adaptive interference cancellation is being developed for next generation satellites.[24] Through its Global Positioning Experiments project, the US is attempting to solve the problem of GPS jamming by developing airborne pseudo-satellites which provide higher powered GPS signals to overpower jammers.[25] The US is also currently developing laser-based communication systems, which could provide a degree of immunity from conventional jamming techniques in addition to more rapid communication. Lastly, in response to several jamming incidents in past years allegedly attributed to the Falun Gong, China launched its first anti-jamming satellite – a communications satellite.[26]

TREND 6.3: Protection of satellites against some direct threats is improving, largely through radiation hardening, system redundancy, and greater use of higher orbits

After attacks on satellite ground stations and communications links, the most significant space systems protection challenge is the defense of satellites from direct attack with conventional, nuclear, or directed energy weapons. Here the primary source of protection for satellites is derived from the difficulties associated with launching an attack into and through the unique space environment. Conventional weapons need to be launched into, and maneuvered through, space to fairly specific locations. Directed energy weapons must overcome atmospheric challenges and be effectively targeted at satellites, which orbit at great distances and move at very high speeds. A general assessment of the capabilities of key space actors to protect against direct threats to satellites is provided in Figure 6.2.

A total of 28 actors are assessed to have a suborbital launch capability that allows them to launch a conventional or nuclear payload into LEO for a few minutes before it descends back into the Earth's atmosphere. A total of 10 actors have developed an orbital launch capability, with eight of these actors having demonstrated the capability to reach GEO. The fact that LEO can be reached in a matter of minutes, while GEO takes about half a day to reach by completing a Hohmann transfer orbit, illustrates the unique protection dynamics associated with different orbits.[27] Not surprisingly, military systems are increasingly being placed into higher orbits such as Medium Earth Orbit (MEO) or GEO.

The distances and speeds involved in satellite engagements can also be exploited to enhance satellite protection. Satellites in lower altitude orbits are more difficult to detect with space-based infrared sensors because of their proximity to the Earth's atmosphere. Lower orbits are also less predictable because of greater atmospheric effects such as fluctuations in density in the upper atmosphere, which alter satellite drag. For example, at around 800 kilometers of altitude, the predictability of orbits is limited to an error of approximately one kilometer for a prediction one day in advance of the calculation, using readily available models. Conversely, higher operational orbits raise the power demands for terrestrial radars, leaving only optical systems capable of tracking satellites in altitudes beyond 5,000 kilometers. Surface finishes and designs optimized for heat dissipation and radar absorption can also reduce the observation signatures of a satellite, further complicating negation targeting efforts.

Protection against conventional weapons

Efforts to protect satellites from conventional weapons such as kinetic hit-to-kill, explosive, or pellet cloud methods of attack assume that it is more or less impossible to provide physical hardening against such attacks because of the high relative velocities of objects in orbit. However, as discussed, the difficulty of attacking into, and maneuvering through, space facilitates the protection of satellites from conventional weapons threats. For example, tests of the Soviet co-orbital ASAT system in the 1960s and 1970s were limited to opportunities when the longitude of the interceptor launch site matched that of the target satellite, which only occurred twice per day. This introduced an average delay of six hours between a decision to attack a satellite in LEO and the launch of an interceptor.

Once an interceptor has been launched toward a satellite, it has committed a significant amount of its limited fuel to a specific attack strategy. This can be exploited by the defending targeted satellite through evasive maneuvers which force an interceptor to expend valuable fuel and time to re-orient its line of attack. While such maneuvers require valuable fuel mass, and few satellites carry extra fuel specifically for this purpose, all operational satellites have some fuel allocated to maintain their orbital positions, known as "station keeping," in case of natural orbital disturbances. These evasive maneuvers must only be large enough to avoid the weapons effects or target acquisition range of the interceptor,[28] but the extra fuel required might represent more than 10-20 percent of the satellite cost.[29] No satellites are known to be designed to carry fuel specifically for such evasive maneuvers.

An interceptor is also vulnerable to deception by decoys deployed from a target. For example, an interceptor's radars could be deceived by the release of a cloud of metal foil known as "chaff," its thermal sensors could be spoofed by devices imitating the thermal signature of the satellite, or its sensors could be jammed.

These defender advantages can be enhanced through a number of general space protection measures, including use of higher orbits, dispersion, autonomy, redundancy, reconstitution, signature reduction, and the use of decoys or evasive maneuvers. Dispersion is a well established practice in terrestrial conflict that can be applied to satellite operations. Redundancy in satellite design and operations offers a number of protection advantages. Since on-site repairs in space are not cost-effective, satellites tend to employ redundant electronic systems to avoid single point failures. Many GEO communications satellites are also bought in pairs and launched separately into orbit to provide system-level redundancy. Over the longer term, in-orbit repair and robotic servicing capabilities will likely further improve the survivability of space systems. Signature reduction has been developed, particularly in the context of reconnaissance satellites. For example, the US National Reconnaissance Office is developing a satellite called Misty-3, which will reportedly employ signature reduction technologies to make it less visible to other actors' space surveillance equipment.[30]

In general, there is currently little redundancy of commercial, military, or civil space systems. This is especially true of the space-based components, due to the large cost per-kilogram of launch. Commercial satellites are, however, increasingly exploiting slack in the commercial telecommunications systems to allow for distribution and redundancy.

With greater dependence on space systems, the motivation for redundancy is increasing. China, ESA and the EU (in partnership with others), and Japan are developing satellite navigation systems that will increase the redundancy of such systems on two levels. First, constellations of satellites such as the GPS and the proposed EU Galileo system are inherently protected by redundancy, since the loss of one satellite might reduce service reliability but not destroy the entire system. Second, different but often interoperable systems could create redundancy of entire navigation systems, so that the same actor may be able to rely upon two separate systems. Indeed, in 2004 the EU and the US agreed to make the Galileo and GPS systems interoperable to ensure a certain degree of redundancy (see Civil Space Programs and Global Utilities).[31]

Higher orbits can also be utilized to take advantage of lengthier warning times and greater access difficulties. To some extent, Russia has led in the use of higher orbits by using HEO applications. The use of this orbit allows Russia to obtain better coverage of the US for a longer duration. Increasingly, the US has begun to recognize and utilize the benefits of higher orbits and other space actors are slowly following suit.

Protection against nuclear attack

Since all current nuclear weapons states also have suborbital space access, the capability to carry out a HAND attack is at least within the capability of these states. While unhardened satellites are quite vulnerable to the effects of nuclear weapons, there are three general measures that can be used to protect them: (1) radiation hardening, (2) electromagnetic pulse (EMP) shielding, and (3) scintillation and blackout avoidance.[32]

Radiation hardening measures enable satellites to withstand the effects of nuclear weapons through the use of radiation-tolerant components and automatic sensors designed to switch off non-essential circuits during a nuclear detonation. Photovoltaic, or solar, cells employed as power sources for many satellites are particularly vulnerable to radiation effects, and can be replaced by nuclear reactors, thermal-isotopic generators, or by fused silica-covered radiation-resistant solar cell models built with gallium arsenide.

EMP shielding protects sensitive satellite components from the voltage surges generated by nuclear detonations reacting with the environment and the internal voltages and currents generated when X-rays from a nuclear detonation penetrate a satellite.[33] Technical measures to protect satellites from external EMP effects include: (1) metal shields and conductive coatings to prevent EMP radiation from entering satellite cavities, (2) linking and grounding of the exterior components of a satellite to create a Faraday cage which will prevent transmission of EMP radiation to interior components, (3) the use of grounding straps and surge arresters to maintain surfaces at the same electrical potential, and (4) the use of microwave filters to isolate internal satellite electronics from external electromagnetic radiation. The use of graphite composites instead of aluminum construction panels can further reduce the number of liberated electrons capable of disrupting components. Electro-optic isolators, specialized diodes, and filters can also be used to shield internal satellite circuits.

Scintillation and blackout protection measures can be used to avoid the disruption and denial of communications between satellites and their ground stations, caused by nuclear detonations that generate an enhanced number of charged particles in the Earth's radiation belts. Protection against these communications failures can be provided by crosslink communications to bypass satellites in a contaminated area and enable communications via other satellites. Higher frequencies that are less susceptible to scintillation and blackout effects, such as EHF/SHF (40/20 gigahertz), can also be used.

Early space protection efforts undertaken by the US and the USSR during the Cold War were aimed at increasing the survivability of strategically important satellites in the face of nuclear attack. US systems such as the DSP early warning, Defense Satellite Communications System communications, and GPS navigation satellites were all hardened against the radiation and EMP effects of nuclear weapon detonations, as are all current generation military satellites of advanced space actors. Robust production lines, the use of satellite constellations, and responsive launch readiness contributed to the survivability of the USSR's space capabilities from nuclear attack. Both the US and Russia maintain hardening to protect against a HAND on their military assets, as do the UK and France. It is not clear from open sources whether or not China, India, and Israel employ such measures.

Most commercial spacecraft must install radiation-hardening to guarantee lifespan (typically 15 years) and include automated switch-off and recovery modes which protect systems from natural radiation events, such as solar flares. But, generally, commercial satellites are not specifically protected from the EMP effects that would result from a HAND. However, some commercial spacecraft components are radiation-hardened by using materials developed for military specifications, which may provide some limited protection. Any physical protection normally results in an increased cost and it seems unlikely that the space industry would harden its satellites without significant prompting and subsidization from governments.[34] Protection measures vary in cost; for example, hardening against the radiation effects of a nuclear detonation is estimated to be about two to five percent of satellite costs, while hardening against the EMP effects of a nuclear detonation can be up to 10 percent of satellite costs.[35]

The US is pursuing technologies other than hardening to reduce the damaging long-term radiation belts caused by a HAND. The US High Frequency Active Auroral Research Program includes research on active measures to reduce the concentration of ionic particles in the upper atmosphere following a HAND.[36] Such measures would reduce the probability of satellite malfunction in a HAND's aftermath.

Protection against a directed energy attack

The simplest form of directed energy weapon makes use of a ground-based laser directed at a satellite to temporarily dazzle, or disrupt, sensitive optics. Optical imaging systems on a reconnaissance satellite or other sensors, such as the infrared Earth sensors which are part of the attitude control system of most satellites, would be most susceptible to laser interference. Because the attacker must be in the line of sight of the instrument, opportunities for attacks are limited to the available territory below the satellite. A more advanced directed energy attack designed to degrade or damage sensitive optical or thermal imaging sensors requires higher laser powers (see Space Systems Negation). Protection measures that address these threats include: (1) laser sensors, mechanical shutters, or spectral or amplitude filters to protect from intense laser illumination; (2) the use of multiple imaging frequencies, including those attenuated by atmospheric absorption, to reduce the effectiveness of the laser weapon itself; and (3) the use of indirect imaging angles to avoid direct ground-based laser illumination. While such measure can help to prevent permanent damage, they may require a temporary disruption of the satellite's functions.

Highly advanced lasers capable of damaging other satellite subsystems through heating or shock require higher powers still. Vulnerable subsystems include solar panels and some electronics. Protection can be provided by ablative coatings and isolated shields on the exterior of spacecraft, the use of spin stabilization to dissipate heat, and the selection of power generation technology other than photovoltaic cells that can be damaged by lasers.[37] The use of higher orbits provides significant protection from this type of attack because of the distances involved; in GEO, modest shields can prevent the destruction of a non-imaging satellite by laser heating.[38] Protection against microwave weapons, which use high-powered short pulse beams to degrade or destroy unprotected electronics, can be provided by over-voltage and over-current protection circuits within a satellite's receivers.

The US currently leads the way in both systems protection policy and technology to protect from directed energy attack. Commercial satellites however, typically lack protection from laser or microwave attack. Besides the US, only the France and Russia are assessed to employ means such as higher orbits or spectral filtering on reconnaissance satellites to provide protection from directed energy attacks.

FIGURE 6.2: Protection capabilities of key actors to *withstand* an attack on a satellite system

Category	Attack capability	China	EU/ ESA	France	UK	India	Israel	Japan	Russia	US
Electronic	Jamming	■	■	■	■	■	■	■	■	■
Conventional	Space-based ASAT			?					■	■
	Ground-based ASAT			?					■	■
Directed energy	Laser ? dazzling / blinding	?		■					?	■
Nuclear	HAND	?		■	■				■	■

Key: ■ = Some degree of capability   □ = Under development   ? = Unclear from open source literature

TREND 6.4: Russia and the US lead in capabilities to rapidly rebuild space systems following a direct attack on satellites

In the wake of a space negation attack, the capability to rapidly rebuild space systems is critical to the maintenance of space utilities. It is assumed that actors capable of operating a satellite are also able to recover from an electronic attack since such attacks do not, in most cases, cause permanent damage. It is also assumed that space actors have the capability to rebuild satellite ground stations. Therefore, this assessment examines capabilities to rebuild space systems by launching new satellites into orbit in a timely manner to replace satellites damaged or destroyed by a space negation attack. A general assessment of the capabilities of key space actors to recover from this type of attack is included in Figure 6.3.

During the Cold War, the USSR and the US led in the development of economical launch vehicles capable of rapidly launching new satellites as a means to repair space systems following an attack. The USSR/Russia has launched less expensive, less sophisticated, and shorter-lived satellites than those of the US, but launched them more often. Soviet-era pressure vessel spacecraft designs, still in use today, have an advantage over Western vented satellite designs that require a period of out-gassing before the satellite can enter service.[39] In principle, Russia has the capacity to deploy redundancy in its space systems at a lower cost and to allow quicker space access to facilitate the reconstitution of its systems. Indeed, in 2004, Russia conducted a large military exercise which included plans for the rapid launch of military satellites to replace space assets lost in action.[40] A significant fraction of current Russian launches, however, are of other nations' satellites, and it struggles to maintain existing military systems in operational condition. Thus, in practice, little redundancy is leveraged through this launch capability.[41]

FIGURE 6.3: Protection capabilities of key actors to rapidly *recover* from an attack on a satellite system

Category	Attack capability	China	EU/ESA	France	UK	India	Israel	Japan	Russia	US
Electronic	Jamming	■	■	■	■	■	■	■	■	■
Conventional	Space-based ASAT								■	■
	Ground-based ASAT								■	■
Directed energy	Laser dazzling	■	■	■	■	■	■	■	■	■
	Laser blinding								■	■
Nuclear	HAND									■

Key: ■ = Some degree of capability □ = Under development ? = Unclear from open source literature

The US is leading in the development of next generation responsive space launch capabilities. The US Air Force Space Command's *Strategic Master Plan FY06 and Beyond* notes, "An operationally responsive spacelift capability is critical to place timely missions on orbit assuring our access to space."[42] Several programs address this concern, including the US Force Application from the Continental US (FALCON) program. It includes a Small Launch Vehicle sub-program for a rocket capable of placing 100-1,000 kilograms into LEO on 24-hours notice for under $5-million.[43]

The US Responsive Access, Small Cargo, Affordable Launch program aims to develop a responsive system to deliver 50-130 kilograms into LEO on short notice, for under $20,000 per kilogram.[44] The US Space Maneuver Vehicle (SMV) is envisioned as a small, powered, reusable space vehicle, operating as an upper stage on top of a reusable launch vehicle or as a reusable satellite bus with a variety of available payloads. An operational SMV might include up to 550 kilograms of payload with a sub-72-hour turnaround time between missions.[45]

There is also increasing interest in the development of air-launched micro-satellites which could rapidly reinforce or replenish critical military space assets in LEO. The Russian MiG-launched kinetic energy anti-satellite weapon program was suspended in the early 1990s, but commercial applications of similar launch methods continue to be explored. The Mikoyan-Gurevich Design Bureau was carrying out research as early as 1997, using a MiG-31 to launch small commercial satellites into LEO.[46] The Mikron rocket of the Moscow Aviation Institute's Astra Centre, introduced in 2002, was designed for launch from under a MiG-31 and is capable of placing payloads of up to 150 kilograms into LEO.[47] The US has been using the Pegasus launcher, first developed by Orbital Sciences Corporation in 1990, to launch certain micro-satellites from a B-52 aircraft.

The US is also pursuing technologies to recover from a HAND. In addition to improving the ability of satellites to withstand the long-duration radiation belt effects of a HAND, the US High Frequency Active Auroral Research Program, allows the US to increase the probability that replacement satellites will be able to survive a normal lifetime in the face of persistent HAND effects.

Actors attempting to recover from a HAND attack must be capable of operating in a space environment that may be hostile to satellites due to enhanced radiation in some orbits. While some actors may be able to use higher orbits, the capability to operate in an enhanced radiation environment is limited to actors that have radiation-hardened satellites, including France, Russia, the UK, and the US.

2005 DEVELOPMENTS

TREND 6.1: The US and Russia lead in general capabilities to detect rocket launches, while the US leads in the development of advanced technologies to detect direct attacks on satellites

2005: US developing geostationary and ground-based space situational awareness

In 2005 the US furthered its lead in space situational awareness capabilities with a number of programs, including the Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS), the Space Surveillance Telescope (SST), the Deep View radar, and the Large Millimeter Telescope. These programs highlight the growing importance of space situational awareness in GEO for the US military. In December 2005, the US Air Force Research Laboratory put out a call for proposals for the development of ANGELS.[48] The ANGELS concept would augment ground-based surveillance capabilities by providing on-orbit monitoring of a space asset using small nanosatellites weighing less than 15 kilograms. With first launch projected for 2009, ANGELS would initially be attached to a host satellite placed into GEO, and would separate from the host to carry out such tasks as monitoring space weather conditions, detecting ASATs, and diagnosing technical problems with the host spacecraft. The entire program has a projected budget of $20-million, and exact capabilities are yet to be determined.[49] The space-based situational awareness of ANGELS would fill current protection gaps by providing continuous monitoring of "keep out zones" in immediate proximity to assets in GEO, and would detect and characterize objects intruding in these zones and changes to the orbital environment. This capacity is key to determine appropriate protection, as well as possible retaliation responses.[50]

The SST program of the Defense Advanced Research Projects Agency (DARPA) is developing an advanced ground-based optical searching and tracking telescope for objects in GEO, to supplement the current Ground-Based Electro-Optical Deep Space Surveillance system.[51] It is anticipated that SST will use key optics and curved focal plane array sensor technologies to provide rapid wide-area search coverage and enable ground-based detection of objects in space for purposes such as asteroid detection and other defense missions. USAF will participate in the testing of SST and is expected to take over operation of SST as part of the US SSN.[52] DARPA is also pursuing a Deep View radar program to fill the gap of high-resolution object characterization at higher orbits, and that is also capable of imaging objects below the minimum size capabilities of current capabilities in all orbits. Program plans include high-power transmitters and very large receiving antennas that can provide high-resolution images for objects in deep space to provide critical monitoring capability for activities in GEO, including the health and status of operational satellites and characterization of unknown objects. Finally, in November 2005, DARPA finished mounting the US-Mexico Large Millimeter Telescope (LMT) in Puebla, Mexico. Once the LMT becomes functional in 2008, it will be the world's largest and most sensitive single-aperture telescope. While such a sensitive receiver is the technology required for Deep View, it is unclear how DARPA intends to use it.[53]

Russia and the US have been pursuing upgrades to their early warning systems. The Early Warning Radar and Missile Attack Warning System in Russia and the SBIRS system in the US could help to detect ground-based attacks on space assets (see Space-Based Strike Weapons). There has also been discussion among EU states on the feasibility of developing an independent space surveillance system (see The Space Environment).

Net assessment:

The development of nanosatellites for space situational awareness and ground-based space surveillance technology could improve space security by enhancing transparency about space activities. Furthermore, greater space situational awareness may help bolster trust and strategic stability by helping to distinguish natural accidents from deliberate attacks on critical space systems. Technologies such as ANGELS could be used to protect satellites by "spoofing" the tracking sensors of anti-satellite weapons and acting as decoys during the terminal pursuit phase of an attack. However, much of the technology used for nanosatellites could be modified for space negation purposes and in particular "defensive" anti-satellites.

TREND 6.2: Protection of satellite ground stations is a concern, while protection of satellite communications links is poor but improving

2005: US successfully tests GPS "pseudolite"

DARPA, in cooperation with the USAF, successfully completed tests in 2005 of unmanned aerial vehicle pseudo-satellites, or "pseudolites," designed to boost the power of GPS satellite signals. The Global Positioning Experiments demonstrated the ability of GPS pseudolites to relay and amplify GPS signals to counter signal jamming. Pseudolite technology allows the US military to overcome the limitations of normal GPS signals, which are weak and easily jammed over battlefield areas, and overpower or "burn through" jamming signals. DARPA's pseudolite program is being transferred to the USAF GPS Joint Office for implementation.[54]

2005: Increasing encryption of satellite communications

Currently very few satellites encrypt the signals they send to their ground stations, and most that do use encryption that is weak and inefficient. Incidents of satellite signal interception are increasing, as is the computational power to break simple encryption algorithms. As computer processing power onboard satellites has increased, it is now feasible to include on satellite hardware robust encryption that uses the latest standards, including the Advanced Encryption Standard (AES) of the US National Institute of Standards and Technology and the US National Security Agency's High Assurance Internet Protocol Encryption standard.

The Turkish research institute Tubitak-Bilten reported in 2005 that it is developing a real-time data encryption/decryption subsystem called GOLGE for Turkey's RASAT earth-observing microsatellite that is scheduled for launch in 2007. It will use two reconfigurable processors for encryption/ decryption using AES and Rivest-Shamir-Adleman algorithms.[55] Researchers at the University of Surrey in the UK, Pennsylvania State University, and the US Naval Research Laboratory are also researching robust encryption onboard satellites.[56]

Net assessment:

The development of signal boosting technology should have a positive impact on space security by reducing the vulnerability of current navigation signals and by quickly compensating for damaged or destroyed GPS satellites. It highlights efforts made by states to transfer certain space-based platforms to less vulnerable Earth-based ones. Developments in satellite encryption should also have a positive impact on space security since ground stations and communications links tend to be the most vulnerable segments of a space system. The relatively low cost of encryption should also help to ensure secure access to space to a wider segment of space actors.

TREND 6.3: Protection of satellites against some direct threats is improving, largely through radiation hardening, system redundancy, and greater use of higher orbits

2005: Improvements in radiation hardened processors

A key to reliable electronics and computing power in satellites is computer chip technology that can survive in high-radiation environments. Radiation-hardening technology addresses natural radiation in space but is also developed to protect military applications from the effects of nuclear weapons. Such radiation-hardened or "rad-hard" chips require engineering concepts that are different from standard commercial chips. The US Defense Threat Reduction Agency (DTRA) Radiation Hardened Microelectronics Accelerated Technology Development program, begun in FY2002, is now bearing fruit in the area of rad-hard silicon-on-insulator (SOI) chips. DTRA, in partnership with the Air Force Research Laboratory, has been modernizing production facilities at BAE Systems and Honeywell Solid State Electronics Center to narrow the performance gap between rad-hard and commercial electronics. The first 150-nanometer feature size (wire thickness) radiation-hardened semiconductors entered production on 27 April 2005.[57] These rad-hard SOI chips will allow for faster computing power on satellites while improving resistance to various types of radiation. This is a key technology for protection from HANDs and may be used on the US Space Tracking and Surveillance Systems, Space Based Radar, and the Miniature Exo-atmospheric Kill Vehicle.[58]

2005: US prepares research satellite to facilitate greater use of Medium Earth Orbit

The Medium-Earth Orbit (MEO) "slot" between 6,000 and 12,000 kilometers has relatively few satellites compared to GEO and LEO, which face greater competition for orbital positions. The MEO environment –especially the nature of the radiation and plasma that exist between the inner and outer Van Allen radiation belts – is not well understood. This so-called "safe zone" is the subject of increased interest due to its low (though fluctuating) radiation levels, sufficient altitude to allow almost full-hemispheric coverage, and closer proximity to Earth, which allows communications to be eight-times faster than from satellites in GEO. To improve understanding of this orbital region, the Air Force Research Laboratory, DARPA, and NASA are developing a Demonstration and Science Experiments (DSX) satellite for launch in 2008. DSX will include experiments to characterize the radiation environment in MEO and its effects on spacecraft electronics and materials. DSX will also include a Wave Particle Interaction Experiment, which will research the physics of very-low frequency (VLF) transmissions in the magnetosphere and the capability of natural and manmade VLF waves to reduce space radiation.[59]

Net assessment:

Research into rad-hard electronics and the ability to reduce space radiation in certain orbits has the potential to increase space security. Understanding and controlling radiation in MEO could greatly increase its utility and relieve certain slot-competition pressures on other orbits. Radiation hardening and radiation-clearing technologies could also help to mitigate the effects of a HAND as well as naturally occurring hazards.

TREND 6.4: Russia and the US lead in capabilities to rapidly rebuild space systems following a direct attack on satellites

2005: Smaller, cheaper launches increasing ability to recover after attack in the US

Efforts continued in 2005 to reduce the costs of launching satellites and to improve the response time for rapid launches. The smallest launch vehicle used so far is Orbital Sciences' Pegasus rocket, which is launched in the air from beneath a high-flying jet; this method still costs approximately $44,500 per kilogram of payload and can currently only be used for small or micro-satellites. NASA's 2005 DART mission used a micro-satellite that was air-launched (see Space Systems Negation).[60] The cheapest launch vehicle in use is the Russian SS18/"Dnepr" launch vehicle at $7-11 million to launch 3,700 kilograms to LEO (about $3,000 per kilogram), while the cheapest US launch vehicles cost five to 10 times as much.[61] Space Exploration Technologies, Corp. (SpaceX) has been developing several launch vehicles of small, medium, and high capacity spacelift, and with its smallest, the Falcon 1, aims to bring costs below $7-million to launch up to 570 kilograms into LEO, bringing cost per kilogram to below $13,300.[62] The maiden launch of the Falcon 1 was delayed until 8 February 2006,[63] but launch contracts with the US Department of Defense, Malaysia (ATSB), SpaceDev, MDA, and Swedish Space Corp. are already in place.[64]

The Force Application and Launch from Continental United States (FALCON) program of USAF and DARPA continued the development of a Small Launch Vehicle (SLV) in 2005. The SLV is designed to provide small-capacity launches into LEO for less than $5-million with 24 hours notice. SLV is a preliminary step in the overall FALCON program, which will be transferred completely to the USAF after the completion of Phase III in 2010. Lockheed Martin completed its second successful test-firing of a hybrid motor at the Air Force Research Laboratory on 10 June 2005 as part of the SLV program. If it is successful, it will significantly increase US capability for responsive spacelift.[65]

2005: Russia continuing to develop air launch capacity

On 23 March 2005, Kazakh Prime Minister Danial Akhmetov and director Yuri Solomonov of the Moscow-based Heat Engineering Institute met to discuss the development of a new Ishim rocket system for launch from beneath Kazakhstan's MiG-31 fighter jets.[66] The system will be capable of launching payloads up to 200 kilogram into LEO. Although only at the feasibility stage, this system is reportedly on schedule for deployment in 2007.[67]

Another Russian air launch system that plans to drop a Polyot launch vehicle from an Antonov An-124-100 Russian carrier aircraft is under development by the Air Launch Aerospace Corporation.[68] The program seeks to be capable of placing commercial small-sized satellites of 3,000 to 4,000 kilograms into LEO and of 600-800 kilograms into GEO.[69] Air Launch reached an agreement on 7 December 2004 with the Indonesian government for the launch of a satellite in 2007.[70] The agreement also included plans to build a launch facility on the equatorial Indonesian island of Biak.[71]

Net assessment:

Efforts on the SLV and the SpaceX Falcon launch vehicle hold promise for more responsive space lift capability in the US. Further development of air-launch could strengthen space security by improving responsive space lift. However, air-launches can at present only be used to launch small or micro-satellites, and only into LEO. Therefore, in 2005 there were relatively few concrete reductions in the cost and time of launching critical space assets.

CHAPTER SEVEN

Space Systems Negation

This chapter assesses trends and developments related to the research, development, testing, and deployment of capabilities designed to negate the use of space systems. It also assesses the development of space situational awareness capabilities, including space surveillance, a key enabling technology for space systems negation, since tracking and identifying targeted objects in orbit are prerequisites to most negation techniques.

Space systems negation efforts can involve taking action, from the ground or from space, against the ground-based components of space systems, the communications links to and from satellites, space launchers, or satellites themselves. Negation can be achieved through the application of cybernetic or electronic interference, conventional weapons, directed energy (lasers), or nuclear capabilities used to carry out what are often referred to as the five Ds – deception, disruption, denial, degradation, and destruction.

Many space negation capabilities apply widely proliferated military equipment and practices. These include conventional attacks on ground stations, hacking into computer systems, jamming satellite communications links, or using false radio transmissions or simple camouflage techniques to conceal the location of military assets from surveillance from space.

Space negation capabilities which involve attacks on satellites themselves require more sophisticated capabilities. With the exception of ground-based laser dazzling or blinding, a basic launch capability is required to directly attack a satellite, as are space surveillance capabilities to effectively target satellites in orbit. Some space-based negation techniques require highly specialized capabilities such as precision maneuverability or autonomous tracking.

Degradation and destruction can be provided by conventional, directed energy, or nuclear anti-satellite (ASAT) weapons.[1] Conventional anti-satellite weapons concepts include precision-guided kinetic-kill vehicles, conventional explosives, and specialized systems designed to spread lethal clouds of metal pellets in the orbital path of a targeted satellite. A space launch vehicle with a nuclear weapon would be capable of producing a High Altitude Nuclear Detonation (HAND), causing widespread immediate electronic damage to satellites, combined with long-term effects to the Van Allen radiation belts, which would have an adverse impact on most satellites in Low Earth Orbit (LEO).[2]

Space Security Impacts

Space systems negation capabilities are directly related to space security since they enable an actor to restrict the secure access to, and use of, space by other actors. It is clear, therefore that the dynamics of space negation and space protection are closely related. For example, robust space negation efforts will likely succeed in the face of weak protection measures. Like other offense-defense relationships in military affairs, this space security negation-protection dynamic raises concern about arms racing and instability, as actors compete for the strategic advantages that space negation capabilities appear to offer.

Space negation-protection arms race dynamics could push actors to develop progressively more destructive negation means in order to overcome enhanced satellite defenses, eroding important distinctions that are currently made between military uses of space judged to be consistent with international law, and the contested efforts to place weapons in space.

Soviet and US concerns that early warning satellites be protected from direct attack as a measure to enhance crisis management were enshrined in bilateral treaties such as the Strategic Arms Limitation Talks and the Anti-Ballistic Missile treaties (see Space Security Laws, Policies, and Doctrines). Recent space war games have also underscored the challenges generated by space negation efforts focused on "blinding" the strategic communications and attack warning capabilities of an adversary.[3]

These security concerns are compounded by the fact that many key space capabilities are inherently dual-use. For example, space launchers are required for many ASAT systems; microsatellites offer great advantages as space-based kinetic-kill vehicles; and space surveillance capabilities can support space debris collision avoidance strategies as well as targeting for ASAT weapons.

Finally, it is noteworthy that the application of some destructive space negation capabilities, such as kinetic-kill ASATs, would generate space debris with the potential to inflict widespread damage on other space systems and undermine the sustainability of space security over the longer term. Similarly, a HAND is indiscriminate in its effects and would generate long-term negative impacts on space security. These concerns have led some experts to argue that space negation efforts may have a positive impact on space security, if, for example, such efforts prevent the target actor from using space systems to inflict widespread and long-term damage to the space environment.

Key Trends

TREND 7.1: Proliferation of capabilities to attack ground stations and communications links

The most vulnerable components of space systems are the ground stations and communications links, which are susceptible to attack from widely accessible weapons and technologies. An attack on the ground segments of space systems with conventional military force is conceivably the most likely space negation scenario. System sabotage; physical attack on the ground facility by armed invaders, vehicle, or missile; and interference with power sources would require modest military means.

Electronic and information warfare techniques, including hacking into computer networks and electronic jamming of satellite communications links, are negation capabilities that are becoming increasingly available to both state and non-state actors. A number of electronic jamming incidents targeting media broadcasts by communications satellites have been reported in recent years, with interruptions in US broadcasts to Iran,[4] Kurdish news broadcasts,[5] and Chinese television allegedly by the Falun Gong.[6] Iraq's acquisition of GPS-jamming equipment for use against US GPS-guided munitions during Operation Iraqi Freedom in 2003 suggested that jamming capabilities are proliferating, as the equipment was reportedly acquired commercially from a Russian company, Aviaconversiya Ltd.[7]

The US leads in developing advanced technologies to temporarily negate space systems by disrupting or denying access to satellite communications. The Department of Defense (DOD) "offensive counterspace" budget line item sees steady funding for offensive programs "to disrupt, deny, degrade or destroy an adversary's space systems, or the information they provide, which may be used for purposes hostile to US national security interests."[8] In 2004, the mobile CounterComm system designed to provide temporary and reversible disruption of satellite communication signals was declared operational.[9] The US Space Control Technology budget item seeks to "continue development and demonstration of advanced counter-communications technologies and techniques (…) leading to future generation counter-communications systems and advanced target characteristics."[10] The mission description for this program element notes that, "consistent with DoD policy, the negation efforts of this program focus only on negation technologies which have temporary, localized, and reversible effects."[11] The 2004 *Presidential Directive on Space-Based Positioning, Navigation and Timing Systems* calls for development of capabilities to selectively deny, as necessary, GPS and other navigation services.[12]

TREND 7.2: US leads in the development of space situational awareness capabilities to support space negation

Driven by Cold War security concerns, the US and USSR were pioneers in the development of space surveillance capabilities. Today, a growing number of space actors are investing in space surveillance to facilitate debris monitoring, satellite tracking, and near Earth object (NEO) detection, although the US remains dominant. Russia maintains relatively extensive capabilities in this area, and China and India have significant satellite tracking, telemetry, and control assets essential to their civil space programs. Canada, France, Germany, and Japan are all actively expanding their ground- and space-based space surveillance capabilities.

The US explicitly links space surveillance with its space control doctrine and desire to achieve "space situational awareness." The 2001 *Quadrennial Defense Review Report* noted that the US would "pursue modernization of the aging space surveillance infrastructure, enhance the command and control structure, and evolve the system from a cataloging and tracking capability to a system providing space situational awareness."[13] Space Control is defined by the US Air Force (USAF) as "combat, combat support, and combat service support operations to ensure freedom of action in space for the United States and its allies, and when directed, deny an adversary freedom of action in space."[14]

While the US Space Surveillance Network is the primary provider of space surveillance data to all space users, it has limited capabilities to provide real-time data collection. The Space Situational Awareness Integration Office was created in 2002 within USAF Space Command, with responsibilities to oversee the integration of space surveillance in order to achieve space situational awareness.[15] Space-based surveillance, demonstrated by the US in the late 1990s through the Space Visible Sensor experiment,[16] is being pursued through the Space-Based Surveillance System (SBSS), described in the 2003 *Transformation Flight Plan* as "a constellation of optical sensing satellites to track and identify space forces in deep space to enable defensive and offensive counterspace operations."[17] A "Pathfinder" SBSS satellite is set for launch in 2007.[18] The US is planning to develop a geostationary Orbital Deep Space Imager designed to "provide a predictive, near-real time operating picture of space to enable space control operations."

TREND 7.3: Ongoing proliferation of ground-based capabilities to attack satellites

As noted in Figure 7.1, a variety of American and Soviet/Russian programs during the Cold War and into the 1990s sought to develop ground-based ASAT weapons employing conventional, nuclear, or directed energy capabilities.

FIGURE 7.1: History of ground-based ASAT programs[19]

System	Actor	Dates	Description of program
Bold Orion air-launched	US	1959,	Air-launched ballistic missile passed within 32 kilometers ballistic missile single test of the US Explorer VI satellite
SAtellite INTerceptor (SAINT) satellite	US (USAF)	1960-1962, idea abandoned in the late 1960s	Designed as a co-orbital surveillance system, the could be armed with a warhead or 'blind' the enemy satellite with paint
Program 505	US (US Army)	1962-1964	Nike-Zeus nuclear-tipped anti-ballistic missile system employed as an ASAT against orbital vehicles
Program 437	US (USAF)	1963-1975	Nuclear-armed Thor ballistic missile launched directly into the path of the target
Co-orbital (IS) ASAT	USSR	1963-1972, 1976-1982	Conventional explosives launched into orbit near target, detonated when within range of one kilometer
Polaris submarine launched ASAT	US (US Navy)	1964-late 1960s	Submarine-launched ballistic missile fitted with tracking sensors and launched into orbit as satellite passed overhead to detonate a warhead filled with steel pellets in satellite's path
Laser ASAT	USSR	1975-1989	Sary Shagan and Dushanbe laser sites reported to have ASAT programs
Air-Launched Miniature Vehicle	US (USAF)	1982-1987	Missile launched from high-orbit F-15 aircraft to destroy satellite with a high-speed collision
MiG-31 Air-launched ASAT	USSR	1980-1985	Exploration of kinetic-kill ASAT to be launched from MiG-31 aircraft, never tested
MIRACL Laser	(US) USAF	1989-1990, tested in 1997 though not recognized as an ASAT test	Megawatt-class chemical laser fired at satellite to disble electronic sensors
Ground-Based Kinetic Energy ASAT	(US) US Army	1990-2004	Kinetic-kill vehicle launched from the ground to intercept and destroy a satellite

Conventional weapons

Launching a payload to coincide with the passage of a satellite in orbit is the fundamental requirement for a conventional ASAT capability. A total of 28 actors have demonstrated sub-orbital launch capabilities, 10 of which have orbital launch ability. With tracking capabilities, a payload of metal pellets or gravel could be launched into the path of a satellite by sub-orbital rockets or missiles (for example a SCUD missile).[20] Kinetic hit-to-kill technology requires more advanced sensors to home in on the target. Targeting satellites from the ground using any of these methods would likely be more cost-effective and reliable than space-based options.

The US Army invested in ground-based kinetic energy ASAT technology in the late 1980s and early 1990s. Although its Kinetic Energy (KE) ASAT program was terminated in 1993, some related research continued and Congress granted funding for the program in FYs 1996, 1997, 1998, 2000, 2001, and 2004.[21] In 2002, program administrators reportedly estimated an on-orbit demonstration of the moth-balled system would cost $60-million.[22] Congress appropriated $7.5-million for the KE ASAT for FY2004 through the Missile Defense Agency's (MDA) Ballistic Missile Defense Technology budget.[23]

The US has deployed a limited number of ground-based exoatmospheric kill vehicle (EKV) interceptors for ballistic missile defense purposes.[24] EKVs use infrared sensors to detect ballistic missiles in mid-course and maneuver into the trajectory of the missile to ensure a hit to kill.[25] Some experts assess that, with limited modification, the EKV could act as an ASAT[26]. With an interceptor capable of launching a kill-vehicle as high as 6,000 kilometers, this system would likely have the capacity to attack satellites in LEO.[27] The total budget for missile defense grew from $4.8-billion for FY2001 to $9.2-billion for FY2005.[28]

US Air Force Doctrine Document 2-2.1 outlines a set of so-called "counterspace operations" designed to "preclude an adversary from exploiting space to their advantage … using a variety of permanent and/or reversible means."[29] The 2004 *Counterspace Operations* describes the planning for and execution of such operations, including legal considerations and targets, which include satellites, communications links, ground stations, launch facilities, command, control, communication, computer, intelligence, surveillance, and reconnaissance systems (C4ISR), or third-party providers. Among the tools for offensive counterspace operations, the document lists direct ascent and co-orbital ASATs, directed energy weapons, and electronic warfare weapons.

Nuclear weapons

A nuclear weapon detonated in space generates an electromagnetic pulse that is highly destructive to unprotected satellites, as demonstrated by the 1962 Starfish Prime test.[30] Given the current global dependence on the use of satellites, such an attack could have a devastating and wide-ranging impact on society. As noted above, both the US and USSR explored nuclear-tipped missiles as missile defense interceptors and ASAT weapons. The Russian Galosh ballistic missile defense system surrounding Moscow employed nuclear-tipped interceptors from the early 1960s through the 1990s.[31]

China, the member states of ESA, India, Israel, Japan, Russia, Ukraine, and the US all possess space launch vehicles capable of launching a nuclear warhead into orbit, although placing weapons of mass destruction in outer space is prohibited by the Outer Space Treaty. North Korea, Iran, and Pakistan are among the 18 states that possess medium-range ballistic missiles that could launch a mass equivalent to a nuclear warhead into outer space without achieving orbit.

There are eight states assessed to possess nuclear weapons: China, France, India, Israel, Pakistan, Russia, the US, and the UK. North Korea has declared itself to be in possession of nuclear weapons and has sub-orbital ballistic missile capability.[32] Iran is suspected by many of pursuing a nuclear weapons program and has an active long-range missile program.[33]

Directed energy weapons

The ASAT potential of high-energy lasers has been extensively explored by the US and to a lesser degree by the USSR/Russia. All states have access to low-powered lasers, which could be used to "dazzle" unhardened satellites in LEO. As many as 30 states may already have the capability to use low-power lasers to degrade unhardened sensors on satellites in LEO.[34] According to the US DOD, China has conducted ground tests of directed energy weapons with potential uses as ASATs. In 1997, the US Mid-Infrared Advanced Chemical Laser (MIRACL) was test-fired against a satellite in a 420-kilometer orbit, damaging the satellite's sensors. Reportedly, it was a 30-watt laser used for alignment that actually damaged the target satellite's sensors,[35] suggesting that even a commercially available low-watt laser functioning from the ground could be used to "dazzle" or temporarily disrupt a satellite.[36] The megawatt class MIRACL laser system is able to dazzle and blind sensors in GEO and heat to kill electronics on satellites in LEO – a significant ASAT capability. Until 2004, the US was developing a Counter Surveillance/Reconnaissance System (CSRS) employing lasers to temporarily disrupt surveillance satellites by dazzling sensors.[37]

The Airborne Laser currently under development is central to plans for future Boost Phase Ballistic Missile Defense. Merging a megawatt class chemical oxygen iodine laser with a Boeing 747-400 aircraft, the system is designed to destroy ballistic missiles in the early boost-phase.[38] The Airborne Laser project achieved "first light" in 2004 in a ground-based test of the chemical oxygen iodine laser.[39] This technology is also assessed to have ASAT capabilities. A summary of the technologies that are required to support the development of ground-based capabilities to attack satellites is provided in Figure 7.2 below.

FIGURE 7.2: Technologies required for the development of ground-based capabilities to attack satellites

Capabilities	Conventional			Directed energy			Nuclear
	Pellet cloud ASAT	Kinetic-kill ASAT	Explosive ASAT	Laser dazzling	Laser blinding	Laser heat-to-kill	HAND
Sub-orbital launch	□	□	□				□
Orbital launch	□	□	□				□
Precision position/ maneuverability		□					
Precision pointing				□	□	□	
Precision space tracking (uncooperative)	□	□			□	□	
Approximate space tracking (uncooperative)			□	□			□
Nuclear weapons							□
Lasers > 1 W				□			
Lasers > 1 KW					□		
Lasers > 100 KW						□	
Autonomous tracking/ homing		□					

Key: □ = Enabling capability

TREND 7.4: Increasing access to space-based negation enabling capabilities

Deploying space-based ASATs, whether using kinetic-kill, directed energy, or conventional explosive techniques, would require somewhat more advanced enabling technologies beyond the fundamental requirements for orbital launch. Many of these technologies could be advantageous for a variety of civil, commercial, or non-negation military programs, but microsatellites, maneuverability, and other autonomous proximity operations are essential building blocks for a space-based negation system. A summary of the existing capabilities of key space actors that have considered enabling technologies for the development of space-based ASATs is provided in Figure 7.3.

Space-based weapons targeting satellites with conventional explosives, referred to as "space mines," could employ microsatellites to maneuver near a satellite and explode within close range. Relatively inexpensive to develop and launch, with a long lifespan, microsatellite technology serves many useful purposes. A microsatellite's purpose would be difficult to determine until detonation and, because of their small size, space-mine microsatellites would be hard to detect.

The proliferation of microsatellite technology has involved a wide array of new state, commercial, and academic actors engaging in satellite research and development. A total of 30 states have at some stage employed microsatellites. The partnership between China and Surrey Satellite Technology Ltd. of the UK saw the 2000 launch of the Tingshua-1 microsatellite and companion Surrey Nanosatellite Application Platform to test on-orbit rendezvous capabilities.[40] China, along with Algeria, Nigeria, Thailand, Turkey, Vietnam, and the UK, has pledged to contribute microsatellites to the Disaster Monitoring Consortium (see Civil Space Programs and Global Utilities).[41] A number of states also employ microsatellites for scientific remote-sensing and surveillance purposes, with no evidence of links to space weapons programs.

The US has a variety of ongoing programs developing advanced technologies that would be foundational for a space-based conventional ASAT program, including maneuverability, docking, and on-board optics. The Experimental Spacecraft System (XSS) employs microsatellites to test proximity operations, including autonomous rendezvous, maneuvering, and close-up inspection of a target. For example, XSS-10 was launched in 2002 and performed maneuvers within 40 meters of another satellite. The Near-Field Infrared Experiment (NFIRE), designed to provide support to ballistic missile defense, would employ a kill vehicle to encounter a ballistic missile at close range, with a sensor to record the findings. Although NFIRE is not designed for space systems negation, it could be modified for such use. Another missile defense technology currently under development which could enable space systems negation is the space-based interceptor (SBI). The SBI, tentatively scheduled for a 2011-2012 deployment, will test ballistic missile interception using small, light-weight kill vehicles from a space-based platform.[42]

FIGURE 7.3: Enabling capabilities of key actors for space-based kinetic-kill ASATs*

Capability	China	EU/ESA	France	UK	India	Israel	Japan	Russia	Ukraine	US
Space launch vehicles										
Land – Fixed[43]	X	X	X		X	X	X	X	X	X
Land – Mobile[44]	L		L	L	L	L		X	L	X[45]
Sea	L[46]							X[47,48]	X[49]	X[50]
Air								D[51]		X[52]
Space tracking (uncooperative)										
Optical (passive)	X[53]	X	X[54]	X[55]			X[56]	X[57]		X[58]
Radar	X[59]		X[60]	X[61]			X[62]	X[63]		X[64]
Laser[65]	X	X	X	X		X	X	X	X	X
Autonomous rendezvous										
Cooperative		D[66]						X[67]		D[68]
Uncooperative		D[69]						F[70]		D
Proximity operations										
Cooperative		D[71]								X[72]
Uncooperative		D[73]								X[74]
High-g, large-?V upper stages	X	X	X	L			X	X	X	X
Micro-satellite construction	X	X	X	X	X	X	X	X	X	X

Key: X = Existing capability F = Flight tested capability D = Under development L = Latent capability

*This figure highlights enabling technologies for space-based kinetic-kill negation capabilities. It does not imply that these actors have such negation systems or even programs to develop them, merely that they have prerequisite technologies that would make acquisition of such a system a shorter-term possibility.

Autonomous rendezvous capacity is also the objective of NASA's Demonstration of Autonomous Rendezvous Technology (DART) spacecraft, relying on the Advanced Video Guidance Sensor and GPS to locate its target.[75] The Defense Advanced Research Projects Agency's (DARPA) Orbital Express program will develop on-orbit refueling and reconfiguring–servicing necessary for maneuvering a space-based ASAT.[76] These programs make use of smaller, lighter components and are consistent with a growing US emphasis on responsive space programs.

The German space agency's on-orbit servicing program, Technology Satellite for Demonstration and Verification of Space Systems (TECSAS), is testing proximity operations and on-orbit maintenance of satellites. It will explore "in-orbit qualification of the key robotics elements (both hardware and software) for advanced space maintenance and servicing systems, especially with regard to docking and robot-based capturing procedures." Germany's Spacecraft Life Extension System project plans a satellite "tugboat" to keep satellites in-orbit beyond their intended lifespan.[77] These technologies could conceivably be modified for space systems negation purposes.

2005 DEVELOPMENTS

TREND 7.1: Proliferation of capabilities to attack ground stations and communications links

2005: State-sponsored jamming incidents in Libya and Iran

Libya has been accused of blocking broadcasts of two international satellites (Eutelsat's Hotbird and Loral Skynet's Telsat 12), interrupting signals of several TV and radio stations serving Europe as well as some American diplomatic, military, and intelligence communications. The primary target is thought to be *Sowt Libya* (Voice of Libya), a British- and Arab-owned commercial radio station broadcasting on human rights issues to Libya. The first jamming incident occurred on 19 September 2005; also jammed were the signals of CNN International, BBC World, and several other stations using Eutelsat's Hotbird satellite. The jamming ended after 50 minutes when *Sowt Libya* went off the air. The radio station then began re-broadcasting several days later as *Sowt Al-amal* (Voice of Hope) from the US using Loral Skynet's Telstar 12 satellite. Jamming resumed less than an hour after *Sowt Al-amal* started broadcasting, blocking several European stations but not affecting *Sowt Al-amal* itself. The station voluntarily suspended its broadcasts and the jamming signal, which stopped broadcasting, was sourced to a transceiver in Tripoli. The issue is reportedly being addressed by US and UK diplomatic officials who are calling on Libya to investigate and apprehend the perpetrators and are considering filing a complaint with the International Telecommunication Union, of which Libya is a member. The jamming succeeded in disrupting US military communications in the Mediterranean, demonstrating the use of ground stations to temporarily negate both commercial and military satellite functions.[78]

Iran continued to jam satellite reception in Tehran in 2005. While satellite dishes are technically banned in Iran, the government has reportedly taken additional steps to prevent reception of international opposition television stations, including Voice of America's Persian-language programming. The jammers did not affect the uplink, but instead broadcast microwave signals across Tehran to prevent reception over the local area, a procedure that is not banned by international law. The US Broadcasting Board of Governors responded on 17 June 2005 in support of Voice of America and other affected stations by providing access to a third satellite to broadcast their signals simultaneously with the current two (Telstar 12 and EutelSat's Hotbird), thus making it more difficult for Iranian authorities to jam the signals.[79] This local jamming technique would be applicable to counter-intelligence or battlefield situations as well, providing the ability to temporarily block satellite reception over specific areas without damaging space assets or disrupting services outside of the area.

2005: Chinese satellite TV suffers further jamming incidents

China continued to be a target of satellite jamming incidents in 2005. AsiaSat's 3S satellite's television service to China was disrupted on 13 March 2005 when six of its transponders were jammed, interrupting at least eight television stations with anti-government messages timed to coincide with annual meetings of the Chinese Communist Party. While AsiaSat promptly blamed the Falun Gong spiritual movement, representatives denied any involvement in the attack and the perpetrators have yet to be apprehended. As the satellite's coverage extends well beyond China's borders, the attack could have originated from any number of neighboring countries.[80] China has responded to past jamming incidents by purchasing and developing "jam-proof" satellites such as the APSTAR VI, launched on 12 April 2005. However, by 3 July 2005, the broadcasts of the CCTV channel to China using the APSTAR VI satellite were overridden by signals also allegedly from the Falun Gong.[81]

Net Assessment:

While still relatively infrequent, satellite jamming incidents continued to have a negative, and at times indiscriminate, effect on the secure use of space in 2005. Radio frequency jamming, interference, and piracy are also becoming a growing concern for the satellite services industry (see The Space Environment). Incidents in China and Iran demonstrated the proliferation of space negation capabilities to both state and non-state actors. The jamming of China's APSTAR, a satellite that was specially designed to be jam-resistant, also illustrated the ongoing vulnerability of space systems to concentrated negation efforts. Jamming incidents in Libya demonstrated how these capabilities are spreading to new states, with potentially long-term negative effects on space security. Under the International Telecommunication Union Convention, the radio frequency spectrum or "airwaves" are considered sovereign to the state.

TREND 7.2: The US leads in the development of space situational awareness capabilities that could support space negation

2005: US restrictions on sharing of space surveillance data and European drive to develop independent capabilities

The new provisions included in the 2004 US Defense Authorization Act that restricts the distribution of space object tracking data were put into effect in 2005 when a new USAF website known as Space Track became the primary surveillance data provider for the public. Downloading data requires approval of a user agreement, with restrictions on redistribution, and advanced analysis functions will require fees. In spite of protests from the amateur and professional astronomy community, there has been no major clarification of the agreement for redistribution of data – an issue of concern for major data redistributors like the Heavens Above website based in Germany, and for other state and non-state space actors requiring the data for mission planning, satellite monitoring, and collision avoidance. The effort to protect US space assets is limited by the nature of satellite tracking; many classified objects are already tracked independently by hobbyists based on sky observation and trajectory calculation. Partly as a consequence of US restrictions on space surveillance information, EU member states indicated their interest in exploring an independent space surveillance capability (see The Space Environment).

Net assessment

US restrictions on space surveillance data could help to thwart space systems negation against US assets. The negative implications for other actors have yet to be seen, but limiting the ability of satellite operators to track debris and other satellites to avoid collisions would undermine space security.[82] Ongoing European efforts in 2005 to develop an independent space surveillance system may have a positive effect on space security by increasing the capacity and redundancy of space surveillance systems, but could also support space systems negation.

TREND 7.3: Ongoing proliferation of ground-based capabilities to attack satellites

2005: Progress on high-energy lasers in the US and on basic laser research in China

High Energy Laser (HEL) weapons have the potential to neutralize targets from a distance rapidly and with precision, and are intended for particular use in missile defense. The US continues to develop powerful HEL weapons capable of reaching space-based targets, seeking to make them lighter, more compact, and less service-dependent so that they can be placed on aircraft and perhaps eventually on satellites in orbit. Targeting HEL weapons on satellites could have several effects depending on the power, focus, and exposure time, from temporarily blinding sensors to overheating and destroying electronic systems or even the physical structure.

Much of the US work on HEL systems is carried out at the Starfire Optical Range and the High Energy Laser Systems Test Facility (HELSTF) at the White Sands Missile Range, home of the megawatt-class MIRACL laser and its partner Sea-lite beam director. Northrop Grumman was awarded a two-year contract in February 2005 for operations and maintenance of lasers and support systems used at the HELSTF facility to test effects against physical threats. The 3.5-meter telescope at Starfire has been fitted with a sodium-beacon laser to enable atmospheric compensation and beam control experiments in 2005; possible applications include anti-satellite weapons, relay mirror systems, satellite tests and diagnostics, and high-resolution satellite imaging. Further funding has been requested for FY2006 and FY2007.[83]

Northrop Grumman and Raytheon are developing the advanced high-power Chemical Oxygen-Iodine Laser for the Airborne Laser project of the MDA. The aircraft for the ABL completed its Low Power System Integration-Passive phase of testing on 26 July 2005. This 8-month period of flight tests included demonstrations of beam control/fire control systems, missile detection sensors, and laser turret. It then entered its active testing phase, after which the actual laser installation is expected to take place, with plans for its first test against a missile in 2008.[84]

Since size and the need for refueling limit current laser weapons designs, the US is pursuing solid state laser (SSL) designs, which are generally lighter, smaller, and of longer operational life, but have not been able to generate the same level of continuous power as other types. The Pentagon's Joint High-Power Solid-State Laser (JHPSSL) program is funding the development of a 25-kilowatt SSL capable of more than 300 seconds of run-time.[85] Twenty-five kilowatts is the approximate minimum power needed to heat-to-kill electronics on satellites in LEO and 300 seconds is the typical flyover time of a satellite in LEO. JHPSSL contractor Northrop Grumman announced on 9 November 2005 that it had successfully tested a 27-kilowatt SSL for 350 seconds, the most powerful continuous SSL to date. The ASAT capabilities of SSLs could potentially go far beyond simply dazzling sensors to blind or heat the satellite components themselves. Further, given the absence of any chemical refueling needs, the potential for use of SSLs on aircraft and spacecraft grows as their size and weight decrease. In space, which is free of the disrupting effects of weather and atmosphere, satellite-disabling effects could be achieved at much lower power.[86]

The range of laser weapons could be extended beyond the line of sight with the use of mirrors. Such possibilities have been explored for battlefield operations using mirrors on unmanned aerial vehicles, and are being developed using a high-altitude airship in what is called the Aerospace Relay Mirror System.[87] Such mirror systems could potentially be used to direct lasers toward space objects, allowing for greater global coverage with few ground facilities and a reduction in atmospheric effects on targeting.[88]

While the US is the only state known to be conducting research and development on HEL with specific ASAT capabilities, it is by no means the only state to conduct research and development of lasers. Over 30 states continue to have such foundational elements for developing a laser ASAT as high-powered lasers, high-quality optics, satellite tracking, and precision telescope pointing and tracking. China, for example, has developed all major laser types for a variety of industrial, medical, commercial, and military applications.[89] Its high power laser program has been operating since as early as 1986, beginning with the LF-12 Shengguang-1 laser at the Chinese Academy of Sciences' Shanghai Institute of Optics and Fine Mechanics. China now has multiple hundred-megawatt lasers.[90] Research in China continued in 2005 on laser frequencies and adaptive optics that can help to maintain laser beam quality over long distances – a condition that is necessary for possible ASAT uses.[91] Some sources indicate that China is developing satellite tracking and laser ranging capabilities as well as fire control systems.[92] Research was also carried out in 2005 on the use of solid state lasers in space, mostly in sensor and altimeter functions,[93] and on the operational effectiveness of laser anti-aircraft weapon systems.[94]

2005: US conventional (kinetic-energy) ASAT program continues

The US Army's small yet long-standing kinetic-energy anti-satellite (KE-ASAT) program is now part of an Applied Counterspace Technology testbed at Redstone Arsenal after program restructuring in 2004. Funding for the program totaled $7.5-million in FY2004 and $14-million in FY2005, through direct appropriations by the US Congress rather than Army budget requests. The current contract with Miltec Corporation includes development of three advanced kill vehicles. No funding is currently allocated for a flight-test program and the future of the program remains uncertain. Opposition is growing from within the USAF to kinetic kill maneuvers due to the consequent debris production that can threaten the security of other space assets.[95]

2005: Upgrades in US and Russian ground-based anti-ballistic missile systems

Both the US and Russia continue research and development of ballistic missile interceptors with dual-use potential as ASATs. The tenth interceptor missile of the MDA's Ground-based Midcourse Defense system was placed in its silo at Fort Greely, Alaska on 20 December 2005, joining seven others at Fort Greely and two at Vandenburg Air Force Base, California.[96] The US Senate also re-implemented previous plans for a kinetic kill vehicle on the NFIRE satellite to be launched in 2006.[97] Both the interceptor missiles and the NFIRE kill vehicle could potentially be used to target satellites in orbit (see Space-Based Strike Weapons).[98]

Russia continued tests of its upgraded A-135 anti-ballistic missile system in 2005 at the Sary Shagan Missile Range in Kazakhstan. The A-135 system includes 100 Gazelle and Gorgon interceptor missiles deployed in underground silos around Moscow and became operational in 1995 to replace the A-35M Galosh system from the 1970s. The Gazelle is a short-range (80 kilometers) missile designed for descent/terminal phase missile defense within the atmosphere, while the Gorgon is a long-range (350 kilometers) exo-atmospheric missile capable of intercepting ballistic missiles in midcourse in space. The Gorgon was originally designed to launch a 1-megaton nuclear warhead for detonation just outside the atmosphere to destroy incoming warheads. Such a high-altitude nuclear detonation could disable any satellite in LEO within line of sight. Due to its long range, the Gorgon is also said to have a conventional anti-satellite capability against targets in LEO.[99]

2005: China, EADS, and UK continue basic research into kinetic kill vehicles

While research and development appear to be most advanced in Russia and the US, a number of other space-faring nations conducted basic research into kinetic kill vehicles in 2005. Chinese academic institutions, including Guangzhou University, Harbin Industrial University, and Hunan Changsha National University of Defense Technology, explored techniques for kinetic energy interceptors. Open-source journals outlined research focused specifically on exo-atmospheric interceptors, and while such applications can be used for ballistic missile defense, they also enable kinetic energy ASATs. Specific topics of research included optimizing fuel consumption, attitude control, interception orbit determination, various methods for midcourse and terminal guidance, and atmosphere-to-space transition.[100]

EADS Space Transportation continued its research on ground-based exo-atmospheric kinetic kill vehicles for missile defense. Its "Exoguard" interceptor family, currently under advanced study, will reportedly be capable of hitting ballistic targets at altitudes higher than 100 kilometers.[101] In 2004 EADS worked on design and also began cooperating with Raytheon for development of European ballistic missile defenses.[102] Since 2001 it has participated in various NATO missile defense feasibility studies in partnership with other European companies.[103] Work by the UK Defence Science and Technology Laboratory on exo-atmospheric interceptors, including guidance systems and decoy detection, continued in 2005.[104]

Net assessment:

The ongoing progress in the development of ground-based space negation technologies, particularly the more advanced laser ASAT programs in the US, could be considered to have a negative effect on space security. Whether with the intention of hedging for future contingencies or for related civil research, an ever greater number of states appear to be developing latent capabilities for directed energy and kinetic ASATs. However, it is also notable that some technologies, such as high-energy lasers, remain outside the capability of many space-faring states. Furthermore, none of these technologies was deployed, tested, or used in 2005, and the case of the US KE-ASAT highlighted the reticence if not outright opposition from military actors to the use of debris-producing weapons.

TREND 7.4: Proliferation of space-based negation enabling capabilities

2005: US microsatellites demonstrate dual-use rendezvous and surveillance capabilities

Many close-proximity, in-orbit activities for both protection and negation require highly sensitive maneuvering capabilities, for which microsatellites play a key role due to their fuel efficiency, small size, increasing technical capabilities, and relatively low cost. In 2005, both civil and military space programs in the US demonstrated such capabilities. The USAF launched the Experimental Satellite System-11 (XSS-11) microsatellite on 11 April and in September, announced that it had flown successful repeat rendezvous maneuvers with the upper stage of the Minotaur I rocket that had deposited it into orbit, taking images from as close as 500 meters. An improvement on the XSS-10 that completed a similar operation in 2003, the XSS-11, during its lifespan of 12 to 18 months, is expected to complete several more missions. Although the satellite has used manual maneuvering from ground control, an autonomous planning system was running in the background and is expected to take over in the future.[105]

NASA also demonstrated similar technologies under its DART program in 2005. DART is an experimental microsatellite designed to autonomously locate and rendezvous with a retired US military communications satellite without human assistance. DART was built by Orbital Services to demonstrate technology with possible future NASA applications in returning Mars samples, servicing satellites, delivering cargo to the International Space Station (ISS), and servicing the Hubble Space Telescope. Intended to approach within 5 meters of its target satellite, DART ran out of fuel earlier than expected and unexpectedly collided with the target satellite during its 15 April 2005 mission. The premature fuel expenditure was apparently caused by faulty communication with GPS satellites that helped the spacecraft navigate.[106] The accidental collision bumped the target satellite into an orbit several kilometers higher than normal, and though not intentional, demonstrates a dual-use for kinetically de-orbiting a target satellite without creating significant debris. The ability to operate autonomously in close proximity to other satellites is a key enabling step for on-orbit characterization of unknown objects and verification of payload contents for protection purposes. It also enables signal reconnaissance and interference, physical manipulation and damage, and close-proximity delivery of kinetic and directed energy weapons.

2005: Near Earth Object missions demonstrate dual-use capabilities

In light of concerns about the potential dangers of NEOs, ESA, Japan, and the US led NEO interception missions in 2005. NASA's Deep Impact program succeeded on 3 July 2005 in hitting Comet Tempel 1 with a 372-kilogram impact probe, which was observed from a flyby spacecraft and from Earth with ground- and space-based telescopes. Labeled a "controlled cratering experiment," the goal of this mission was to gain data on the composition of the comet. Deep Impact demonstrated some key negation-enabling capabilities, including launch of a projectile from a space asset at another space object and real-time space monitoring.[107]

Japan's highly anticipated 2005 mission to collect samples from an asteroid and return them to Earth apparently failed in the final stages. The Hayabusa spacecraft was launched in 2003 to rendezvous with the Itokawa asteroid. The spacecraft succeeded in landing on 20 November 2005, but apparently failed to collect samples. Its small robot lander, Minerva, was also lost in November after failing to touch down on the asteroid. While the intended mission was not a success, it demonstrated autonomous firing and rendezvous technologies which could potentially serve negation purposes.[108]

Lastly, ESA continued its mission study for an asteroid deflection experiment called Don Quixote in 2005. The mission is being designed to improve understanding of asteroids and to test methods for determining precise characteristics of an asteroid in order to change its trajectory. Such an asteroid deflection mission will demonstrate enabling technologies for space-based negation through kinetic energy impact and flyby observation.

2005: Strengthening of commercial actors in the microsatellite market

Microsatellites are becoming more common in all space sectors. Orbital Recovery made a major entrance into the commercial microsatellite market in 2005, marketing its "space tug" services to reposition other satellites.[109] UK-based Surrey Satellite Technology, Ltd. continued to be the leading microsatellite provider. Its high-resolution Earth observation microsatellites, built for China and the UK, were successfully launched on 27 October 2005. Progress on the "RapidEye" five-satellite Earth observation constellation continues with a launch contract signed with Russian-Ukrainian ISC Kosmotras.[110]

The ConeXpress Orbital Life Extension Vehicle (CX-OLEV), currently being developed by Orbital Recovery, is set to be the first commercial satellite that is specifically designed, using its own thrusters, to rendezvous with a target satellite in GEO, latch onto it, and provide it with renewed propulsion, navigation, and guidance capability.[111] The CX-OLEV will also use an extremely efficient electric ion-plasma propulsion system, reducing fuel storage size and weight. Although this propulsion system is slower than other thruster systems, requiring 4 to 6 months to move from LEO to GEO, it makes docking much safer. Orbital Recovery signed its first reservation for a servicing mission in October 2005.[112]

2005: Europe's Automated Transfer Vehicle delayed to 2007

ESA has been developing an Automated Transfer Vehicle (ATV) for supplying the ISS. Though its first launch was originally planned for 2005 or 2006, due to several recent testing failures, the launch has been delayed until 2007. The ATV will autonomously navigate to rendezvous and dock with the ISS to deliver supplies and then dispose of wastes in a self-destructive re-entry. The ATV is also designed to use its thrusters to adjust the ISS's orbit, including attitude control, to perform debris avoidance maneuvers, and to boost the Station's orbit to overcome the effects of atmospheric drag. While the Russian-designed ATV docking mechanism is made specifically for the ISS, it employs several technologies that include precise, autonomous navigation, which could enable negation activities involving orbit manipulation or rendezvous. There are assertions that the ATV is specifically designed not to collide with the host, but this technology could still be modified in the future to provide basic kinetic kill maneuver capability.[113]

2005: Robotic technologies for on-orbit servicing demonstrated on International Space Station

On-orbit servicing is a key research priority for German and Canadian civil space programs and supporting commercial companies. The Canadian space robotics program has a long history with the Shuttle and ISS Canadarm robotic arms, while Germany has recently developed significant capacity for smaller-scale robotics. Robotic Components Verification on ISS (ROKVISS), the space robot project of the German Aerospace Centre (in cooperation with the Russian Space Agency and several private companies[114]), was successfully delivered to the ISS on 24 December 2004 and mounted to the outer wall of the Russian Zvesda module during a spacewalk on 26 January 2005. In experiments throughout 2005, ROKVISS demonstrated light-weight robotics technologies and advanced telepresence remote control. It also tested the effects of the space environment on robotics, including radiation, micro gravity, and temperature changes.[115]

The Canadarm 2 Mobile Manipulator System on the ISS demonstrated for the first time remote control of arm motion from the ground on 24 February 2005. Rather than use real-time controls, it initiated several simple preplanned trajectories, which are expected to lead to more complex ground-controlled maneuvers that could relieve ISS crews from time-consuming robotics operations. This development is the foundation for the Canadian Space Agency's next generation robotic hand called the Special Purpose Dexterous Manipulator or "Dextre."[116]

Both ROKVISS and Canadian robotics work are foundational for the TECSAS, a joint German-Russian-Canadian on-orbit servicing project currently under development. The goal of TECSAS is to test key robotics and navigation elements for advanced space maintenance and servicing systems. These include, among others, approach and rendezvous, inspection fly around, formation flight, capture, flight maneuvers, manipulation of the target satellite, active ground control via telepresence remote control, and passive ground control during autonomous operations.[117]

DARPA has also expressed significant interest in developing capacity for in-orbit servicing, repair, and orbit manipulation using space robotics with manipulator/grapple arms. Proposals appeared in the FY2006 and FY2007 budget requests for the Spacecraft for the Universal Modification of Orbits program totaling almost $35-million. According to DARPA, the overall purpose is to extend the life of commercial and military satellites, with specific objectives in 2006-2007 to develop and demonstrate an autonomous rendezvous and grappling front end system at low cost for both LEO and GEO. It is also intended to provide "safe and calculated de-orbit" for other satellites, something currently being explored as an option for re-entry of the Hubble Space Telescope at the end of its life.[118]

2005: Research, development, and testing of homing sensors in China, Europe, and the US.

Homing sensors are a foundational technology for all types of space rendezvous activities, as well as more negation-oriented actions such as kinetic energy anti-satellite weapons, space-based ballistic missile interceptors, and on-orbit rendezvous for manipulation or signal interception. In 2005 a number of dual-use systems demonstrated homing capability, including the German space robotics experiment ROKVISS, the US and Japanese asteroid/comet interception missions, and the USAF XSS-11 microsatellite proximity operation (see above).

Chinese researchers at the Beijing University of Aeronautics and Astronautics, the Chinese Academy of Space Technology, and Qinghua University continued research on on-orbit homing and rendezvous methods in 2005, although it is unclear whether the work is new and Chinese-led or is merely a review of previously conducted foreign research. This work includes simulations of transfer control, position keeping, and docking, as well as the use of a rendezvous lidar sensor system linked to attitude controls.[119] Researchers at other Chinese universities have been investigating multisensor homing techniques (e.g., radar and infrared) and integration of multiple sensor data streams.[120]

Net assessment:

The proliferation of microsatellite technology and advances in space robotics in 2005 could have both positive and negative impacts on space security. Microsatellites may drive down the cost of space access, but also provide precursor technologies for space negation. The XSS-11 illustrates the potential of microsatellites to serve as capable and cost-effective vehicles for in-orbit protection and negation activities, including close-proximity surveillance, inspection, signal reconnaissance, and signal interference, and also for intercept functions as "space mines" to destroy incoming objects, or perform kinetic kill maneuvers and close-proximity delivery of energy weapons.[121] Space robotics projects are developing technology that will help increase the lifespan of space assets and facilitate more efficient use of human resources in space, thus at least indirectly increasing space security. These technologies, as well as research into homing sensors, have dual-use potential for space system negation by providing capabilities that could subsequently be directed at targeting, damaging, disorienting, or de-orbiting satellites. It is notable, however, that these *capabilities* remain latent: none of these dual-use technologies have been explicitly linked to space-based negation programs nor directly used for space systems negation.

CHAPTER EIGHT

Space-Based Strike Weapons

This chapter assesses trends and developments related to the research, development, testing, and deployment of space-based strike weapons (SBSW). SBSW are systems operating from Earth orbit with the capability to damage or destroy either terrestrial targets (land, sea, or air) or terrestrially launched objects passing through space (e.g., ballistic missiles), via the projection of mass or energy. Earth-to-space and space-to-space weapons, often referred to as anti-satellite (ASAT) weapons, are addressed in the Space Systems Negation chapter.

Mass-to-target SBSW collide with a target, damaging it through the combined mass and velocity of the weapon; or hit a target with inert or explosive devices. One mass-to-target SBSW concept is the US missile defense Space-Based Interceptor (SBI), which is designed to accelerate toward and collide with a ballistic missile in its boost phase. Another mass-to-target SBSW concept is the hypervelocity rod bundle, an orbital uranium or tungsten rod that would be decelerated from orbit and re-enter the Earth's atmosphere at high velocity to attack ground targets.

Energy-to-target SBSW, often called directed energy weapons, transfer energy through a beam designed to generate sufficient heat or shock to disable or destroy a target. This beam could be generated using lasers, microwaves, or neutral particle beams. An example of an energy-to-target SBSW is the US Space-Based Laser (SBL) concept planned for missile defense. An SBL would attempt to use a satellite to direct an intense laser beam at a missile during its launch phase, heating it to the explosion point. An SBL satellite would require an energy source to power the laser, optical systems to generate the laser, and precise attitude control to point the laser beam accurately at the target for a relatively sustained period of time.

While no SBSW systems have yet been tested or deployed in space, the US and USSR devoted considerable resources to the development of key SBSW capabilities during the Cold War. The US continues to develop SBI within the context of its missile defense program. In addition to assessing the status of these dedicated SBSW programs, this chapter also assesses efforts of space actors to develop key technologies required for SBSW, even if they are not being pursued for SBSW purposes. It is generally accepted that only the most advanced space-faring states could overcome the technical hurdles to deploy effective SBSW within the foreseeable future.

Space Security Impacts

SBSW can have a direct impact on all aspects of space security. An actor with an SBSW capability, such as an SBI, could use such a system to deny or restrict another actor's ability to access space by attacking its space launch vehicles. Moreover, since some space-based interceptors may also be capable of attacking satellites, SBSW systems could be used to restrict or deny the use of space assets.

The deployment of SBSW would enable an actor to threaten and even attack actors on Earth with very little warning and would constitute a departure from current practice regarding the military use of space. It would also raise questions regarding the interpretation of the "use of outer space for peaceful purposes" as enshrined in the preamble of the Outer Space Treaty, which remains a point of contention in space law.[1] It would also directly threaten space security since actors would no longer enjoy freedom from space-based threats.

Because actors may seek to offset space-based threats, the deployment of space-based weapons would most likely encourage the development of ASAT weapons and legitimize attacks on space assets. Certain normative restrictions and moratoria upon such attacks could be undermined. Moreover, the testing and deployment of SBSW and kinetic ASAT systems in response to SBSW development would likely generate space debris, potentially undermining the sustainable use of space for all actors over the longer term (see The Space Environment).

Some have argued that SBSW may be necessary to protect space systems from attack.[2] Indeed, the protection of satellites and the missile defense potential of SBSW are two of the most commonly cited justifications offered in support of SBSW development. For example, as noted in the Space Systems Negation chapter, it has been argued that SBSW could be used to protect the security of space assets against nuclear space negation attacks that might inflict long-term and disproportionate damage to the space environment.

Key Trends

TREND 8.1: While no SBSW has yet been tested or deployed in space the US is continuing the development of a space-based interceptor for its missile defense system

There have been no known integrated SBSW systems tested or deployed in space.[3] While space negation systems such as the American and Soviet ground-based and airborne ASAT systems were developed between the 1960s and 1990s (see Space Systems Negation), there has not been any testing or deployment of space-to-Earth or space-to-missile weapons systems.

The most advanced SBSW work during the Cold War was primarily focused on the development of mass-to-target weapons. In the 1960s, the USSR developed the Fractional Orbit Bombardment System (FOBS) to deliver a nuclear weapon by launching it into a Low Earth Orbit (LEO) at 135-150 kilometers in altitude, and then de-orbit after flying only a fraction of one orbit to destroy an Earth-based target.[4] FOBS, as such, was not an SBSW, although it demonstrated capabilities that could be used in the development of a space-based orbital bombardment system. A total of 24 launches, 17 of which were successful, were undertaken between 1965 and 1972 to develop and test the USSR FOBS system.[5] The system was phased out in January 1983 to comply with the Strategic Arms Limitation Treaty II, under which deployment of FOBS was prohibited. It is believed that no nuclear weapons were orbited through the FOBS efforts.

The US and USSR both pursued development of energy-to-target SBSW systems in the 1980s, although today these programs have largely been halted. In 1985 the US held underground tests of a nuclear-pumped X-ray laser for the SBL, under the Strategic Defense Initiative (SDI). It also performed a Relay Mirror Experiment in 1990, which tested ground-based laser re-directing and pointing capabilities for the SBL.[6] In 1987, the USSR's heavy-lift Energia rocket launched a 100-ton payload named Polyus, which by some reports included a neutral particle beam weapon and a laser. Due to a failure of the attitude control system, the payload did not enter orbit.[7]

The USSR's neutral particle beam experiments were reportedly halted in 1985. The US SBL program was concluded in 2000, and the SBL office closed in 2002.[8] However, some indirect research and development continue for SBL through the US Missile Defense Agency (MDA). For example, over $120-million was allocated to Department of Defense (DOD) Directed Energy Programs in FY2003,[9] and other larger classified budgetary programs are suspected of continuing work on space-based directed energy technologies.[10]

Under SDI in the 1980s, the US invested several billion dollars in research and development of an SBI concept called Brilliant Pebbles. While the SDI never developed and deployed a fully operational SBSW, the US did test some propulsion and targeting subsystems for Brilliant Pebbles. Research and development efforts in the US for SBI capabilities declined in the 1990s, but have been revived since 2000 through the MDA. The current US SBI concept was developed as a contribution to missile defense by providing a capability to intercept missiles as they pass through space. Like ground-based ASAT systems, SBI capabilities could conceivably be used for offensive attacks on satellites.

One of the first key tests of US SBI-enabling technologies was the 1994 Clementine mission. This was a lunar mission to test lightweight spacecraft designs "at realistic closing velocities using celestial bodies as targets."[11] The US Near-Field Infrared Experiment (NFIRE), scheduled for launch in 2006 or 2007, is projected to include many of the key capabilities required for an SBI, including appropriate sensors, propulsion, and guidance units.[12] There is ongoing debate within the US Congress on whether the NFIRE system should be allowed to launch an independent "kill vehicle" to intercept a missile, and the mission has been revised several times.[13] Under no revisions has the kill vehicle included the propulsion unit required for homing in on a missile, so it could not be called an integrated SBSW. The US has also completed a phase one study for the Micro-Satellite Propulsion Experiment (MPX) which would include two two-stage, anti-missile propulsion units – a key requirement for an SBI capability.[14]

Longer-term US plans include the deployment of a testbed of three to six integrated SBI by 2011-2012, following tests in 2010-2011.[15] While such a system would have limited operational utility, it could constitute the first deployment of a weapons system in outer space. A summary of completed and planned US SBI-related missions is provided in Figure 8.1.

FIGURE 8.1: Recent and planned US space missions testing SBI technologies or integrated systems

Mission	Stage	Launch	Agency	Description
Clementine	Complete	1994	DOD & NASA	Testing lightweight sensors at realistic closing velocities using the moon and asteroids as targets
NFIRE	Under development	2006/2007	MDA	SBI with lightweight sensors and propulsion unit
MPX	Planned	N/A	MDA	Two two-stage anti-missile propulsion units
SBI test-bed	Planned	2010-2012	MDA	Three to six integrated SBIs as a test-bed for a full SBI system

Although much of the budget for SBI development is classified, the scale of funding for this effort can be estimated by examining allocations to a few key programs. For example, approximately $68-million was being spent in FY2005 on the development of the NFIRE satellite. A typical technology development and demonstration satellite of this type would cost several hundred million dollars for research, development, deployment, and operation. Therefore, while the annual SBI budget is only estimated to be about $100-million within a broader MDA budget of $10-billion, even at these funding levels, the timeline for developing the technical capabilities for SBI appears to be decreasing.

While the development of an integrated SBI vehicle may be possible within years rather than decades, building a militarily effective SBI system with global coverage remains a significant challenge. A truly global system would require hundreds or even thousands of SBI vehicles in

orbit, and thus a launch capacity about five to 10 times greater than the current US launch capacity.[16] An examination of the technical feasibility of an SBI system conducted by the American Physical Society estimated that launch costs alone for a system covering latitudes that include Iran, Iraq, and North Korea would likely exceed $44-billion.[17] The US Congressional Budget Office estimated the full cost of an SBI system with a similar coverage of the globe, but with the capability to intercept only liquid-fueled ballistic missiles with longer launch timelines, would be 27 to 40 billion dollars for a system that presumed considerable advances in kill vehicle components. Without such advances, such coverage would cost between 56 and 78 billion dollars.[18]

In summary, there have been no SBSW tested or deployed in space to date, although Cold War-era SBSW programs did support considerable development and testing of key technologies. Prohibitive costs and reduced perceived needs led Russia and, to a lesser degree, the US to drastically cut funding for SBSW programs, especially the energy-to-target types. More recently, the US has pursued the development of SBI in the context of its ballistic missile defense program, although challenges to the SBI's completion remain.

TREND 8.2: A growing number of countries developing an increasing number of SBSW precursor technologies, which could be used for SBSW systems

Due to the potentially significant effects of SBSW systems upon space security dynamics, it is important to assess research into various prerequisite technologies that could enable the development of SBSW capabilities. The SBSW prerequisite technologies described below are simply dual-use. None are related to dedicated SBSW programs, but are part of other civil, commercial, or non-SBSW military space programs. While there is no evidence to suggest that states pursuing these enabling technologies intend to use them for SBSW systems, advances do bring these actors technologically closer to such a capability.

The advanced enabling capabilities listed in Figure 8.2 are those required for each of the major SBSW concepts over and above basic space access and use capabilities, such as orbital launch capability, satellite manufacturing, satellite telemetry, tracking and control, and mission management. This analysis is based on the characteristics of these weapons systems as widely described in open source literature.[19]

FIGURE 8.2: Advanced SBSW prerequisite capabilities

Capability	Conventional			Nuclear	Directed energy	
	SBI	Hypervelocity rod bundle	SB munitions delivery	SB munitions delivery	SBL	Neutral particle beams
Precision position maneuverability	☐	☐	☐	☐		
High-G thrusters	☐					
Large Δ-V thrusters	☐	☐	☐	☐		
Global positioning	☐	☐	☐	☐	☐	☐
Missile homing sensors	☐				☐	
Global missile tracking	☐				☐	☐
Global missile early warning	☐				☐	☐
Launch on demand	☐	☐	☐	☐	☐	☐
Microsatellite construction	☐					
High-power laser systems					☐	
High-power generation					☐	☐
Large deployable optics					☐	
Precision attitude control					☐	☐
Precision re-entry technology		☐	☐	☐		
Nuclear weapons				☐		

Key: ☐ = Required D = Needed but not necessarily on the primary SBSW craft(s)

A *precision position maneuverability* capability, to ensure that an object can be moved to a specific location with an accuracy of less than 10 meters, has been demonstrated by only a few actors. Both the US and Russia have performed a large number of space dockings which require such capability. The European Space Agency has almost completed the development of this capability for its Automated Transfer Vehicle, which will dock at the International Space Station.[20]

High-G thrusters that provide the large acceleration required for final stages of missile homing are under development by the US for the SBI. No other state is currently assessed to have such a capability. A *large delta* (Δ)*-V thruster* capability that enables a change in velocity required to maneuver in orbit to reach the target is fundamental for several different SBSW concepts. This is a relatively common capability that has been demonstrated by all actors with rocket technology, including the 10 states that have demonstrated orbital space access and the further 18 that have demonstrated suborbital space access.

Accurate *global positioning* capabilities required for all SBSW concepts are possessed primarily by the US (with its Global Positioning System) and Russia (with GLONASS), although the GLONASS system is not fully operational at present. All other actors with space access are involved to some degree in the development of navigation systems, for example the planned EU Galileo system, the Chinese Beidou constellation, or the Japanese Quazi-Zenith Satellite System (see Civil Space Programs and Global Utilities). It is also noteworthy that many actors could make use of the global positioning afforded by the US and Russian systems. *Missile homing sensors*, which provide real-time directional information during the missile homing phase required for SBI concept, are a capability common to most advanced military powers, including the US, Russia, and Israel, which have developed such systems for their ground-based missile defense capabilities. Japan is also currently developing this capability.[21]

Relatively extensive *global missile warning and missile tracking* capabilities, required for SBI and SBL concepts, were developed by the US and the USSR during the Cold War (see Space Support for Terrestrial Military Operations). Early warning of missile launches is currently provided by the US Defense Support Program satellites and the Russian Oko and Prognoz satellites, and both states are currently working on upgrades and/or replacements for these systems. The US Space-Based Infrared System (SBIRS)-High and Space Tracking and Surveillance System are designed to be the most advanced in this regard (see Space Systems Protection). No other states currently have such capabilities, but France is developing two early-warning satellites called Spirale-1 and -2 for this purpose, scheduled for launch in 2008.[22]

Launch on demand capabilities to maintain an effective global SBI system are provided by rockets with an operational readiness of less than one week. Russia currently leads in this capability with the shortest average period between launches, but it does not yet possess a true launch on demand system. The US is developing responsive launch capability through its Force Application and Launch from Continental US program (FALCON). Some commercial actors, in particular Space-X, are aiming to provide more responsive and less expensive space launches. No other space actors have such launch on demand capabilities (see Space Systems Protection).[23] Military space planes, currently only in the conceptual stage in the US, could also serve launch on demand purposes.

Microsatellite construction, which reduces the weight and increases the responsiveness of space-based interceptors, is also a key enabling capability for an effective SBI system. China, ESA, France, Israel, Russia, the UK, and the US have all developed microsatellites, and 21 other states have launched a microsatellite, mainly through the launch capability of another state (see Figure 8.3). India is also developing a microsatellite capability.[24]

Figure 8.3 International microsatellite capabilities

High-power laser systems, suitable for an SBL, have only been developed to any extent by the US, initially through its SBL effort, and more recently through its Airborne Laser and MIRACL programs (see Space Systems Negation). *High-power generation* systems for space, suitable for the SBL concept, in particular nuclear reactors, have been developed and deployed both by the US and Russia. For example, the US System for Nuclear Auxiliary Power-10A mission launched in 1965 had a 45-kilowatt thermonuclear reactor. Between 1967 and 1988, the USSR launched 31 low-powered reactors in Radar Ocean Reconnaissance Satellites.[25] While no other states have developed such capabilities for space, all states with a launch capability also have nuclear power programs.

Large deployable optics and precision attitude control, both needed for the SBL concept, have been developed by a number of actors, including China, ESA, France, Japan, Russia, and the US, for military reconnaissance or civil astronomical telescope missions.[26] India and Israel are currently developing such capabilities (see Civil Space Programs and Global Space Utilities). China has announced plans for a civilian telescope that will demonstrate precision attitude control capabilities.[27]

Precision re-entry technology, needed for hypervelocity rod bundles and other space-based munitions delivery concepts, has been developed by states with a human spaceflight capability – China, Russia, and the US. ESA has this capability under development with its Applied Re-entry Technology program and through the joint US National Aeronautics and Space Agency-European Space Agency Crew Return Vehicle (X-38).[28] France's Centre National d'Etudes Spatiales (ONERA) has announced the development of a new re-entry vehicle program for civil space purposes.[29] In addition, the Japan Aerospace Exploration Agency has some experimental re-entry vehicle programs.[30] Nuclear weapons states have also developed precision re-entry technologies for their nuclear warhead re-entry vehicles.

Figure 8.4 provides a schematic overview of the SBSW prerequisite capabilities possessed, or under development, by key space actors, as discussed above. Only actors that have developed orbital space access are included, since this is a prerequisite for all SBSW systems.

FIGURE 8.4: SBSW-enabling capabilities of key space actors[31]

Advanced capabilities	China	EU/ESA	France	UK	India	Israel	Japan	Russia	Ukraine	US
Precision position maneuverability		□						■		■
High-G thrusters										♂
Large Δ-V thrusters	■	■	■	■	■	■	■	■	■	■
Accurate global positioning	□	□			□	□	□	■	□	■
Anti-missile homing sensors			■	■		■	□	■		■
Global missile tracking								■		■
Global missile early warning			□					■		■
Launch on demand								■		□
Microsatellite construction	■	■	■	■	■	■	■	■	■	■
High-power laser systems										□
High-power generation								(■)		□
Large deployable optics	■	■	■		□	□	□	■		■
Precision attitude control	□	■	■		□	■	■	■		■
Precision re-entry technology	■	□	■	■				■		■
Nuclear weapons	■		■	■	■	■		■		■
SBSW										
Space-based laser								(□)		(□)
Space-based interceptors								(□)		□
Hypervelocity rod bundle										
SB munitions delivery (conventional)										
Neutral particle beam								(□)		(□)

Key: ■ = Some capability □ = Capability under development (□) = Past development (■) = Past capability

2005 DEVELOPMENTS

TREND 8.1: While no space-based strike weapons have yet been tested or deployed in space, the US continues to develop a space-based interceptor for its missile defense system

2005: US NFIRE Kill Vehicle test currently cancelled

Maintaining the status quo, no space-based weapons were tested or deployed in 2005. In the US, the question of whether the MDA should deploy and test a "kill vehicle" for NFIRE once again came under US Congressional scrutiny. In 2004, the US House of Representatives instructed the MDA to remove the kill vehicle from the planned 2006 NFIRE test. The US Senate Appropriations Committee reviewing the NFIRE program, however, urged the MDA to return the missile defense interceptor ("kill vehicle") to the originally scheduled test, despite the concern of some that doing so might lead to the deployment of weapons in space. The committee, which approved $13.7-million for the NFIRE program, told the MDA to "complete development and mission integration of the deployable NFIRE Kill Vehicle."[33] Critics, however, suggest NFIRE is an actual weapons system, and that recommendations to move NFIRE into a new budget category (Ballistic Missile Defense Technology Program) only confirm the intended use of NFIRE as a space weapon.[34] The MDA, for its part, claims its 2006 test would not have allowed the kill vehicle to strike the target, but instead was to collect data on the in-flight ballistic missile.[35] There are suggestions that NFIRE might test MDA's hypertemporal imager, a device that could potentially detect a hostile missile shortly after its launch.[36]

Despite the recommendation of the Senate Appropriations Committee, the MDA has removed the kill vehicle portion of the planned test, saying it posed a risk of technical failure.[37] This freed up room on the satellite for a German laser communications terminal, to be used in joint US-German experiments to determine the effectiveness of laser communications that could replace existing radio frequency forms of communication.[38]

Net assessment:

The ongoing absence of space-based strike weapons testing or deployment continued to bode well for space security in 2005. The controversial NFIRE program, however, may eventually demonstrate the capabilities of an integrated SBSW system. The debates in the US over NFIRE highlight the challenges of balancing terrestrial missile defense requirements with the need to maintain freedom from space-based threats.

TREND 8.2: A growing number of countries developing an increasing number of SBSW precursor technologies, which could be used for SBSW systems

2005 Development of precision re-entry technology in US, Russia, China, and Europe

Precision re-entry technology is required for space-based munitions delivery, though to date, few states have developed such technologies. In 2005, Russian and US officials announced developments in next-generation missile technology. Russia announced that its military had tested a hypersonic missile system that allows missiles to change both their altitude and the direction of flight, demonstrating precision re-entry capabilities that can be used to evade missile defense interceptors.[39] The US Air Force (USAF) Space Command has said that engineers are applying the same principle used by Russia to give US missiles maneuverability. US forces are also seeking to develop a new conventional ICBM warhead that can shape its own trajectory on re-entry, greatly improving its accuracy.[40]

Both the US and ESA continued to develop hypersonic flight programs. Under the aegis of Prompt Global Strike, the US continued work on the Common Aerothermodynamic Vehicle (CAV) and the FALCON programs. If completed, the CAV will be an unpowered, maneuverable, hypersonic glide vehicle capable of carrying 455 kilograms of munitions, with a range of approximately 4,830 kilometers.[41] The FALCON will be a reusable hypersonic cruise vehicle that can strike targets approximately 14,500 kilometers away in less than two hours, while carrying a payload close to 5,500 kilograms comprised of CAVs, cruise missiles, small diameter bombs, or other munitions.[42] FALCON could also conceivably be used for launch-on-demand of SBSW or other space assets. The European Union (EU) has begun work on the European Experimental Re-entry Testbed (EXPERT), which is an in-flight aerothermodynamic research program.[43] France's ONERA has proposed measurement techniques to be employed on EXPERT in order to continue the studies on re-entry aerothermodynamics, as well as thermal protection systems.[44]

Researchers in Chinese academic institutions continued work in 2005 on re-entry techniques for "space-based ground attack weapons systems."[45] However, the scope, funding, and political support for such basic research remain unclear. Also relevant to precision re-entry technology, in 2005 China launched a pair of FSW-3 satellites (JianBing-4A3 and JianBing-4B3) four weeks apart. Both were later successfully recovered after re-entry.[46]

2005 Upgrades in US and Russian global missile tracking and warning

A key component for any future SBSW systems, especially as such systems may be applied to space-based ballistic missile defense interceptors, will be missile tracking and warning capabilities. A number of countries are working towards establishing or improving these capabilities, primarily in the context of missile defense. USAF is seeking congressional approval to begin work on a new missile warning satellite to follow SBIRS, which is being scaled back to three satellites from the five originally sought.[47] The new system will take advantage of more up-to-date sensor and software technology. Nevertheless, the SBIRS system does offer significant upgrades to the current Defense Support Program (DSP): each SBIRS satellite will employ two sensors, one for scanning large swaths of territory in a sweeping fashion, and another for staring continuously at smaller areas identified as likely missile launch facilities.[48] Currently, DSP does not have staring capabilities. While the US is committed to fielding missile defense systems, congressional pressure concerning cost overruns for space-based missile defense components may threaten these initiatives.

Russia continues to maintain its missile attack warning system (MAWS), despite concerns of disrepair and age. One of the key 2005 MAWS objectives identified by the Russian Defense Minister Sergei Ivanov was the modernization of the antiballistic missile (ABM) system.[49] Plans to test a new early-warning radar (EWR) station near St. Petersburg in 2005 were announced by Russia in 2005. The new-generation EWR is described as smaller, lighter, and less expensive than Russia's previous EWR stations, requiring minimal on-site preparation while covering all likely avenues of missile approach.[50] Russian analysts claim that these capabilities substantially exceed those of the US and other Western states.[51] The Okno optic-electronic complex, in particular, is meant for automatic detection of high-orbit objects in space, at altitudes to 40,000 kilometers; tracking their orbits; and determining their class, destination, state, and origin.[52] The status of future Russian use of the Qabala MAWS radar station in Azerbaijan, which has the capability of detecting anything larger than a football in LEO, remains uncertain as Russian officials voiced concerns over Azerbaijan's increasingly close relationship with the US.[53] There are similar apprehensions over Russia's two MAWS stations in Ukraine. Russia also maintains a strategic ABM System around Moscow. However, this system is based on the use of nuclear technology to intercept attacking missiles (see Space Systems Negation).[54]

There is discussion in Moscow of Russian-Western cooperation in deploying a low-orbit satellite target designation system (STDS). An STDS would considerably enhance the capabilities of a potential Russian-American joint-ABM system that was envisioned during the September 1998 discussions about establishing a Joint Data Exchange Center in Moscow to share information on ballistic missile and space launches. STDS spacecraft, about 650 kilograms each, with infrared and visible-band sensors, are to be orbited at 1,350-1,400 kilometers in altitude. The Russian-Ukrainian Dnepr Project, could be used to launch the sensor craft.[55]

Finally, Chinese researchers are currently working on target tracking technologies that may be used as key components for any future Chinese missile tracking system. Present basic research revolves around obtaining greater tracking precision and real-time accuracy.[56]

2005 US, Europe, China, Russia, and India continue research and development of global positioning systems

A number of countries continued to develop, upgrade, or sign-on to global positioning systems in 2005 (see Civil Space Programs and Global Utilities). Global positioning capabilities are required for all SBSW concepts. In 2005, the US continued its program of modernizing GPS.[57] Russia made plans to cooperate with China and India on GLONASS.[58] A new generation of GLONASS satellites (Glonass-M) will have longer in-orbit lives that should ease pressure on the system. They are designed to have a seven-year service life, compared to three years for the current GLONASS. While India will cooperate with Russia on GLONASS, it is also developing a separate GAGAN civilian satellite navigation system.[59]

The European Galileo satellite navigation system saw significant development in 2005. On 28 December, the first satellite of Galileo's testing phase was launched.[60] India, Israel, Morocco, Saudi Arabia, and Ukraine announced that they would participate in the Galileo project,[61] while negotiations continued with Argentina, Australia, Brazil, Canada, Chile, Malaysia, Mexico, Norway, and South Korea.[62]

Net Assessment

Space-based weapons designed to strike terrestrial targets will require sophisticated technological developments that, at present, few space-faring states seem able to exploit. The development of dual-use capabilities which also provide enabling technologies for SBSW systems continued in 2005 although there was no evidence that states were developing such capabilities for SBSW purposes. Research and development into re-entry technologies as well as missile tracking could eventually facilitate the development of orbital bombardment systems and SBI. While the integration of such technologies into an SBSW capability could be very difficult and take many years, their development does bring states closer to an SBSW capability, should a future decision be made to pursue it.

2006 Space Security Survey

Methodology

The 2006 Space Security Survey was open for participation between 1 February and 1 March 2006. Invitations to participate in the Survey, along with a set of background briefing notes, were sent to over 600 international space security experts. In extending invitations to national space experts from the civil, commercial, and military space sectors, the hope was to achieve a representation that broadly reflected the international space community. One hundred and twenty experts from 25 countries completed the 2006 online survey. While not considered scientific, the quantitative assessments and qualitative comments provided by the 2006 Space Security Survey respondents were used to inform the development of *Space Security 2006*.

1. The Space Environment

Overall, how have developments related to the space environment in 2005 affected space security?

Enhanced	1	0.91%
Somewhat enhanced	33	30%
Little or no effect	55	50%
Somewhat reduced	16	14.55%
Reduced	5	4.55%

2. Laws, Policies and Doctrines

Overall, how have developments related to space security laws, policies, and doctrines in 2005 affected space security?

Enhanced	1	0.93%
Somewhat enhanced	14	13.08%
Little or no effect	47	43.93%
Somewhat reduced	31	28.97%
Reduced	14	13.08%

3. Civil Space Programs and Global Utilities

Overall, how have developments related to civil space programs and global utilities in 2005 affected space security?

Enhanced	4	3.74%
Somewhat enhanced	37	34.58%
Little or no effect	41	38.32%
Somewhat reduced	19	17.76%
Reduced	6	5.61%

4. Commercial Space

Overall, how have developments related to commercial space in 2005 affected space security?

Enhanced	7	6.86%
Somewhat enhanced	32	31.37%
Little or no effect	43	42.16%
Somewhat reduced	18	17.65%
Reduced	2	1.96%

5. Space Support for Terrestrial Military Operations

Overall, how have developments related to space and terrestrial military operations in 2005 affected space security?

Enhanced	5	4.46%
Somewhat enhanced	13	11.61%
Little or no effect	40	35.71%
Somewhat reduced	41	36.61%
Reduced	13	11.61%

6. Space Systems Protection

Overall, how have developments related to space systems protection in 2005 affected space security?

Enhanced	3	2.78%
Somewhat enhanced	38	35.19%
Little or no effect	52	48.15%
Somewhat reduced	11	10.19%
Reduced	4	3.7%

7. Space Systems Negation

Overall, how have developments related to space systems negation in 2005 affected space security?

Enhanced	1	0.97%
Somewhat enhanced	15	14.56%
Little or no effect	38	36.89%
Somewhat reduced	38	36.89%
Reduced	11	10.68%

8. Space-Based Strike Weapons

Overall, how have developments related to space-based strike weapons in 2005 affected space security?

Enhanced	3	2.88%
Somewhat enhanced	6	5.77%
Little or no effect	61	58.65%
Somewhat reduced	20	19.23%
Reduced	14	13.46%

Space Security Working Group Meeting

Institute of Air and Space Law, McGill University
Montreal, Quebec
1-2 May 2006

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ANNEX THREE: MILITARY SATELLITES

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Chile					
Fasat-Bravo	Zenit-2	Russia	Imaging	LEO	10/07/1998
China					
Zhongxing-20 (Feng Huo)	Chang Zheng 3A	China	Communications	HEO	14/11/2003
Feng Huo 1	Chang Zheng 3A	China	Communications	GEO	25/01/2000
Zi Yuan 2C	Chang Zheng 4B	China	Imaging	LEO	06/11/2004
Beidou 3	Chang Zheng 3A	China	Navigation	GEO	24/05/2003
Beidou	Chang Zheng 3A	China	Navigation	GEO	20/12/2000
Beidou	Chang Zheng 3A	China	Navigation	HEO	30/10/2000
SJ-7	Chang Zheng 2D	China	Technology	LEO	05/07/2005
France					
Syracuse 3A	Ariane 5GS	France	Communications	GEO	13/10/2005
Helios IIA	Ariane 5G+	France	Imaging	LEO	18/12/2004
Helios 1B	Ariane 40	France	Imaging	LEO	03/12/1999
Helios 1A	Ariane 40	France	Imaging	LEO*	07/07/1995
Clementine	Ariane 40	France	Signals Intelligence	LEO	03/12/1999
Essaim 4	Ariane 5G+	France	Signals Intelligence	LEO	18/12/2004
Essaim 3	Ariane 5G+	France	Signals Intelligence	LEO	18/12/2004
Essaim 2	Ariane 5G+	France	Signals Intelligence	LEO	18/12/2004
Essaim 1	Ariane 5G+	France	Signals Intelligence	LEO	18/12/2004
CERISE	Ariane 40	France	Signals Intelligence	LEO*	07/07/1995
India					
TES	PSLV	India	Imaging	LEO	22/10/2001
Israel					
Ofeq-5	Shaviyt 1	Israel	Imaging	LEO	28/05/2002
Italy					
Sicral	Ariane 44L	France	Communications	GEO	07/02/2001
Japan					
IGS-1b	H-IIA 2024	Japan	Imaging	LEO	28/03/2003
IGS-1a	H-IIA 2024	Japan	Imaging	LEO	28/03/2003
Russia					
Kosmos-2416	Kosmos-11K65M	Russia	Communications	LEO	21/12/2005
Kosmos-2409	Kosmos 11K65M	Russia	Communications	LEO	23/09/2004
Kosmos-2408	Kosmos 11K65M	Russia	Communications	LEO	23/09/2004

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Raduga-1	Proton-K/DM-2	Russia	Communications	GEO	27/03/2004
Kosmos-2401	Kosmos 11K65M	Russia	Communications	LEO	19/08/2003
Kosmos-2400	Kosmos 11K65M	Russia	Communications	LEO	19/08/2003
Molniya-1T	Molniya 8K78M	Russia	Communications	HEO	02/04/2003
Kosmos-2391	Kosmos 11K65M	Russia	Communications	LEO	08/07/2002
Kosmos-2390	Kosmos 11K65M	Russia	Communications	LEO	08/07/2002
Kosmos-2386	Tsiklon-3	Russia	Communications	LEO	28/12/2001
Kosmos-2385	Tsiklon-3	Russia	Communications	LEO	28/12/2001
Kosmos-2384	Tsiklon-3	Russia	Communications	LEO	28/12/2001
Raduga-1	Proton-K/DM-2	Russia	Communications	GEO	06/10/2001
Molniya-3	Molniya 8K78M	Russia	Communications	HEO	20/07/2001
Raduga-1	Proton-K/DM-2	Russia	Communications	GEO	28/08/2000
Kosmos-2371	Proton-K/DM-2	Russia	Communications	GEO	04/07/2000
Molniya-3	Molniya 8K78M	Russia	Communications	HEO	08/07/1999
Raduga-1	Proton-K/DM-2	Russia	Communications	GEO	28/02/1999
Kosmos-2357	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Kosmos-2356	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Kosmos-2355	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Kosmos-2354	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Kosmos-2353	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Kosmos-2352	Tsiklon-3	Russia	Communications	MEO	15/06/1998
Molniya-1T	Molniya 8K78M	Russia	Communications	HEO	24/09/1997
Kosmos-2339	Tsiklon-3	Russia	Communications	LEO	14/02/1997
Kosmos-2338	Tsiklon-3	Russia	Communications	LEO	14/02/1997
Kosmos-2337	Tsiklon-3	Russia	Communications	LEO	14/02/1997
Molniya-1T	Molniya 8K78M	Russia	Communications	HEO	28/09/1998
Molniya-3	Molniya 8K78M	Russia	Communications	HEO	01/07/1998
Molniya-3	Molniya 8K78M	Russia	Communications	HEO	24/10/1996
Molniya-1T	Molniya 8K78M	Russia	Communications	HEO	14/08/1996
Gorizont	Proton-K/DM-2	Russia	Communications	GEO	25/05/1996
Gorizont	Proton-K/DM-2	Russia	Communications	GEO	25/01/1996
Gals 2	Proton-K/DM-2	Russia	Communications	GEO*	17/11/1995
Molniya-3	Molniya 8K78M	Russia	Communications	HEO*	09/08/1995
Molniya-3	Molniya 8K78M	Russia	Communications	HEO**	23/08/1994
Rimsat-2	Proton-K/DM-2	Russia	Communications	GEO*	20/05/1994

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Gals 1	Proton-K/DM-2M	Russia	Communications	GEO*	20/01/1994
AP-1	Proton-K/DM-2	Russia	Communications	GEO*	18/11/1993
Gorizont	Proton-K/DM-2	Russia	Communications	GEO*	28/10/1993
Raduga	Proton-K/DM-2	Russia	Communications	GEO*	30/09/1993
Raduga	Proton-K/DM-2	Russia	Communications	GEO*	25/03/1993
Gorizont	Proton-K/DM-2	Russia	Communications	GEO*	27/11/1992
Gorizont	Proton-K/DM-2	Russia	Communications	GEO*	14/07/1992
Gorizont	Proton-K/DM-2	Russia	Communications	GEO*	02/04/1992
Molniya-1T	Molniya 8K78M	Russia	Early Warning	HEO	18/02/2004
Kosmos-2393	Molniya 8K78M	Russia	Early Warning	HEO	24/12/2002
Kosmos-2388	Molniya 8K78M	Russia	Early Warning	HEO	01/04/2002
Kosmos-2379	Proton-K/DM-2	Russia	Early Warning	GEO	24/08/2001
Kosmos-2368	Molniya 8K78M	Russia	Early Warning	HEO	27/12/1999
Kosmos-2351	Molniya 8K78M	Russia	Early Warning	HEO	07/05/1998
Kosmos-2342	Molniya 8K78M	Russia	Early Warning	HEO	14/05/1997
Kosmos-2340	Molniya 8K78M	Russia	Early Warning	HEO	09/04/1997
Kosmos-2312	Molniya 8K78M	Russia	Early Warning	HEO**	24/05/1995
Kosmos-2286	Molniya 8K78M	Russia	Early Warning	HEO**	05/08/1994
Kosmos-2392	Proton-K/17S40	Russia	Imaging	MEO	25/07/2002
Kosmos-2419	Proton-K/DM-2	Russia	Navigation	MEO	25/12/2005
Kosmos-2418	Proton-K/DM-2	Russia	Navigation	MEO	25/12/2005
Kosmos-2417	Proton-K/DM-2	Russia	Navigation	MEO	25/12/2005
Kosmos-2414	Kosmos 11K65M	Russia	Navigation	LEO	20/01/2005
Kosmos-2413	Proton-K/DM-2	Russia	Navigation	MEO	26/12/2004
Kosmos-2412	Proton-K/DM-2	Russia	Navigation	MEO	26/12/2004
Kosmos-2411	Proton-K/DM-2	Russia	Navigation	MEO	26/12/2004
Kosmos-2407	Kosmos 11K65M	Russia	Navigation	LEO	22/07/2004
Kosmos-2404	Proton-K/Briz-M	Russia	Navigation	MEO	10/12/2003
Kosmos-2403	Proton-K/Briz-M	Russia	Navigation	MEO	10/12/2003
Kosmos-2402	Proton-K/Briz-M	Russia	Navigation	MEO	10/12/2003
Kosmos-2398	Kosmos 11K65M	Russia	Navigation	LEO	04/06/2003
Kosmos-2396	Proton-K/DM-2M	Russia	Navigation	MEO	25/12/2002
Kosmos-2395	Proton-K/DM-2M	Russia	Navigation	MEO	25/12/2002
Kosmos-2394	Proton-K/DM-2M	Russia	Navigation	MEO	25/12/2002
Kosmos-2389	Kosmos 11K65M	Russia	Navigation	LEO	28/05/2002

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Kosmos-2380	Proton-K/DM-2	Russia	Navigation	MEO	01/12/2001
Kosmos-2381	Proton-K/DM-2	Russia	Navigation	MEO	01/12/2001
Kosmos-2382	Proton-K/DM-2	Russia	Navigation	MEO	01/12/2001
Kosmos-2378	Kosmos 11K65M	Russia	Navigation	LEO	08/06/2001
Kosmos-2376	Proton-K/DM-2	Russia	Navigation	MEO	13/10/2000
Kosmos-2375	Proton-K/DM-2	Russia	Navigation	MEO	13/10/2000
Kosmos-2374	Proton-K/DM-2	Russia	Navigation	MEO	13/10/2000
Nadezhda	Kosmos 11K65M	Russia	Navigation	LEO	28/06/2000
Kosmos-2366	Kosmos 11K65M	Russia	Navigation	LEO	26/08/1999
Kosmos-2361	Kosmos 11K65M	Russia	Navigation	LEO	24/12/1998
Nadezhda	Kosmos 11K65M	Russia	Navigation	LEO	10/12/1998
Kosmos-2346	Kosmos 11K65M	Russia	Navigation	LEO	23/09/1997
Kosmos-2341	Kosmos 11K65M	Russia	Navigation	LEO	17/04/1997
Kosmos-2336	Kosmos 11K65M	Russia	Navigation	LEO	20/12/1996
Kosmos-2334	Kosmos 11K65M	Russia	Navigation	LEO	05/09/1996
Kosmos-2327	Kosmos 11K65M	Russia	Navigation	LEO	16/01/1996
Kosmos-2321	Kosmos 11K65M	Russia	Navigation	LEO*	06/10/1995
Kosmos-2315	Kosmos 11K65M	Russia	Navigation	LEO*	05/07/1995
Kosmos-2310	Kosmos 11K65M	Russia	Navigation	LEO**	22/03/1995
Tsikada	Kosmos 11K65M	Russia	Navigation	LEO**	24/01/1995
Kosmos-2364	Proton-K/DM-2	Russia	Navigation	MEO	30/12/1998
Kosmos-2363	Proton-K/DM-2	Russia	Navigation	MEO	30/12/1998
Kosmos-2362	Proton-K/DM-2	Russia	Navigation	MEO	30/12/1998
Kosmos-232	Proton-K/DM-2	Russia	Navigation	MEO*	14/12/1995
Kosmos-2324	Proton-K/DM-2	Russia	Navigation	MEO*	14/12/1995
Kosmos-2323	Proton-K/DM-2	Russia	Navigation	MEO*	14/12/1995
Kosmos-2317	Proton-K/DM-2	Russia	Navigation	MEO*	24/07/1995
Nadezhda	Kosmos 11K65M	Russia	Navigation	LEO*	12/03/1991
Nadezhda	Kosmos 11K65M	Russia	Navigation	LEO**	04/07/1989
Kosmos-2406	Zenit-2	Russia	Signals Intelligence	LEO	10/06/2004
Kosmos-2405	Tsiklon-2	Russia	Signals Intelligence	LEO	28/05/2004
Kosmos-2369	Zenit-2	Russia	Signals Intelligence	LEO	03/02/2000
Kosmos-2360	Zenit-2	Russia	Signals Intelligence	LEO	28/07/1998
Kosmos-233	Zenit-2	Russia	Signals Intelligence	LEO	04/09/1996
Kosmos-2322	Zenit-2	Russia	Signals Intelligence	LEO*	31/10/1995

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Spain					
XTAR-EUR	Ariane 5ECA	France	Communications	HEO	12/02/2005
Thailand					
Thai Puht (TO-31)	Zenit-2	Russia	Communications	LEO	10/07/1998
UK					
Skynet 4F	Ariane 44L	France	Communications	GEO	07/02/2001
Skynet 4E	Ariane 44L	France	Communications	GEO	26/02/1999
Skynet 4D	Delta 7925-9.5	US	Communications	GEO	10/01/1998
Skynet 4C	Ariane 44LP	France	Communications	GEO**	30/08/1990
Topsat	Kosmos 11K65M	Russia	Imaging	LEO	27/10/2005
STRV 1d	Ariane 5G	France	Technology	HEO	16/11/2000
STRV 1c	Ariane 5G	France	Technology	HEO	16/11/2000
STRV 1B	Ariane 44LP	France	Technology	GEO*	17/06/1994
STRV 1A	Ariane 44LP	France	Technology	GEO*	17/06/1994
US					
USA 169 (Milstar 6)	Titan 401B/Centaur	US	Communications	GEO	08/04/2003
DSCS III A-3	Delta 4M	US	Communications	GEO	11/03/2003
USA 164	Titan 401B/Centaur	US	Communications	UKN	16/01/2002
USA 162	Atlas IIAS	US	Communications	HEO	11/10/2001
USA 157	Titan 401B/Centaur	US	Communications	GEO	27/02/2001
USA 155	Atlas IIAS	US	Communications	HEO	06/12/2000
USA 153	Atlas IIA	US	Communications	GEO	20/10/2000
USA 179	Atlas IIAS	US	Communications	HEO	31/08/2004
UHF F/O F11 (USA 174)	Atlas 3B	US	Communications	GEO	18/12/2003
DSCS III B-	Delta 4M	US	Communications	GEO	29/08/2003
USA 148	Atlas IIA	US	Communications	GEO	21/01/2000
UHF F/O F10	Atlas IIA	US	Communications	GEO	23/11/1999
MUBLCOM	Pegasus XL/HAPS	US	Communications	LEO	18/05/1999
PANSAT (PO-34)	Space Shuttle	US	Communications	LEO	29/10/1998
UHF F/O F9	Atlas IIA	US	Communications	GEO	20/10/1998
UHF F/O F8	Atlas II	US	Communications	GEO	16/03/1998
CAPRICORN	Atlas IIA	US	Communications	HEO	29/01/1998

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
USA 135	Atlas IIA	US	Communications	GEO	25/10/1997
UFO F7	Atlas II	US	Communications	GEO	25/07/1996
USA 125	Titan 405A	US	Communications	LEO	03/07/1996
Milstar DFS 2	Titan 401A/Centaur	US	Communications	GEO*	06/11/1995
UFO F6	Atlas II	US	Communications	GEO*	22/10/1995
USA 113	Atlas IIA	US	Communications	UKN*	31/07/1995
UFO 5	Atlas II	US	Communications	GEO*	31/05/1995
UHF F/O F4	Atlas II	US	Communications	GEO*	29/01/1995
UHF F/O F3	Atlas I	US	Communications	GEO*	24/06/1994
Milstar DFS 1	Titan 401A/Centaur	US	Communications	GEO*	07/02/1994
NATO 4B	Delta 7925	US	Communications	GEO*	08/12/1993
USA 97	Atlas II	US	Communications	GEO*	28/11/1993
UHF F/O F2	Atlas I	US	Communications	GEO*	03/09/1993
USA 93	Atlas II	US	Communications	UKN*	19/07/1993
USA 89	Space Shuttle	US	Communications	LEO*	02/12/1992
USA 82	Atlas II	US	Communications	GEO*	02/07/1992
USA 78	Atlas II	US	Communications	UKN*	11/02/1992
NATO 4A	Delta 7925	US	Communications	GEO*	08/01/1991
USA 67	Space Shuttle	US	Communications	LEO**	15/11/1990
FLTSATCOM F8	Atlas G Centaur	US	Communications	GEO**	25/09/1989
DSCS III A-2	Titan 34D/Transtage	US	Communications	UKN**	04/09/1989
FLTSATCOM F7	Atlas G Centaur	US	Communications	GEO**	05/12/1986
DSCS III B-5	Space Shuttle	US	Communications	UKN**	03/10/1985
DSCS III B-4	Space Shuttle	US	Communications	UKN**	03/10/1985
DSCS III A-1	Titan 34D/IUS	US	Communications	GEO**	30/10/1982
FLTSATCOM F4	SLV-3D Centaur	US	Communications	GEO**	31/10/1980
FLTSATCOM F1	SLV-3D Centaur	US	Communications	GEO**	09/02/1978
LES 9	Titan IIIC	US	Communications	GEO**	15/03/1976
DSP F21 (USA 159)	Titan 402B/IUS	U	Early Warning	GEO	06/08/2001
DSP F20 (USA 149)	Titan 402B/IUS	U	Early Warning	GEO	08/05/2000
DSP F22	Titan 402B/IUS	US	Early Warning	GEO	14/02/2004
DSP F18	Titan 402B/IUS	US	Early Warning	GEO	23/02/1997
DSP F17	Titan 402A/IUS	US	Early Warning	UKN*	22/12/1994

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
DSP F16	Space Shuttle	US	Early Warning	GEO*	24/11/1991
DSP F15	Titan 402A/IUS	US	Early Warning	MEO**	13/11/1990
DSP F13	Titan 34D/Transtage	US	Early Warning	UKN**	29/11/1987
USA 186	Titan 404B	US	Imaging	LEO	19/10/2005
USA 182	Titan 405B	US	Imaging	LEO	30/04/2005
USA 161	Titan 404B	US	Imaging	LEO	05/10/2001
USA 152	Titan 403B	US	Imaging	LEO	17/08/2000
USA 144	Titan 404B	US	Imaging	LEO	22/05/1999
DMSP 5D-3 F-16	Titan II SLV	US	Imaging	LEO	18/10/2003
DMSP 5D-3 F-15	Titan II SLV	US	Imaging	LEO	12/12/1999
USA 133	Titan 403A	US	Imaging	LEO	24/10/1997
USA 129	Titan 404	US	Imaging	LEO	20/12/1996
USA 69	Titan 403A	US	Imaging	LEO*	08/03/1991
Navstar GPS IIR-M1	Delta 7925-9.5	US	Navigation	MEO	26/09/2005
Navstar GPS IIR-13	Delta 7925-9.5	US	Navigation	HEO	06/11/2004
Navstar GPS IIR-12	Delta 7925-9.5	US	Navigation	MEO	23/06/2004
Navstar GPS IIR-11	Delta 7925-9.5	US	Navigation	MEO	20/03/2004
Navstar GPS IIR-10 (USA 175)	Delta 7925-9.5	US	Navigation	MEO	21/12/2003
Navstar GPS IIR-9 (USA 168)	Delta 7925-9.5	US	Navigation	MEO	31/03/2003
Navstar GPS IIR-8 (USA 166)	Delta 7925-9.5	US	Navigation	MEO	29/01/2003
GPS IIR-7	Delta 7925-9.5	US	Navigation	MEO	30/01/2001
GPS IIR-6	Delta 7925-9.5	US	Navigation	MEO	10/11/2000
GPS IIR-5	Delta 7925-9.5	US	Navigation	MEO	16/07/2000
GPS IIR-4	Delta 7925-9.5	US	Navigation	MEO	11/05/2000
GPS SVN 46	Delta 7925-9.5	US	Navigation	MEO	07/10/1999
GPS SVN 38	Delta 792	US	Navigation	MEO	06/11/1997
GPS SVN 43	Delta 7925	US	Navigation	MEO	23/07/1997
Navstar SVN 30	Delta 7925	US	Navigation	MEO	12/09/1996
Navstar SVN 4	Delta 7925	US	Navigation	MEO	16/07/1996

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Navstar GPS 33	Delta 7925	US	Navigation	MEO	28/03/1996
Navstar GPS 36	Delta 7925	US	Navigation	MEO*	10/03/1994
Navstar GPS 34	Delta 7925	US	Navigation	MEO*	26/10/1993
Navstar GPS 35	Delta 7925	US	Navigation	MEO*	30/08/1993
Navstar GPS 39	Delta 7925	US	Navigation	MEO*	26/06/1993
Navstar GPS 37	Delta 7925	US	Navigation	MEO*	13/05/1993
Navstar GPS 31	Delta 7925	US	Navigation	MEO*	30/03/1993
Navstar GPS 22	Delta 7925	US	Navigation	MEO*	03/02/1993
Navstar GPS 29	Delta 7925	US	Navigation	MEO*	18/12/1992
Navstar GPS 32	Delta 7925	US	Navigation	MEO*	22/11/1992
Navstar GPS 27	Delta 7925	US	Navigation	MEO*	09/09/1992
Navstar GPS 26	Delta 7925	US	Navigation	MEO*	07/07/1992
Navstar GPS 25	Delta 7925	US	Navigation	MEO*	23/02/1992
Navstar GPS 24	Delta 7925	US	Navigation	MEO*	04/07/1991
Navstar GPS 23	Delta 7925	US	Navigation	MEO**	26/11/1990
Navstar GPS 15	Delta 6925	US	Navigation	MEO**	01/10/1990
Navstar GPS 17	Delta 6925	US	Navigation	MEO**	11/12/1989
Navstar GPS 19	Delta 6925	US	Navigation	MEO**	21/10/1989
Navstar GPS 16	Delta 692	US	Navigation	MEO**	18/08/1989
NNS O-31	Scout G-1	US	Navigation	LEO**	25/08/1988
NNS O-32	Scout G-1	US	Navigation	LEO**	26/04/1988
NNS O-29	Scout G-1	US	Navigation	LEO**	16/09/1987
USA-181 P/L 2	Atlas 3B	US	Signals Intelligence	LEO	03/02/2005
USA 181	Atlas 3B	US	Signals Intelligence	LEO	03/02/2005
USA 173 P/L 2	Atlas IIAS	US	Signals Intelligence	LEO	02/12/2003
USA 173	Atlas IIAS	US	Signals Intelligence	LEO	02/12/2003
USA 171	Titan 401B/Centaur	US	Signals Intelligence	GEO	09/09/2003
USA 160 P/L 2	Atlas IIAS	US	Signals Intelligence	LEO	08/09/2001
USA 160	Atlas IIAS	US	Signals Intelligence	LEO	08/09/2001
USA 139	Titan 401B/Centaur	US	Signals Intelligence	GEO	09/05/1998
USA 136	Titan 401A/Centaur	US	Signals Intelligence	HEO	08/11/1997
USA 122	Titan 403A	US	Signals Intelligence	LEO	12/05/1996
USA 12	Titan 403A	US	Signals Intelligence	LEO	12/05/1996
USA 120	Titan 403A	US	Signals Intelligence	LEO	12/05/1996
USA 11	Titan 403	US	Signals Intelligence	LEO	12/05/1996

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
USA 118	Titan 401A/Centaur	US	Signals Intelligence	GEO	24/04/1996
USA 116	Titan 404A	US	Signals Intelligence	LEO*	05/12/1995
USA 112	Titan 401A/Centaur	US	Signals Intelligence	HEO*	10/07/1995
USA 110	Titan401A/Centau	US	Signals Intelligence	UKN*	14/05/1995
USA 105	Titan 401A/Centaur	US	Signals Intelligence	UKN*	27/08/1994
USA 103	Titan 401A/Centaur	US	Signals Intelligence	HEO*	03/05/1994
USA 8	Titan II SLV	US	Signals Intelligence	LEO*	25/04/1992
USA 48	Space Shuttle	US	Signals Intelligence	GEO**	23/11/1989
USA 37	Titan 34D/Transtage	US	Signals Intelligence	UKN**	10/05/1989
RADCAL	Scout G-1	US	Calibration	LEO	25/06/1993
DMSP 5D-2 F-14	Titan II SLV	US	Meteorology	LEO	04/04/1997
DMSP 24547	Atlas E	US	Meteorology	LEO**	24/03/1995
DMSP 23545	Atlas E	US	Meteorology	LEO*	29/08/1994
Coriolis	Titan II SLV	US	Science	LEO	06/01/2003
MTI	Taurus 111	US	Science	LEO	12/03/2000
ARGOS	Delta 7920-10	US	Science	LEO	23/02/1999
GFO	Taurus 2210	US	Science	LEO	10/02/1998
FORTE	Pegasus XL	US	Science	LEO	29/08/1997
REX I	Pegasus XL	US	Science	LEO**	09/03/1996
STP-	Minotau	US	Technology	LEO	23/09/2005
XSS-11 (USA 165)	Minotaur	US	Technology	LEO	11/04/2005
SAPPHIRE (NO-45)	Athena-1	US	Technology	LEO	30/09/2001
GeoLITE	Delta 7925-9.5	US	Technology	GEO	18/05/2001
TSX-5	Pegasus XL	US	Technology	LEO	07/06/2000
MSX	Delta 7920-10	US	Technology	LEO**	24/04/1996
APEX	Pegasus	US	Technology	LEO**	03/08/1994
STEP M2	Pegasus/HAPS	US	Technology	LEO*	19/05/1994
STEP M	ARPA Taurus	US	Technology	LEO*	13/03/1994

Key: * = Older than 10 years ** = Older than 15 years (or suspected of being dead)

Chapter One Endnotes

1 As of 1994, there were reportedly some 505 known pieces of debris from these tests remaining in elliptical orbits with perigee as low as 230 kilometers as a result of Soviet ASAT tests. See Table 4 in Phillip S. Clark, "Space debris incidents involving Soviet/Russian launches," Molniya Space Consultancy, 1994. Online: http://www.friends-partners.org/oldfriends/jgreen/bispaper.html.

2 "Space Control: Reentry Assessment and Space Surveillance," US Strategic Command Public Affairs, Offutt Air Force Base, Fact sheet. Latest data for July 2003 provided by a NASA official in August 2003.

3 *Orbital Debris Quarterly News* 8 (2004), p. 5.

4 Jeremy Singer, "Space-Based Missile Interceptors Could Pose Debris Threat," Space News, 13 September 2004.

5 US National Research Council, *Orbital Debris: A Technical Assessment* (Washington, DC: National Academy Press, 1995), p. 30. Online: http://books.nap.edu/books/0309051258/html/index.html.

6 "Monthly Number of Catalogued Objects in Earth Orbit by Object Type," Orbital Debris Quarterly News 9 (2005), p. 10.

7 US National Research Council, *Orbital Debris: A Technical Assessment* (Washington, DC: National Academy Press, 1995), pp. 4-5. Online: http://books.nap.edu/books/0309051258/html/index.html.

8 "Space Debris Basics: What Are the Risks?" Center for Orbital and Reentry Debris Studies, Fact Sheet. Online: http://www.aero.org/capabilities/cords/debris-risks.html.

9 NASA Orbital Debris Program Office, Photo Gallery. Online: http://sn-callisto.jsc.nasa.gov/photogallery/beehives.html#leo.

10 *Orbital Debris*, p. 4.

11 *Orbital Debris*, p. 4.

12 Nicholas L. Johnson, "Space Debris, Its Causes and Management," Presentation to Congress in Washington, DC, sponsored by Representative Adam Schiff, D-CA and organized by the Monterey Institute of International Studies, 24 July 2002.

13 Johnson.

14 The cases mentioned in the text box are from the following sources, respectively: (1) Kenneth Silber, "Space Junk Piles High," *Insight on the News*, 18 November 1996; (2) Johnson, 2002; Keith Phucas, "Impact of space debris," *Times Herald*, 2 February 2003; (3) Rob Stein, "NASA Explores Whether Space Debris at Fault: Possibility That Columbia Was Fatally Wounded by Rock, Rubble Is Considered," *Washington Post*, 6 February 2003, p. A14; (4) Michael Katz-Hyman, "The Death of the Solwind Satellite," Henry L. Stimson Center, Space Security Briefs, 14 July 2005. Online: http://www.stimson.org/?SN=WS20050714867; (5) Phillip S. Clark, "Space debris incidents involving Soviet/Russian launches," Molniya Space Consultancy, 1994; D S McKnight, "Determining the Cause of a Satellite Breakup: a Case Study of the Kosmos 1275 Breakup," *Aviation Week & Space Technology*, 9 March 1992, p. 19; David J Nauer, "History of On-Orbit Satellite Fragmentations," p. 154; (5) Kenneth Silber, "Space Junk Piles High," *Insight on the News*, 18 November 1996.

15 Alessandro Rossi, "The Earth Orbiting Space Debris," *Serbian Astronomical Journal*, 170 (2005), pp. 1 - 12.

16 "National Space Policy," White House National Science and Technology Council, Fact Sheet, 19 September 1996.

17 Peter de Selding, "FCC Enter Orbital Debris Debate," Space News, 28 June 2004.

18 *ESA Space Debris Mitigation Handbook* (Noordwijk, NE: 19 February 1999); R. Walker et al., *Update of the ESA Space Debris Mitigation Handbook*, European Space Agency, QinetiQ, July 2002. Online: http://www.esrin.esa.it/gsp/completed/execsum00_N06.pdf.

19 "European Space Debris Safety and Mitigation Standard," Issue 1, Revision 0, 27 September 2000; F. Alby et al., "A European Standard for Space Debris," 1999. Online: http://www.estec.esa.nl/wmwww/wma/Collaborations/NoCDebris/Publications/Alby%20et%20al-ANAE-2002.pdf.

ENDNOTES

20 "Support to the IADC Space Debris Mitigation Guidelines," Inter-Agency Space Debris Coordination Committee, 5 October 2004, pp. 3, 13. Online: http://www.iadconline.org/docs_pub/IADC.SD.AI20.3.10.2004.pdf.

21 "Support to the IADC Space Debris Mitigation Guidelines," pp. 3, 13.

22 United Nations Committee on the Peaceful Uses of Outer Space, 511th Meeting, Unedited transcripts. 17 June 2003, p. 5. Online: http://www.oosa.unvienna.org/Reports/transcripts/copuos/2003/COPUOS_T511E.doc.

23 "Orbital Debris Graphics," NASA Orbital Debris Program Office. Online: http://www.orbitaldebris.jsc.nasa.gov/photogallery/beehives.html.

24 "Protection Manual Version 3.3," Inter-Agency Space Debris Coordination Committee, April 2004. Online: http://www.iadc-online.org/index.cgi?item=docs_pub.

25 "New FCC Orbital Debris Ruling: ISO TC20/SC14 to develop standard for orbital debris mitigation," American Institute of Aeronautics and Astronautics, 6 June 2004. Online: http://intranet.aiaa.org/industryresources/PDF/FCCSATRulingPR.pdf.

26 "Space researchers respond to EU Security initiative," European Commission, Press Release, 22 April 2004. Online: http://europa.eu.int/comm/space/news/article_914_en.html; "Space researchers respond to EU Security initiative," European Commission, Press Release, 15 June 2004. Online: http://europa.eu.int/comm/space/news/article_1224_en.html.

27 "Electrodynamic Tethers: Clean Up Debris - Power or Boost Spacecraft," Technovelgy.com, 11 May 2004; "The Terminator Tether Aims to Clean Up Low Earth Orbit," Technovelgy.com, 5 November 2004. Online: http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=252; "Terminator Tether - EDT Solution To Space Debris Update," Technovelgy.com, 17 November 2004. Online: http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=264; Orbital Recovery Fact sheet, Orbital Recovery Ltd. Online: http://www.orbitalrecovery.com/images/fact_sheet_v1_5.pdf; Tariq Malik, "Orbital Assistance: ConeXpress Spacecraft Could Extend Satellite Missions," Space.com, 2 June 2004. Online: http://www.space.com/businesstechnology/technology/conexpress_techwed_040602.html; Gunter Dirk Krebs, "ConeXpress-OLEV (CX-OLEV)," Gunter's Space Page. Online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/conexpress-ors.htm.

28 Tim Bonds et al., *Employing Commercial Satellite Communications: Wideband Investment Options* for DoD (Santa Monica, CA: RAND Corporation, 2000), p. 17. Online: http://www.rand.org/publications/MR/MR1192/.

29 Michael Calabrese and J.H. Snider, "Up in the Air," *Atlantic Monthly*, September 2003, pp. 46-47; Albert "Buzz" Merill and Marsha Weiskopf, "Critical Issues in Spectrum Management for Defense Space Systems," *Crosslink* (Winter 2002) pp 14-19. Online: http://www.aero.org/publications/crosslink/winter2002/02.html.

30 Merill and Weiskopf, p. 18.

31 Philip McAlister, "Follow the Money: Satellite Opportunities with the US Government," Futron Corporation, 17 November 2003. Online: http://www.futron.com/pdf/sat%20oppor%20with%20us%20govt.pdf.

32 Glen Elfers and Stephen B. Miller, "Future U.S. Military Satellite Communication Systems," Crosslink, (Winter 2002). Online: http://www.aero.org/publications/crosslink/winter2002/08.html.

33 "Wideband Gapfiller Satellite," Boeing Satellite Systems, Fact Sheet: The last four of the 14 Defense Satellite Communications System satellites received these Service Life Enhancement modifications, providing "substantial capacity improvements." "Defense Satellite Communications System," MILSATCOM. Online: http://www.losangeles.af.mil/SMC/MC/dscs.htm.

34 Theresa Hitchens, *Future Security in Space: Charting a Cooperative Course* (Washington, DC: Center for Defense Information, September 2004), p. 49.

35 Hitchens, p. 49.

36 John C. Tanner, "SPACE JAM: Fighting satellite interference from the ground up," Telecomasia.net, 1 November 2003. Online: http://www.telecomasia.net/telecomasia/article/articleDetail.jsp?id=73752.

37 Tanner.

38 Jefferson Morris, "Spectrum plan would require relocation of Defense Department users by 2008," *Aerospace Daily*, 24 July 2002.

39 "EU and US a step further to agreement over Galileo satellite navigation," European Commission, Press Release, 25 February 2004. Online: http://www.eurunion.org/news/press/2004/20040030.htm.

40 International Telecommunication Union, Constitution and Convention of the International Telecommunication Union: Final Acts of the Plenipotentiary Conference (Marrakesh, 2002), ITU.For an excellent description of the role of ITU see Francis Lyall, "Communications Regulations: The Role of the International Telecommunication Union," *Journal of Law and Technology 3* (1997). Online: http://elj.warwick.ac.uk/jilt/commsreg/97_3lyal/lyall.DOC.

41 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Plenipotentiary Conference (Marrakesh, 2002)*, ITU, Article 45 para. 197.

42 Merill and Weiskopf, p. 15.

43 Merill and Weiskopf, p. 16.

44 Alvin M. Saperstein, "Weaponization vs. Militarization of Space," Forum on Physics and Society of the American Physical Society, American Physical Society, July 2002. Online: http://www.aps.org/units/fps/newsletters/2002/july/saperstein.pdf.

45 Joel D. Scheraga, "Establishing Property Rights in Outer Space," *Cato Journal 6* (1987), p. 891.

46 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Additional Plenipotentiary Conference*, Geneva: ITU, 1993, Article 33 (2).

47 Col. John E. Hyten, USAF, "A Sea of Peace or a Theater of War? Dealing with the Inevitable Conflict in Space," *Air and Space Power Journal* 16 (Fall 2002), p. 90, note 11.

48 Scheraga, p. 891.

49 "DBS Spacing," US Federal Communications Commission. Online: http://www.fcc.gov/ib/sd/dbs_spacing/.

50 Scheraga, p. 892.

51 Tim Bonds et al., *Employing Commercial Satellite Communications: Wideband Investment Options for DoD*, (Santa Monica, CA: RAND Corporation, 2000), p. 17. Online: http://www.rand.org/publications/MR/MR1192/.

52 Theresa Foley, "The World's Hottest Real Estate: Orbital Slots Are Prime Property," *Via Satellite* 16 (10 September 2001).

53 "Pakistan planning to build first indigenous satellite," *The News*, 6 July 2004.

54 Liching Sung, "ITU's Cost recovery: The Satellite factor," *Via Satellite* (1 September 2004); see also "Ad Hoc Group on Cost Recovery for Satellite Network Filings," International Telecommunications Union. Online: http://www.itu.int/council/adhoc-snf/.

55 Personal correspondence with USAF Space Command official, May 2006.

56 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108–136–24, November 2003. Online: http://www.celestrak.com/Norad/elements/Section913.pdf.

57 Bruce deBlois, Richard Garwin, Scott Kemp, and Jeremy Marwell, "Space Weapons Crossing the US Rubicon," *International Security* 29 (Fall 2004), pp. 50-84; Jeremy Singer, "Surveillance Remains Most Pressing Space Control Need," *Space News*, 11 October 2004.

58 "Deep View," DARPA, Tactical Technology Office, 5 October 2004. Online: http://www.darpa.mil/tto/.

59 "Space Surveillance Telescope," DARPA, Tactical Technology Office, 5 October 2004. Online: http://www.darpa.mil/tto/.

60 John A. Tirpak, "Securing the Space Arena," *Air Force Magazine*, Vol. 87, No. 7, July 2004. Online: http://www.afa.org/magazine/July2004/0704space.asp.

61 20th Space Control Squadron, Detachment 1, Fact Sheet. Online: http://www.peterson.af.mil/21SW/library/fact_sheets/20spcs_det1.htm.

62 "The SSS Space Surveillance System," Jane's Space Directory, 23 December 2003.

63 Pavel Podvig, "Strategic Defense," Russian Strategic Forces, Last modified May 2006. Online: http://russianforces.org/eng/defense/.

64 Podvig.

65 "The SSS Space Surveillance System."

66 "The SSS Space Surveillance System."

67 "GRAVES Space Surveillance System," ONERA, 2003. Online: http://www.onera.fr/photos-en/instexp/graves.php.

68 "German Space Agencies," GlobalSecurity.org. Online: http://www.globalsecurity.org/space/world/germany/agency.htm#ref21; W. Flury, "Agenda Item 8: Space Debris, European Space Agency," Presentation to the 41st session of UN Scientific and Technical Subcommittee on the Peaceful Uses of Outer Space (UNCOPUOS), 16-27 February 2004, p. 7. Online: http://www.oosa.unvienna.org/COPUOS/stsc/2004/presentations/flury2.ppt.

69 "Space Debris," European Space Agency, 24 August 2004. Online: http://www.esa.int/spacecraftops/ESOCArticle-fullArticle_par-47_1092735450198.html; "Space Debris Spotlight," European Space Agency, 31 March 2005. Online: http://www.esa.int/esaCP/SEMHDJXJD1E_FeatureWeek_0.html; W. Flury, "Agenda Item 8: Space Debris, European Space Agency," Presentation to the 41st session of UN Scientific and Technical Subcommittee on the Peaceful Uses of Outer Space, 16-27 February 2004. pp. 15-16. Online: http://www.oosa.unvienna.org/COPUOS/stsc/2004/presentations/flury2.ppt.

70 Heiner Klinkrad, "Monitoring Space – Efforts 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. Online: http://www.fas.org/spp/military/program/track/klinkrad.pdf.

71 "Spacecraft Operations, Space Debris Avoidance," European Space Agency. Online: http://www.esa.int/spacecraftops/ESOC-Article-fullArticle_idBanner-1092735449782_item_selected-19_5_00_par-47_1091629030048.html.

72 "China reports progress in space debris research," Xinhua, 14 August 2003. Online: http://news.xinhuanet.com/english/2003-08/14/content_1113433.htm.

73 "Alarm system warns of space debris," *China Daily*, 11 August 2003.

74 "China first space debris monitoring center settles PMO," *People's Daily*, 11 March 2005 and "CAS sets up the first space debris monitoring center in China," *People's Daily*, 16 March 2005.

75 "Chinese Space Facilities," Globalsecurity.org, last modified 19 October 2005, Online: http://www.globalsecurity.org/space/world/china/facility.htm.

76 "Space Debris Radar Station Operational," *Japan Times*, 9 April 2004.

77 IADC Observation Campaigns, Inter-Agency Space Debris Coordination Committee presentation to 43rd Session of COPUOS Science and Technology Sub-Committee, February 2006. Online: http://www.iadc-online.org/docs_pub/UN_Presentation_2006_final.pdf.

78 "MOST," University of British Columbia. Online: http://www.astro.ubc.ca/MOST/milestones.html.

79 "Canada considers military microsatellites," *Space News*, 1 September 2003; "MDA wins contract."

80 Large and medium sized objects refer to objects over 10 centimeters in diameter. *Orbital Debris Quarterly News* 10 (January 2006), p. 7.

81 The number of objects being tracked is only a representation of what sensors are online and their capability. With improvements to tracking capabilities, the database will increase even if the amount of debris is going down. The amount of debris that can cause damage to space assets could easily exceed 100,000 objects.

82 Comparison of "Orbital Box Score" data from to *Orbital Debris Quarterly News* 9 (January 2005) p. 9 to *Orbital Debris Quarterly News* 10 (January 2006) p.7.

83 At present the CIS includes Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan, and Ukraine.

84 "Orbital Box Score" (2006), p. 7.

85 "Recent Satellite Breakups," *Orbital Debris Quarterly News* 9 (July 2005), p. 1.

86 "Space Transportation With a Twist," NASA, last updated 22 June 2005. Online: http://www.nasa.gov/vision/universe/roboticexplorers/tethered_spacecraft.html.

87 "Progress in Space Tether Sever Modeling," *Orbital Debris Quarterly News* 9 (October 2005), p. 4.

88 "Innovative Space Tug Could Prolong Life of GEO Satellites," European Space Agency, Press Release, 21 November 2005.

89 "Large Area Debris Collector (LAD-C) Update," *Orbital Debris Quarterly News* 10 (January 2006), p. 2.

90 "Increasing greenhouse gases lead to dramatic thinning of upper atmosphere," American Geophysical Union Naval Research Laboratory, Joint Press Release, 2 February 2004.

91 "Space Debris Poses Collision Threat," *New Boundaries: University of Southampton Research* 2 (July 2005), p. 6. Online: http://www.soton.ac.uk/img/unipublications/nb_july05.pdf.

92 Theresa Hitchens, "Safeguarding Space: Building Cooperative Norms to Dampen Negative Trends," *Disarmament Diplomacy* 81 (Winter 2005).

93 "Space Debris Mitigation Guidelines at the UN," *Orbital Debris Quarterly News* 9 (July 2005), p. 1.

94 "NASA's Implementation Plan for International Space Station Continuing Flight," NASA, Vol.2, Rev. 2, 15 February 2005. Online: http://www.nasa.gov/pdf/110883main_Station_CFT_Rev2.pdf.

95 Traci Watson, "Shuttle study finds higher risk of fatal hit by debris," *USA Today*, 6 July 2005.

96 John Kelly, "Debris is Shuttle's Biggest Threat," *Florida Today*, 5 March 2005.

97 Watson.

98 "Mitigation of Orbital Debris," *Federal Register* 70 (12 October 2005), p. 59276.

99 "Interference Matrix Database," Satellite Users Interference Reduction Group. Online: http://www.suirg.org/interference/report_display.php.

100 "Promoting Online Services and Applications to Realize e-ASEAN," Association of South East Asian Nations, Joint Media Statement, 27 September 2005. Online: http://www.aseansec.org/17759.htm.

101 Maricel E. Estavillo, "ASEAN to harmonize radio frequency spectrum," *BusinessWorld*, 4 October 2005.

102 *A Forward Looking Radio Spectrum Policy for the European Union: Second Annual Report*, European Commission Communication to the Council and European Parliament document COM (2005) 411 final, June 2005. Online: http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/com/2005/com2005_0411en01.pdf.

103 *Report of the Panel of Experts on Space and Security*, European Commission Project Number 200446, 1 March 2005, p. 26. Online: http://europa.eu.int/comm/space/news/article_2262.pdf.

104 "Radiofrequency Spectrum Management," Government Accountability Office Briefing for Congressional Committees, document GAO-06-212R, 10 November 2005.

105 "Interference Matrix Database," Satellite Users Interference Reduction Group. Online: http://www.suirg.org/interference/report_display.php.

106 "First Iranian Satellite launched," *BBC News*, 27 October 2005.

107 "First Norwegian satellite launched," Norway Ministry of Foreign Affairs, 27 October 2005. Online: http://www.emb-norway.ca/education/news/satellite.htm.

108 "Kazsat launch postponed until 2006," RIA Novosti, 21 December 2005.

109 "War-ravaged Sudan to put first satellite in space this year," Agence France-Presse, 6 February 2005.

110 Peter Nowack, "New Zealand's first satellite gets go-ahead to fly," *New Zealand Herald*, 17 December 2005.

111 Pham Le, "Satellite Project Picks up Speed," *Saigon Times Weekly*, 12 November 2005.

112 *United Nations Report of the Committee on the Peaceful Uses of Outer Space*, UN General Assembly document A/60/20, 2005.

113 "Notice Concerning JSAT-PanAmSat Joint Satellite Business Expand Satellite Business in North America," JSAT, Press Release, 27 June 2005.

114 "Echostar eyeing 101 degrees W, but MSV got there first," *Communications Daily,* 26 August 2005.

115 International Telecommunication Union Decision 482 (modified 2005), 25 July 2005.

116 "Broad Agency Announcement VS-06-03, Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS)," Air Force Research Laboratory Space Vehicles Directorate, US Air Force, 2 December 2005. Online: http://fs1.fbo.gov/EPSData/USAF/Synopses/2682/BAA-VS-06-03/BAASolicitationforANGELS(Final2Dec05).doc.

117 "Air Force to Experiment with Geostationary-Orbit Sentinel," *Space News*, 28 November 2005.

118 "Real-time Survey and Follow-up Observations of GEO Debris," *Orbital Debris Quarterly News* 9 (October 2005), p. 2.

119 William B. Scott, "Space Warriors: The 21st Space Wing stakes its claim as the first U.S. 'space superiority' unit," *Aviation Week & Space Technology*, 7 March 2005.

120 "Space Based Space Surveillance Completes Preliminary Design Review," *Inside the Air Force* 16 (2005).

121 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108-136-24, November 2003.

122 William Harwood, "Satellite users worried about Air Force restrictions," *Spaceflight Now*, 2 March 2005. Online: http://www.spaceflightnow.com/news/n0503/02observing/.

123 "MDA wins Canadian space contract," Globe and Mail, 11 January 2005.

124 "MDA reports 4th quarter and year end 2004 results," MacDonald, Dettwiller and Associates Ltd. (MDA), Press Release, 22 February 2005.

125 "China establishes 1st space trash observation center," Xinhua, 11 March 2005.

126 Report of the Panel of Experts on Space and Security, European Commission Project Number 200446, 1 March 2005, p. 26. Online: http://europa.eu.int/comm/space/news/article_2262.pdf.

127 Peter B. de Selding, "Europe Interested in its own Space Surveillance Network," C4ISR Journal, 12 May 2005.

128 de Selding, "Europe Interested in its own Space Surveillance Network."

129 "Imminent Delivery of the French Surveillance System," France ST Special Reports 75 (24 August 2005). Online: http://www.fitscience.org/media/upload/FranceST_075.pdf.

130 Jacques Bouchard as quoted in "Imminent Delivery of the French Surveillance System," France ST Special Report 75 (24 August 2005). Online: http://www.fitscience.org/media/upload/FranceST_075.pdf.

131 "Law on the Activities of Launching, Flight Operations or Guidance of Space Objects," Government of Belgium. Online: http://www.belspo.be/belspo/res/rech/spatres/Loi/Loi_en.pdf.

Chapter Two Endnotes

1 "Charter of the United Nations," 26 June 1945, TIAS 7739.

2 Elizabeth Waldrop, "Weaponization of Outer Space: U.S. National Policy," High Frontier, 1 (Winter 2005), p. 37. Online: http://www.peterson.af.mil/hqafspc/news/images/JournalWinter05Web.pdf.

3 *Historical summary on the consideration of the question on the definition and delimitation of outer space, Report of the Secretariat*, UN General Assembly document, Committee on the Peaceful Uses of Outer Space document A/AC.105/769, 18 January 2002.

4 The US interpretation of "peaceful" as synonymous with "non-aggressive" was a logical extension of the US effort to gain international recognition of the permissibility of reconnaissance satellites while simultaneously discouraging military space activities that threatened these assets – two major goals of US policy during the period predating the Outer Space Treaty (1957-67). See Paul B. Stares, *The Militarization of Space: US Policy*, 1945-84 (Ithaca NY: Cornell University Press, 1988), pp. 59-71.

5 Ivan A. Vlasic, "The Legal Aspects of Peaceful and Non-Peaceful Uses of Outer Space," in Bupendra Jasani, ed., *Peaceful and Non-Peaceful Uses of Space: Problems of Definition for the Prevention of an Arms Race in Outer Space* (London: Taylor and Francis, 1991).

6 Lucy Stojak, "Key Concepts in Space Arms Control," Report to Foreign Affairs Canada, February 2005, p. 11.

7 "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Opened for signature 27 January 1967; entered into force 10 October 1967, 610 UNTS 119.

8 Canada, China, France, Germany, Italy, Japan, and the UK have failed to register 3, 35, 15, 16, 6, 10, and 10 satellites respectively. "Large nations fail to register satellites," Reuters, 17 August 2001.

9 "Agreement on the Activities of States on the Moon and Other Celestial Bodies," 5 December 1979, ILM 1434, Article 3(4).

10 "Agreement on the Activities of States…," 1979.

11 "Backgrounder: International Legal Agreements Relevant to Space Weapons," Union of Concerned Scientists, February 2004. Online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1157.

12 United Nations General Assembly Resolution Database, United Nations. Online: http://www.un.org/documents/resga.htm.

13 Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control* (Washington DC: US Government Printing Office, September 1985), p. 93.

14 "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article III, UN Doc. A/RES/2222(XXI), 25 January 1967, TIAS no. 6347.

15 "Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water," 7 October 1963, UST 14, no.1363. Hereinafter referred to as the Limited-Test Ban Treaty.

16 US Department of State, "Treaty between the United States and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems," 26 May 1972, TIAS 7503.

17 "Agreement on Measures to Improve the US-USSR Direct Communications Link," 30 September 1971, UNTS 806, no. 402 (1972). See also, UNTS 807, no. 57.

18 Some believe that the ABM Treaty, annulled in 2002, was particularly important because it prohibited the development, testing, or deployment of space-based ABM systems, as well as limiting the development of other types of ABMs.

19 "The Convention on the Prohibition of Military or any other Hostile Use of the Environmental Modification Techniques," 18 May 1977, UST 31, no. 333.

20 *Anti-Satellite Weapons, Countermeasures, and Arms Control*, p. 93.

21 "Agreement Between the Government of the United States of America and the Government of the Union of Soviet Socialist Republics on Notification of Launches of Intercontinental Ballistic Missiles and Sub-marine Launched Ballistic Missiles," 31 May 1988.

22 "Treaty on Conventional Armed Forces in Europe," 9 November 1992, 30 ILM 1. Article XV(2).

23 "Treaty between the United States of America and the Union of Soviet Socialist Republics on Limitation of Strategic Offensive Arms," Article XV, 18 June 1979 not in force, ILM 18, no. 1112; "Treaty on the Reduction and Limitation Strategic Offensive Arms," Article IX, 31 July 1991, Strategic Treaty Documents no. 102-20.

24 "Treaty Between the United States and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles," 8 December 1987, ILM 27 no.90, Article XII.

25 "Memorandum of Agreement Between the Government of the United States and Government of the Russian Federation on the Establishment of a Joint Center for the Exchange of Data from Early Warning Systems and Notifications of Missile Launches," White House Fact Sheet, 4 June 2000.

26 Given the usefulness of some space technologies in the development of missiles, MTCR export controls are perceived by some countries, notably those outside the regime, as a restrictive cartel impeding access to space.

27 See Missile Technology Control Regime Website. Online: http://www.mtcr.info/english/index.html.

28 Brought into effect 25 November 2002.

29 Michel Bourbonnière, "LOAC and the Neutralization of Satellites or lus in Bello Satellitis," International Security Research and Outreach Programme Report, Department of Foreign Affairs and International Trade, Canada, May 2003, pp. 17-23.

30 Ambassador Thomas Graham Jr., "The Law and the Military Uses of Outer Space," Speech delivered at the Naval War College, Newport Rhode Island, 1 May 2003. Online: http://www.eisenhowerinstitute.org/programs/globalpartnerships/fos/newfrontier/grahambriefing.htm.

31 Dr. Peter Van Fenema, interview by author, McGill University, Montreal, 25 February 2005.

32 "Review of the Implementation of the Recommendations of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space" UN General Assembly Document A/59/174, 23 July 2004. "Vienna Declaration on Space and Human Development Adopted by UNISPACE III, as it Concludes Two-Week Session," UNISPACE III Conference, Press Release, 30 July 1999. Online: http://www.un.org/events/unispace3/.

33 Detlev Wolter, *Common Security in Outer Space and International Law*, Geneva: United Nations Institute for Disarmament Research, UNIDIR/2005/29, p 132.

34 Wolter, pp 131-136.

35 "Possible Elements of the Future International Legal Instrument on the Prevention of the Weaponization of Outer Space," CD/1645, 6 June 2001.

36 Union of Concerned Scientists, "A Treaty Limiting Anti-Satellite Weapons," May 1983. Online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1153.

37 The Henry L. Stimson Center, "Model Code of Conduct for the Prevention of Incidents and Dangerous Military Practices in Outer Space," 2004. Online: http://www.stimson.org/wos/pdf/codeofconduct.pdf.

38 "Safeguarding Space for All: Security and Peaceful Uses, Geneva, 25-26 March 2004," Conference Report, United Nations Institute for Disarmament Research, March 2004. Online: http://www.unidir.ch/pdf/activites/pdf-act254.pdf.

39 COPUOS has two standing subcommittees, the Scientific and Technical Subcommittee and the Legal Subcommittee, as well as the stand-alone IADC. COPUOS and its two subcommittees each meet annually to consider questions put before them by UNGA, reports submitted, and issues raised by the Member States. The committee and the subcommittees, working on the basis of consensus, make recommendations to the UN General Assembly. *Question of the peaceful use of outer space,* UN General Assembly Resolution 1348, 15 December 1958. COPUOS was made permanent by *International co-operation in the peaceful uses of outer space*, UN General Assembly Resolution 1472, 12 December 1959.

40 Inter-Agency Space Debris Coordination Committee, *IADC Guidelines*, p. 8, section 5.2.

41 See "Working Paper on the Prevention of an Arms Race in Outer Space," submitted by the Mongolian People's Republic to the Committee on Disarmament, CD/272, 5 April 1982.

42 "Prevention of an Arms Race in Outer Space," Official Records of the General Assembly, A/RES/40/87, 12 December 1985. See also, "Mandate for the Ad Hoc Committee under item 5 of the agenda of the Conference on Disarmament entitled Prevention of an Arms Race in Outer Space," Conference on Disarmament, CD/1059, 14 February 1991, and previous documents under the same title.

43 These recommendations included: improved registration and notification of information, the elaboration of a code of conduct or of rules of the road as a way to reduce the threat of possible incidents in space; the establishment of "keep-out zones" around spacecraft; the elaboration of an agreement dealing with the international transfer of missile technology and other sensitive technology; and widening the protection offered to certain satellite systems under US-USSR/Russia arms control agreements.

44 Hereinafter referred to as the "Amorim proposal."

45 "National Space Policy," US National Science and Technology Council, US White House Fact Sheet, 19 September 1996. Online: http://www.ostp.gov/NSTC/html/fs/fs-5.html.

46 "National Space Policy."

47 "Russia May Cooperate with US in Space Programs," *Itar-Tass*, 21 January 2004.

48 "Status Report Requested of RAMOS Program," *CDI Missile Defence Update*, No. 16, 2003.

49 Susan Eisenhower, Thomas Graham Jr., and Robert J. Lawson, *Space Security 2003*, The Eisenhower Institute (Toronto: Northview Press, 2004), p.37.

50 "China's Space Activities," PRC Information Office of the State Council, 2000. Online: http://english.peopledaily.com.cn/features/spacepaper/spacepaper.html.

51 Signatories include China, Iran, Republic of Korea, Mongolia, Pakistan, and Thailand.

52 "China's Space Activities.".

53 David Long, "The Evolution and Shape of European Space Policy," Report to Foreign Affairs Canada, May 2004, p. 18.

54 Joint Publication 3-14 is all but silent on the space strike mission, stating only that "currently there are no space force application assets operating in space." US Department of Defense, "Joint Doctrine for Space Operations," Joint Publication 3-14, 9 August 2002, p. x.

55 "Joint Doctrine for Space Operations," p. x.

56 US Air Force, Future Concepts and Transformation Division, *Transformation Flight Plan* (November 2003). Online: http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf.

57 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1, 2 August 2004, p. 2. The *Counterspace Operations* document represents the views of the USAF and not necessarily that of the US Government.

58 For a discussion of the spectrum of views regarding space weapons see Peter L. Hays, "Current and Future Military Uses of Space," *Outer Space and Global Security* (Geneva: UNIDIR, 2003), pp 21-64. Online: http://www.unidir.org/bdd/fiche-article.php?ref_article=1989.

59 US Department of Defense, *Space Policy Directive 3100.10*, Updated 9 July 1999.

60 US Department of Defense, *Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations*, Joint Publication 3-14; US Air Force, *2004 USAF Posture Statement*, 2003.

61 National Missile Defense Act of 1999, Public Law 106-38, 6 January 1999.

62 "Fiscal Year (FY) 2004/FY 2005 Biennial Budget Estimates Submission," Missile Defense Agency, Press Release, January 2003, p. 16.

63 See Government of the Russian Federation, "The Basic Provisions of the Military Doctrine of the Russian Federation," FBIS-SOV 19, no. 222, 1993, Section 3.1. First Published: *Rossiiskie vesti*, 18 November 1992, pp. 1-2; Government of the Russian Federation, "Draft Russian Military Doctrine," *BBC Monitoring*, 1999, Section 1.5. First Published: *Krasnaya Zvezda*, 9 October 1999, pp. 3-4; Government of the Russian Federation, "Russian Federation Military Doctrine," *Nezavisimaya Gazeta*, 22 April 2000, Section I.5; Russian Federation Ministry of Defence, "Russian Federation Ministry of Defence Brochure: Urgent Tasks of the Development of the Russian Federation Armed Forces," Moscow, 2003, Section II, p. 13.

64 Government of the Russian Federation, "Draft Russian Military Doctrine," *BBC Monitoring*, 9 October 1999, Section 1.10.a.

65 Government of the Russian Federation, "Russian Federation Military Doctrine," *Nezavisimaya gazeta*, 22 April 2000, Section II.3; Russian Federation Ministry of Defence, "Russian Federation Ministry of Defence Brochure: Urgent Tasks of the Development of the Russian Federation Armed Forces," Moscow, 2003, Section IV, pp. 18-19.

66 "Russian Space Forces Commander Outlines Priorities," *BBC Monitoring*, 30 April 2001.

67 "Putin Reiterates Priorities in Developing Space Forces," Interfax, 7 April 2003.

68 "Svobodny Cosmodrome Has Special Role in Russia's Space Programs - Space Troops Chief," Interfax, 14 April 2003.

69 Andrew Gowers, Robert Cottrell, and Andrew Jack, "Transcript: Interview with Vladimir Putin, 13 December," *Financial Times*, 15 December 2001, p. 2.

70 Steve Gutterman, "Reports: Russia threatens retaliatory steps if any country deploys weapons in space," Associated Press, 2 June 2005; Rebecca Johnson, "PAROS Discussions at the 2004 UN First Committee," Acronym Institute for Disarmament Diplomacy, 20 October 2004. Online: http://www.acronym.org.uk/un/2004paro.htm.

71 Government of China State Council Information Office, "China's National Defense in 2004," 27 December 2004. Online: http://www.fas.org/nuke/guide/china/doctrine/natdef2004.html.

72 "Russia-China CD Working Paper on New Space Treaty," CD/1679, 28 June 2002.

73 "Space: a new European frontier for an expanding Union: An action plan for implementing the European Space Policy," White Paper, European Commission, 2003, pp. 6-7. Online: http://europa.eu.int/comm/space/whitepaper/pdf/spwhpap_en.pdf.

74 Stefano Silvestri, "Space and Security Policy in Europe: Executive Summary," *Occasional Paper*, No. 48, December 2003, p. 9.

75 "European Space Policy," Green Paper, European Commission, 2003, p. 4. Online: http://europa.eu.int/comm/space/doc_pdf/space-green-paper_en.pdf; "Space: a new European frontier for an expanding Union: An action plan for implementing the European Space Policy," White Paper, European Commission, 2003. Online: http://europa.eu.int/comm/space/whitepaper/pdf/spwhpap_en.pdf.

76 Michèle Alliot-Marie, "Discours de Madame le Ministre de la Défense: Lancement du satellite HELIOS II," French Ministry of Defense, 18 December 2004.

77 Article II, "Convention for the Establishment of a European Space Agency," Open for signature 30 May 1975, entered into force 30 October 1980, 14 ILM 864.

78 Vivek Raghuvanshi, "India Embraces New War Doctrine," *Defense News*, 8 November 2004.

79 *Strategic Vectors: Air Force Transformation Vision*, Department of National Defence, Canada, 2004, pp. 14-16. Online: http://www.airforce.forces.gc.ca/vision/strategic_e.asp.

80 UNGA First Committee Voting Record on Prevention of an Arms Race in Outer Space, A/C.1/60/L.27, 25 October 2005. Online: http://www.reachingcriticalwill.org/political/1com/1com05/votes/L.27.pdf.

81 UNGA Voting Record on Prevention of an Arms Race in Outer Space,.A/60/462, 8 December 2005. Online: http://www.reachingcriticalwill.org/political/1com/1com05/ga/96.pdf.

82 Ambassador Erik M. Javitz, "Speech on outer Space," Speech delivered to the Conference "Future Security in Space," Mountbatten Centre of International Studies, New Place, Southampton, England, 28 May 2005. Online: http://www.acronym.org.uk/docs/0205/doc17.htm.

83 Statement by Ambassador John Freeman of the UK to the Conference on Disarmament, CD/PV.988, 30 June 2005.

84 "Outer Space Arms Race Now Credible Threat, New Legal Agreement Needed to Block any Possible Weapon Deployment, First Committee Told," United Nations General Assembly, Press Release, 12 October 2005.

85 UN General Assembly First Committee Voting Record on Transparency and Confidence Building Measures in Outer Space Activities, A/C.1/60/L.31/Rev.1, 28 October 2005. Online: http://www.reachingcriticalwill.org/political/1com/1com05/votes/L.30Rev1.pdf.

86 "Definition Issues Regarding Legal Instruments on the Prevention of Weaponization of Outer Space," Non-Paper submitted by the Chinese and Russian Delegations to the Conference on Disarmament, 9 June 2005.

87 *United Nations Report of the Committee on the Peaceful Uses of Outer Space*, UN General Assembly document A/60/20, 2005.

88 *Report of the Committee on the Peaceful Uses of Outer Space*, 2005.

89 Draft Elements of an UNGA60 First Committee Resolution, "Initiating work on priority disarmament and non-proliferation issues," sponsored by Brazil, Canada, Kenya, Mexico, New Zealand and Sweden, 5 October 2005. Online: http://www.reachingcriticalwill.org/political/1com/1com05/docs/draftelementsinitiating.pdf.

90 Original text of memo circulated by US Delegation at UNGA First Committee, "UNGA First Committee Draft Resolution on Ad Hoc Committees," Online: http://www.reachingcriticalwill.org/political/1com/1com05/docs/ungafirstcommdraft.pdf.

91 Germany, France, South Africa, Sri Lanka, Ireland, Canada, Ethiopia (on behalf of the G21), the United Kingdom, Peru, China, Brazil, Russia, Pakistan, Sweden, Italy, New Zealand, Argentina, Mexico, Syria, Malaysia, South Korea, and Cuba delivered statements during this meeting.

92 Russia also announced that all Collective Security Treaty Organization member states, including Armenia, Belarus, Kazakhstan, Kyrgyzstan, and Tajikistan, share Russia's commitment to no first deployment. Statement by Ambassador Leonid Skotnikov, Permanent Representative of the Russian Federation at the Plenary Meeting of the Conference on Disarmament, 30 June 2005. Online: http://www.reachingcriticalwill.org/political/cd/speeches05/June30Russia.pdf; "Report: Russian defense minister warns about space weapons," Associated Press, 2 June 2005.

93 "Summary of the second open-ended meeting on the issue of the prevention of an arms race in outer space (PAROS) held by the Russian Federation," 16 August 2005. Online: http://www.reachingcriticalwill.org/political/cd/speeches05/Sept6ParosRussia.pdf.

94 "Prevention of an arms race in outer space at the United Nations," Reaching Critical Will. Online: http://www.reachingcriticalwill.org/legal/paros/parosindex.html.

95 "Parliamentary hearing on space security," e-parliament, 14 September 2005. Online: http://www.e-parl.net/pages/space_hearing.htm.

96 "The CD Report," Reaching Critical Will, 31 January 2005. Online: http://www.reachingcriticalwill.org/political/cd/speeches05/reports.html.

97 "Cooperation in Space Gets Major Boost," European Commission, Press Release, 18 February, 2005. Online: http://europa.eu.int/comm/space/news/article_2151_en.html.

98 "Further Steps Towards a European Space Policy," European Space Agency, Press Release, 7 June 2005. Online: http://www.esa.int/esaCP/Pr_29_2005_p_EN.html.

99 "European Ministers deliberate on discovery and competitiveness," European Space Agency, Press Release, 9 December 2005.

100 "European Ministers deliberate.".

101 Colin Clark, "Congress Clears NASA to Purchase Russian Spacecraft," *Space News*, 9 November 2005. Online: http://www.space.com/news/051109_congress_soyuz.html.

102 "Russia to remain leading space power - head of Roscosmos," RIA Novosti, 19 August 2005.

103 "Russian government approves 2006-2015 Federal Space Program," RIA Novosti, 25 October 2005.

104 "Russia Increases Space Budget – Hopes to Rationalize Space Industry," Forecast International Space Systems, 16 August 2005.

105 "JAXA Vision – JAXA 2025," Japan Aerospace Exploration Agency, 31 March 2005. Online: http://www.jaxa.jp/about/vision_missions/long_term/jaxa_vision_e.pdf.

106 Kenji Hall, "Japan Announces Manned Moon Flight by 2025," Associated Press, 6 April 2005.

107 "China to walk in space, but new rocket to reach moon still pending," Agence France-Presse, 3 November 2005.

108 Min Lee, "China aims to put man on moon by 2020," Associated Press, 27 November 2005.

109 "China's Endeavors for Arms Control, Disarmament and Non-Proliferation," China Information Office of the State Council, 1 September 2005.

110 "Kazakhstan Predicts Major Developments for its Space Program," PR Newswire, 30 November 2005.

111 Ali Akbar Dareini, "Iran snaps up space technology," Associated Press, 29 November 2005.

112 "Japan: Military Programs," Centre for Nonproliferation Studies. Online: http://cns.miis.edu/research/space/japan/mil.htm.

113 Barbara Opall-Rome, "Israeli official urges space-based weapons," *Defense News*, 11 January 2005.

114 "Air Chief asks to prepare for star wars," Chennai Online, 26 April 2005. Online: http://www.chennaionline.com/colnews/newsitem.asp?NEWSID=%7BA5D72B41-8CBB-4763-8B60-1DE998DA6F5F%7D&CATEGORYNAME=National.

115 Sandeep Dikshit, "Centre taking steps for Aerospace Command," *The Hindu*, 20 July 2005.

116 *Report of the Panel of Experts on Space and Security*, European Commission Project Number 200446, 1 March 2005, p. 26. Online: http://europa.eu.int/comm/space/news/article_2262.pdf.

117 *Report of the Panel of Experts on Space and Security*, European Commission Project Number 200446, 1 March 2005 p 26. Online: http://europa.eu.int/comm/space/news/article_2262.pdf.

118 Tim Weiner, "Air Force seeks Bush's approval for space arms," *New York Times*, 18 May 2005, p. A1.

119 "US Conducts Space War Game to Test Warfighting Capability," SPX, 14 February 2005. Online: http://www.spacedaily.com/news/milspace-05e.html.

Chapter Three Endnotes

1 Sea Launch is a consortium of four companies – Boeing Commercial Space Company (USA), Kvaerner ASA (Norway), RSC-Energia (Russia), and SDO Yuzhnoye/PO Yuzhmash (Ukraine) – that provides a sea-based launch platform using the Zenit rocket for space access. Online: http://www.sea-launch.com.

2 International Launch Services (ILS) uses the launch vehicles of three companies – the Khrunichev State Research and Production Space Center (KhSC) (Russia), which provides the Proton and Angara launch vehicles; Lockheed Martin Space Systems Company (USA), which provides the Atlas family of launch vehicles; and RSC Energia (Russia), the previous supplier of the Block DM fourth stage for the Proton K. Online: http://www.ilslaunch.com/partnerships/.

3 Data from unter Dirk Krebs, Gunter's Space Page. Online: http://www.skyrocket.de/space/.

4 The European Space Agency (ESA) is a regional space program with many member states.

5 Via Sea Launch: Ukraine has not formerly conducted an independent launch, but it is a Ukrainian company that builds the Zenit rockets used by Sea Launch.

6 Krebs, "Gunter's Space Page"

7 Surrey Satellite Technology Ltd. Online: http://www.sstl.co.uk/index.php?loc=5.

8 "Satellite Catalogue and Launch Catalogue," Jonathan's Space Report. Online: http://planet4589.org/space/log/satcat.txt; "Chronology 2004," Encyclopedia Astronautica. Online: http://www.astronautix.com/.

9 Fernand Verger, Isabelle Sourbes-Verger, Raymond Ghirardi and Xavier Pasco, *The Cambridge Encyclopedia of Space* (Cambridge: Cambridge University Press, 2003), p. 101.

10 Verger, et al. p. 81.

11 Verger, et al. pp. 68-69.

12 Olga Zhdanovich, Discussion with author, Montreal, Quebec, 26 February 2005.

13 Data from Verger, et al.

14 "Disaster Monitoring Constellation Partners Hold 4th Meeting," Spacedaily.com, 14 December 2003.Online: http://www.spacedaily.com/news/eo-03zzzzl.html.

15 "Bush unveils vision for moon and beyond," CNN, 15 January 2004. Online: http://www.cnn.com/2004/TECH/space/01/14/bush.space/.

16 Data from Verger, et al.

17 Verger, et al. pp. 68-69.

18 "China to launch permanent manned space station within 15 years," Agence France-Presse, 18 May 2004.

19 Verger, et al. pp. 73-77.

20 Verger, et al. p. 69.

21 Fred Weir, "As space work goes on, Russia key," *Christian Science Monitor*, 4 February 2003.

22 Jane's Space Directory (Surrey, UK: Jane's Information Group, 2001), p. 14.

23 Verger, et al. pp. 68-69.

24 Verger, et al. pp. 96-97.

25 Global Monitoring for Environment and Security. Online: http://www.gmes.info/what_is/index.html.

26 "Milestones of the Indian Space Research Organization (ISRO)," Indian Space Research Organization. Online: http://www.isro.org/mileston.htm.

27 "Surrey Launches Two More Satellites from Russia," Surrey Satellites Technologies Ltd, Press Announcement, 10 July 1998. Online: http://www.ee.surrey.ac.uk/SSC/CSER/UOSAT/press/tmsat-fasat-pr3.html.

28 Sean O'Keefe, "Remarks at the U.S. Space Foundation Annual Symposium," Colorado Springs, Colorado, 31 March 2004. Online: http://www.nasa.gov/audience/formedia/speeches/ok_colorado_springs_033104.html.

29 NASA, Spinoff 2004 (Washington DC: US Government Printing Office, 2004), Online: http://www.sti.nasa.gov/tto/.

30 Data from Verger, et al..

31 "Mir Station," Videocosmos. Online: http://www.videocosmos.com/mir.shtm

32 "History of Shuttle-Mir," NASA. Online: http://spaceflight.nasa.gov/history/shuttle-mir/images/timeline.pdf.

33 "How Much Does it Cost?" ESA, last updated 20 October 2004. Online: http://www.esa.int/export/esaHS/ESAQHA0VMOC_iss_0.html.

34 "Global Earth Observation System of Systems (GEOSS)," US Environmental Protection Agency. Online: http://www.epa.gov/geoss/index.html.

35 "Declaration of the Earth Observation Summit," Group on Earth Observations, 31 July 2003; "Global

Earth Observation System of Systems (GEOSS)," US Environment Protection Agency. Online: http://www.epa.gov/geoss/basic.html.

36 "China, Brazil to Co-Launch 2nd Satellite in Latter Half Year," *People's Daily*, 13 July 2002.

37 Futron Corporation, Trends in Space Commerce, US Department of Commerce, Office of Space Commercialization, June 2000.

38 "The sky's the limit," *Economist*, 8 March 2001.

39 "Trends in Space Commerce," US Department of Commerce, Office of Space Commercialization, June 2001.

40 "Coordinational Scientific Information Center," Russian Ministry of Defense. Online: http://www.glonass-center.ru/constel.html.

41 Pavel Podvig, "Russia and Military Uses of Space," from the working paper, "The American Academy of Arts and Sciences Project 'Reconsidering the Rules of Space,'" June 2004. Online: http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml.

42 "Satellite Navigation," European Union, 6 April 2006. Online: http://europa.eu.int/comm/space/russia/sector/satellite_navigation_en.html.

43 "Satellite Catalogue and Launch Catalogue," Jonathan's Space Report. Online: http://planet4589.org/space/log/satcat.txt; Mark Wade, "Chronology 2004," Encyclopedia Astronautica. Online: http://www.astronautix.com/,

44 "The Beidou system," presentation to the Union of Concerned Scientists, Summer Syposium, Beijing, August 2004.

45 Chen Lan, "China prepares to build satellite constellation," *Flight International*, 28 June 2005.

46 "Joint Announcement, Second Japan-US GPS Plenary Meeting, 2002," Interagency GPS Executive Board, 16 October 2002.

47 Paul Kallender, "Impass Over Japan's QZSS System Persists," *Space News*, 23 December 2004.

48 "GALILEO : YES, at last!" European Commission, Press Release, 26 March 2002. Online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/02/478.

49 "Galileo: contracts for the first satellites," ESA, Press Release, 11 July 2003. Online: http://www.esa.int/export/esaCP/Pr_43_2003_p_EN.html.

50 "Commission pursues Galileo cooperation agreement with Ukraine," EU Business, 8 September 2004; "Galileo," European Satellite Navigation System. Online http://www.galileo.ws/.

51 "Where it's at: a European satellite-navigation network is on its way," *Economist*, 29 January 2004.

52 "EU and US a step further to agreement over Galileo satellite navigation," Delegation of the European Commission to the United States, Press Release, 25 February 2004. http://www.eurunion.org/news/press/2004/20040030.htm.

53 "Galileo Services," European Union, 1 March 2006. Online: http://europa.eu.int/comm/dgs/energy_transport/galileo/programme/services_en.htm.

54 "Satellite Catalogue and Launch Catalogue," Jonathan's Space Report. Online: http://planet4589.org/space/log/satcat.txt.

55 "Current Polar-Orbiting Satellites Coordinated within CGMS (as of 4 Nov 2005)," WMO Space Programme, 25 November 2005.

56 "SSTL readies first DMC satellite for November launch," Surrey Satellite Technologies, Press Release, 19 November 2002.

57 COSPAS-SARSAT Secretariat, interview with author, 16 May 2005.

58 COSPAS-SARSAT Secretariat, interview with author, 16 May 2005.

59 "Iran Seeks to Master Space Technology," Associated Press, 29 November 2005; Gunter Dirk Krebs, "Sinah 1," Orbital Launches of 2005, Gunter's Space Page, last updated 28 October 2005. Online: http://www.skyrocket.de/space/.

60 "First Iranian satellite launched," BBC News, 27 October 2005. Online: http://news.bbc.co.uk/2/hi/middle_east/4381436.stm.

61 "Iran Seeks to Master Space Technology," Associated Press, 29 November 2005.

62 "Iran Seeks to Master Space Technology"; "In Orbit," *Flight International*, 8 February 2005, p. 40.

63 Paul Betts, "Heavy load weighs on European space plans," *Financial Times*, 7 January 2005, p. 14.

64 "Ariane 5 to be further developed," Deutsche Presse-Agenture, 5 December 2005; "Ariane 5 ECA," ESA, 5 January 2006. Online: http://www.esa.int/SPECIALS/Launchers_Access_to_Space/SEM0LR2PGQD_0.html.

65 "Japan's rocket is 'go' for launch at last," Associated Press, 8 February 2005.

66 "Plasma engine passes initial test," *BBC News*, 14 December 2005. Online: http://news.bbc.co.uk/1/hi/technology/4527696.stm.

67 "NASA deferring Prometheus, shifting FY 2006 funds to CEV, CLV," *Aerospace Daily & Defense Report*, November 2005, p. 1.

68 "Prometheus Nuclear Systems and Technology," Exploration Systems, NASA, 29 December 2005. Online: http://exploration.nasa.gov/programs/prometheus/.

69 Vladimir Isachenkov, "Russian Space Agency: Solar Sail Launch Failed," Associated Press, 22 June 2005.

70 "Nothing ventured…," *New Scientist*, 2 July 2005, p. 18.

71 "Launch Reports 2005," Futron Corporation, January 2005-January 2006. Online: http://www.futron.com/spaceandtelecom/src/foflist.htm.

72 Martin Redfern, "Prometheus looks to nuke future," *BBC News,* 8 March 2005. Online: http://news.bbc.co.uk/1/hi/sci/tech/4329645.stm; "Nothing ventured…," p. 18.

73 Rick Weiss and Guy Gugliotta, "Engineers to Tackle Cause of Foam Shedding," *Washington Post*, 20 August 2005, p. A10; "Discovery is home," *CNN News*, 10 August 2005.

74 Guy Gugliotta, "NASA Unveils $104 Billion Plan to Return to the Moon by 2018," *Washington Post*, 20 September 2005.

75 "NASA plans return to Moon by 2020," *BBC News*, 19 September 2005. Online: http://news.bbc.co.uk./1/hi/sci/tech/4261522.stm.

76 Gugliotta.

77 "NASA's Exploration Systems Architecture Study: Final Report," NASA, NASA-TM-2005-214062, November 2005. Online: http://www.nasa.gov/mission_pages/exploration/news/ESAS_report.html.

78 "Chinese astronauts blast off," CNN News, 13 October 2005.

79 "China's first women in space could go on Shenzhou IX in five years," Agence France-Presse, 12 October 2005.

80 "China announces space agenda," CDI Space Security Update #11, 10 November 2005. Online: http://www.cdi.org/program/document.cfm?DocumentID=3210&from_page=../index.cfm.

81 Min Lee, "China aims to put man on moon by 2020," Associated Press, 28 November 2005.

82 Mark Wade, "Shenzhou 6," *Encyclopedia Astronautica,* 20 November 2005; Jonathan Watts, "China plans first space walk in 2007," *Guardian* (London), 18 October 2005, p. 16.

83 "The government has approved," *Aviation Week & Space Technology*, 7 November 2005, p. 28.

84 "Russia approves space funding," *CNN News*, 26 October 2005.

85 Dmitry Pieson, "ESA officials support Energia's Clipper program," A*erospace Daily & Defense Report, 14 June 2005, p. 6.*

86 Helen Briggs, "Analysis: Europe's roadmap for space," BBC News, 7 December 2005. Online: http://news.bbc.co.uk/2/hi/science/nature/4507122.stm.

87 Eiichiro Sekigawa, "Return Vision; Japan's space agency counts ISS at centre of 20-year road map," *Aviation Week & Space Technology*, April 2005, p. 32.

88 Helen Briggs, "Europe debates its space goals," *BBC News*, 5 December 2005. Online: http://news.bbc.co.uk/2/hi/science/nature/4500106.stm

89 Briggs, 5 December 2005.

90 Briggs, 7 December 2005.

91 "Human Space Exploration," Royal Astronomical Society, 18 October 2005. Online: http://www.ras.org.uk/index.php?option=com_content&task=view&id=847&Itemid=1.

92 Douglas Barrie, "Crewed Argument; Britain urged to rethink investment policy in run-up to Aurora discussions," *Aviation Week & Space Technology*, October 2005, p. 28.

93 Frank Morring Jr and Michael Mecham, "One JAXA: Restructured Japanese space agency has big plans, but uncertain funds," *Aviation Week & Space Technology*, November 2005, p. 64.

94 "The government has approved," *Aviation Week & Space Technology*, 7 November 2005, p. 28.

95 "ESA approves space budget," *CNN News*, 6 December 2005; "How big is ESA's budget?" European Space Agency, 1 December 2005.

96 "Area-wise distribution of funds," Department of Space, Indian Space Research Organisation, 22 December 2005. Online: http://www.isro.org/resources.htm.

97 "Financial Tables: Departmental Planned Spending and Full Time Equivalents," *The Canadian Space Agency 2005-2006 Estimates: Reports on Plans and Priorities*, 2005, p. 50. Online: http://www.space.gc.ca/asc/pdf/rpp-2005.pdf.

98 "Funding: Source of Funds," BNSC, last modified 8 December 2005. Online: http://www.bnsc.gov.uk/default.aspx?nid=4691.

99 "Deep Impact: First Look Inside a Comet," NASA Jet Propulsion Laboratory, Fact Sheet, 12 September 2005. Online: http://deepimpact.jpl.nasa.gov/mission/factsheet-color.pdf; Gunter Dirk Krebs, "Deep Impact (Discovery7)," Gunter's Space Page, last updated 21 September 2005. Online: http://www.skyrocket.de/space/doc_sdat/deep_impact.htm.

100 "Japan: Success for asteroid probe," *CNN News*, 26 November 2005.

101 "Japan space probe may have missed asteroid samples," Reuters, 7 December 2005.

102 "ESA picks target for anti-NEO mission," *Aerospace Daily and Defense Report*, September 2005, p. 6.

103 "Russia, China Move Forward on Space Cooperation," Interfax-China, 29 June 2005. Online: http://www.space.com/astronotes/astronotes.html; "Russia, China to develop space nuclear energy," RIA Novosti, 7 September 2005. Online: http://en.rian.ru/russia/20050907/41326624.html.

104 "US and Japan Sign Satellite Back-Up Agreement," SPX, 28 March 2005. Online: http://www.spacedaily.com/news/weather-05p.html.

105 "U.S.-India joint Working Group on Civil Space Cooperation Joint Statement," US Department of State, Press Release, 14 July 2005.

106 "Russia and USA plan joint development of rocket engines for flights to Mars," RIA Novosti, 16 June 2005. Online: http://en.rian.ru/science/20050616/40534078.html.

107 "Moon mission to carry 3 European instruments," *The Hindu*, 27 June 2005; "ESA Gives Go-Ahead To Cooperation With Indian Lunar Mission," ESA, Press Release, 22 March 2005. Online: http://www.spacedaily.com/news/lunar-05m.html; "India and Venezuela Sign MOU On Space Cooperation," SPX, 7 March 2005. Online: http://www.spacedaily.com/news/india-05j.html.

108 Arie Egozi, "France joins Israel for Micro Venus," *Flight International*, 18 October 2005; "Israel and France to Build Multispectral Imager," *Aviation Week & Space Technology*, April 2005, p. 18.

109 "Bangladesh, Pakistan team up with China on Space Cooperation," SPX, 31 October 2005. Online: http://www.spacedaily.com/news/china-05zzzzzzzzzn.html.

110 "China, European Space Agency Sign Deal on Space Co-Op," Xinhua, 23 November 2005.

111 Jefferson Morris, "ISS partners agree on plans to finish station by 2010," *Aerospace Daily & Defense Report*, January 2005, p. 4; "Joint Statement by International Space Station Heads of Agency," NASA, Press Release, 26 January 2005. Online: http://spaceref.com/news/viewpr.html?pid=15997.

112 Colin Clark, "Congress Clears NASA to Purchase Russian Spacecraft," *Space News*, 9 November 2005.

113 Peter de Selding, "Europe's Two Competing Galileo Consortia Now Expected to Merge," *Space News,* 7 March 2005; "Transport: Joint Eurely/Inavsat Bid Wins Galileo Contract," Europe Information Service, 29 June 2005; "An 8th Partner for Galileo?" *Intelligence Online*, 28 October 2005.

114 Yu Zheng, "Chinese Company Joins Galileo Project," Xinhua, 11 March 2005.

115 "Morocco signs Galileo partnership agreement with EU," Al-Bawaba, Comtex News Network, 9 November 2005; "Israel joins Galileo: The Israel Entity MATIMOP, on the way to becoming a Member of the Galileo Joint Undertaking," Galileo Joint Undertaking, Press Release, 18 May 2005; "EU, Ukraine Initial Galileo Agreement," United Press International, 16 June 2005; Martial Tardy, "India Joins Galileo; Parliament Considers Funds," *Aviation Daily*, 9 September 2005, p. 7; Mark Milner, "Satellites: Saudi Arabia expected to navigate with Galileo," *Guardian* (London), 29 September 2005, p. 21.

116 "Morocco joins EU's Galileo satellite program," Associated Press, 8 November 2005.

117 Esha Bhandari, "For Europe, A GPS of Its Own: Eager to have a satellite navigation system not under the US military's control, a public-private consortium is betting $4 billion on Galileo," *Business Week Online*, 29 December 2005.

118 "France-UK base for Galileo office," *International Herald Tribune*, 5 December 2005.

119 "EU launches Galileo satellite," Associated Press, 28 December 2005.

120 "Disputes Block Funding for Europe's Satellite Navigation System," *BBC Monitoring International Reports*, 17 October 2005.

121 "Russia to Expand Use of Glonass Satellite Navigation System," *BBC Monitoring International Reports*, 14 June 2005.

122 "Russia, China space rockets equipped with GLONASS," ITAR-TASS, 3 November 2005; "Russia, India to cooperate in satellite navigation," RIA Novosti, 16 November 2005. Online: http://en.rian.ru/russia/20051116/42110098.html.

123 "India set to help renew Glonass," *Flight International*, 12 July 2005.

124 Adrian Schofield, "Blakey Pledges US Support for India's GAGAN Program," *Aviation Daily*, 26 October 2005, p. 2.

125 M. Somasekhar, "Indigenous satellite navigation system on the anvil," *The Hindu*, 11 May 2005.

126 "144th Report on Demands for Grants (2005-2006) of the Department of Space (Demand No. 89)," Department-Related Parliamentary Standing Committee on Science and Technology, Environment and Forests, Parliament of India, April 2005. Online: http://rajyasabha.nic.in/book2/reports/science/144threport.htm.

127 Chu Haibin et al., "Constellation Optimum Design of Satellite Positioning System Based on MEO and GEO Satellites," *Chinese Space Science and Technology* 25, No. 2, April 2005.

128 Wang Wei et al., "Study on Pseudolite Augmented "Bei Dou" Double Star Positioning System and Algorithm," *Chinese Space Science and Technology* 25, No. 3, June 2005.

129 Rich Tuttle, "Lockheed Martin delivers first modernized GPS IIR satellite," *Aerospace Daily & Defense Report*, February 2005, p. 5.

130 Evan Sweetman, "Successful launch of Navstar Block IIR GPS satellites," *Jane's Defense Weekly*, 3 October 2005.

131 "USAF readies modernized GPS satellite for launch," Wireless Satellite & Broadcasting Newsletter, 10 March 2005.

132 Frank Morring, Jr. and Michael A. Taverna, "Aftermath Mapping; Commercial satellite imagery guides tsunami relief, reconstruction work," *Aviation Week & Space Technology*, 10 January 2005, p. 25; "Global Space Cooperation For Disaster Relief," European Space Agency, 11 January 2005.

133 "Tsunami-Warning-System," Canadian Press, 14 March 2005.

134 "Earth observation: Global cooperation becomes a reality," Third Earth Observation Summit, Press Release, 16 February 2005. Online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/05/185&format=HTML&aged=0&language=EN.

135 "Basic Information," Global Earth Observation System of Systems, US Environmental Protection Agency, 22 April 2005. Online: http://www.epa.gov/geoss/basic.html.

136 Fiona Harvey, "Satellite to monitor Africa's climate," *Financial Times*, 17 February 2005, p. 9.

137 "Satellites support Kyoto Protocol through forest mapping service," Securing Our Environment: Observing the Earth, European Space Agency, 15 December 2005. Online: http://www.esa.int/esaEO/SEMV5V638FE_environment_0.html; "About GSE Forest Monitoring," GSE Forest Monitoring, GMES Service Element, January 2006. Online: http://www.gmes-forest.info/pages/about.htm.

138 David Lague, "Guiding China's Missiles: EU satellite project could improve accuracy," *International Herald Tribune*, 19 April 2005, p. 1.

139 Jonathan McDowell, Satellite Database.

Chapter Four Endnotes

1 "Facts & Figures: The European Space Industry in 2002," Eurospace, 2004, p. 7. Online: http://www.eurospace.org/.

2 "The Economic Impact of Commercial Space Transportation on the US Economy: 2002 Results and Outlook for 2010," US Federal Aviation Administration, March 2004, p. 3. Online: http://ast.faa.gov/files/pdf/2004Economic_Impact.pdf.

3 Communications Satellite Corporation, or COMSAT, is a private communications satellite company organized and started by the US Congress. See "Comsat International History," Comsat International. Online: http://www.comsatinternational.com/about/history.html; "Satellite Task Force Report, Factsheet," President's National Security Telecommunications Advisory Committee (NSTAC), March 2004. p. 6.

4 John Higginbotham, "Private Possibilities in Space," in Edward L. Hudgins, ed., *Space: The Free Market Frontier* (New York: Cato Institute, 2002), p. 146.

5 "2004 Satellite Industry Statistics," Futron Corporation, June 2005, p. 5. Online: http://futron.com/pdf/SIA_2004_Indicators.pdf.

6 "2004 Satellite Industry Statistics."

7 "Satellite Task Force Report, Factsheet," p. 6.

8 "2004 Satellite Industry Statistics."

9 "2004 Satellite Industry Statistics."

10 "Futron Launch Report," Futron Corporation, January 2006. Effective 1 January 2006, commercial launches are defined by Futron as including launches where at least one payload procured launch services commercially. This definition differs from the standard used by the Federal Aviation Administration's Office of Commercial Space Transportation; "Commercial Space Transportation: 2005 Year in Review," Federal Aviation Administration, January 2006. Online: http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf.

11 Tamar H. Mehuron, "2004 Space Almanac," *Air Force Magazine*, August 2003. Online: http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf; "Futron Launch Report," Futron Corporation, January 2006. Russia accounted for 47 percent of the 2005 worldwide commercial market share for commercial orbital launches. However, two of the total of eight commercial launches failed.

12 "Commercial Space Transportation: 2005 Year in Review," p. 7.

13 US Senate, Senate Subcommittee on Science, Technology and Space, Testimony of Jerry Rising, Lockheed Martin Corporation, 23 September 1998. Online: http://www.senate.gov/~commerce/hearings/0923ris.pdf.

14 "Space Transportation Costs: Trends in Price per pound to Orbit 1990-2000," Futron Corporation, 6 September 2002, pp. 4-5. Online: http://www.futron.com/pdf/FutronLaunchCostWP.pdf.

15 "China eyes commercial space flights in 20 years," Agence-France Presse, 3 November 2004.

16 All data derived from "Commercial Space Transportation Year in Review," Federal Aviation Administration, 1997 through 2005. http://ast.faa.gov/rep_study/yir.htm.

17 Frank Sietzen, Jr., "The H-II Failure: Japan's Commercial Launch Industry Take a Hit," Space.com, 18 November 1999. Online: http://www.space.com/missionlaunches/launches/hs_japan_991118.html.

18 US Senate, "Space Launch Cost Reduction Act of 1998, Introduced in Senate," 22 May 1998; Marcia Smith, "Space Launch Vehicles: Government Activities, Commercial Competition, and Satellite Exports," Issue brief for the US Congress, 3 February 2003, p. 16. Online: http://fpc.state.gov/documents/organization/17353.pdf.

19 History," Sea Launch. Online: http://www.sea-launch.com/history.htm.

20 "Sea Launch Facilities," Sea Launch. Online: http://www.sea-launch.com/slfacilities.htm.

21 A number of commercial space companies such as Orbital Sciences Corporation, Airlaunch LLC, Transformational Space Corporation, and Northrop Grumman are working on air-launch technologies, which may have implications for the commercial launch industry. "Pegasus," Orbital Sciences Corporation. Online: http://www.orbital.com/PrinterFriendly.php?NavMenuID=291; "t/Space Demonstrates New Air-Launch Technology," Press Release, Transformational Space Corporation, 14 June 2005. Online: http://www.spaceref.com/news/viewpr.html?pid=17117; Jeremy Singer, "DoD Small-Rocket Contract Produces Fierce Competition," *C4ISR Journal*, 2 June 2005. Online: http://www.c4isrjournal.com/story.php?F=890851; Leonard David, "Hybrid Air-Rocket Concept Touted for Rapid Launch," *Space News*, 4 April 2006; Haninah Levine, "The future is coming – will we notice the difference?" Center for Defense Information, 26 September 2005. Online: http://www.cdi.org/program/document.cfm?documentid=3152&programID=68&from_page=../friendlyversion/printversion.cfm.

22 "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000," Futron Corporation, 6 September 2002, p. 3. Online: http://www.futron.com/pdf/FutronLaunchCostWP.pdf.

23 Prices quoted per pound and converted to per kilogram. "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000," p. 4.

24 "2005 Commercial Space Transportation Forecasts," Federal Aviation Administration and the Commercial Space Transportation Advisory Committee (COMSTAC), May 2005. p.8, 34.

25 "SpaceShipOne Makes History: First Private Manned Mission to Space," Scaled Composites, Press Release, 21 June 2004. Online: http://www.scaled.com/projects/tierone/062104-2.htm.

26 US Congress, "Commercial Space Launch Amendments Act of 2004," H.R. 3752, 108th Congress, 8 March 2004; Erica Werner, "Congress Passes Bill Allowing Space Tours," Associated Press, 9 December 2004; "No waiting on commercial space launch bill," *Space News*, 25 October 2004.

27 "Survey of satellite industry professionals," Futron Corporation, June 2004, p. 4. Online: www.futron.com/pdf/2004%20ISCe%20Survey%20results.pdf.

28 D. Dowd Muska, "Houston, We Have no Purpose," Nevada Journal (November 1998). Online: http://nj.npri.org/nj98/11/cover_story.htm.

29 Mark Wade, "USAF to subsidize EELVs," Encyclopedia Astronautica. Online: http://www.astronautix.com/lvs/atlasv.htm.

30 Jeff Foust, "A year-end reality check," *Space Review*, 29 December 2003. Online: http://www.thespacereview.com/article/78/1.

31 "Space: a new European frontier for an expanding Union: An action plan for implementing the European Space policy," European Union White Paper, 11 November 2003.

32 Rockets: Angara Family," Russian Space Web. Online: http://www.russianspaceweb.com/angara.html; "On Measures to Fulfill the Russian Federal Space Program and International Space Agreements, Decree No. 42, Selected Examples of National Laws Governing Space Activities: Russian Federation," Government of the Russian Federation, 12 April 1996. Online: http://www.oosa.unvienna.org/SpaceLaw/national/russian_federation/decree_422_1996E.html.

33 "Cash-strapped Russia says ISS may have to be mothballed," Center for Defense Information Russia Weekly, No. 224, 27 September 2002. Online: http://www.cdi.org/russia/224-7.cfm.

34 "Satellite Insurance Rates On the Rise: Market Correction or Overreaction?" Futron Corporation, 10 July 2002. Online: http://www.futron.com/pdf/Futron-SatInsurance.pdf.

35 Michael A. Taverna, "Worsening Insurance Crunch Worries Space Industry," *Aviation Week & Space Technology*, 20 May 2002, p. 47.

36 Taverna, p. 47; "Commercial Space Transportation Quarterly Launch Report, 4th Quarter," US Federal Aviation Administration, 2002, p. 10. Online: http://ast.faa.gov/files/pdf/FourthQuarterFinal.pdf.

37 US Congress, "A Bill to Facilitate Commercial Access to Space, and for Other Purposes," Public Law No: 100-657, H.R. 04399, 14 November 1988.

38 US Congress, "Commercial Space Act of 2003," H.R. 3245, 108th Congress, 2 October 2003.

39 "US Space Transportation Policy Review," Satellite Industry Association, 11 October 2002. Online: http://www.sia.org/agenda/launch/Space%20Transportation%20Review.pdf.

40 Missile Technology Control Regime. Online: http://www.mtcr.info/english/.

41 "China's Export Controls," Nuclear Threat Initiative. Online: http://www.nti.org/db/china/excon.htm.

42 Steven Pifer, "The U.S. and Russia: Space Cooperation and Export Controls," Testimony before the House Science Committee, Subcommittee on Space and Aeronautics, 11 June 2003. Online: http://www.state.gov/p/eur/rls/rm/2003/21487.htm.

43 "Council Regulation (EC) No 2432/2001 of 20 November 2001 amending and updating Regulation (EC) No 1334/2000 setting up a Community regime for the control of exports of dual-use items and technology," *Official Journal of the European Communities*, 20 December 2001; "Definitions for Terms in Groups 1 and 2," Department of Foreign Affairs and International Trade Canada, Online: http://www.dfait-maeci.gc.ca/trade/eicb/military/gr1-2-en.asp?#spac; "Regulations of the People's Republic of China on Export Control of Missiles and Missile-related Items and Technologies," Center for Nonproliferation Studies, August 2002. Online: http://cns.miis.edu/research/china/chiexp/misreg.htm; Seema Galut and Anupam Srivastava, "Nonproliferation Export Controls in India," Center for International Trade and Security, June 2005. Online: www.uga.edu/cits/documents/pdf/EXEC%20SUMMARY%2020050616.pdf.

44 "Background: Satellite Export Controls," Satellite Industry Association. Online: http://www.sia.org/agenda/trade/History%20of%20Export%20Controls.pdf.

45 "Satellite Task Force Report, Factsheet," p. 5.

46 "Effects of Export Controls on the U.S. Satellite Industry: Anecdotal Evidence," Satellite Industry Association, p. 2. Online: http://www.sia.org/agenda/trade/Effects%20of%20Export%20Control.pdf.

47 V.S. Arunachalam, "Desire and Denial: The Nullification of Cryogenic Rocket Motor Technologies to India," The Eisenhower Institute, Future of Space Program. Online: http://www.eisenhowerinstitute.org/programs/globalpartnerships/fos/newfrontier/arunarticle.htm; "India's Cryogenic Engine Comes of Age," Good News India, 12 March 2003. Online: http://www.goodnewsindia.com/Pages/content/newsclip/story/69_0_2_0_C/.

48 "U.S. Commercial Remote Sensing Space Policy," The White House, Fact Sheet, 13 May 2003. Online: http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html; "Business Report," *Space News*, 27 May 2003.

49 Peter B. de Selding, "France Reviews Spot Imagery Policy," *Space News*, 19 October 2001.

50 K.S. Jayaraman, "Russia Wants Access to Indian Satellite Imagery Market," *Space News*, 27 January 2003.

51 John C. Baker, Ray A. Williamson, and Kevin M. O'Connell, *Commercial Observation Satellites – At the Leading Edge of Global Transparency*, (Santa Monica: RAND Corporation, 2001), p. 431. Online: http://www.rand.org/pubs/monograph_reports/MR1229/; "Proceedings of the Standing Senate Committee on Foreign Affairs, Issue 21 – Evidence – November 22 meeting," 22 November 2005. Online: http://www.parl.gc.ca/38/1/parlbus/commbus/senate/Com-e/fore-e/21eva-e.htm?Language. Bill C-25 fulfills Canada's international and bilateral obligations to regulate the remote sensing space activities of its nationals as required pursuant to the 1967 Outer Space Treaty and the 2000 Canada-US Intergovernmental Agreement concerning the operation of commercial remote sensing satellite systems.

52 Jason Bates, "The Brave New World of Commercial Imagery," *Space News*, 21 January 2003. Governments refer to "shutter-control" as "buy-outs" of sensitive imagery to prevent dissemination.

53 Philip McAlister, "Follow the Money: Satellite Opportunities with the US Government," Futron Corporation, 17 November 2003. Online: http://www.futron.com/pdf/sat%20oppor%20with%20us%20govt.pdf.

54 McAlister.

55 Patrick Chisholm, "Buying Time: Disconnects in Satcom Procurement," Military Information Technology, 29 November 2003. Online: http://www.military-information-technology.com/article.cfm?DocID=285.

56 US General Accounting Office, *Satellite Communications – Strategic Approach Needed for DOD's Procurement of Commercial Satellite Bandwidth*, GAO-04-206, December 2003; David Helfgott, "Satellite Communications Poised for Rebound," SIGNAL (April 2004). Online: http://www.afcea.org/signal/articles/anmviewer.asp?a=90&print=yes.

57 "Satellite Task Force Report, Factsheet," p. 10.

58 "U.S. Commercial Remote Sensing Space Policy," The White House, Fact Sheet, 13 May 2003. Online: http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html.

59 "Futron Launch Report," Futron Corporation, January 2006.

60 Peter B. de Selding, "Satellite Manufacturers End Year With Low Commercial Sales," *Space News*, 18 January 2006; "Manufacturers of Satellites Launched in 2005 by Orbit and Commercial Status," *Futron Satellite Manufacturing Report*, January 2006.

61 Scott Sacknoff, "Investing in the Defense, Homeland Security, and Space Market: SPADE Defense Index," presentation at the California Space Authority Conference on Space Transformation, 1 December 2005, p. 3.

62 Rachel Villain, "Key Trends for the Satellite Industry," Euroconsult, 26 April 2005. Online: http://www.euroconsult-ec.com/news.php?ref=16.

63 "Space and Satellite Market Surpasses $103 Billion, to Reach $158 Billion by 2010," International Space Business Council, Press Release, 9 August 2005.

64 Scott Sacknoff, "Investing in the Defense, Homeland Security, and Space Market: SPADE Defense Index," presentation at the California Space Authority Conference on Space Transformation, 1 December 2005, pp. 2-3.

65 "OECD Broadband Statistics," Organization for Economic Cooperation and Development, June 2005. Online: http://www.oecd.org/documentprint/0,2744,en_2649_35526608_1_1_1_1,00.html.

66 "Satellite Broadband Services Generating Solid Revenues and Creating New Markets," Northern Sky Research, 17 November 2005. Online: http://www.northernskyresearch.com/aboutus/press/pr11_17_05.html. Northern Sky Research has recently released "Global Assessment of Satellite Demand," 2nd Edition.

67 "Satellite Broadband Services Generating Solid Revenues and Creating New Markets."

68 Villain.

69 "The declining US role in the commercial launch industry," Futron Corporation, June 2005, p. 7. Online:
http://www.futron.com/pdf/US%20Commercial%20Launch%20Industry%20White%20Paper.pdf.

70 Phil McAlister, "Future Trends and the Replacement Market: What's Around the Bend?" International Satellite and Communications Exchange Conference, Futron Corporation. Online: http://www.isce.com/media_newsletters.shtml#2.

71 McAlister, "Future Trends and the Replacement Market: What's Around the Bend?"

72 Sacknoff, p. 18.

73 "U.S. Satellite Industry Dominates Despite Overcapacity," SPX, 23 August 2005. Online: http://www.spacedaily.com/news/industry-05zk.html.

74 "U.S. Satellite Industry Dominates Despite Overcapacity."

75 "UPDATE: XM Tops 6.5 Million Subscribers," Dow Jones, 3 April 2006.

76 Darrell Dunn, "Satellite Radio Subscriptions, Financial Losses on the Rise," *Information Week*, 7 January 2005. Online: http://informationweek.com/story/showArticle.jhtml?articleID=57300715.

77 "Sirius Satellite Radio SIRI," Reuters Online:
http://quicktake.morningstar.com/Stock/Diagnostics.asp?Country=USA&Symbol=SIRI&stocktab=interpret.

78 Robert Jaques, "Global satellite market consolidating fast," vnunet.com, 5 September 2005. Online: http://www.vnunet.com/2141832.

79 Jo Twist, "Clawing back demand for satellites," BBC News, 26 December 2004. Online: http://news.bbc.co.uk/go/pr/fr/-/2/hi/science/nature/3721312.stm.

80 "Facts and Figures," Satellite Broadcasting and Communications Association. Online: http://www.sbca.com/index.asp.

81 "Hannover Fairs, USA Announces ISCe 2005 Survey of Government Leaders and Commercial Satellite Executives Evaluates Future Industry Trends," ISCe, Press Release, 2 June 2005. The satellite industry survey was conducted at the International Satellite Communications conference and expo – ISCe 2005 – by Futron Corporation.

82 McAlister, "Future Trends and the Replacement Market: What's Around the Bend?"

83 "Satellite Manufacturing Report," Futron Corporation, December 2005. Online: http://www.futron.com/spaceandtelecom/src/sm.htm.

84 Villain.

85 Richard Wolf, "President's Message: Intelsat-PanAmSat: will it make for a better mousetrap?" *The Orbiter* (November/December 2005).

86 New technologies have reduced transponder needs by as much as 30 percent, thereby decreasing demand for satellite production.

87 "U.S. Satellite Industry Dominates Despite Overcapacity," SPX, 23 August 2005. Online: http://www.spacedaily.com/news/industry-05zk.html.

88 "Satellite Consolidation: The Next Shoe Drops," Futron Corporation, December 2005. Online: http://www.futron.com/pdf/SatelliteConsolidationPart2.pdf.

89 Howard Greenfield, "Satellite and IT: At the Digital Crossroads," *Satmagazine*, January 2006. Online: www.satmagazine.com.

90 Greenfield.

91 "Satellite Operator Consolidation…Who's Left?" Northern Sky Research, 11 January 2006. Online: http://www.northernskyresearch.com/reports/GASD2/ISB.html.

92 "Satellite Operator Consolidation…Who's Left?".

93 "What's up with satellite consolidation?" Futron Corporation, September 2005. Online: http://www.futron.com/spaceandtelecom/src/whitepapers.htm.

94 "Satellite Operator Consolidation…Who's Left?"

95 "Launch Reports 2005," Futron Corporation, January 2005-January 2006. Online: http://www.futron.com/spaceandtelecom/src/foflist.htm.

96 "Commercial Space Transportation: 2005 Year in Review," Federal Aviation Administration, January 2006. p. 3. Online: http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf; "The declining US role in the commercial launch industry," Futron Corporation, June 2005, p. 4. Online:
http://www.futron.com/pdf/US%20Commercial%20Launch%20Industry%20White%20Paper.pdf.

97 "Commercial Launch Services Want Incentives But Not Regulatory Burdens," *Satellite Week*, 25 April 2005.

98 "Commercial Launch Services Want Incentives But Not Regulatory Burdens."

99 Brian Berger, "SpaceX Fighting for USAF Launches," *Space News*, 31 October 2005.

100 "The declining US role in the commercial launch industry," Futron Corporation, June 2005, p. 8. Online:
http://www.futron.com/pdf/US%20Commercial%20Launch%20Industry%20White%20Paper.pdf.

101 "The declining US role in the commercial launch industry," p. 4.

102 "The declining US role in the commercial launch industry," pp. 3, 8.

103 "The declining US role in the commercial launch industry," p. 3.

104 "Boeing launch strike continues," spacetoday.net, 11 January 2006. Online: http://www.spacetoday.net. Eric Fleischauer, "Boeing strike talks fall flat," *The Decatur Daily News*, 11 January 2006.

105 "The declining US role in the commercial launch industry," p. 4.

106 "Boeing Delta II delivers first modern GPS satellite to orbit," Boeing Corporation, Press Release, 25 September 2005.

107 "Boeing awarded National Geospatial-Intelligence Agency Security Data Contracts," Boeing Corporation, Press Release, 1 November 2005. Online: http://www.boeing.com/news/releases/2005/qr4/nr_051101m.html.

108 Keith Cowing, "Falcon 1 Launch Scrubbed," Commercial Space Watch, 19 December 2005. Online: http://www.comspacewatch.com/news/viewnews.html?id=1083.

109 Brian Berger, "SpaceX Fighting for USAF Launches," *Space News*, 31 October 2005.

110 "Futron Launch Report" (2006)

111 "Commercial Space Transportation: 2005 Year in Review," Federal Aviation Administration, January 2006. pp.11, 17. Online: http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf. The 13 October 2005 launch of the Galaxy 15 commercial communications satellite was part of a dual-launch by the Ariane 5 vehicle, which also included the launch of the French military satellite Syracuse 3A.

112 "Launch Update," Analytical Graphics (AGI). Online: http://www.agi.com/resources.

113 "Arianespace Launch Review 2004-2005," Arianespace, Press Release.

114 "Europe's super-rocket rides high," *BBC News*, 12 February 2005. Online: http://newsvote.bbc.co.uk/mpapps/pagetools/print/news.bbc.co.uk/1/hi/sci/tech/4256907.stm.

115 "Record satellite lift for Ariane," *BBC News*, 4 August 2005. Online: http://news.bbc.co.uk/2/hi/science/nature/4142088.stm.

116 "Launch Reports 2005"

117 "Sea Launch wins Multiple Launch Award with PanAmSat: Agreement includes first Land Launch," Boeing Corporation, Press Release, 28 July 2005. Online: http://www.boeing.com/news/releases/2005/q3/nr_050728s.html.

118 "Sea Launch wins Multiple Launch Award with PanAmSat"

119 "Land Launch Receives First Order with PanAmSat," Boeing Corporation, Press Release, 28 July 2005. Online: http://www.boeing.com/news/releases/2005/q3/nr_050728t.html.

120 "Land Launch Receives First Order with PanAmSat."

121 "Launch Reports 2005"

122 "The declining US role in the commercial launch industry," p. 8..

123 "The declining US role in the commercial launch industry," p. 8.

124 Since 2002, Alcatel Alenia Space has made it company policy to offer satellites that do not contain components subject to US International Traffic in Arms Regulations. "Alcatel Alenia Space wins new communication and broadcast satellite contract Chinasat 6B from ChinaSatcom, bolstering cooperation with China," Press release, Alcatel Alenia, 5 December 2005. Online: http://www.home.alcatel.com/vpr/vpr.nsf/DateKey/05122005uk.

125 "Alcatel Alenia Space wins new communication and broadcast satellite contract Chinasat 6B from ChinaSatcom, bolstering cooperation with China."

126 "The declining US role in the commercial launch industry," p. 8.

127 "Governor Bush and Space Adventures Announce the Opening of a Suborbital Vehicle and Spaceport Development Office," PR Newswire US, 18 July 2005; Bjorn Carey, "Space Adventures Announces Next Private Space Explorer," *Space News*, 3 November 2005.

128 Tariq Malik, "Jet Lag Aside, US Space Tourist Greg Olsen Feels Fine," *Space News*, 6 October 2005.

129 "Space Adventures Offers Private Voyage to the Moon," PR Newswire US, 10 August 2005.

130 "Russian rocket maker offer $100-million moon rides," Associated Press, 28 July 2005. Online: http://www.theglobeandmail.com/servlet/story/RTGAM.20050728.wmoon0728.

131 "Suborbital Reusable Launch Vehicles and Emerging Markets," Office of Commercial Space Transportation, Federal Aviation Administration, February 2005, p. 7. Online: http://ast.faa.gov/rep_study/sp_reports.htm.

132 "Richard Branson's and Burt Rutan's firms will start a company to design suborbital craft," *Los Angeles Times*, 29 July 2005.

133 "Richard Branson's and Burt Rutan's firms will start a company to design suborbital craft."

134 "Virgin Galactic and New Mexico Announce Spaceport Agreement," Virgin Galactic, Press Release. Online: http://www.virgingalactic.com/en/news.asp.

135 "Suborbital Reusable Launch Vehicles…," p. 32.

136 Leonard David, "New Mexico Spaceport: Getting Down to Business," *Space News*, 2 January 2006.

137 "SpaceDev Announces SpaceDev Dream Chaser Space Transport System," Space Daily, 17 November 2005.

138 "SpaceDev Announces SpaceDev Dream Chaser Space Transport System."

139 "Suborbital Reusable Launch Vehicles…," p. 23.

140 "Xerus," XCOR Aerospace. Online: http://www.xcor.com/suborbital.html.

141 S. Suzette Beard and Janice Starzyk, "Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel," Futron Corporation, October 2002, p. 56. Online: http://www.spaceportassociates.com/tourism.pdf.

142 Janice Starzyk, e-mail correspondence with author, 28 December 2005; Beard and Starzyk, p. 56.

143 Jurgen Cloppenburg, "Legal Aspects of Space Tourism," in *Space Law: Current Problems and Perspectives for Future Regulation*, ed. Marietta Benko and Kai-Uwe Schrogl (Utrecht: Eleven International Publishing, 2005), p. 204.

144 Darlene Superville, "Government Issues Proposed Space Tourism Rules," Associated Press, 30 December 2005.

145 Cloppenburg, p. 204.

146 Leonard David, "Rutan blasts FAA's suborbital safety regulations," *Space News*, 25 April 2005.

147 Michael A. Taverna, "Off the Shelf: France, U.S. turn to commercial satcom providers, reinforcing global trend," *Aviation Week & Space Technology*, 13 June 2005, p. 192.

148 Michael Beavin, Director Government Relations, Satellite Industry Association, e-mail correspondence, 15 May 2006. Mr. Beavin noted that while the US DOD accounted for approximately $300-million of the $600-million generated by US government contracts in the satellite services sector, the remainder is probably attributable to intelligence uses which are not "trackable."

149 Paul Dykewicz, "Commercial operators expand military offerings," *Space News*, 13 June 2005.

150 Dykewicz.

151 Virgil Labrador, "Continued Demand for Satellite Services by the Military and Government Sectors," Satmagazine, December 2004. Online: http://www.satmagazine.com/dec2004/dec2004.pdf.

152 "Hannover Fairs, USA Announces ISCe 2005 Survey of Government Leaders and Commercial Satellite Executives Evaluates Future Industry Trends," ISCe, Press Release, 2 June 2005. Online: http://www.isce.com/media_newsletters.shtml#2.

153 "Hannover Fairs, USA Announces ISCe 2005 Survey of Government Leaders and Commercial Satellite Executives Evaluates Future Industry Trends."

154 Labrador.

155 Beavin.

156 "Space and Satellite Market Surpasses $103 Billion, to Reach $158 Billion by 2010," International Space Business Council, Press Release, 9 August 2005.

157 Dave Weldon, "Export control policy hampering US competitiveness," *Space News*, 27 June 2005.

158 "Alcatel Alenia Space wins new communication and broadcast satellite contract Chinasat 6B from ChinaSatcom, bolstering cooperation with China," Press release, Alcatel Alenia, 5 December 2005. Online: http://www.home.alcatel.com/vpr/vpr.nsf/DateKey/05122005uk; de Selding "Satellite Manufacturers End Year with Low Commercial Sales."

159 Donna Borak, "Analysis: Why US Telecom Has Fallen Behind," United Press International, 18 August 2005.

160 "Commercial Launch Services Want Incentives But Not Regulatory Burdens," *Satellite Week*, 25 April 2005.

161 "US Satellite Industry Dominates Despite Overcapacity," SPX, 23 August 2005. Online: http://www.spacedaily.com/news/industry-05zk.html.

162 David J. Whalen, "Satellite 101/Industry Overview: Technology and Basics," paper presented at the DOD/Civil SATCOM Users Workshop, Satellite Industry Association, Arlington, VA, 15-18 November 2005. Online: http://www.sia.org/Civil-Presentations/Dave%20Whalen%20-%20Satellite%20101.pdf.

163 Peter B. de Selding, "Intelsat Cutting more Expenses, Including Insurance," *Space News*, 7 March 2005.

164 de Selding, "Intelsat Cutting more Expenses, Including Insurance."

165 Peter B. de Selding, "Paradigm Forgoes Insurance, Buys Another Satellite Instead," *Space News*, 20 December 2005.

166 "Paradigm signs 2 year extension to Skynet 5 contract," Paradigm Secure Communications Ltd., Press Release, 20 December 2005. Online: http://www.paradigmsecure.com/?OBH=30&ID=63.

167 Richard DalBello, Vice President, Government Relations, Intelsat General Corporation., Space Security Working Group, Institute of Air and Space Law, McGill University, Montreal, Canada, 2-3 May 2006.

168 Peter B. de Selding, "Some space insurance premiums are dropping," *Space News*, 5 September 2005.

169 de Selding, "Some space insurance premiums are dropping."

170 Peter B. de Selding, "Liability at Guiana to be shared," *Space News*, 16 December 2005.

171 Jonathan McDowell, Satellite Database.

Chapter Five Endnotes

1 Such statistics should acknowledge that purchasing power will vary among states and affect how much can be purchased within a specific budget. "Government Space Budgets to Continue Growth," Spacedaily.com, 11 December 2003. Online: http://www.spacedaily.com/news/satellite-biz-03zzzl.html.

2 Ted Molczan and John Pike, "Tables of operational military satellites," Globalsecurity.org, 31 December 2004. Online: http://www.globalsecurity.org/space/library/report/2005/satellitetables2004.htm.

3 Molczan and Pike.

4 Tamar A. Mehuron, "2004 Space Almanac," *Air Force Magazine*, August 2004, p. 43. Online: http://www.afa.org/magazine/Aug2004/0804space_alm.pdf.

5 Mehuron, p. 44.

6 Glen Elfers and Stephen B. Miller, "Future U.S. Military Satellite Communications Systems," *Crosslink*, Winter 2002.

7 Mehuron, pp. 43-46.

8 Fernand Verger, Isabelle Sourbes-Verger, and Raymond Ghirardi, *The Cambridge Encyclopedia of Space* (Cambridge: Cambridge University Press, 2003), pp. 70-72; Gunter Dirk Krebs, "Chronology," Gunter's Space Page. Online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/home.htm; "Worldwide Space Launches 2004," NASA. Online: http://www.hq.nasa.gov/osf/2004/launch04.html.

9 Verger, et al., p. 344.

10 Mehuron, p. 44.

11 Verger, et al., p. 336.

12 Verger, et al., p. 337.

13 Verger, et al., pp. 337, 339.

14 Verger, et al., p. 338.

15 Molczan and Pike.

16 Mehuron, p. 44.

17 Mehuron, p. 44.

18 Arthur K. Cebrowski, Director of Force Transformation, Office of the Secretary of Defense Statement before the Subcommittee on Strategic Forces, Armed Services Committee, United States Senate, 25 March 2004, p. 3. Online: http://www.oft.osd.mil/initiatives/ors/Cebrowski%20Testimony.doc.

19 James Canan, "Renaissance for military space," *Aerospace America*, June 2003. Online: http://www.aiaa.org/aerospace/Article.cfm?issuetocid=364&ArchiveIssueID=39.

20 Robert K. Ackerman, "Small Satellite Offers Glimpse of the Future," *Signal Magazine*, January 2004; Gunter Dirk Krebs, "TacSat 1" Gunter's Space Page, 1 January 2005. Online: http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sdat/tacsat-1.htm.

21 M. Hurley, "Tactical Microsatellite Experiment (TacSat 1)," Navy Research Laboratory Review, 2004. Online: http://www.nrl.navy.mil/content.php?P=04REVIEW207.

22 Mehuron, pp. 40, 43-45; Verger, et al., p. 337; Molczan and Pike.

23 Evolved Expendable Launch Vehicle," US Air Force, Fact Sheet, April 2003. Online: http://www.af.mil/factsheets/factsheet.asp?fsID=169; Anthony Young, "Heavy Lifting for the New Millennium," *The Space Review,* 26 April 2004.

24 Young; Tariq Malik, "Delta 4 Heavy rocket lifts off for first time," MSNBC, 21 December 2004. Online: http://www.msnbc.msn.com/id/6743383/.

25 "Evolved Expendable Launch Vehicle," January 2005.

26 "Report of the Commission to Assess United States National Security Space Management and Organization," 11 January 2001, pp. 8-9. Online: http://www.defenselink.mil/pubs/space20010111.html. While established by the US Government, the Commission does not formally set new US policy in this area. See also "Rumsfeld Asks if Pentagon is Over-Reliant on Space Systems," *Space News*, 13 May 2002, p. 4.

27 "Weapons in Space and Global Security," Report of the NATO Parliamentary Assembly Sub-Committee on the Proliferation of Military Technology, 156 STCMT 03 E, 2003, p. 5.

28 Pavel Podvig, "Russia and Military Uses of Space," Working paper, The American Academy of Arts and Sciences Project, "Reconsidering the Rules of Space," June 2004. Online: http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml.

29 Podvig.

30 Podvig.

31 Podvig; see also Verger, et al., p. 349.

32 Pavel Podvig, "History and the current status of the Russian early warning system," *Science and Global Security* 10 (2002), pp. 21-60.

33 Podvig, "History and the current status of the Russian early warning system," pp. 21-60.

34 Podvig, "History and the current status of the Russian early warning system."

35 Verger, et al., pp. 70-72; Gunter Dirk Krebs, "Chronology," Gunter's Space Page. Online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/home.htm; "Worldwide Space Launches 2004," NASA. Online: http://www.hq.nasa.gov/osf/2004/launch04.html.

36 Verger, et al., p. 341.

37 Podvig, "Russia and Military Uses of Space."

38 Podvig, "Russia and Military Uses of Space."

39 Verger, et al., pp. 319-323.

40 Podvig, "Russia and Military Uses of Space,".

41 International Institute for Strategic Studies, *Military Balance 2003-2004* (Oxford: Oxford University Press, 2003), pp. 88-89.

42 Podvig, "Russia and Military Uses of Space"; Center for Defense Information, "Russian general comments on Russian Space Forces initiatives… stands firm on no nuclear weapons in space," CDI Space Security Update 14, 21 July 2004. Online: http://www.cdi.org/program/issue/document.cfm?DocumentID=2322&IssueID=140&StartRow=1&ListRows=10&appendURL=&Orderby=DateLastUpdated&ProgramID=68&issueID=140#3; "Russia does not plan launching nuclear weapons in space," ITAR-TASS, 14 July 2004.

43 "No more reductions of Russian satellite fleet planned," Interfax, 14 July 2004.

44 Verger, et al., pp. 70-72; Molczan and Pike.

45 Gunter Dirk Krebs, "Telecom 1A, 1B, 1C," Gunters Space Page, 24 February 2005. Online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/sat.htm.

46 Verger, et al., pp. 70-72.

47 Verger, et al., p. 72.

48 Verger, et al., p. 72; Gunter Dirk Krebs, "Spacecraft: Military," Gunter's Space Page. Online: http://www.skyrocket.de/space/space.html; "Modern military small satellites," Small Satellites Home Page, Surrey Satellite Company. Online: http://centaur.sstl.co.uk/SSHP/list/list_mil.html.

49 Bertrand de Montluc, e-mail correspondence with author, 17 May 2006.

50 "Pléiades: a multi-missions concept and a partnership program," CNES. Online: http://smsc.cnes.fr/PLEIADES/.

51 Peter B. de Selding, "German Military Prepares for 2005 SAR-Lupe Deployment," *Space News*, 7 July 2005; Gunter Dirk Krebs, "SAR-Lupe 1, 2, 3, 4, 5," Gunters Space Page, 10 February 2005. Online: http://space.skyrocket.de/doc_sdat/sar-lupe.htm.

52 "COSMO-Skymed," Alenia Spazio. Online: http://www.aleniaspazio.it/earth_observation_page.aspx?IdProg=23.

53 *Military Balance 2003-2004*, p. 230.

54 *Military Balance 2003-2004*, p. 257.

55 For a discussion see Online: http://www.fas.org/spp/guide/france/military/imint/.

56 *Military Balance 2003-2004*, p. 230.

57 David Long et al., "The Evolution and Shape of European Space Policy: Preliminary Report for DFAIT," Government of Canada, Department of Foreign Affairs and International Trade, International Security Research and Outreach Programme, 2004, p. 25.

58 Andrew B. Godefroy, "Europe in a Changing Global Context: Space Policy, Security, and Non-Weaponization," Government of Canada, Department of Foreign Affairs and International Trade, International Security Research and Outreach Programme, 2004, p. 14.

59 J.A.C. Lewis, "Interview: François Auque, Chief Executive Officer, EADS Space," *Jane's Defence Weekly*, 20 April 2005.

60 "China Military Space Projects," GlobalSecurity.org. Online: http://www.globalsecurity.org/space/world/china/military.htm.

61 Mark Stokes, "Appendix III: Space Support for Strategic Modernization," p. 173, and "Chapter 2: Foundations of Strategic Modernization," p. 6, both in *China's Strategic Modernization: Implications for the United States*, Strategic Studies Institute, September 1999.

62 "China and Imagery Intelligence," GlobalSecurity.org. Online: http://www.globalsecurity.org/space/world/china/imint.htm.

63 "Government and Non Government Space Programs: China," Jane's Space Directory, 14 October 2004.

64 Military Balance 2003-2004, pp. 230, 304.

65 "Weapons in Space and Global Security," Report of the NATO Parliamentary Assembly Sub-Committee on the Proliferation of Military Technology, 156 STCMT 03 E, 2003, p. 6.

66 John Pike, "The Military Uses of Outer Space," SIPRI Yearbook 2002 (Oxford: Oxford University Press: 2002), p. 24; "China: Military Programs," Center for Nonproliferation Studies. Online: http://cns.miis.edu/research/space/china/mil.htm.

67 Pike, p. 24.

68 Geoffrey Forden, "Strategic uses for China's Bei Dou satellite system," *Jane's Intelligence Review*, 16 September 2003; Geoffrey Forden, "The Military Capabilities and Implications of China's Indigenous Satellite-Based Navigation System," *Science and Global Security* 12 (2004), p. 232.

69 James Lewis, "China as a Military Space Competitor," Space Policy Institute, p. 12. Online: http://www.gwu.edu/~spi/spaceforum/China.pdf.

70 Wendy Elliman, "Israel in Space," Israel Ministry of Foreign Affairs, January 2003. Online: http://www.mfa.gov.il/mfa/mfaarchive/2000_2009/2003/1/focus%20on%20israel-%20israel%20in%20space.

71 "Israel Launch New Satellite," *Defense Update*, Updated 9 July 2002. Online: http://www.defense-update.com/news/ofeq5.htm; *Military Balance 2003-2004*, p. 230. The launch of Ofek-4 in 1999 failed. *Military Balance 2003-2004*, p. 281.

72 "Weapons in Space and Global Security, Draft Report," Report of the NATO Parliamentary Assembly Sub-Committee on the Proliferation of Military Technology 156 STCMT 03 E 2003, p. 6.

73 Arieh O'Sullivan, "Israeli Air Force changes its Name," *Jerusalem Post*, 29 January 2004.

74 *Military Balance 2003-2004*, p. 291.

75 *Military Balance 2003-2004*, p. 292.

76 Gunter Dirk Krebs, "IGS-Optical 1, 2," Gunter's Space Page, 4 January, 2005. Online: http://www.skyrocket.de/space/doc_sdat/igs-optical-1.htm; Gunter Dirk Krebs, "IGS-Radarl 1, 2," Gunter's Space Page, 4 January 2005. Online: http://www.skyrocket.de/space/doc_sdat/igs-radar-1.htm.

77 "Information Gathering Satellites: Imagery Intelligence," Globalsecurity.org. Online: http://www.globalsecurity.org/space/world/japan/imint.htm.

78 Paul Kallender-Umezu, "Japan plans to launch 3 satellites," *Defense News*, 13 September 2004, p. 23; "Japan Plans to Develop Advanced Spy Satellite," SPX, 27 September 2004. Online: http://www.spacedaily.com/news/spysat-04c.html.

79 "Information Gathering Satellites: Imagery Intelligence."

80 Pike, p. 641.

81 The order was placed in 1996. Military Balance 2003-2004, p. 306.

82 Kim Yong-ho, "Air Force Begins Establishment of the Space Command Center in Full-Scale," *Seoul Kukpang Journal*, 1 December 2003.

83 "Thailand signs deal with French company for spy satellite," Agence-France Presse, 19 July 2004.

84 Surrey Satellite Technology Ltd. Online: http://www.sstl.co.uk/index.php?loc=5.

85 "Australia and Satellite Communication Systems," Globalsecurity.Org, Online: http://www.globalsecurity.org/space/world/australia/comm.htm.

86 Stephen Butler, "DSTO plans unique test phase to model new era Defence C1 communications satellite," Australian Defence Science and Technology Organization, 23 June 2003. Online: http://www.dsto.defence.gov.au/news/3775/.

87 Gunter Dirk Krebs, "Optus C1 (Optus and Defence C1)," Gunter's Space Page, 21 September 2005. Online: http://space.skyrocket.de/doc_sdat/optus-c.htm.

88 Douglas Jehl, "Review Leads to Upheaval in Spy Satellite Programs," *New York Times*, 30 September 2005.

89 Jehl.

90 Walter Pincus, "Spy Satellites Under Scrutiny: Negroponte to Advise Congress on Funding New Systems," Washington Post, 15 August 2005.

91 Pincus; Jehl.

92 Michael Fabey, "USAF, Contractors Under Fire Over Space Programs," *Defense News*, 3 October 2005.

93 Rebecca Christie, "US Air Force: Satellite System May Face Delays," Dow Jones, 8 August 2005.

94 Christie.

95 Christie.

96 Fabey.

97 Fabey.

98 Program developments in 2005 saw two major contractor teams, competing for the satellite segment development and production, complete their TSAT design reviews. A Lockheed Martin/Northrop Grumman team, and another led by Boeing – each awarded a $514-million risk reduction and system definition study contract – completed their TSAT design review in July 2005. Their work continues through 2006, when the US government is scheduled to select a single contractor to proceed with the acquisition and operation phase. While the APS system was initially proposed for a 2008-2010 timeframe to replace the systems already in use, fiscal year 2005 funding supported a fiscal year 2013 launch. Robbie Samantha Roy, "The Long-term Implications of Current Plans for Investment in Major Unclassified Military Space Programs," Congressional Budget Office, 12 September 2005. Online: http://www.cbo.gov/ftpdocs/66xx/doc6637/09-12-MilitarySpace.pdf.

99 Fabey.

100 "Russia to remain leading space power – head of Roscosmos," RIA Novosti, 19 August 2005.

101 "Russia to remain leading space power."

102 Andrei Kislyakov, "Restructuring Russia's Space Program," *Space News*, 28 November 2005.

103 "What the Russian papers say: Nezavisimaya Gazeta: Why do Russian satellites fail to reach orbit?" RIA Novosti, 23 June2005.

104 "Russian Space Boss Says 80% of Military Satellites Need Replacing," MosNews, 11 November 2005.

105 Kislyakov.

106 Yuri Zatitsev, "Russia Developing New Space Radars," RIA Novosti, 3 March 2005.

107 "Uneven Contest Between Russian, US Spy Satellites: Russian General," *Space News*, 11 November 2005.

108 Pavel Felgenhauer, "Growing Nuclear Blindness," *Moscow Times*, 28 June 2005.

109 "Rocket and satellite fragments found," RIA Novosti, 23 June 2005.

110 The Monitor-E belongs to a new generation of spacecraft with intelligent on-board systems. It is unpressurized and modular in design, cutting construction time, and equipped with two electronic optical cameras with resolutions of 8 meters and 20 meters. "An in-depth look at the Russian press, October 14: Izvestia: Russia has no remote sensing satellites," RIA Novosti, 14 October 2005.

111 "Russian Military Satellite Fails to Separate from Booster Rocket," MosNews, 28 October 2005.

112 "UCS Satellite Database," Union of Concerned Scientists, 12 December 2005. Online: http://www.ucsusa.org/assets/documents/global_security/UCSSatelliteDatabase_11-15-05.xls.

113 Gunter Dirk Krebs, "Parus (11F627)," Gunter's Space Page, 21 September 2005. Online: http://skyrocket.de/space/doc_sdat/parus.htm.

114 "Russian Communication, Security Satellites Sent into Orbit," MosNews, 22 December 2005.

115 Stephen Clark, "Kosmos Rocket Launched," *Spaceflight Now*, 21 December 2005.

116 "Russia to Launch 3 GLONASS Satellites," *Space News*, 28 November 2005.

117 "Russian Space Boss Says 80% of Military Satellites Need Replacing."

118 The Lavochkin Science and Production Association agreed to build the Arkon-2 multirole radar satellite for the Federal Space Agency. It is designed to take high-resolution and medium-resolution photos for federal clients, and to use the information for national defense programs. Yuri Zatitsev, "Russia Developing New Space Radars," RIA Novosti, 3 March 2005.

119 Zatitsev, 3 March 2005.

120 For example, see: Lars Koren Nesheim and Arne Edmund Ofstad, "Satellite Coverage for GPS, GLONASS and GALILEO in Nordic Waters," Norwegian Hydrographic Service, presentation at Nordic SatNav User Conference, Oslo, 29-30 November 2005. Online: http://www.torkildsen.no/Nornav/Presentations/Nesheim_SatellittCoverage.ppt.

121 "Taiwan Planning Spy Satellite: Report," Agence France-Presse, 10 October 2005.

122 "Nation May Launch Spy Satellite by 2007: Report," *Taipei Times*, 11 October 2005; "Taiwan Plans Launch of Spy Satellite," *Mail and Guardian*, 10 October 2005.

123 "Taiwan Plans Launch of Spy Satellite."

124 "Taiwan Planning Spy Satellite"; "Taiwan Plans Launch."

125 "Japan Eyes Smaller Spy Satellite," *Space News*, 11 January 2005.

126 "Japan to Deploy Intelligence System," *Space News*, 14 March 2005.

127 "Pakistan to launch remote sensing satellite system," Dawn, 22 August 2005.

128 "China's space ambitions potential threat to US: analysts," Agence France-Presse, 11 October 2005.

129 "Disaster Monitoring and High-Resolution Imaging," SSTL Space Missions, Surrey Satellite Technologies Ltd., 2005. Online: http://www.sstl.co.uk/index.php?loc=121.

130 "China Urged to Take Full Part in Europe's Galileo Space Project," *Space News*, 1 July 2005.

131 David Lague, "Guiding China's Missiles: EU satellite project could improve accuracy," *International Herald Tribune*, 19 April 2005, p. 1.

132 "Chinese takeout?" *Investor's Business Daily*, 14 October 2005.

133 "Chinese takeout?"

134 *The Military Power of the People's Republic of China 2005*, Office of the Secretary of Defense, US Department of Defense, July 2005. Online: http://www.defenselink.mil/news/Jul2005/d20050719china.pdf; Leonard David, "Report: China working on anti-satellite systems," USA Today, 28 July 2005.

135 *The Military Power*; David; "New Questions About US Intelligence on China," Union of Concerned Scientists, 15 September 2005.

136 "China in Space: The Possibilities and Threats," *Space News*, 28 November 2005.

137 Mark Wade, "Shenzhou 6," *Encyclopedia Astronautica*, 20 November 2005. Online: http://www.astronautix.com/flights/shezhou6.htm.

138 Gregory Kulacki, e-mail correspondence with author, 11 January 2006.

139 "New Report Evaluates European Security Needs in the Space Sector," European Space Policy, European Union, 18 March 2005. Online: http://europa.eu.int/comm/space/news/article_2262_en.html.

140 "First Galileo Satellite Arrives at ESA for Testing," *Space News*, 9 August 2005.

141 "Europe Opens Up Civil Navigation System with Galileo Satellite," *Space News*, 28 December 2005.

142 John McCarthy, "Space Systems / Loral-Built XTAR-EUR Satellite Successfully Launched," Loral Space and Communications, 12 February 2005. Online: http://www.loral.com/inthenews/050212.html.

143 "European Rocket Sends French Military Satellite Aloft," *Space News*, 13 October 2005.

144 Ben Vogel, "France accepts Syracuse 3A comms satellite," *Jane's Defence Weekly*, 1 February 2006.

145 Vogel.

146 "European Rocket Sends French Military Satellite Aloft."

147 Bertrand de Montluc, e-mail correspondence with author, 17 May 2006.

148 "Thales To Supply New Tactical Communications System For French Forces," *Space News*, 3 July 2005; "Thales to supply new HF tactical communication system for French forces," Thales, Press Release, 30 June 2005.

149 Clifford Beal, "New Vistas for UK Military Space," Royal United Services Institute for Defence and Security Studies, Summer 2005.

150 "Skynet 5," Paradigm Secure Communications. Online: http://www.paradigmsecure.com/?OBH=38&ID=6.

151 "Third Skynet Satellite to Aid British Military Communications," e-Government and Public Sector IT News, 21 December 2005. Online: http://www.publictechnology.net/print.php?sid=4214 .

152 "Third Skynet Satellite."

153 Andrew Chuter, "TopSat Reflects UK Interest in Small Military Satellites," *C4ISR Journal*, 29 November 2005.

154 "QinetiQ announces first TopSat images," *Jane's Defence Weekly*, 4 January 2006.

155 Chuter.

156 Yitaf S. Shapir, "The Spirit is Willing: Iran's Effort to Conquer Space," *Tel Aviv Notes*, No. 152, 8 November 2005; Iddo Genuth, "Iran to Launch Spy Satellite by the End of September," IsraCast, 23 September 2005.

157 Ali Akbar, "Iran Now Says Satellite Can Spy on Israel," Associated Press, 16 November 2005.

158 While there was some speculation that development on the Shehab-4 had been abandoned in favor of a more advanced Shehab-5 missile, Iranian officials say the country is still working on the Shehab-4 SLV. Shapir.

159 K. S. Jayaraman and Barbara Opall-Rome, "Israel Chooses Indian PSLV to Launch New Spy Satellite," *Space News*, 14 April 2005; Martin Sieff, "Israel Expands Space Effort, EU Ties," *World Peace Herald*, 1 July 2005.

160 Jayaraman and Opall-Rome.

161 John C. K. Daly, "UPI Intelligence Watch," Washington Times, 11 April 2005.

162 Sieff.

163 Sieff.

164 Alon Ben-David, "Israel to Launch Recon Satellite from India," *Jane's Defence Weekly*, 17 November 2005.

165 Ben-David.

166 Jayaraman and Opall-Rome.

167 Jeffrey T. Richelson, "The Whole World is Watching," *Bulletin of the Atomic Scientists*, January/February 2006;
Arieh O'Sullivan, "Successful Test of New Rocket Launcher," *Jerusalem Post*, 14 July 2005.

168 "India to Set Up Military SBS System by 2007," *Space News*, 9 August 2005.

169 Jayaraman and Opall-Rome.

170 "India Building a Military Satellite Reconnaissance System," *Defense Industry Daily*, 10 August 2005.

171 "Indian Space Research Organization Annual Report 2004-2005," Indian Space Research Organization, 2005. Online: http://www.isro.org/rep2005/EOS.htm.

172 "Project Polar Epsilon Will Enhance Canada's Surveillance and Security Capability," DND/CF News Release, 2 June 2005. Online: http://www.forces.gc.ca/site/newsroom/view_news_e.asp?id=1674.

173 Stephen Thorne, "Feds look to satellite to assert Arctic sovereignty," Canadian Press, 28 August 2005.

174 Jonathan McDowell, Satellite Database.

Chapter Six Notes

1 Bruce deBlois, Richard Garwin, Scott Kemp, Jeremy Marwell, 2004, "Space Weapons Crossing the US Rubicon," *International Security* 29 (Fall 2004), pp. 50-84.

2 deBlois, et al. pp. 50-84.

3 Gunter Dirk Krebs, "SPIRALE 1, 2" Gunter's Space Page. Online: http://www.skyrocket.de/space/doc_sdat/spirale-1.htm.

4 Pavel Podvig, "History and the current status of the Russian early warning system," *Science and Global Security* 10 (2002), pp. 21-60.

5 V. G. Morozov, "Vsevidashcheye oko Rossii (The all-seeing eyes of Russia)," *Nezavisimoye voyennoye obozreniye*, 14 April 2000.

6 *Strategic Master Plan FY06 and Beyond*, Air Force Space Command, 1 October 2003. Online: http://www.cdi.org/news/space-security/afspc-strategic-master-plan-06-beyond.pdf.

7 Marcia Smith, "Military Space Programs: Issues Concerning DoD's SBIRS and STSS Programs," CRS Report for Congress, RS21148, 3 November 2003, pp. 10-11. Online: http://www.fas.org/spp/starwars/crs/RS21148.pdf.

8 Marcia Smith, "Military Space Programs: Issues Concerning DoD's SBIRS and STSS Programs," CRS Report for Congress, RS21148, 3 November 2003, p.3. Online: http://www.fas.org/spp/starwars/crs/RS21148.pdf.

9 Jefferson Morris, "First SBSS Satellite Launch to Slip Several Months," *Aerospace Daily & Defense Report*, 4 October 2004.

10 "Yuan Wang Tracking Ships," Globalsecurity.org, last updated 23 July 2005. Online: http://www.globalsecurity.org/military/world/china/yuan-wang.htm; "Large Phased-Array Radar (LPAR)", Globalsecurity.org, last updated 28 April 2005. Online: http://www.globalsecurity.org/wmd/world/china/lpar.htm.

11 Heiner Klinkrad, "Monitoring Space – Efforts 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. Online: http://www.fas.org/spp/military/program/track/klinkrad.pdf

12 "RAF Fylingdales," Globalsecurity.org, last updated 27 April 2005. Online: http://www.globalsecurity.org/space/facility/fylingdales.htm

13 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108–136—, 24 November 2003. Online: http://www.celestrak.com/Norad/elements/Section913.pdf.

14 "Radio Frequency Threat Warning and Attack Reporting Factsheet," Air Force Research Laboratory, Fact Sheet.

15 "A -- Rapid Attack Identification, Detection, and Reporting System Spiral 2 Studies," FBO Daily, Issue #1033, 24 September 2004. Online: http://www.fbodaily.com/archive/2004/09-September/24-Sep-2004/FBO-00679518.htm.

16 Gunter Dirk Krebs, "Vela," Gunter's Space Page. Online: http://space.skyrocket.de/ .

17 "Satellite Taskforce Report, Factsheet," President's National Security Telecommunications Advisory Committee (NSTAC), Fact Sheet, March 2004. Online: http://www.ncs.gov/nstac/reports/2004/Satellite%20Task%20Force%20Fact%20Sheet%20(March%202004).pdf; Theresa Hitchens, e-mail communication with author, 17 March 2005.

18 EADS-Astrium UK, e-mail communication with author, December 2004.

19 Scott A. Henderson, Lt. Col, USAF, former commander, 2nd Space Operations Squadron – GPS, telephone conversation with author, 2 May 2005.

20 "Critical Infrastructure Protection: Commercial Satellite Security Should Be More Fully Addressed," Report to the Ranking Minority Member, Permanent Subcommittee on Investigations, Committee on Governmental Affairs, US Senate, US General Accounting Office, GAO-02-781, August 2002. Online: http://www.gao.gov/new.items/d02781.pdf.

21 M. R. Frater, and M. Ryan, *Electronic Warfare for the Digitized Battlefield* (Boston: Artech House, 2001). The electronic warfare treatment of this chapter was largely drawn from the approach provided in this book; "Electromagnetic Pulse (EMP) and TEMPEST Protection for Facilities, Engineering and Design," Pamphlet EP 1110-3-2, U.S. Army Corps of Engineers, December 1990; W.E. Burrows, *Deep Black Space Espionage and National Security* (Random House: New York, 1986), p. 182.

22 Frater and Ryan,

23 Don J. Hinshilwood and Robert B. Dybdal, "Adaptive Nulling Antennas for Military Communications," *Crosslink*, The Aerospace Corporation, 3 (Winter 2001/2002) pp. 30-37. Adaptive antenna systems contain five major components: a means of detecting interference; a means of distinguishing desired signals from interference; a control processor for determining how to combine the antenna elements; antenna elements and circuitry to respond to commands from the control processor; and, a performance monitor to identify changes in the interference environment and respond accordingly.

24 Hinshilwood and Dybdal; Mark Wade, "Milstar," Encyclopedia Astronautica. Online: http://www.astronautix.com/craft/milstar.htm.

25 "Global Positioning Experiments (GPX)," DARPA, 2003. Online: http://www.darpa.mil/spo/.

26 "China to launch its first anti-jamming satellite next year," *China Daily*, 4 March 2004.

27 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual*. (Cambridge MA: American Academy of Arts & Sciences, 2005).

28 Lt. Col. Richard E. Fitts, ed., *The Strategy of Electromagnetic Conflict* (Peninsula Publishing: Los Altos, 1980).

29 Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Stimson Center, 2003).

30 Dana Priest, "New Spy Satellite Debated On Hill," *Washington Post*, 11 December 2004; Dana Priest, "Lawmakers balk at cost of satellite few admit exists," *Washington Post*, 12 December 2004.

31 "Loyola de Palacio welcomes the outcome of EU/US discussions on GALILEO," European Commission, Press Release, 26 February 2004. Online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/264&format=HTML&aged=0&language=EN&guiLanguage=en; "GALILEO and GPS will navigate side by side: EU and US sign final agreement," European Commission, Press Release, 26 June 2004. Online: http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/805&format=HTML&aged=0&language=en&guiLanguage=en.

32 Dennis Papadapolous, "Satellite Threat Due to High Altitude Nuclear Detonations," University of Maryland. Online: http://www.lightwatcher.com/chemtrails/Papadopoulos-chemtrails.pdf.

33 Dennis Papadapolous, "Satellite Threat Due to High Altitude Nuclear Detonations," University of Maryland. Online: http://www.lightwatcher.com/chemtrails/Papadopoulos-chemtrails.pdf.

34 Michael Krepon and Christopher Clary, *pace Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Stimson Center, 2003).

35 Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Stimson Center, 2003).

36 John Foster et al., "Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack," US Arms Services Committee, 22 July 2004. Online: http://www.globalsecurity.org/wmd/library/congress/2004_r/04-07-22emp.pdf.

37 Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security* 10 (Spring 1986) pp. 46-98; "Laser ASAT Test Verification," Federation of American Scientists; Wright, et al.

38 Carter, p. 79.

39 Tamar H. Mehuron, "2004 Space Almanac," *Air Force Magazine*, August 2003. Online: http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf.

40 "Military Planning Nuclear Exercises," *Moscow Times*, 2 February 2004.

41 Pavel Podvig, "Russia and Military Uses of Space," Russian Strategic Nuclear Forces, June 2004. Online: http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml.

42 *Strategic Master Plan FY06 and Beyond*, p. 5.

43 "FALCON Broad Agency Announcement, Phase I Proposer Information Pamphlet," DARPA, 29 July 2003.

44 "Responsive Access, Small Cargo, Affordable Launch," DARPA, 5 October 2004. Online: http://www.darpa.mil/tto/.

45 "Space Maneuver Vehicle," Air Force Research Laboratories, Fact Sheet, September 2002.

46 "Clearing Skies", *Jane's Defense Weekly*, 29 April 1998.

47 Alexander Zhelezniakov, "New Space Carrier Rocket 'Mikron'," Russian Pereplet, 15 February 2002. Online: http://www.pereplet.ru/cgi/science.cgi?id=61.

48 "Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS)," Department of the Air Force Federal Business Opportunities, BAA-VS-06-03. Online: http://www.fbo.gov/spg/USAF/AFMC/AFRLPLSVD/BAA%2DVS%2D06%2D03/listing.html; "Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS)," Air Force Research Laboratory Space Vehicles Directorate, 2 December 2005. Online: http://www.fbo.gov/EPSData/USAF/Synopses/2682/BAA%2DVS%2D06%2D03/BAASolicitationforANGELS%28Final2Dec05%29%2Edoc.

49 Jeremy Singer, "Air Force ANGELS: Satellite Escorts to Take Flight," *Space News*, 30 November 2005.

50 Lt.Col. Jim Shoemaker, "DARPA Space Activities: Space Situational Awareness and Mission Protection," presentation at DARPATech 2005, 9-11 August 2005.

51 "Department of Defense Fiscal Year (FY) 2006/FY 2007 Budget Estimates, Research, Development, Test, and Evaluation, Defense-Wide, Volume 1: Defense Advanced Research Projects Agency (DARPA)," US Department of Defense, February 2005, p. 262. Online: http://www.dod.mil/comptroller/defbudget/fy2006/budget_justification/pdfs/rdtande/DARPA.pdf.

52 "Department of Defense Fiscal Year (FY) 2006/FY 2007 Budget Estimates"; "Space Surveillance Telescope," DARPA, 29 October 2005. Online: http://www.darpa.mil/tto/programs/sst.htm; Tim Grayson, "Space Situational Awareness: What was that? Where is it going? What is it doing?" presentation at DARPA Tech 2002.

53 Dane Schiller, "Telescope has military uses," *El Universal*, 11 December 2005; "The Large Millimeter Telescope," The Large Millimeter Telescope Project. Online: http://www-lmt.phast.umass.edu/; "Department of Defense Fiscal Year (FY) 2001 Budget Estimates, Research, Development, Test, and Evaluation, Defense-Wide, Volume 1: Defense Advanced Research Projects Agency (DARPA)," US Department of Defense, February 2000, pp. 213-215; Andrew Lawler, "Millimeter Astronomy: U.S.-Mexican Telescope Gains Firmer Footing," Science 291 (9 February 2001), pp. 974 – 975.

54 "Fiscal Year 2006/2007 Budget Estimates. Research, Development, Test and Evaluation (RDT&E) Descriptive Summaries, Volume I: Defense Advanced Research Projects Agency," US Department of Defense, February 2005, p. 423. Online: http://www.dtic.mil/descriptivesum/Y2006/DARPA/0603768E.pdf; Maj Earl Odom, "Future Missions for Unmanned Aerial Vehicles: Exploring Outside the Box," *Aerospace Power Journal*, Summer 2002. Lt. Col. Gregory Vansuch, "Navigation & Guidance," DARPA Special Projects Office, Presentation at DARPATECH 2002; David C. Hardesty, "Space-based weapons: long-term strategic implications and alternatives," *Naval War College Review* (Spring 2005), p.8.

55 S. Yesil, R. Sever, B. Okcan, N. Ismailoglu, "GOLGE: a case study of a secure data communication subsystem for micro-satellites," Proceedings of 2nd International Conference on Recent Advances in Space Technologies (RAST 2005), pp. 438-41; N. Ismailoglu, O. Benderli, S. Yesil, R. Sever, B. Okcan, R. Oktem, "GEZGIN-2: an advanced image processing subsystem for Earth-observing small satellites," Proceedings of 2nd International Conference on Recent Advances in Space Technologies (2005), pp. 605-10; "VLSI Design Group," Tübitak Bilten. Online: www.bilten.metu.edu.tr/Web_2002_v1/en/sayfa_d12.asp?sayalim=sayfa_d12.

56 Roohi Banu, Tanya Vladimirova, and Martin Sweeting, "On-Board Encryption in Satellites," presented at 2005 MAPLD International Conference, Washington, DC, 7-9 September 2005. Abstract online: http://klabs.org/mapld05/abstracts/184_banu_a.html; Eric Swankoski and Vijaykrishnan Narayanan, "Dynamic High-Performance Multi-Mode Architectures for AES Encryption," presented at 2005 MAPLD International Conference, Washington, DC, 7-9 September 2005. Abstract online: http://klabs.org/mapld05/abstracts/103_swankoski_a.html.

57 For comparison, some of the newest commercial Pentium 4 chips have a feature size of 90 nanometers.

58 "DTRA Celebrates Milestone in RADHARD," Defense Threat Reduction Agency, Press Release. Online: http://www.dtra.mil/Toolbox/Directorates/td/TDN/radhard.cfm; Robert Wall, "Intelligent Action," *Aviation Week & Space Technology*, 6 February 2005, p. 55; "New Honeywell Wafer Foundry will Produce Industry's First 150-Nanometer Radiation Hardened Semiconductors," Honeywell Aerospace Electronics, Press Release, 27 April 2005. Online: http://myspaceparts.com/new/20050427.html; Ann R. Thryft, "Rad-Hard Chips Fly High," *COTS Journal* 7 (August 2005); Thomas Romanko and Brian Clegg, "SOI eases radiation-hardened ASIC designs," *EE Times*, 25 July 2005. Online: http://www.eetimes.com/showArticle.jhtml?articleID=165700727; Don Tuite, "Chips In Space: On-The-Fly Intelligence," *Electronic Design Online*, 23 August 2004. Online: http://www.elecdesign.com/Articles/Index.cfm?AD=1&AD=1&ArticleID=8583&pg=1; "Annual Industrial Capabilities Report to Congress," US Department of Defense, February 2005, pp. 48-49. Online: www.acq.osd.mil/ip/docs/annual_ind_cap_rpt_to_congress-2005.pdf.

59 While space plasma experiments in the past have used satellites to detect the effects of natural and ground-based VLF transmissions (e.g. from Siple Station and South Pole VLF transmitters in Antarctica and the High Frequency Active Auroral Research Program transmitter in Alaska), WPIx will itself be able to transmit waves in the 10 to 50 kilohertz range and work with ground transmitters and other space receivers to carry out experiments. "Demonstration and Science Experiments (DSX) Satellite," Air Force Research Laboratory Space Vehicles Directorate, Factsheet, September 2005. Online: http://www.vs.afrl.af.mil/FactSheets/DSX.pdf; Michael P. Kleiman, "Firm foundation laid for premier research and development spacecraft," Air Force Research Laboratory, Press Release, October 2005. Online: http://www.afrl.af.mil/news/oct05/features/firm_foundation.pdf.

60 David Young, "Responsive Access Small Cargo Affordable Launch (RASCAL) Independent Performance Evaluation," AE8900 Special Project Report, School of Aerospace Engineering, Space System Design Laboratory, Georgia Institute of Technology, Atlanta, Georgia, 3 May 2004, p. 1; "Orbital Issues DART Mission Recap," Orbital Sciences, Press Release, 18 April 2005.

61 V. Andreev et al. "DNEPR Program: Prospects and Advantages for Responsive SpaceÇ, AIAA-LA Section/SSTC 2003-8003, 1st Responsive Space Conference 1-3 April, 2003, Redondo Beach, US. Online: http://www.responsivespace.com/psearch.asp?cat=I5.

62 "Falcon Overview," SpaceX. Online: http://www.spacex.com/index.html?section=falcon&content=http%3A//www.spacex.com/falcon_overview.php.

63 "Falcon 1 Maiden Flight Update," SpaceX, Press Release, 9 January 2006. Online: http://www.spacex.com/index.html?section=media&content=http%3A//www.spacex.com/launch_info.php.

64 "Company Description," SpaceX. Online: http://www.spacex.com/index.html?section=aboutus&content=http%3A//www.spacex.com/aboutus.php. SpaceX is also trying to compete for contracts under the Evolved Expendable Launch Vehicle (EELV) program with their Falcon 5 and Falcon 9 vehicles; it filed a lawsuit against Boeing and Lockheed Martin on 19 October 2005 alleging unfair monopolistic behavior in blocking SpaceX participation in the program. Peter Pae, "Rocket Maker Sues Boeing, Lockheed," *Los Angeles Times*, 21 October 2005.

65 K.L. Vantran, "FALCON Phase 1 Contractors Selected," American Forces Press Service, 22 December 2003. Online: http://www.defenselink.mil/news/Dec2003/n12222003_200312221.html; "Falcon," Defense Advanced Research Projects Agency, 29 October 2005. Online: http://www.darpa.mil/tto/programs/falcon.htm; "DARPA/USAF FALCON Program," Environmental Aeroscience Corporation. Online: http://www.hybrids.com/falcon.htm; Philip Lorenz, "Tunnel 9 completes vehicle testing," Air Force Link, 1 November 2005. Online: http://www.af.mil/mediacenter/transcripts/story.asp?storyID=123012647; "Lockheed Martin Successfully Test Fires Second Falcon Small Launch Vehicle Hybrid Motor," Lockheed Martin, Press Release, 16 June 2005. Online: http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=16895&rsbci=0&fti=112&ti=0&sc=400.

66 Viktor Litovkin, "Russia-Kazakh space plan," United Press International, 27 January 2006; "USSR/CIS Miniature ASAT," Globalsecurity.org. Online: http://www.globalsecurity.org/space/world/russia/mini.htm;

67 Litovkin.

68 "Russia Plans First-Ever Satellite Launch from Plane," Agence France-Presse, 16 August 2001. "Info", Air Launch Aerospace Corporation. Online: http://www.airlaunch.ru/HTML_O/Info/infp.htm.

69 "Payload Capabilities," Air Launch Aerospace Corporation. Online: http://www.airlaunch.ru/HTML_O/Payload_Capabilities/payload_capabilities.htm.

70 "Russia To Launch Indonesian Satellite," United Press International, 7 December 2004.

71 "Russia, Indonesia to Build Rocket-Launching Pad on Remote Island," MosNews, 14 February 2006. Online: http://mosnews.com/news/2006/02/14/rusindonessatellite.shtml.

Chapter Seven Endnotes

1 Negation of space systems is called 'offensive counterspace' in current Air Force terminology, and includes the 'Five Ds' mission. *Air Force Doctrine Document 2-2.1*, US Air Force, 2 August 2004, p. 3. Online: http://www.fas.org/irp/doddir/usaf/afdd2_2-1.pdf.

2 The Van Allen belts are two rings consisting of highly energetic protons trapped by the Earth's magnetic field. The lower belt is situated between 1,000 and 5,000 kilometers about the equator. The second belt is situated between 15,000 and 25,000 kilometers above the equator. David Stern, "Radiation Belts," NASA, 25 November 2001. Online: http://www-istp.gsfc.nasa.gov/Education/Iradbelt.html. See also "Van Allen belts," *A Dictionary of Physics*, Alan Isaacs, ed. (Oxford: Oxford University Press, 2000).

3 Bruce DeBlois et al., "Space Weapons: Crossing the US Rubicon," *International Security* 20 (Fall 2004), p. 66.

4 In July 2003, broadcasts of Persian-language Voice of America and other Iranian broadcasts emerging from the US were blocked by a signal believed to originate in Cuba. "US broadcasts 'jammed by Cuba,'" BBC News, 18 July 2003. Online: http://news.bbc.co.uk/1/hi/world/americas/3077303.stm.

5 Broadcasting from the UK and Belgium, Med-TV was a satellite network operated by Kurdish exiles. Beginning in 1995 it experienced several interruptions in service blamed on a jamming signal originating in Turkey, before its closure in 1999. "World: Middle East Kurds retaliate in Turkish jam war," *BBC News*, 16 October 1998. Online: http://news.bbc.co.uk/1/hi/world/middle_east/193529.stm.

6 The Falun Gong has been accused of jamming SINOSAT signals to block broadcasts and override transmission with pirate broadcasts in several incidents through 2002 and 2003. "Jamming harms world trade," *China Daily*, 30 September 2002.

7 Frank Vizard, "Safeguarding GPS," *Scientific American*, 14 April 2003.

8 "Counterspace Systems," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Project Element 0604421F, February 2003, p. 1. Online: http://www.dtic.mil/descriptivesum/Y2004/AirForce/0604421F.pdf.

9 Capt. Angie Blair, Air Force Spokesperson quoted in Jim Wolf, "US Deploys Satellite Jamming System," Reuters, 29 October 2004.

10 "Space Control Technology," Unclassified RDT&E Budget Item Justification, Exhibit R-2, Project Element 0603438F, February 2004, p. 3. Online: http://www.dtic.mil/descriptivesum/Y2005/AirForce/0603438F.pdf.

11 "Space Control Technology," p. 1.

12 "U.S. Space-Based Positioning, Navigation, and Timing Policy," Office of Science and Technology Policy, Fact Sheet, 15 December 2004. Online: http://www.ostp.gov/html/FactSheetSPACE-BASEDPOSITIONINGNAVIGATIONTIMING.pdf.

13 "Quadrennial Defense Review Report," US Department of Defense, 30 September 2001, p. 45. Online: http://www.defenselink.mil/pubs/qdr2001.pdf.

14 *Air Force Doctrine Document 2-2.1*, p. vii.

15 "Space Situational Awareness Integration Office," United States Air Force, Fact Sheet, April 2004. Online: http://www.peterson.af.mil/hqafspc/Library/FactSheets/FactsSheets.asp?FactChoice=23.

16 Launched in 1996, the MSX satellite has expended its intended lifespan. For system details see Grant H. Stokes et al., "The Space-Based Visible Program," *Lincoln Laboratory Journal* 11 (1998). Online: http://www.ll.mit.edu/ST/sbv/sbv.pdf.

17 "Appendix D: Brief Descriptions of Programs, ACTDs and Future System Concepts," *US Air Force Transformation Flight Plan*, US Air Force, November 2003, p. D-10. Online: http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf.

18 "Boeing snags 189 million Pentagon space contract," Space Wire, 31 March 2004. Online: http://www.spacedaily.com/2004/040330232730.r3ab2j2p.html.

19 System details taken from Clayton K.S. Chun, "Shooting down a 'Star' Program 437, the US nuclear ASAT System and Present Day Copycat Killers," Cadre Paper No. 6 (Maxwell Air Force Base, Alabama, Air Force University Press, April 2000), p. 4. Online: http://www.fas.org/spp/military/program/asat/ADA377346.pdf; Laura Grego, "A History of US and Soviet ASAT Programs," Union of Concerned Scientists, 9 April 2003. Online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1151; David Baker, "Soviet ASAT Series," *Jane's Space Directory*, 17 September 2003; David Baker, "United States ASAT Series," *Jane's Space Directory*, 3 March 2004.

20 DeBlois et al. estimate that the North Korean Nodong missile or a GPS-guided bomb could achieve the altitude and accuracy for this kind of attack. Deblois et al., p. 61.

21 Funding appropriated by Congress for the system included $30-million in FY1996, $50-million in FY1997, $37.5-million in FY1998, $7.5-million in FY2000, $3-million in FY2001 and $7.5-million in FY2004. Marcia Smith, "U.S. Space Programs: Civilian, Military, and Commercial," CRS Issue Brief for Congress, 21October 2004. Online: http://www.fas.org/spp/civil/crs/IB92011.pdf.

22 "Funding Sought for KE ASAT Program," *Defense Daily*, 17 December 2002.

23 Keith J. Costa, "ASAT Technology Test Bed in the Works at Redstone Arsenal," *Inside Missile Defense*, 22 December 2004.

24 "Raytheon Delivers Exoatmospheric Kill Vehicle Payloads for Fort Greely," *Space Daily*, 18 August 2004. Online: http://www.spacedaily.com/news/bmdo-04y.html.

25 "Ground-Based Midcourse Defense (GBM) Exoatmospheric Kill Vehicle (EKV)," Raytheon, Fact Sheet. Online: http://raytheonmissiledefense.com/matrix/pdfs/fs/fs_ekv.pdf.

26 David Wright and Laura Grego, "ASAT Capabilities of Planned US Missile Defense System," *Disarmament Diplomacy* 68 (December 2002-January 2003), pp 7-10.

27 Wright and Grego, p 7.

28 "Fiscal 2005 Department of Defense Budget Release," US Department of Defense, News Release, 2 February 2004.

29 *Air Force Doctrine Document 2-2.1*, p. 3.

30 Approximately 80 percent of all the energy from a nuclear weapon detonated in outer space appears in the form of X-rays, in addition to small amounts of gamma radiation and neutrons, small fractions in residual radio activity, and in the kinetic energy of bomb debris. An electromagnetic pulse (EMP) is also generated by a HAND when X-rays and gamma rays create an electron flux in the upper atmosphere of the Earth that re-radiates its energy in the radio frequency portion of the electromagnetic spectrum. When this radio frequency hits space systems it induces currents and voltages that may damage or destroy electronic systems not hardened against these effects. Satellites in GEO would experience an EMP of smaller magnitude than either LEO satellites or ground facilities located within a line of sight of the HAND. Long after the initial detonation of a nuclear device, electrons liberated by the device would join the naturally occurring radiation in the Van Allen belts. Satellites not specifically designed for operations after detonation of a nuclear weapon may fail quickly in this enhanced radiation environment due to a rapid accumulation of total ionizing doses on the critical electronic parts of a satellite. Wiley J. Larson and James R. Wertz, eds., *Space Mission Design and Analysis*, 2nd ed. (Dordrecht: Kluwer Academic Publishers, 1992), pp. 215-228.

31 "History of Russia's ABM System," Union of Concerned Scientists, 27 October 2002. Online: http://www.ucsusa.org/global_security/missile_defense/page.cfm?pageID=609.

32 The International Atomic Energy Agency has never been able to fully verify the status of the North Korea nuclear safeguards agreement and reports that it is non-compliant with its obligations. Although claims have been made that North Korea reprocessed nuclear fuel for weapons, they remain unsubstantiated as inspectors have been denied access to nuclear facilities since 2002. International Atomic Energy Agency General Conference, "Implementation of the Safeguards Agreement between the Agency and the Democratic People's Republic of Korea Pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons," GC(48)/17, 16 August 2004. Online: http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48-17.pdf.

33 Iran's nuclear power program has been repeatedly investigated by the IAEA for links to a nuclear weapons program, which have not been demonstrated. International Atomic Energy Agency General Conference, "Implementation of the IAEA Safeguards Agreement in the Islamic Republic of Iran," International Atomic Energy Agency GOV/2005/87, 18 November 2005.

34 S. Karamow, "Army scores a hit on satellite in test of laser," *USA Today*, 21 October 1997, p. A6.

35 Laura Grego, "A History of US and Soviet ASAT Programs," Union of Concerned Scientists, 9 April 2003. Online: http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1151.

36 Prior to the MIRACL laser test in 1997, "that a commercially available laser and a 1.5 m mirror could be an effective ASAT highlighted a US vulnerability that had not been fully appreciated." The 30-watt laser used in the test was capable of temporarily blinding the target satellite. Grego.

37 "Counterspace Systems," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Program Element 0604421F, February 2004, p. 875. Online: http://www.dtic.mil/descriptivesum/Y2005/AirForce/0604421F.pdf.

38 "The Airborne Laser," Missile Defense Agency, Fact Sheet, last updated May 2006. Online: http://www.mda.mil/mdalink/pdf/laser.pdf.

39 Tariq Malik, "The Power of Light: An Airborne Laser for Missile Defense," Space.com, 17 November 2004. Online: http://www.space.com/businesstechnology/airborne_laser_techwed_041117.html.

40 The Surrey Space Center partnership with China to develop microsatellite technology has been the source of much speculation about Chinese ASAT intentions, although there is no evidence of an official Chinese ASAT program. Surrey Satellites' CEO posted a statement on its website that "there have been a number of reports in the press that have portrayed SSTL's commercial satellite business with PR China in a very misleading light (…) SSTL has carried out two micro-satellite projects for PR China. Both projects are entirely civil in nature and both have been executed strictly within export controls specifically approved for each project by the UK government (…) No propulsion technologies 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." "News," Surrey Satellite Technology, 23 March 2005. Online: http://www.sstl.co.uk/index.php?loc=6. For an analysis of China's interest in ASAT weapons, including the Chinese academic debate about this subject, Phillip Saunders et al., "China's Space Capabilities and the Strategic Logic of Anti-Satellite Weapons," Center for Nonproliferation Studies, 22 July 2003. Online: http://cns.miis.edu/pubs/week/020722.htm; a full description of the Tsinghua-1/SNAP mission is at http://www.ee.surrey.ac.uk/SSC/.

41 "Microsatellite Constellation to Watch Over Disasters Forges Ahead," Space Daily, 15 May 2002.

42 "Ballistic Missile Defense System Interceptors," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Program Element 0603886C, February 2004. Online: http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf.

43 Mark Wade, "Rockets," Encyclopedia Astronautica, May 2005. Online: http://www.astronautix.com.

44 See for example the mobile land- and sea-based ballistic missiles identified in Hajime Ozu, *Missile 2000 Reference Guide to World Missile Systems* (Tokyo: Shinkigensha, 2000).

45 "Overview of the Taurus Rocket," SpaceFlight Now, 19 September 2001. Online: http://www.spaceflightnow.com/taurus/t6/010919taurus.html.

46 See note 44.

47 Sea Launch Web Site, May 2005. Online: http://www.sea-launch.com/.

48 See for example the SHTIL SLBM launch identified in Brian Harvey, *Russia in Space the Failed Frontier?* (Chichester, UK: Springer-Praxis Books, 2001), p. 236.

49 Sea Launch Web Site.

50 Sea Launch Web Site.

51 Muhammad Shamsui Kamal Adnan and Md. Azlin Md. Said, "Aircraft-Based Satellite Launching (ABSL) System - Future Space Transportation System." Online: http://www.dlr.de/iaa.symp/archive_5/pdf/0810P_Kama_Adnan.pdf.

52 "Space Launch Systems," Orbital Sciences Corporation, May 2005. Online: http://www.orbital.com/.

53 "China Tracks Space Debris," Space.Com. Online: http://www.space.com/astronotes/astronotes.html.

54 The TAROT and ROSACE space debris monitoring programs are surveyed in Fernand Alby et al, "Status of CNES Optical Observations of Space Debris in Geostationary Orbit," *Advances in Space Research*, Vol. 34, No. 5 (2002), pp. 1143-1149.

55 "Status of CNES Optical Observations," pp. 1143-1149.

56 "Space Debris Optical Observation and Orbit Determination Experiment Initiated," National Space Development Agency of Japan, September 2000. Online: http://www.nasda.go.jp/lib/nasda-news/2000/09/head_e.html.

57 Harvey, p. 209.

58 "Space Surveillance," US Air Force, May 2005. Online: http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm.

59 Wei Long, "Chinese Space Workers Celebrate Their Labour to Launch Shenzhou," Space Daily, 9 January 2002.

60 Heiner Klinkrad, "Monitoring Space – Efforts 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, Franc, 27-28 November 2002. Online: http://www.fas.org/spp/military/program/track/klinkrad.pdf.

61 Klinkrad.

62 "Introduction to MU Radar," Radio Atmospheric Science Center, Kyoto University. Online: http://www-lab26.kuee.kyoto-u.ac.jp/study/mu/mu_e.html.

63 Harvey, p. 209.

64 "Space Surveillance."

65 "Satellite Laser Ranging for ERS-1," Department of Earth Observation and Space Systems, Delft University, 8 August 1998. Online: http://www.deos.tudelft.nl/ers/tracking1/global.html.

66 "ConeXpress Orbital Life Extension Vehicle (CX-OLEV)," ESA, May 2005. Online: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=17870.

67 "Soyuz Launches Progress Cargo Flight to ISS/Automated Rendezvous Tests," Space and Tech, 26 June 2002. Online: http://www.spaceandtech.com/digest/flash2002/flash2002-060.shtml.

68 "DART Mission," Dart Mission, NASA, May 2005. Online: http://www.nasa.gov/mission_pages/dart/main/.

69 "ConeXpress Orbital Life Extension Vehicle."

70 Mark Wade, "Polyot 11A59," Encyclopedia Astronautica, May 2005. Online: http://www.astronautix.com/lvs/pol11a59.htm.

71 "ConeXpress Orbital Life Extension Vehicle."

72 "Autonomous Proximity Microsatellites," Technology Horizons, December 2003. Online: http://www.afrlhorizons.com/Briefs/Dec03/VS0304.html.

73 "ConeXpress Orbital Life Extension Vehicle (CX-OLEV)," ESA , May 2005. Online: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=17870.

74 "Autonomous Proximity Microsatellites."

75 The Advanced Video Guidance Sensor was first demonstrated in the 1990s with the space shuttle in NASA's Automated Rendezvous and Capture project. "DART Demonstrator to Test Future Autonomous Rendezvous Technologies in Orbit," NASA, Fact Sheet, September 2004.

76 Lt. Col. James Shoemaker, "Orbital Express Space Operations Architecture," DARPA, 19 October 2004.

77 Gerd Hirzinger et al., "DLR's Robotics Technologies for On-Orbit Servicing," *Advanced Robotics*, No. 2 (2003), pp. 139-174. Online: http://www.robotic.dlr.de/Klaus.Landzettel/ars.pdf.

78 David Hencke and Owen Gibson, "Protest to Libya after satellites jammed," *The Guardian* (London), 3 December 2005; "International satellite broadcasts disrupted in order to jam London-based radio station," Reporters without Borders, Press Release, 7 December 2005. Online: http://www.rsf.org/article.php3?id_article=15855; "Libya jams western broadcasts," *World Tribune*, 5 December 2005; Adam Ereli, "Daily Press Briefing," US State Department, 8 December 2005. Online: http://www.state.gov/r/pa/prs/dpb/2005/57831.htm.

79 Siavosh Ghazi, "Iran jams TV channels," *The Courier-Mail*, 7 June 2005; "Islamists frying Iranians brains to stay in power," *Taipei Times*, 8 June, p. 6; "Jamming Communications," Globalsecurity.org, 27 April 2005. Online: http://www.globalsecurity.org/space/world/iran/jam.htm; "Khatami, Karroubi order action to check jamming satellites in Iran," Payvand's Iran News, 22 April 2003.; "US broadcasts 'jammed by Cuba'," *BBC News*, 18 July 2003; Safa Haeri, "Cuba blows the whistle on Iranian jamming," *Asia Times*, 22 August 2003; "BBG Works to Overcome Iran's Jamming of Persian Satellite News Broadcasts," Broadcasting Board of Governors, Press Release, 17 June 2005. Online: http://www.bbg.gov/_bbg_news.cfm?articleID=127&mode=general.

80 Florence Chan, "Falungong sabotages Chinese satellite TV," Asia Times, 26 March 2005; "AsiaSat 3S Satellite Transmissions Attacked By Illegal Signals," Xinhua News Agency, 16 March 2005. Online: http://www.spacedaily.com/news/cyberwar-05h.html; "Falun Gong Denies Sending China Pirate Signals," Reuters, 16 March 2005. Online: http://www.dailyexcelsior.com/web1/05mar17/inter.htm#10; "Interception of Nine Commentaries Message on TV Was a 'Good Thing.'" *The Epoch Times*, 31 March 2005; "Bejing Alleges Falun Gong Hijacked Chinese TV Sat During World Cup," Xinhua News Agency, 8 July 2002. Online: http://www.spacedaily.com/news/cyberwar-02f.html.

81 "APSTAR VI Successfully Launched from Xichang Satellite Launch Center," APT Satellite Holdings Limited, Press Release, 12 April 2005. Online: http://www.apstar.com/pressroom/press/press50.htm; "China plans jam-proof communications satellite to keep ahead of Falungong," Agence France-Presse, 4 March 2004. Online: http://www.spacedaily.com/2004/040304070611.ulqsbxq4.html; "APT Satellite Group Appeals to the International Community to Strongly Denounce Malicious Satellite Interference Acts," APT Satellite Holdings, Press Release, 4 July 2005. Online: http://www.apstar.com/pressroom/press/press51.htm; Qin Chuan, "Jam-proof satellite going up next year," China Daily, 3 March 2004; "China Puts off Launch of First Direct-broadcast Satellite," China Education and Research Network, 24 March 2005. Online: http://www.edu.cn/20050324/3132150.shtml.

82 William Harwood, "Satellite watchers worried about Air Force restrictions," *Spaceflight Now*, 2 March 2005. Online: http://www.spaceflightnow.com/news/n0503/02observing/; Capt. Angie Blair, "New AFSPC Website Provides Worldwide Space Surveillance Support," US Air Force Space Command, Press Release, 3 January 2005. Online: http://www.peterson.af.mil/hqafspc/News/News_Asp/nws_tmp.asp?storyid=05-001.

83 "HELSTF Laser Systems," HELSTF Directorate, US Army Space and Missile Defense Command, 9 April 2002. Online: http://helstf-www.wsmr.army.mil/sys.htm; John Donnelly, "Laser of 30 Watts Blinded Satellite 300 Miles High," *Defense Week*, 8 December 1997, p. 1; Grego; "U.S. Army Awards Northrop Grumman Laser-Facility Operations and Maintenance Contract," Northrop Grumman Press Release, 1 March 2005. Online: http://www.it.northropgrumman.com/pressroom/press/2005/pr223.html.
"Starfire Optical Range Facilities," Starfire Optical Range. Online: http://www.de.afrl.af.mil/SOR/SORfacilities.htm; "Fiscal Year 2006/2007 Budget Estimates: Descriptive Summaries, Volume I: Scientific And Technology Budget Activities 1 – 3," US Air Force, February 2005, pp. 491-492.

84 "Airborne Laser Completes Initial Passive Testing," Missile Defense Agency, 1 August 2005. Online: http://www.mda.mil/mdalink/pdf/05fyi0055.pdf; "Airborne Laser Conformal Window Exposed During Flight," Missile Defense Agency, 20 May 2005. Online: http://www.mda.mil/mdalink/pdf/05fyi0051.pdf; "Aerospace Targets Airborne Laser Project," SPX, 30 August 2005. Online: http://www.spacewar.com/news/laser-05p.html; Christopher Bolkcom and Steven A. Hildreth, "Airborne Laser (ABL): Issues for Congress," Congressional Research Service, 18 August 2005.

85 Beam quality refers to how well the beam can be focused to reach a target. A perfect laser beam has a beam quality of "1." By comparison, a typical industrial laser for welding would have a beam quality exceeding "20."

86 David A Fulghum, "Lights, Laser, Combat," *Aviation Week & Space Technology*, 13 June 2005, pp. 122-123; "Joint High Power Solid State Laser (JHPSSL)," GlobalSecurity.org, 7 September 2005. Online: http://www.globalsecurity.org/military/systems/ground/jhpssl.htm; "Northrop Grumman Surpasses Power, Run-Time Requirements of Joint High Power Solid-State Laser Program for Military Uses," Northrop Grumman, Press Release, 9 November 2005. Online: http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=89438.

87 Geoff Fein, "AFRL Moves Aerospace Relay Mirror System Demonstration To 2006," *Defense Daily*, 20 October 2005, p. 5A; "Aerospace Relay Mirror System (ARMS)," GlobalSecurity.org, 7 September 2005. Online: http://www.globalsecurity.org/military/systems/aircraft/systems/arms.htm; George Marsh, "Airships: Making a Comeback," *Avionics Magazine*, 1 April 2004. Online: http://www.avionicsmagazine.com/cgi/av/show_mag.cgi?pub=av&mon=0404&file=0404airships.htm; Jason Sherman, "Laser Weapon Research: Rumsfeld Orders U.S. Services To Coordinate Programs," Defense News, 24 May 2004.

88 The further a laser must travel through the atmosphere, the more it can be refracted, diffracted and absorbed as it passes through various types of weather and pressure systems. A line straight up to a mirror that would then direct the beam above the atmosphere would eliminate many of these effects and make targeting somewhat easier.

89 China's high power laser program has been operating since as early as 1986, beginning with the LF-12 Shengguang-1 laser at the Chinese Academy of Sciences' Shanghai Institute of Optics and Fine Mechanics. China now has multiple hundred-megawatt lasers. China has developed significant capacity in gas, chemical, dye, excimer, solid-state, semi-conductor, and free electron lasers, both for pulse and continuous wave functions. Subtypes developed by China include krypton-fluoride, helium-argon-xenon, neodymium-doped yttrium aluminium garnet (Nd:YAG), oxygen-iodine, carbon-dioxide, neodymium glass (Nd:Glass), titanium-sapphire, quantum cascade, xenon-fluoride, both infrared and x-ray free electron lasers, and others. See the *Chinese journals Chinese Journal of Lasers*, *Infrared and Laser Engineering*, *High Powered Laser and Particle Beams*, *Chinese Optics Letters*, and *Laser and Infrared*. Sun ChengweiZhang, NingDu, Xiangwan, "Recent developments of Chinese activities in lasers and laser beam interactions with materials," AIAA-1995-1920, 26th Plasmadynamics and Lasers Conference, San Diego, CA, 19-22 June 1995. Online: http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=82509; Huang He, "A Dust-Laden Secret: Review and Prospects for China's Optical Instruments and Laser Weapons," *Defense International*, 1 April 1998, pp. 100-115; "LD-Pumped Nd: YAG Microchip Laser with 62.5MW CW Output Power," *Chinese Journal of Lasers*, 3 May 1994; "Ti-Sapphire Laser Attains CW Output Power of 650MW," *Chinese Journal of Lasers*, December 1994; Hui Zhongxi, "Sg-1 FEL Amplifier Output Reaches 140MW," *High Power Laser and Particle Beams*, December 1994; "A GW Power Level High Power CO2 Laser System," *Chinese Journal of Lasers*, June 1990; IAEA, "World Survey of Activities in Controlled Fusion Research, Special Supplement," International Atomic Energy Agency, 2001. Online: http://epub.iaea.org/fusion/public/ws01/ws_toc.html; "Directed Energy Weapons and Sensors," in *China's Aerospace and Defence Industry*, Jane's Chem-Bio Web, 1 December 2000; Mark A. Stokes, "China's Strategic Modernization: Implications for the United States," Strategic Studies Institute, US Army War College, September 1999. Online: http://www.strategicstudiesinstitute.army.mil/pdffiles/PUB74.pdf.

90 Sun, et al; Huang, pp.100-115; "LD-Pumped Nd"; "Ti-Sapphire Laser Attains CW Output Power of 650MW"; Hui; "A GW Power Level High Power CO2 Laser System"; "World Survey of Activities in Controlled Fusion Research"; "Directed Energy Weapons and Sensors"; Stokes.

91 Yang Wen-shi, Wang Wei-li, Sun Wei-na, Bi Guo-jiang, Zhu Chen, Wang Xiao-han, "Beam quality of the high power DPL," *Infrared and Laser Engineering*, No. 5 (2005), pp. 511-516.

92 See multiple articles from 2005 in the *Chinese journals Infrared and Laser Engineering*, *Chinese Space Science and Technology*, and *Journal of Astronautics*; "Directed Energy Weapons and Sensors," in *China's Aerospace and Defence Industry*, Jane's Chem-Bio Web, 1 December 2000.

93 Shi Xiang-chun, Chen Wei-biao, Hou Xia, "Application of all solid state laser in space," I*nfrared and Laser Engineering*, No. 2 (2005), pp. 127-131.

94 Cheng Hong-jun, Zhu Xue-ping, Cao Ning, "Operational effectiveness research of laser air defense weapon system," *Modern Defence Technology*, No. 3 (2005), pp. 14-17, 21. Online: www.wanfangdata.com.cn/qikan/periodical.Articles/xdfyjs/xdfy2005/0503/050304.htm.

95 David C. Isby, "US Army continues with KE-ASAT," *Jane's Missiles and Rockets*, March 2005; Costa; Sandra I. Erwin, "U.S. Space Command Chief Warns About Technological Complacency," National Defense, May 2001. Online: http://www.nationaldefensemagazine.org/issues/2001/May/US_Space.htm; "Contracts: Army," United States Department of Defense, Press Release No. 503-04, 25 May 2004. Online: http://www.defenselink.mil/contracts/2004/ct20040525.html.

96 "Tenth Interceptor Emplaced for the Ballistic Missile Defense System," Missile Defense Agency, 05-FYI-0071, 20 December 2005. Online: http://www.mda.mil/mdalink/pdf/05fyi0071.pdf.

97 David Ruppe, "Committee Urges Kill Vehicle Use in NFIRE Test," Global Security Newswire, 29 September 2005. Online: http://www.nti.org/d_newswire/issues/2005_9_29.html#126031C4.

98 Wright and Grego, pp. 7-10.

99 Hans M. Kristensen, Matthew G. McKinzie, and Robert S. Norris, "The protection paradox," *Bulletin of the Atomic Scientists*, No. 2 (March/April 2004), pp. 68-77; Michael Jasinski, "Russia: Strategic Early Warning, Command and Control, and Missile Defense Overview," Centre for Nonproliferation Studies, March 2001. Online: http://www.nti.org/db/nisprofs/russia/weapons/abmc3/c3abmovr.htm; "Gorgon (SH-11/ABM-4)," Missilethreat.com. Online: http://www.missilethreat.com/systems/gorgon.html.

100 Wang Qing, Yang Bao-Qing, Ma Ke-mao, "PWPF Optimizing Design and Its Application Research to Terminal Guidance of Kinetic Killing Vehicle," *Journal of Astronautics*, No. 5 (2005), pp. 576-580; Gao Da-yuan, Chen Ke-jun, Hu De-we, "Modeling and Simulation of Guidance and Control of Kinetic Kill Vehicle in Terminal Process of Interception," *Journal of Astronautics*, No. 4 (2005), pp. 420-424, 435; Liu Shi-yong, Wu Rui-lin, Zhou Buo-zhao, "Bearings-only Passive Ranging for Exo-atmospheric Interceptor," *Journal of Astronautics*, No.3 (2005), pp. 307-313; Wang Qing-chao, Li Da, "A Study of Kinetic Interceptor Attitude Control System Based on Feedback Linearization," *Journal of Astronautics* No. 3 (2005); Liu Shi-yong, Wu Rui-lin, Zhou Bo-zhao, "Research on Midcourse Guidance for Fuel-Exhaustion-Shutoff exo-Atmospheric Interceptor," *Journal of Astronautics*, No. 2 (2005), pp. 156-163; Lu Yadong, Yang Ming, and Wang Zicai, "Midcourse Guidance of Interceptor Based on Zero Effort Miss Forecasting," Aerospace Control, No. 6 (2005), pp. 17-21; Yu Jiang and Yu Yao, "Analysis of Attitude Control Effect for Extra-atmospheric Mass Moment Spinning Interceptor," Aerospace Control, No. 5 (2005), pp. 4-8; Liu Shiyong, Wu Ruilin, and Zhou Bozhao, "Midcourse Guidance Based on the Interception Point for Exo-atmospheric Interceptor," *Aerospace Control*, No. 2 (2005), pp. 54-58; Cheng Long and Chen Yong, "A Method of Determining Intercepting Orbit," *Aerospace Control*, No. 1 (2005), pp. 65-68. Key articles from previous years include Chen De-yuan and Liu Qinghong, "The development and application of hit-to-kill kinetic vehicle technology," *Modern Defense Technology*, 1997, No. 5 (1997), pp. 10- 17; Zhou Di, Mu Chun-Di, and Xu Wen-li, "Integrated attitude control of the space interceptorm," *Tsinghua Science and Technology*, No. 1 (1999), pp. 106-109; Liu Shi-yong, Wu Rui-lin, Zhou Bo-zhao, "Research on burnout reference guidance law for an exo-atmospheric interceptor," *Aerospace Control*, No. 2 (2004), pp. 24-28; Zhou Hongjian, Zhao Yongjun, Wu Ruilin, "Application of PWPF modulator in space interceptor side force control," *System Engineering and Electronics*, No. 2 (1997), pp. 9-12; Tang Guojian, Ren Xuan, Wu Ruilin, "A method for attitude control of space interceptor rapidly tracking LOS," *Aerospace Control*, No. 2 (2000), pp. 52–58; Ma Kemao, Shi Xiaoping, and Wang Zicai, "Terminal guidance law design in space interception," *Aerospace Control*, No. 1 (1998), pp. 39-42; Chen Fen-zhou, Wan Ziming, and Cheng Shi-lu, "Terminal guidance analysis of extra atmospheric kinetic kill vehicle," *Flight Dynamics*, No. 1 (2002), pp. 38-41; Jia Peiran and Tang Guojian, "Realization of Target Satellite Interception with Velocity-Gain Guidance," *National University of Defense Technology Journal*, No. 2 (1992), pp. 72-77.

101 M. Malassigne, M. Baillion, and P. Clar, "EXOGUARD: The Exo-Atmospheric Interceptors Family," Presented at the 2nd AAAF International Conference on Missile Defence "Challenges In Europe," Florence, 15-17 September 2004. Abstract online: http://www.aaaf.asso.fr/contenu2id-88.html; "Ballistic

missile defence," EADS Space, 2005. Online: http://www.space.eads.net/families/a-safer-world/futuredefnce/missile-defence-systems-exoguard; "EADS SPACE - At the heart of european space defence," EADS Space, Press Release 10 June 2005. Online: http://www.space.eads.net/press-center/press-documents/467-en.

102 "Raytheon, EADS ST sign cooperative agreement for ballistic missile defense interceptors," EADS ST Press Release, 15 September 2004. Online: http://www.space.eads.net/press-center/archives/2004/384.

103 "NATO Missile Defence Feasibility Study Transatlantic Industry Study Team selected," NATO, Press Release, 29 September 2003. Online: http://www.nato.int/docu/pr/2003/p03-109e.htm; "EADS SPACE - At the heart of european space defence."

104 M. Benett, "Optimal Guidance & Control of Exo-Atmospheric Kill Vehicles," Presented at the 2nd AAAF International Conference on Missile Defence. Abstract online: http://www.aaaf.asso.fr/contenu2id-77.html.

105 "Cutting edge micro satellite achieves milestones," Air Force Research Laboratory Space Vehicles Directorate, Press Release, 21 October, 2005. Online: http://www.vs.afrl.af.mil/News/05-22.pdf; Leonard David, "Air Force Satellite Shows Off Rendezvous Skills," Space.com Technology News, 12 September 2005. Online: http://www.space.com/businesstechnology/050912_XXS-11_update.html; "XSS-11 Micro Satellite," Air Force Research Laboratory, Fact Sheet, December 2005. Online: http://www.vs.afrl.af.mil/FactSheets/XSS11-MicroSatellite.pdf; James Oberg, "Air Force microsatellite passes key first tests," MSNBC, 9 September 2005. Online: http://msnbc.msn.com/id/9271610/.

106 The ATV project is carried out by lead contractor EADS Launch Vehicles, its subsidiaries Daimler Chrysler Aerospace Bremen (Germany) and Aerospatiale Les Mureaux (France), and partners Alenia Spazio (Italy), Matra Marconi Space (France), Oerlikon Contraves (Switzerland), Alcatel Bell Telephone (Belgium), and will use Ariane-5 launch vehicles. "DART Demonstrator to Test Future Autonomous Rendezvous Technologies in Orbit," Marshall Space Flight Center, NASA, Fact Sheet, September 2004. Online: http://www.nasa.gov/centers/marshall/pdf/100402main_dart.pdf; Brian Berger, "Fender Bender: NASA's DART Spacecraft Bumped Into Target Satellite," *Space News*, 23 April 2005; Michael Braukus and Kim Newton, "On Orbit Anomaly Ends DART Mission Early," NASA, Press Release, 16 April 2005. Online: http://www.nasa.gov/mission_pages/dart/media/05-051.html.

107 "Making a Deep Impact," NASA Jet Propulsion Laboratory, NASA, Fact Sheet. Online: http://deepimpact.jpl.nasa.gov/mission/factsheet-postencounter.pdf; "Deep Impact: First look inside a comet," NASA Jet Propulsion Laboratory, Fact Sheet. Online: http://deepimpact.jpl.nasa.gov/mission/factsheet-color.pdf.

108 "Japan Says Landmark Asteroid Probe Likely To Have Failed," Agence France-Presse, 7 December 2005; JAXA, "Status of the Hayabusa," Japan Aerospace Exploration Agency, Press Release 14 December 2005. Online: http://www.jaxa.jp/press/2005/12/20051214_hayabusa_e.html; Stephen Clark, "Fate of Japan's troubled asteroid probe still uncertain," *Spaceflight Now*, 11 December 2005. Online: http://spaceflightnow.com/news/n0512/11hayabusa/; "Hayabusa," Missions, JAXA. Online: http://www.isas.jaxa.jp/e/enterp/missions/hayabusa/index.shtml.

109 "Orbital Recovery Group Signs a Reservation for the First Satellite Servicing Mission Using its CX-OLEVTM 'Space Tug,'" Orbital Recover Group, Press Release, 11 October 2005. Online: http://www.orbitalrecovery.com/news15.html.

110 "SSTL's Latest Microsatellites Launched Successfully," Surrey Satellite Technologies Ltd., Press Release, 27 October 2005. Online: http://www.sstl.co.uk/index.php?loc=6; "Countdown Started for SSTL's Latest Microsatellite Launch on Thursday," Surrey Satellite Technologies Ltd., Press Release, 26 October 2005. Online: http://www.sstl.co.uk/index.php?loc=6; "Surrey Satellite Technology Ltd sign RapidEye Launch Agreement with ISC Kosmotras," Surrey Satellite Technologies Ltd., Press Release, 11 April 2005. Online: http://www.sstl.co.uk/index.php?loc=27&id=805; Theresa Hitchens, "Developments in Military Space: Movement toward space weapons?" Center for Defense Information, 11 October 2003. Online: http://www.cdi.org/pdfs/space-weapons.pdf; "SSTL Contract for Los Alamos," *Surrey Space Newsletter,* Summer 2004, p. 2. Online: http://www.sstl.co.uk/documents/SurreySpace5.pdf.

111 A partnership with ESA, Dutch Space, DLR (German Space Agency), Swedish Space Corporation, SENER, Kayser-Threde, Arianespace, GMV, CASA, Snecma and Contraves Space. "Cone Express," Dutch Space, Fact Sheet. Online: http://www.dutchspace.nl/uploadedFiles/Products_&_Services/ConeXpress/ConeXpress%20OLEV.pdf.

112 "Orbital Recovery Group Signs a Reservation for the First Satellite Servicing Mission Using its CX-OLEVTM 'Space Tug'"; "Innovative space tug to prolong the lives of satellites," European Space Agency, Press Release, 18 November 2005. Online: http://www.esa.int/esaCP/SEMMD1ULWFE_index_0.html; "Cone Express."

113 "Technical challenges push the launch of the ATV to 2007," ESA, Press Release, 7 November 2005. Online: http://www.esa.int/SPECIALS/ATV/SEMEHL638FE_0.html; "The Automated Transfer Vehicle," ESA, 1 June 2005. Online: http://www.esa.int/SPECIALS/ATV/ESAE021VMOC_0.html; "Automated Transfer Vehicle (ATV) – Summary," Satellite platform database, Space and Tech. Online: http://www.spaceandtech.com/spacedata/platforms/atv_sum.shtml.

114 These include EADS SPACE Transportation, Kayser-Threde, Hoerner & Sulger, and the Russian company RKK Energia.

115 "International Space Station Status Report #05-4," Johnson News, NASA, 26 January 2005. Online: http://www.nasa.gov/centers/johnson/news/station/iss05-04.html; "Robotics Component Verification on ISS," German Aerospace Center. Online: http://www.dlr.de/rm/en/Desktopdefault.aspx/tabid-484/665_read-913/; "NASA Space Station On-Orbit Status 17 May 2005," Status Report, NASA HQ, 17 May 2005. Online: http://www.spaceref.com/news/viewsr.html?pid=16659; "German space robotic system on its way to the International Space Station," EADS Space, 20 December 2004. Online: http://www.spaceref.com/news/viewpr.html?pid=15743; Hirzinger, G. et al, "ROKVISS - Robotics Component Verification on ISS Current Experimental Results on Parameter Identification," 8th International Symposium on Artificial Intelligence, Robotics and Automation in Space, 5 September 2005.

116 "Canadarm2," Canadian Space Agency, Press Release, 24 February 2005.

117 "Ongoing Space Robotics Missions: TEChnology SAtellite for demonstration and verification of Space systems," German Aerospace Center. Online: http://www.dlr.de/rm/en/Desktopdefault.aspx/tabid-484/665_read-718/; Bernd Sommer and Michael Turk, "Automation and Robotics in the German Space Program: Unmanned on-orbit servicing (OOS), ROKVISS and the TECSAS mission," DLR German Aerospace Center, presentation at ASTRA 2004, Noordwijk, The Netherlands. Online: http://www.on-orbit-servicing.com/pdf/ASTRA2004-Berndsommer-Pres.pdf; Roberto Lampariello, "Motion Planning for the On-orbit Grasping of a Tumbling Target with Large Momentum," German Aerospace Center, International Workshop on Motion Planning in Virtual Environments, LAAS-CNRS, Toulouse, France, 7-8 January 2005. Online: http://www.laas.fr/~nic/MOVIE/Workshop/Slides/Roberto.Lampariello.pdf; G. Hirzinger, K. Landzettel et al., "DLR's robotics technologies for on-orbit servicing," *Advanced Robotics* 18 (2004), pp. 139-174.

118 "Department of Defense Fiscal Year (FY) 2006/FY 2007 Budget Estimates: Research, Development, Test, and Evaluation, Defense-Wide, Volume 1: Defense Advanced Research Projects Agency (DARPA)," US Department of Defense, February 2005, p. 262. Online: http://www.dod.mil/comptroller/defbudget/fy2006/budget_justification/pdfs/rdtande/DARPA.pdf; Sean O'Keefe, *Letter dated December 23, 2004 from NASA Administrator Sean O'Keefe Addressed to Christopher S. Bond, Committee on Appropriations*, 23 December 2004. Online: http://www.nasa.gov/pdf/107781main_FY_05_op_plan.pdf; "NASA Solicitation: Dexterous Robot and Grapple Arm for HST Robotic Servicing and Deorbit Mission (HRSDM)," Goddard Space Flight Center, NASA Status Report, 16 June 2004. Online: http://www.spaceref.com/news/viewsr.html?pid=13150; "HST End of Mission (EOM) Options," Goddard Space Flight Center, HST Program Office, NASA, 21 July 2003.

119 Zhu Renzhang, Tang Yi, and Meng Wei, "The Control Method and Control Algorithm for Homing and Closing Phases of Space Rendezvous," *Chinese Space Science and Technology*, No. 5 (2005); Zhu Renzhang and Yin Yan, "Guidance Strategy Design for the Final Translation of Space Rendezvous," *Chinese Space Science and Technology*, No. 5 (2004); Han Chao and Xie Huawei, "Research on Algorithm of Loopy Lambert Transfer in Space Rendezvous," *Chinese Space Science and Technology*, No. 5 (2004). http://www.cast.ac.cn/en/ShowArticle.asp?ArticleID=301; Li Zifeng, "A Relative Guidance Algorithm for Proximity of Docking," *Aerospace Control*, No. 5 (2005), pp. 27-30, 41. Online: http://www.wanfangdata.com.cn/qikan/periodical.Articles/htkz/htkz2005/0505/050507.htm; Cheng Long, Chen Yong, "A Method of Determining Intercepting Orbit," *Aerospace Control*, No. 1 (2005), pp. 65-68; Zhu Renzhang, Yin Yan, and Tang Yi, "The Control Strategy for the Final Translation of Space Rendezvous," *Chinese Space Science and Technology*, No. 4 (2005); Sun Xing, Wan Zi-ming, Cheng Chu-zhi, "Energy required analysis of space intercept terminal guidance," *Modern Defence Technology*, No. 6

(2005), pp. 28-31,
www.wanfangdata.com.cn/qikan/periodical.Articles/xdfyjs/xdfy2005/0506/050607.htm.

120 Wang Chaoqun, "Semi Physical Simulation Technique about the RF/IR Dual-mode Integrated Homing Guidance System," *Aerospace Control*, No. 1 (2005), pp.76-78; Zhu Zhiyu, Zhang Bing, Jiang Changsheng, "Corrected Kalman Filter Using BP Neural Network," *Aerospace Control*, No. 6 (2005), pp. 22-26.

121 Some of these negation uses were highlighted in Matt Bille, Robyn Kane and Mel Nowlin, "Military microsatellites - Matching requirements and technology," presentation at the American Institute of Aeronautics and Astronautics Space 2000 Conference and Exposition, Long Beach, CA, 19-21 September 2000. Online: http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=7362.

Chapter Eight Endnotes

1 Elizabeth Waldrop, "Weaponization of Outer Space: US Policy," *Annals of Air and Space Law* 29 (2004), pp. 1-28.

2 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1, 2 August 2004, p. 2 (the *Counterspace Operations* document represents the views of the USAF and not necessarily that of the US Government); Marc J. Berkowitz, "National Space Policy and National Defense," in Peter Hayes ed., *Spacepower for a New Millennium: Space and U.S. National Security* (New York: McGraw-Hill, 2000); Everett Dolman, Classical Geopolitics in the Space Age (London: Frank Cass, 2002); Tom Wilson, "Threats to United States Space Capabilities," Prepared for the Commission to Assess United States National Security Space Management and Organization, 2003. Online: http://www.fas.org/spp/eprint/article05.html#33.

3 Bob Preston et al., *Space Weapons, Earth Wars* (Santa Monica: RAND Corporation, 2002). Online: http://www.rand.org/publications/MR/MR1209/.

4 J.C. McDowell, Personal communication with author, 3 April 2005.

5 J.C. McDowell, "The Soviet Fractional Orbital Bombardment System, A Short History," publication in preparation; personal communication with author, 3 April 2005.

6 Robert Scheer, "Pssst. Want to Know a Secret? Just Ask Teller," *Los Angeles Times*, 25 May 1999; Joseph Nilsen, "Legacy of the X-ray Laser Program," Lawrence Livermore National Laboratory, November 1994. Online: http://www.llnl.gov/etr/pdfs/11_94.2.pdf; "Relay Mirror Experiment," Ball Aerospace. Online: http://www.ball.com/aerospace/rme.html; Preston et al.; Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Henry L. Stimson Center, 2003); "Brilliant Pebbles: Fact Sheet," Ball Aerospace. Online: http://www.ball.com/aerospace/bpebbles.html.

7 Mark Wade, "Chronology 2004," Encyclopedia Astronautica. Online: http://www.astronautix.com/; "Satellite Catalogue and Launch Catalogue," Jonathan's Space Report. Online: http://planet4589.org/space/log/satcat.txt.

8 "Space Based Laser Put on Hold," *Arms Control Today*, December 2002.

9 "Space-Based Laser Research," Air Force Research Laboratory, August 2004. Online: http://www.afrlhorizons.com/Briefs/Aug04/DE0302.html; Jeffrey Lewis, "Liftoff for Space Weapons," Center for International and Security Studies at Maryland (CISSM), 21 July 2003.

10 David Pugliese, "U.S. wants to build space laser in total secrecy: Weapon could be in use before it's made public, Canadian military fears," *Ottawa Citizen*, 1 July 2004.

11 "Clementine – DSPSC," US Naval Research Laboratory, 2002. Online: http://www.cmf.nrl.navy.mil/clementine/; "Clementine Project Information," NASA-GSFC. Online: http://nssdc.gsfc.nasa.gov/planetary/clementine.html.

12 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification," February 2004. Online: http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf.

13 David Ruppe, "House Committee Cuts Space Interceptor Test Program," Global Security Newswire, 15 June 2004. Online: http://www.nti.org/d_newswire/issues/2004/6/15/ed3ecef6-efb6-4740-a39c-b49388ec20a9.html; Jeremy Singer, "MDA to remove "kill vehicle" sensor from NFIRE," *Space News*, 23 August 2004.

14 "Microsatellite Propulsion Experiment Industry Day," Air Force Material Command, 30 August 2004.Online: http://www.spaceref.com/news/viewsr.html?pid=13807.

15 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification," February 2004. Online: http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf.

16 David Barton et al., "Report of the APS Study Group on Boost-Phase Intercept Systems for National Missile Defense," American Physical Society, 15 July 2003. Online: http://www.aps.org/public_affairs/popa/reports/nmd03.cfm.

17 Barton et al.

18 "Alternatives for Boost-Phase Missile Defense," Congressional Budget Office, July 2004. Online: http://www.cbo.gov/ftpdoc.cfm?index=5679&type=1.

19 Preston et al.; Krepon and Clary; Bruce de Blois, Richard Garwin, Scott Kemp and Jeremy Marwell, "Space Weapons Crossing the US Rubicon," *International Security* 29 (Fall 2004), pp. 50-84.

20 "Automated Transfer Vehicle," European Space Agency. Online: http://www.esa.int/esaMI/ATV/index.html.

21 John Pike and Peter Voth, "Current plans for missile defence," *Disarmament Forum*, No. 1 (2001), p. 7.

22 Gunter Dirk Krebs, "Spirale 1, 2," Gunter's Space Page. Online: http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/spirale-1.htm.

23 Space Exploration Technologies, Company Description. Online: http://www.spacex.com/.

24 "India to launch microsatellite developed by engg students Saikat Chakraborty," Organisation of Asia-Pacific News Agencies, 23 November 2003.

25 "Nuclear Reactors in Space," Briefing Paper 8, Uranium Information Centre, January 2004. Online: http://www.uic.com.au/nip82.htm.

26 Gunter Dirk Krebs, "Military Satellites," Gunter's Space Page. Online: http://www.skyrocket.de/space/sat.htm.

27 "China to launch first space solar telescope in 2008," *Press Trust of India*, 24 October 2004.

28 "Crew Return Vehicle for the International Space Station," European Space Agency. Online: http://www.esa.int/esaHS/ESARZS0VMOC_iss_0.html.

29 "CNES and Aquitaine Regional Council join forces for atmospheric re-entry programmes," CNES, 8 November 2004. Online: http://www.cnes.fr/html/_455_463_1545_2863_.php.

30 "Research on Flight Demonstrations," Japanese Aerospace Exploration Agency (JAXA). Online: http://www.ista.jaxa.jp/res/b01/0b02.html.

31 The SBSW section of the table does not imply the existence of a program for integrating these into an actual SBSW system, nor the capability to deploy that SBSW, just the existence of some capability for each of the necessary prerequisite technologies for that particular SBSW system. This clarification is important since integration of these technologies into a working system, including testing, can take many years. Nevertheless, with the prerequisite technologies in hand, the SBSW systems are considerably closer to the reach of that actor. It is clear that only the US and Russia currently have all the prerequisite technologies for SBSW systems.

32 The capabilities in each prerequisite technology can vary a great deal. The filled square only indicates that there is some capability.

33 Cited by David Ruppe, "Committee Urges Kill Vehicle Use in NFIRE Test," Global Security Newswire, 29 September 2005.

34 Ruppe, "Committee Urges Kill Vehicle Use in NFIRE Test."

35 The experiment was designed to track target missiles launched from Vandenberg Air Force Base, gather information on ballistic missile conditions in space, and then eventually attempt to intercept a target missile using a ground-based kill vehicle.

36 "Near Field Infrared Experiment (NFIRE)," MissileThreat.com. Online: http://www.missilethreat.com/systems/nfire_usa.html?PAGE_PRINT=yes.

37 David Ruppe, "Committee Urges Kill Vehicle Use in NFIRE Test."

38 MDA hopes to conclude an agreement on the laser terminal with Germany in early 2006. "German Payload to Fly Aboard NFIRE Satellite," *Space News*, 19 August 2005; Marc Sellinger, "NFIRE proposal may spark Hill debate on space weapons," *Aerospace Daily & Defense Report*, 4 October 2005.

39 Vladimir Isachenkov, "Putin boasts Russia has missiles capable of piercing and missile defense system," Associated Press, 31 January 2006.

40 Martin Seiff, "Rumsfeld Developing New First Strike Doctrine," United Press International, 9 February 2006.

41 "Hypersonic Cruise Vehicle – Force Application and Launch from CONUS."

42 "Hypersonic Cruise Vehicle – Force Application and Launch from CONUS."

43 "EXPERT," European Space Agency, 15 November 2004.

44 "ONERA: Annual Report 2004-2005," ONERA, 2005. Online: http://www.onera.fr/actualites/onera-annual-report-2004-2005-en.pdf.

45 Yuan Guoxiong, "Reentry Guidance Laws of Weapon System of Space Based Attack Ground," *Control Technology of Tactical Missile*, No.3 (2004), pp. 72-76. Online: http://www.wanfangdata.com.cn/qikan/periodical.Articles/zsddkzjs/zsdd2004/0403/040316.htm; Yuan Guoxiong, "Study on Reentry Guidance Technique for Orbit Weapon Fighting Cabin," *Aerospace Control* 23, No.2 (2005), pp. 4-7. Online: http://www.wanfangdata.com.cn/qikan/periodical.Articles/htkz/htkz2005/0502/050202.htm.

46 "Fanhui shi weixing (FSW-3) / Jianbing-4 recoverable satellite," *China Defence Today*, 11 March 2006. Online: http://www.sinodefence.com/.

47 Senior Pentagon officials cited intractable technical difficulties as the reason for the change to the SBIRS plan. Jeremy Singer, "Pentagon Scales back SBIRS Program," *C4ISR Journal*, 4 January 2006.

48 Singer.

49 "Russia successfully tests anti-missile missile in Kazakhstan," Interfax, 29 November 2004.

50 "New Russian Early-Warning Radar," ITAR-TASS, 27 May 2005.

51 Vladimir Dvorkin, "An Outlook for Joint Countering of Security Threats," *Russia in Global Affairs,* No.4, (October-December 2005). Online: http://eng.globalaffairs.ru/numbers/13/966.html.

52 Dimitry Litovkin, "Thirty Years is not the Maximum: Russia's missile defense capabilities will be updated," Center for Defense Information, Weekly #241, 23 January 2003. Online: http://www.cdi.org/russia/241-6.cfm.

53 Dvorkin.
"Russian Radar in Azerbaijan Profiled," *BBC Monitoring*, 28 February 2005. Online: http://www.missilethreat.com/news/200502280828.html.

54 Dvorkin.

55 Dvorkin.

56 Duan Xiaojun et al., "Detection of Systematic Error Based on Integral Matched Filter," *Chinese Space Science and Technology* 26, No.1 (February 2006). Online: http://www.cast.ac.cn/en/ShowArticle.asp?ArticleID=1384.
Liu Yuan et al., "Relatively Locating a Space Target Using Angle Only Measurements," *Chinese Space Science and Technology* 26, No.1 (February 2006). Online: http://www.cast.ac.cn/en/ShowArticle.asp?ArticleID=1384.

57 "USAF readies modernized GPS satellite for launch," *Wireless Satellite & Broadcasting Newsletter*, 10 March 2005.

58 "Russia, China space rockets equipped with GLONASS," ITAR-TASS, 3 November 2005; "Russia, India to cooperate in satellite navigation," RIA Novosti, 16 November 2005. Online: http://en.rian.ru/russia/20051116/42110098.html.

59 Adrian Schofield, "Blakey Pledges US Support for India's GAGAN Program," *Aviation Daily*, 26 October 2005, p. 2.

60 "EU launches Galileo satellite," *Associated Press*, 28 December 2005.

61 "Morocco signs Galileo partnership agreement with EU," *Al-Bawaba*, Comtex News Network, 9 November 2005; "Israel joins Galileo: The Israel Entity MATIMOP, on the way to becoming a Member of the Galileo Joint Undertaking," *Galileo Joint Undertaking*, Press Release, 18 May 2005; "EU, Ukraine Initial Galileo Agreement," United Press International, 16 June 2005; Martial Tardy, "India Joins Galileo; Parliament Considers Funds," *Aviation Daily*, 9 September 2005, p. 7; Mark Milner, "Satellites: Saudi Arabia expected to navigate with Galileo," *Guardian* (London), 29 September 2005, p. 21.

62 "Morocco joins EU's Galileo satellite program," Associated Press, 8 November 2005.

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