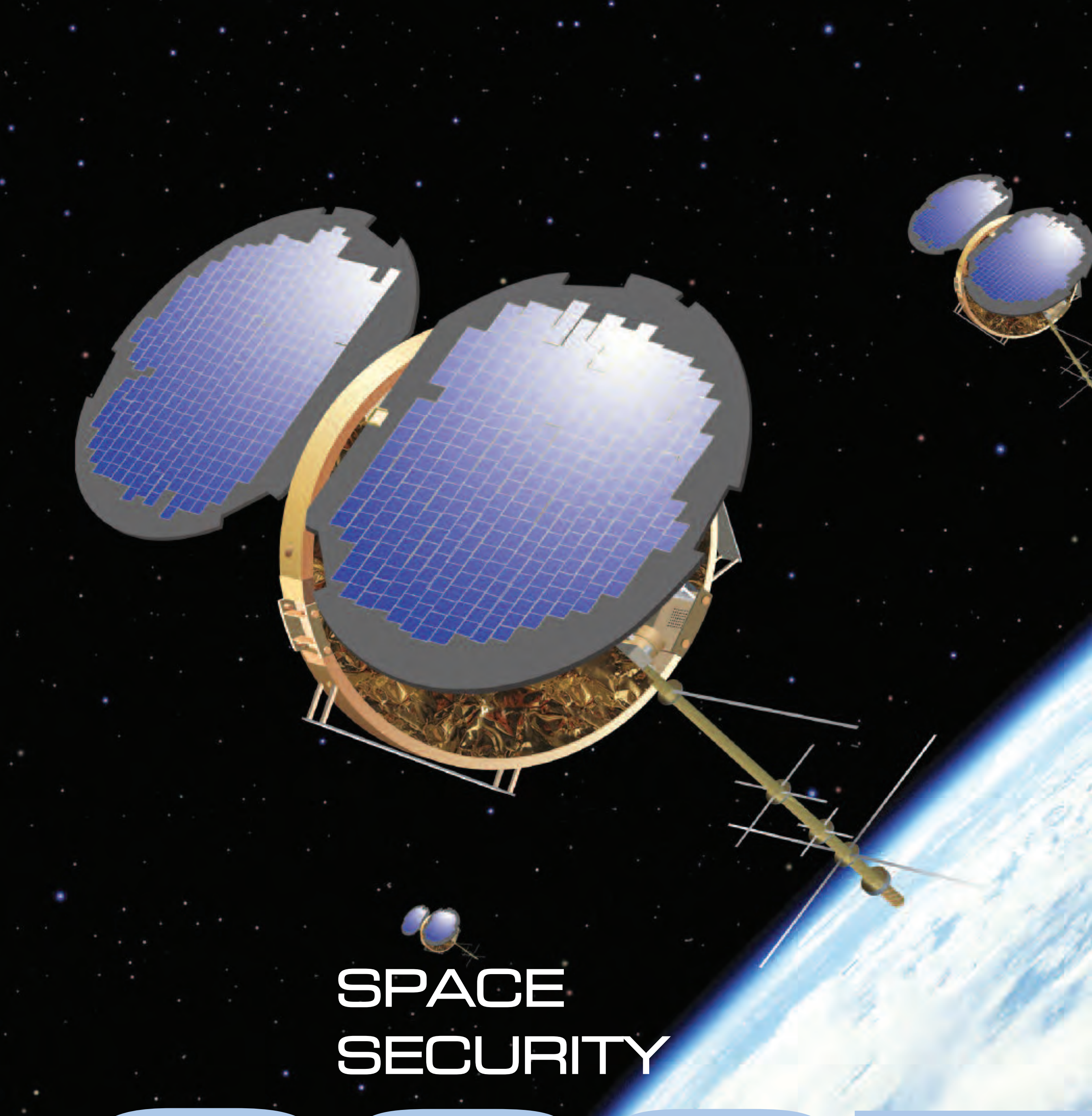


SPACE SECURITY

2007

SPACESECURITY.ORG

SPACE SECURITY 2007

SPACESECURITY.ORG

Library and Archives Canada Cataloguing in Publications Data

Space Security 2007

ISBN: 978-1-895722-58-1

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

Cover image: Orbital Sciences Corporation. Artists' illustration of six microsatellites launched 14 April 2006 to form COSMIC, the Constellation Observing System for Meteorology, Ionosphere, and Climate, a joint project between the United States and Taiwan.

Printed in Canada

First published August 2007

Please direct inquiries to:
Project Ploughshares
57 Erb Street West
Waterlo, Ontario
Canada N2L 6C2
Telephone: 519-888-6541
Fax: 519-888-0018
Email: plough@ploughshares.ca

TABLE OF CONTENTS

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

Space Security 2007 is the fourth annual report on trends and developments in space, covering the period January to December 2006. It is part of a wider Space Security Index project that seeks to facilitate dialogue on space security challenges and potential responses. Keeping with the intent of the 1967 Outer Space Treaty, that space is to be a global commons used for peaceful purposes, the definition of space security that guides this report is:

The secure and sustainable access to, and use of, space and freedom from space-based threats.

The primary consideration is not the interests or the security of specific actors operating in space, but the security of space as an environment that can be sustained for use by all actors. Threats to the sustainable use of the space environment can originate in outer space or from Earth. Also of concern is the vulnerability of Earth to threats from space.

The status of space security is assessed according to the following eight indicators:

- The space environment
- Space laws, policies and doctrines
- Civil space programs and global utilities
- Commercial space
- Space support for terrestrial military operations
- Space systems protection
- Space systems negation
- Space-based strike systems

Because space is a particular, and a particularly sensitive, environment it presents unique challenges to the international community. The growing number and diversity of actors using space demonstrate the vital importance of this environment, but intensifying space use creates governance challenges in managing space traffic, limiting the destructive potential of increased orbital debris, and distributing scarce resources such as orbital slots and radio frequencies. Moreover, technologies that better enable the use of space for some can have the inherent potential to deny the secure use of space for others. It is clear that technological developments are outstripping the existing governance framework for outer space. The goal of *Space Security 2007* is to improve transparency with respect to space activities, and thereby support the development of policy to ensure secure access for all.

This annual report also strives to track and document changes in long-term trends affecting the security of outer space so that the international community might better assess the impact of the use and regulation of that environment. Each chapter provides a description of a specific indicator and its impact on space security. A discussion of the prevailing trends associated with each indicator is followed by an overview of key developments throughout the year and an assessment of their effect on established trends and the broader security of outer space. Several long-term changes have been captured and reflected in our characterization of different indicators. For example, a prolonged decline in the annual amount of new space debris produced, described in Trend 1.1 under the Space Environment, reversed in 2004 and rates are once again increasing. As the project has evolved, so too has the nature of this assessment. The goal is no longer to determine an absolute positive or negative impact caused by annual events, but rather to consider the range of implications that developments have on the security of space, just as policymakers must reflect on the multiple effects of their decisions.

Space Security 2007 has made an exception to covering events in the strict calendar year of 2006 to include the immediate details of the hit-to-kill intercept of a redundant weather satellite on 11 January 2007 by the People's Liberation Army of China. This anti-satellite demonstration followed two previously unreported Chinese attempts to intercept a satellite with a ballistic missile in 2005 and 2006. It is the first openly conducted anti-satellite demonstration since 1985 and is considered to be one of the worst manmade space debris-creating events in history. This single event had a direct bearing on the space environment, space law, technologies to protect and deny the use of space, and the ability of all actors to operate securely in the space environment. The consequences of the Chinese satellite destruction will be covered in *Space Security 2008*.

The fact that some space actors maintain a level of secrecy in their activities for strategic or commercial reasons inevitably poses a challenge to the comprehensive nature of this report. *Space Security 2007* is based entirely on open source information. Great effort was made to ensure a complete, neutral, and accurate description of events based on a critical appraisal of the available information and consultation with international experts.

Expert participation in the Space Security Index is a crucial component of the project. Research gathered is reviewed through the annual Space Security Survey and the Space Security Working Group consultation held each spring. The Working Group is also an important forum for dialogue on space security challenges and potential responses. While the survey provides invaluable insights into the perceptions, concerns, and priorities of space stakeholders around the world, as well as feedback on the research, the results of the 2007 survey have not been published in this report due to the limitations of the statistical data. They are available on the project's website.

For further information about the Space Security Index, its methodology, project partners, and sponsors, please visit the website **www.spacesecurity.org**.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the many advisors and expert participants who have supported this project since its inception in 2003. Simon Collard-Wexler and Sarah Estabrooks deserve special mention for their past service and for their continuing willingness to provide advice despite no longer having direct roles in the project. Dr. William Marshall provides invaluable ongoing technical expertise. Managing Editor Jessica West took hold of her responsibilities in September 2006 and has provided the day-to-day guidance and coordination without which the project would be impossible.

Research for *Space Security 2007* was carried out under the direction of Dr. Ram Jakhu and supervision of Dr. Maria Buzdugan at the McGill University Institute of Air and Space Law. The researchers were Ms. Martine De Serres, Mr. Joseph Hillier, Mr. Yaw Nyampong, Mr. Karan Singh, Ms. Susan Trepczynski, and Mr. Brian Wong. For copyediting and design, we would like to thank Ms. Wendy Stocker at Project Ploughshares and Graphics at the University of Waterloo. For comments on early drafts of the text we would like to thank Mr. Douglas Aldworth, Mr. Phil Coyle, Mr. Richard DalBello, Dr. Paul Dempsey, Dr. Nancy Gallagher, Air Marshall Lord Garden, Dr. Tom Gillon, Ms. Theresa Hitchens, Mr. Lars Hostbeck, Dr. Jeffrey Lewis, Dr. John Logsdon, Dr. William Marshall, Dr. Jonathan McDowell, Dr. Goetz Neuneck, Dr. Isabelle Sourbes-Verger, and Dr. Lucy Stojak. We would also like to thank those who provided valuable input through the online Space Security Survey and the Space Security Working Group (see Annex One). For organizing the Space Security Working Group meeting on 15-16 March 2007, we are grateful to the McGill University Institute of Air and Space Law, in particular Dr. Maria Buzdugan, Ms. Maria D'Amico, Dr. Paul Dempsey, Dr. Nicholas Kasirer, and Dr. Ram Jakhu.

This project would not be possible without the generous financial and in-kind support from the Ford Foundation, the Secure World Foundation, The Simons Foundation, the International Security Research and Outreach Programme at the Department of Foreign Affairs and International Trade Canada, the Social Science and Humanities Research Council of Canada, and the Nicolas Mateesco Matte Fund for Space Law of McGill University.

While we as the Governance Group for the Space Security Index have benefited greatly from the input of many experts in the development of Space Security 2007, responsibility for any errors or omissions in this volume rests with us. The content does not necessarily reflect the views of the Spacesecurity.org partners – the McGill University Institute of Air and Space Law, Project Ploughshares, the Secure World Foundation, the Simons Centre for Disarmament and Non-Proliferation Research, the Space Generation Foundation – or the Department of Foreign Affairs and International Trade Canada.

The Space Security Index Governance Group:

Ms. Cynda Collins Arsenault

Amb. Thomas Graham Jr.

Dr. Wade Huntley

Dr. William Marshall

Dr. Ram Jakhu

Mr. Andrew Shore

Mr. John Siebert

The Space Environment

Growing debris threats to spacecraft

Traveling at speeds of 7.5 kilometers per second, space debris poses a significant threat to spacecraft. The number of objects in Earth orbit have increased steadily; today there are an estimated 35 million pieces of space debris. Approximately 13,000 of the objects in orbit that are large enough to seriously damage or destroy a spacecraft – over 90 percent of which are space debris – are being tracked. The annual growth rate of tracked debris began to decrease in the 1990s, largely due to national debris mitigation efforts, but this trend was reversed in 2004.

Previously unreported Chinese attempts to intercept a satellite with a ballistic missile in 2005 and 2006 culminated with the hit-to-kill explosion of an aging Chinese weather satellite on 11 January 2007. It is considered to be one of the worst manmade debris-creating events in history. Over 1,300 pieces of large debris from the event have been catalogued by the US Space Surveillance Network, many of which are expected to remain in orbit for years or decades. Eight incidents of accidental satellite fragmentation also took place in 2006 – the highest number of incidents since 1993 – including the unexpected breakup of a US Delta-4 second stage.

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

Significant on-orbit collisions and tracking efforts have encouraged the recognition of space debris as 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 debris mitigation standards.

In 2006 the Space Debris Working Group of the UN Committee on the Peaceful Uses of Outer Space drafted non-binding international space debris mitigation guidelines that significantly include avoiding intentional destruction and other harmful activities in space.

Space surveillance capabilities to support collision avoidance slowly improving

Efforts to create an international space surveillance system to support collision avoidance and debris re-entry have been unsuccessful. The US Space Surveillance Network uses 30 sensors worldwide to monitor over 13,000 space objects in all orbits, but has moderated access to its data since 2004 out of concern for national security. Russia maintains a Space Surveillance System using its early-warning radars 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 independent space surveillance capabilities.

In 2006 US efforts to expand its space surveillance capabilities in GEO suffered from funding cuts and program delays. Launch of the first Space-Based Surveillance System (SBSS) satellite was delayed until 2009 and the Orbital Deep Space Imager program was cut. There were also indications that funding will be cut for future upgrades to the Space Fence radar portion of the Space Surveillance Network. Russia and the UK announced plans to improve their space surveillance capabilities.

Growing demand for radio frequencies

Expanding satellite applications are driving demand for limited resources in space, including radio frequency spectrum. More satellites are operating in the frequency bands that are commonly used by GEO satellites and are causing increasing frequency interference. Satellite operators now spend about five percent of their time addressing frequency interference issues, including conflicts such as the disagreement over frequency allocation between the US Global

Positioning System and the EU Galileo navigational system. The growth in military bandwidth consumption has also been dramatic: the US military used some 700 megabytes per second of bandwidth during Operation Enduring Freedom in 2003, compared to 99 megabytes per second during Operation Desert Storm in 1991.

The growing demand for radio frequencies was managed in 2006; there were fewer reported cases of satellite radio frequency interference. Nonetheless, growing military demand created challenges. Key technologies to increase available military bandwidth experienced delays, while use by applications, including unmanned aerial vehicles, increased. Moreover, China announced that its proposed Compass navigation system may use the military frequencies reserved for the EU's Galileo encrypted service and the US military GPS signal.

Growing demand for orbital slots

There are more than 800 operational satellites in orbit today: about 46 percent in LEO, 6 percent in MEO, 42 percent in GEO, and 6 percent in HEO. Increased competition for orbital slot assignments, particularly in GEO where most communications satellites operate, has caused occasional disputes between satellite operators. The International Telecommunication Union has been pursuing reforms to address slot allocation backlogs and related financial challenges.

Implications of growing demand for GEO orbital slots were demonstrated in 2006. The US Federal Communications Commission granted EchoStar's application to operate in the 86.5o West Latitude orbital location against opposition from Telesat Canada. Telesat claimed that the EchoStar satellite positioning would violate the standard nine degrees of separation for Direct Broadcast Satellites, resulting in interference. There are no clear rules in the US for smaller DBS satellite spacing.

Space Laws, Policies, and Doctrines

Development of legal framework for outer space activities

The international legal framework for outer space establishes the principle that space should be used for "peaceful purposes." Since the signing of the Outer Space Treaty (OST) in 1967, this framework has grown to include the Astronaut Rescue Agreement (1968), the Liability Convention (1972), the Registration Convention (1975), and the Moon Agreement (1979), as well as a range of other international and bilateral agreements and relevant rules of customary international law. The OST prohibits the stationing of nuclear weapons or any other weapons of mass destruction anywhere in space. The termination 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.

Since 1981 the UN General Assembly (UNGA) has adopted a resolution requesting that states refrain from actions contrary to the peaceful use of outer space and 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 near-unanimous support for the PAROS resolution; however, the US and Israel cast the first negative votes in 2005.

Events related to the intentional Chinese destruction of a satellite in 2006 and early 2007 raised questions about the spirit with which the OST is being implemented internationally. Meanwhile, in the Committee on the Peaceful Uses of Outer Space (COPUOS) Legal Subcommittee states disagreed over the adequacy of the existing international regime to prevent the weaponization of outer space, with the US arguing that no new legal tools are needed.

COPUOS remains active, but the CD has been deadlocked on space weapons issues since 1998

A range of international institutions, such as the UNGA, COPUOS, ITU, and the CD, have been mandated to address issues related to space security; however, the CD has been deadlocked without an agreed plan of work since 1998 and so has been unable to move forward on the PAROS mandate to develop an instrument relating to space security and the weaponization of space.

The CD remained deadlocked in 2006, although several informal discussion sessions were organized. The Space Debris Working Group of the Scientific and Technical Subcommittee of COPUOS drafted space debris mitigation guidelines consistent with those of the Inter-Agency Debris Coordination Committee and recommended voluntary implementation by all member states.

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, but often with caveats based on national security concerns.

The US has recently announced plans for peaceful space exploration of the Moon and Mars, while there is growing interest in manned space programs. The national space policies of many developing countries, such as Brazil and India, tend to focus on the utility of space cooperation for social and economic development.

The US and China adopted new space policies in 2006 that emphasize both international cooperation and national security. The US released an unclassified version of a new National Space Policy similar to the 1996 version but with notable emphasis on US freedom of action in space and opposition to new legal regimes or other restrictions on US access to, or use of, space. It maintains the tradition of US cooperation on peaceful uses of outer space. China released a White Paper on Space Activities that stresses the importance of international cooperation and exchanges, while linking China's space activities to its national interests and strengths.

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

Fueled by the technological revolution in military affairs, the military doctrine of a growing number of actors (led by China, Russia, the US, and key European states) increasingly emphasizes 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 to ensure US freedom of action in space, through the use, when necessary, of "counterspace operations" that prevent adversaries from accessing space.

Security uses of outer space continued to figure prominently in 2006. The new US National Space Policy declared freedom of action in space as important to the US as air and sea power. China's White Paper, "China's National Defense," stressed "informationization" as a key strategy in the modernization of the People's Liberation Army, although there is no express mention of the use of outer space for national defense. The ruling Liberal Democratic Party in Japan formulated a bill that would allow the Japanese government to carry out space activities expressly for non-aggressive military and/or defense purposes. India continued to consider the creation of an integrated Aerospace Command.

Civil Space Programs and Global Utilities

Growth in the number of actors gaining access to space

The rate at which new states gain access to space increased dramatically in the 1990s. By 2006 10 actors had demonstrated independent orbital launch capacity and 47 states had launched civil satellites, either independently or in collaboration with others. China recently joined Russia and the US as the only space powers with demonstrated manned spaceflight capabilities.

The year 2006 saw the launch of 47 civil spacecraft, including the first satellite owned by Kazakhstan, which became the 47th state to access space. Although launch vehicle technology continued to develop, the failure of the Indian Space Research Organization's Geo-Synchronous Satellite Launch Vehicle hindered its efforts to become one of the few states with the capability to launch heavy payloads into GEO.

Changing priorities and funding levels within civil space programs

Civil expenditures on space have continued to increase in India and China in recent years, while past decreases in the US, the EU, and Russia have begun to rebound. Increasingly, civil space programs include security and development applications. Algeria, Brazil, Chile, Egypt, India, Malaysia, Nigeria, South Africa, and Thailand are all placing a priority on satellites to support social and economic development. Dual-use applications such as satellite navigation and Earth observation are a growing focus of US, European, and Chinese civil space programs.

There was a marked focus on lunar exploration and human spaceflight in statements by civil space agencies in 2006. NASA, Russia, China, and India announced plans for future lunar missions and the ESA successfully completed its SMART mission, which crashed a spacecraft onto the lunar surface. Both the US and China referred to future human missions to the moon and lunar bases. Moreover, India announced its intention to proceed with a human spaceflight program. In the US, this focus appeared to come at the expense of NASA's space science budget. Despite these long-term policy announcements, civil space budgets generally increased only modestly in 2006.

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 such joint NASA-ESA projects as Skylab. The most prominent example of international cooperation is the International Space Station (ISS), involving 16 states, 56 launches, and an estimated cost of over $100-billion to date. International civil space cooperation has played a key role in the proliferation of technical capabilities for states to access space.

By 2006 China had signed 16 international space cooperation agreements with 13 different countries, space agencies, and international organizations. Major international cooperation initiatives in 2006 included an India/NASA agreement for technology exchange, a deal between India and Russia to jointly use Russia's GLONASS navigation system, and an agreement for the EU's EUMETSAT and the US NOAA to share meteorological information during times of crisis or war. Although NASA Chief Administrator Michael Griffin visited China in September 2006, there is no evidence that there will be substantial cooperation between the two countries in the near future.

Continued growth in global utilities as states seek to expand applications and accessibility

The use of space-based global utilities, including navigation, weather, and search and rescue systems, has grown substantially over the last decade. These systems have spawned space applications that are almost indispensable to the civil, commercial, and military sectors. Advanced economies are heavily dependent on these space-based systems. Currently China, the EU, India, Japan, Russia, and the US are developing satellite-based navigation capabilities; there are now approximately 48 navigation satellites in operation. The strategic value of satellite navigation was underscored by the conflict over frequencies for Galileo and GPS, resolved in 2004.

Expansion of space-based global utilities continued in 2006. The US moved forward with initial steps to modernize its GPS system, while Russia launched three more GLONASS satellites, bringing the system closer to full operational status. States continued to seek independent capabilities: India announced that it will create an independent Regional Navigation Satellite System and China indicated that it will extend its Beidou regional system into a global system called Compass. Meanwhile, the operational date of the EU Galileo satellite navigation system has been rescheduled from 2008 to 2011. Security concerns encroached on the use of global utilities when the EU agreed with the US NOAA to create a "data denial list" restricting certain agencies from accessing weather data from EUMETSAT.

Commercial Space

Continued growth in the global commercial space industry

Growth in the commercial space industry is dominated by satellite services, which have tripled in size since 1996 to account for 60 percent of the $88.8-billion commercial satellite sector in 2005. Individual consumers are a growing source of demand for these services. Key commercial satellite telecommunications companies include Intelsat, SES Global, Eutelsat, and Telesat Canada. In recent years Russia has dominated the space launch industry while US companies have led in the satellite manufacturing sector.

Satellite services continued to dominate the commercial space market in 2006, accounting for 60 percent of satellite industry revenues. The market was in a period of growth – there were 21 commercial launches in 2006 – nine of these by Russia – compared to 17 in 2005. US companies produced 59 percent of all satellites launched in 2006. Major corporate consolidations in the commercial communications industry indicated market efficiencies and expanding business opportunities; however, mergers in the US launch industry suggest market weakness.

Declining commercial launch costs support increased access to space

Commercial space launches have contributed to cheaper space access. 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 beginning to consolidate. In 2000, payloads could be placed in LEO for as little as $5,000/kilogram. In recent years European and Russian space agencies have been the most active space launch providers. Today's commercial launch providers include Arianespace in Europe, Energia in Russia, Lockheed Martin and Boeing Launch Services in the US, 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 sub-orbital manned spaceflight sector.

The US continued to lose commercial launch market share to Europe and Russia in 2006, while corporate consolidations between Boeing and Lockheed Martin (United Launch Alliance) and Rocketplane Ltd. and Kistler Aerospace Corporation (Rocketplane-Kistler) suggest a struggling US launch market. Moreover, the malfunction of the SpaceX Falcon-1 temporarily dashed hopes for a new, low-cost American commercial space launcher. The space tourism industry received a boost from new business and investment initiatives in 2006, but continued to face challenges posed by a lack of international legal safety standards, high launch costs, and export regulations. There was evidence of increasing space launch costs as market overcapacity diminished.

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

The commercial space sector is significantly shaped by national governments and security concerns. 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 industry also receive important space contracts from government programs. 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.

At a cost of $1-billion per year, the US Department of Defense continued to be the single largest consumer of commercial satellite services. National security concerns placed ongoing restrictions on the commercial space industry in 2006, particularly for satellite imagery service providers, which faced additional government resistance to the public availability of images covering what are described as strategic locations. The close relationship between governments, militaries, and space industries was re-established in the US and China, with national policies that link domestic space industries to national security.

Space Support for Terrestrial Military Operations

The US and Russia continue to lead in developing military space systems

By the end of the Cold War, the US and USSR had developed extensive military space systems designed to provide military attack warning, communications, reconnaissance, surveillance, and intelligence, as well as navigation and weapons guidance applications. By 2006 the US and USSR/Russia had launched more than 4,800 military satellites, while the rest of the world had launched only 80 to 90.

The US has dominated the military space arena since the end of the Cold War and currently accounts for roughly 95 percent of total global military space expenditures with approximately 130 operational military-related satellites – over half of all military satellites in orbit. Russia is believed to have some 60 dedicated military and 18 multipurpose 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.

In 2006 the US launched 14 military satellites, maintaining dominance in military space. However, a report issued by the Government Accountability Office called attention to ongoing cost overruns and delays of several high-profile space acquisition programs, including the Space Based Infrared System, the Wideband Global SATCOM, and the Advanced Extremely High Frequency programs.

While Russia's military space budget increased by about one-third in 2006, it was still dwarfed by US spending. Russia launched eight military satellites in an attempt to maintain the capacity of its aging reconnaissance, early warning, and communications system, and to bring its constellation of GLOSNASS navigation satellites closer to completion.

More states developing military space capabilities

Regional tensions are a significant driver of military space acquisitions. Declining costs for space access and the proliferation of space technology are enabling more states to develop and deploy their own military satellites via 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 access to 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, Spain, Belgium, and Greece jointly use the Helios- 1 military optical observation satellite system in LEO, which provides images with a one-meter resolution. France, Germany, and Spain have also developed a range of radar reconnaissance and communications capabilities and France is developing a missile early-warning system. The UK maintains a constellation of three dual-use Skynet 4 communications satellites in GEO. The joint EU-European Space Agency 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's civil space agency maintains its Technology Experimental Satellite for remote sensing, but it also provides military reconnaissance capabilities. Japan operates the commercial Superbird satellite for military communications and has three reconnaissance satellites – two optical and one radar. Thailand operates a military communications satellite and is developing its first intelligence and defense satellite.

Ongoing regional tensions continued to drive military space developments in 2006. Although China did not launch any dedicated military satellites, the launch of spacecraft with dual-use applications, including communications and radar imaging, potentially expanded its access to military space capabilities. Japan launched its third reconnaissance satellite and, following a series of missile tests by North Korea, tabled a bill to relax restrictions on military space applications. South Korea launched its first military satellite, Koreasat 5, which will provide military and commercial communications. India continued to work on the Military Surveillance and Reconnaissance System and to consider an integrated Aerospace Command.

Germany launched its first dedicated military satellite – SAR-Lupe – a radar reconnaissance satellite that will join France's Helios A and Italy's Cosmos Skymed (2007) to provide France, Germany, Italy, Spain, Belgium, and Greece with reconnaissance capabilities. Debate continued over the potential dual-use of European space capabilities, as the Galileo navigation system progressed and the European Space Agency considered investing in dual-use, security-related research. Canada took steps to increase its access to military space applications, including the future US Advanced Extremely High Frequency satellite system and imagery from Radarsat-2 through a new Joint Space Support Project.

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

The timely detection and warning of attacks are key for enabling defensive responses in space. Only the US and Russia can reliably detect rocket launches. US Defense Support Program satellites provide early warning of conventional and nuclear ballistic missile attacks; Russia began rebuilding its aging system in 2001 by upgrading its Oko series satellites. France is developing two missile-launch early-warning satellites – Spirale-1 and -2. 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. It is very difficult to obtain advance warning of directed energy attacks that move at the speed of light.

US efforts to upgrade its missile early-warning system progressed in 2006 with the launch of a Space Based Infrared System sensor; however, the program was over budget, behind schedule, and risked replacement by the newly initiated Alternative Infrared Satellite System. Russia closed a seven-year coverage gap in its northwestern region when its new Voronezh meter-band early warning radar was put online in 2006. Russia also brought its space-based Oko early-warning constellation back up to minimum operational status with the launch of a fourth satellite, but the system does not provide global coverage.

The ability to detect satellite interference was a concern in 2006. US STRATCOM put new procedures in place to determine the source and attribution of satellite disturbances: to improve response times, all cases are assumed to be deliberate. China was upgrading its Xi'an Satellite Monitoring Center to enable monitoring and diagnosis of satellite malfunctions, eliminate harmful interference, and prevent purposeful damage to satellite communications links. In 2006 both Japan and Europe turned to a commercial service to provide satellite interference data support.

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. The vast majority of commercial space systems have only one operations center and one ground station, leaving them 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 unique to military systems and the capabilities of more technically advanced states. China and the US have been aggressively pursuing a variety of anti-jamming capabilities.

In 2006 Europe, Japan, and the United States each made some progress in the development of satellite laser communications, but the capability remains remote. The US Transformational Satellite Communication program demonstrated the ongoing challenges related to laser communications. The program continues to face technical difficulties, cost overruns, and schedule delays – the first reduced capacity satellite is not expected to launch until 2014.

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

The primary source of protection for satellites comes from the difficulties associated with launching an attack into space. Increasingly, states are placing military satellites into higher orbits where vulnerability to attacks is lower. Satellite protection measures also include system redundancy and interoperability, which has become characteristic of satellite navigation systems. Most key US, European, and Russian military satellites are hardened against the effects of a high-altitude nuclear detonation. Reflecting concerns about the protection of commercial satellites, in 2002 the US General Accounting Office recommended that "commercial satellites be identified as critical infrastructure."

After facing potential cancellation due to cost overruns, the Orbital Express program was brought back on track in 2006 and is scheduled for launch in 2007. The program is designed to demonstrate automated approach and docking, fuel transfer, and components exchange, which could extend the life of satellites, enable greater manoeuvrability and help protect against some direct threats in space. The University of Florida and Honeywell are experimenting with a new type of spacecraft protection through software rather than hardware design.

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

The ability to rapidly rebuild space systems after an attack is critical. Although the US and Russia are developing various elements of responsive space systems, no state currently has this capability. The key US responsive launch initiative is the Falcon program, which seeks to develop a rocket capable of placing 100-1,000 kilograms into LEO within 24 hours.

There is a growing interest in rapid air-launch capabilities. The QuickReach rocket, part of the US Small Launch Vehicle project, passed several tests in 2006 and NASA Ames signed an agreement with its manufacturer, AirLaunch LCC, to collaborate on air-launched space boosters. Kazakhstan's KazCosmos also announced plans to develop the Ishim air-launched rocket system, based on the Soviet era ASAT system. China indicated that it will design a three-stage air-launched rocket released from a modified H-6 bomber. Despite these initiatives, no state has developed a launch-on-demand capability.

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 incidents of intentional jamming of communications satellites have been reported in recent years. 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. 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.

Commercial satellite systems were targets of negation in 2006. Libyan nationals were identified as the source of months-long jamming of the mobile phone services of Thuraya Satellite Telecommunications. Moreover, the potential for commercial satellites to be third-party targets during conflict was demonstrated in the 2006 Israel-Lebanon war, during which Israel tried, but failed, to jam the Al-Manar satellite channel transmitted by the Arab Satellite Communications Organization. Amateur hackers in Indonesia demonstrated the vulnerabilities of some older commercial satellite systems by collecting transmitted data.

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

Space surveillance capabilities for debris monitoring and transparency can also support satellite tracking for space negation purposes. The US and Russia maintain the most extensive space surveillance capabilities and the US has explicitly linked its development of enhanced space surveillance systems to efforts to enable offensive counterspace operations. China and India also have satellite tracking, telemetry, and control assets essential to their civil space programs. Canada, France, Germany, and Japan are actively expanding their ground-based space surveillance capabilities.

Updates to China's Xi'an Satellite Monitoring Center in 2006 reportedly included increased orbit determination and tracking capabilities, which were demonstrated when it successfully intercepted a satellite on 11 January 2007. US efforts to develop space surveillance capabilities that could support negation efforts were largely stalled in 2006, particularly in GEO. Despite progress on the Space Based Surveillance System, launch of the initial pathfinder satellite was further delayed to 2009 and the Orbital Deep Space Imager program was cut.

Ongoing proliferation of ground-based capabilities to attack satellites

The development of ground-based ASAT weapons employing conventional, nuclear, and directed energy capabilities dates back to the Cold War when a variety of US and USSR programs were initiated. Since then technologies have proliferated. 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. Some 28 states have demonstrated sub-orbital launch capability and, of those, 10 have orbital launch capability. As many as 30 states may have 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 has advanced laser programs, both of which have inherent satellite negation capabilities in LEO.

China became the third state to successfully conduct a kinetic hit-to-kill intercept of a satellite on 11 January 2007 when it destroyed a weather satellite at an altitude of approximately 850 kilometers. This was the first openly conducted ASAT demonstration since 1985. It followed US reports that a Chinese ground-based laser illuminated an American reconnaissance satellite as it passed over Chinese territory. Given the few details released about the incident, it is difficult to determine either the intensity or the intent. of the laser. Both the US and China are conducting ongoing research on high-energy lasers. Funds to testfire a US laser against a satellite in LEO from the Starfire Optical Range were initially revoked, then restored in 2006, following denial that it would be used as an ASAT test.

Proliferation of space-based negation enabling capabilities

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

In 2006 the US experimented with potential space-based negation technologies in GEO, using two classified microsatellites to assess their potential for defense applications. The US Air Force also requested funding for an Experimental Small Satellite-11 follow-on mission, which demonstrates proximity operations and autonomous rendezvous capabilities in LEO – capabilities that could be used for passive reconnaissance missions in space or hostile negation efforts in the future.

Space-Based Strike Systems

While no space-based strike systems have been tested or deployed, 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 strike systems. Under the Strategic Defense Initiative in the 1980s, the US invested several billion dollars in the development of a space-based interceptor concept called Brilliant Pebbles, and tested targeting and propulsion components required for such a system. The US and USSR were both developing directed energy strike systems in the 1980s, although today these programs have largely been halted.

No space-based strike systems were tested or deployed in 2006. Despite US efforts to move forward on technology, including a ground-based Multiple Kill Vehicle demonstration and budget requests by the Missile Defense Agency for a Space Based Interceptor Test Bed, space-based technology experiments, and a second NFIRE test, the Congressional Subcommittee on Strategic Forces banned the use of funds for the development of anti-satellite capabilities and space-based interceptors for the time being.

A growing number of actors are developing advanced space-based strike enabling technologies through other civil, commercial, and military programs

The majority of advanced, space-based strike enabling technologies are dual-use and are developed 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 space-based strike purposes, such development does bring these actors technologically closer to this capability. For example, China, India, and Israel are developing precision attitude control and large deployable optics for civil space telescope missions. There are also five states in addition to the European Union that are developing independent, high-precision satellite navigation capabilities. China, India, and the EU are developing Earth re-entry capabilities that provide a basis for the more advanced technologies required for the delivery of mass-to-target weapons from space to the Earth.

The development of dual-use technologies that also provide enabling capabilities for space-based strike systems – including hypersonic flight and Earth re-entry technologies, global missile tracking and warning, precision navigation, and high energy lasers – continued in 2006. The technological challenges of space-based strike systems remain daunting, however, and there was no evidence that states were developing capabilities for strike purposes.

The Space Environment

CHAPTER ONE

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, which includes both naturally generated and man-made objects, 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 in various orbits, space surveillance capabilities that track space debris to enable collision avoidance, and efforts to reduce new debris and to remove existing space debris.

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 here. 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 geostationary orbit must obtain an appropriate “orbital slot” in which to do so and secure a portion of the radio spectrum to carry their satellite communications. Both radio frequencies and orbital slots are indispensable tools for all space operations and their national assignments are coordinated through the International Telecommunication Union (ITU) and recognized by the ITU Constitution as “limited natural resources,” given their finite number.

Given that, according to 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 developed by the ITU in order to manage the use and 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 the potential for collisions with spacecraft. Due to very high orbital velocities of 7.8 kilometers per second (~30,000 kilometers per hour) in Low Earth Orbit (LEO), debris as small as 10 centimeters in diameter carries the kinetic energy of a 35,000-kilogram truck traveling at up to 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. See Figure 1.1 for types of Earth orbits.

The total amount of space debris in orbit is growing each year. LEO is the most highly contaminated orbit. Some debris in LEO will reenter the Earth's atmosphere and disintegrate in a relatively short amount of time due to gravitational pull, but debris in orbits above 600 kilometers will remain a threat for decades and even centuries. There have already been a number of 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.

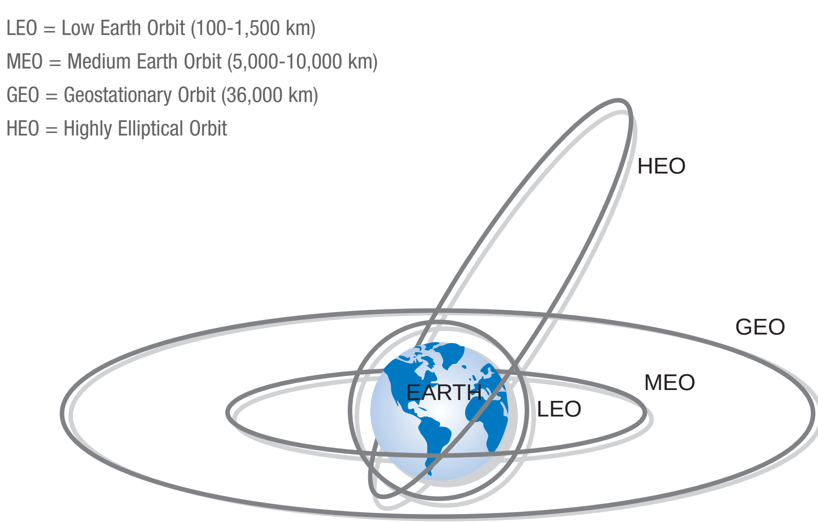
The development of surveillance capabilities to track space debris and enable collision avoidance clearly provides significant space security advantages. Efforts to mitigate the production of new debris through compliance with national and international guidelines, standards, and practices can also have a positive impact on space security. Technical measures to efficiently remove debris could have a positive impact on space security in the future.

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 the use of these resources.

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 pressure and increase the availability of these scarce resources. There are strong incentives for space actors to cooperate in the registration and use of radio frequencies 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

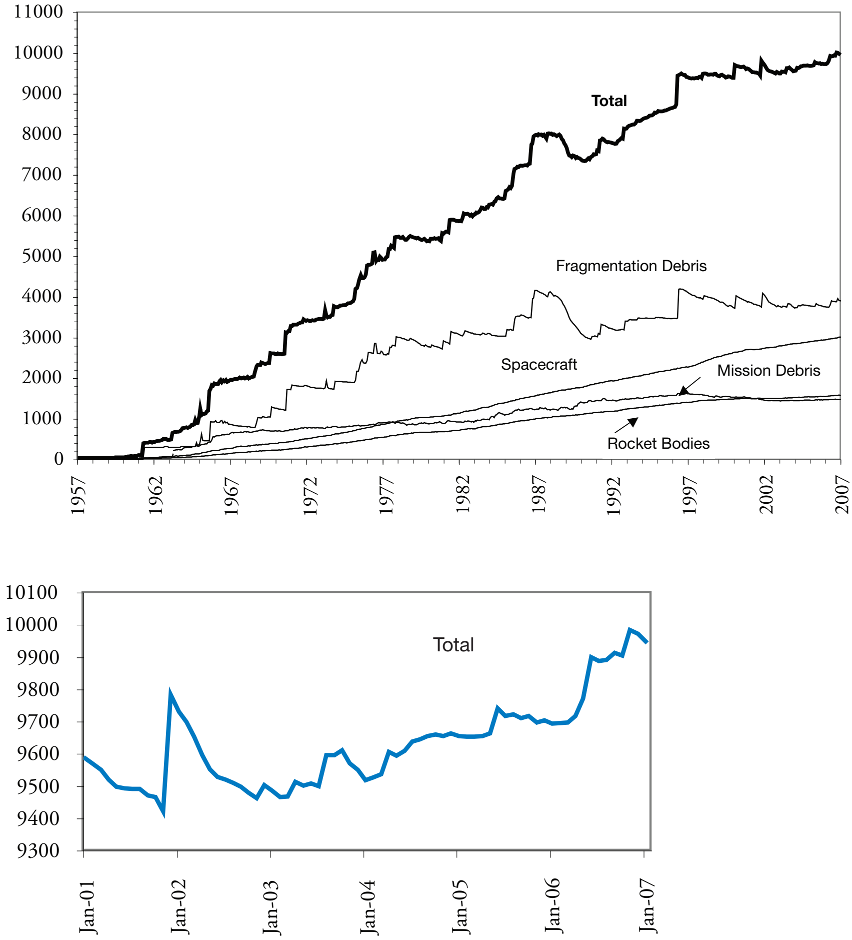
The US Space Surveillance Network (SSN) is the system that most comprehensively tracks and catalogues space debris, although technological factors limit it to spot checking rather than continuous surveillance, and limit the size of tracked objects to those greater than 10 cm in LEO and much larger in GEO. According to NASA's latest estimates, the US Department of Defense (DOD) is tracking more than 13,000 objects approximately 10 cm or larger. It is believed that there are over 100,000 objects measuring between 1 and 10 cm in diameter, and millions smaller.[2] By the end of 2006, 9,948 of the tracked objects had been catalogued, of which only eight to nine percent are operational satellites.[3] The total number of catalogued objects increased in 2003, when the US Cobra Dane collateral sensor radar that had been taken offline in 1994 was reinstated in the SSN.[4] See Figure 1.2 for an overview.

Two key factors affecting the amount of space debris are the number of objects in orbit and the number of debris-creating launches each year. Growth in the debris population increases the probability of inter-debris collisions that have the potential to create even more debris. A recent study by NASA has shown that, in LEO, debris-debris collisions will become the dominant source of debris production within the next 50 years.[5] As debris collides and multiplies, it will eventually create a "cascade of collisions" that will spread debris to levels threatening sustainable space access.[6] As of 2003 it was estimated that 43 percent of tracked debris resulted mostly from explosions and collisions.[7] Additional 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.[8]

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, particularly given the increased resolution of the system. This decline can be related in large part to international debris mitigation efforts, which increased significantly in the 1990s, combined with a lower number of launches per year. An increase in the annual rate of debris production has been observed again since 2004.

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 smaller than 10 centimeters in size and approximately 100,000 between one and 10 centimeters (i.e., larger than a marble). Particles as small as two millimeters pose a serious hazard to the security of spacecraft, threatening unprotected fuel lines and other sensitive components.[9] 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 and 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."[10]

Figure 1.2: Number of catalogued objects in Earth orbit[11]



Today, collisions between space assets like the International Space Station and very small pieces of debris are a daily but manageable problem.[12] 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.[13]

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."[14] 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.x[15] While major collisions have so far been rare, there have been several incidents of varying severity as noted in Figure 1.3 below.

Figure 1.3: Space debris incidents[16]

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. Several thermal windows must be replaced after each Shuttle mission because of space debris damage.
The 10-year-old Hubble Space Telescope, which orbits in LEO, had a three-quarter-inch hole in its antenna that is was 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, though officially assessed by Russian authority to have been caused by battery failure.
In 1985, a US kinetic energy ASAT test produced over 250 pieces of catalogued debris, some of which later came within 1.3 kilometers of the International Space Station. The last piece of debris generated from this test de-orbited in 2002.
The Long Duration Exposure Facility, a school bus-sized satellite in LEO, 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 guidelines for debris mitigation

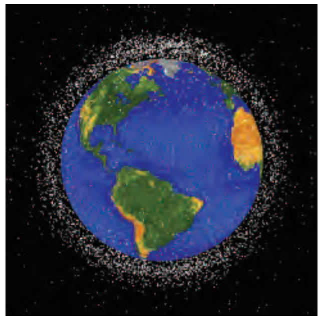
Growing awareness of space debris threats has led to the development of a number of international and national debris mitigation guidelines. The Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) began discussions of space debris issues 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, on which it based its own draft guidelines in 2005.[17] The IADC includes representatives of the space agencies of China, Europe (ESA), France, Germany, India, Italy, Japan, Russia, Ukraine, the UK, and the US.

At the national level, NASA issued guidelines on limiting orbital debris in the August 1995 *NASA Safety Standard 1740*. In December 2000, the US Government issued formal orbital debris mitigation standards for space operators. These standards were developed by DOD and NASA. In 2004, the US Federal Communications Commission imposed requirements for satellite operators to move geostationary satellites at the end of their operating life into "graveyard orbits" some 200 to 300 kilometers above GEO and in 2005 new rules went into effect requiring satellite system operators to submit orbital debris mitigation plans.[18] The ESA initiated a space debris mitigation effort in 1998.

The *ESA Space Debris Mitigation Handbook* was published in 1999 and revised in 2002.[20] Also in 2002, ESA issued the European Space Debris Safety and Mitigation Standardxxi and issued new debris mitigation guidelines in 2003. Japan and Russia also appear to strongly support the mitigation of space debris production. China, although a member of the IADC, has not formally adopted debris mitigation guidelines and no national policies have been put into place as yet. 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 reflected in the space debris mitigation guidelines developed by the Coordination Committee."[21]

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.[22] 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.[23]

Figure 1.4: Space debris in LEO[24]



In April 2004, the IADC released a revised debris "Protection Manual" describing design measures for spacecraft survivability against debris.[25] In addition, a subcommittee of the International Organization for Standardization started drafting a set of standards incorporating elements of the IADC guidelines.[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 in the future.[27]

TREND 1.3: Space surveillance capabilities to support collision avoidance slowly improving

Space surveillance capabilities are vital to the mitigation of environmental hazards. Efforts to create an international space surveillance mechanism date to the 1980s. In 1986 Canada presented the so-called PAXSAT study, which proposed a space-to-space remote sensing system (PAXSAT A) based on non-superpower technology available at the time. In 1989 France proposed the creation of an Earth-based space surveillance system consisting of radar and optical sensors allowing the international community to track the trajectory of space objects. This proposal was presented in the Conference on Disarmament and evolved into a proposal to establish an International Trajectography Centre (UNITRACE). It was suggested that, in the context of the rapid technological advances and easier access to high-quality information, the UNITRACE proposal could be revisited and updated. Such an initiative could complement the US-Russian agreement to establish the Joint Center for the Exchange of Data from Early Warning Systems and Notification of Missile Launches and would be consistent with that agreement's anticipated multilateralization.[28] In the absence of an international system, countries are establishing independent space surveillance capabilities, with some degree of information exchange.

The US Space Surveillance Network (SSN) is the network that most systematically tracks and catalogues orbital debris. The system is comprised of 30 radars and optical sensors at 16 sites worldwide, as well as one dedicated satellite.[29] The SSN can track objects in LEO with a radar cross-section of five centimeters in diameter or greater. It uses a tasked sensor approach, which means that not all of orbital space is searched at all times; 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 protected against with shielding on satellites, are not detectable by the system. The Air Force Space Surveillance System or Space Fence, which forms the radar portion of the SSN, is the oldest US space surveillance system and consists of three transmitters and six receivers capable of making some 5-million detections each month of objects larger than a basketball.[30] Since 2004, the US has implemented stricter regulations on access to its SSN data according to national security interests.[31]

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.[32] In response, the US has programs to bolster such capabilities, but they are generally under-funded and behind schedule. The US Deep View program plans to develop a high-resolution radar-imaging capability to characterize smaller objects in Earth orbit by 2010.[33] The US Space Surveillance Telescope program intends to "demonstrate an advanced ground-based optical system to enable detection and tracking of faint objects in space, while providing rapid, wide-area search capability" by 2009.[34] Also under development is the Space Based Space Surveillance System (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, and are also relevant for the broader US space control mission (see Space Systems Negation Trend 7.2).[35]

Russia is the only other state with a dedicated 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.[36] The main optical observation system, Okno, located at an altitude of 2,200 meters in the mountains near the Tajik eastern city of Nurek, aims principally at objects of 2,000 to 40,000 kilometers in altitude.[37] The system cannot track satellites at very low inclinations and the operation of Russian surveillance sensors is reportedly erratic.[38] The network as a whole carries out some 50,000 observations daily, contributing to a catalogue of approximately 5,000 objects, mostly in LEO.[39] While information from the system is not classified, Russia does not have a formal structure to widely disseminate information about observations.[40]

Other states, France and Germany in particular, also emphasize space surveillance for debris monitoring. Since 1999, France has operated the Graves radar, which tracks satellites over French territory, primarily those below 1,000 kilometers. The development of this system was reportedly motivated by a desire for independence from US and Russian space surveillance capabilities.[41] The German Defense Research Organization operates the FGAN Tracking and Imaging Radar. 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.[42]

The European Union maintains information from the SSN in 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.[43] 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.[44] ESA's Space Operations Centre in Germany has begun to provide a Space Debris Avoidance Service using data from DISCOS for satellite operators.[45] In 2004, space situational awareness topped the list of EU security research, in recognition of the importance of environmental awareness for collision avoidance.[46]

Since joining the IADC in 1995, China has also maintained its own catalogue of space objects, using data from the SSN to perform avoidance maneuver calculations and debris modeling.[47] 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.[48] 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.[49] 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 one each in Namibia and Pakistan, as well as a fleet of four Yuan Wang satellite-tracking ships.[50] These assets provide the foundation for space surveillance but are believed to 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.[51] 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[52] – 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.[53] 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).[54] Canada's planned Near Earth Orbit Surveillance Satellite (NEOSsat) asteroid discovery and tracking mission, being developed by Defence Research and Development Canada and the Canadian Space Agency, will also have space surveillance capabilities at high altitudes between 15,000 and 40,000 km.[55]

TREND 1.4: Growing demand for radio frequencies

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 (1-2 gigahertz) and S-band (2-4 gigahertz) for mobile phones, ship communications, and messaging. The C-band (4-8 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, 8-12 gigahertz, and 18-27 gigahertz, respectively) for the US military.[56]

For technical reasons, most satellite communication falls below 60 gigahertz, meaning actors are competing for a relatively small portion of the radio frequency spectrum, with competition particularly intense for spectrum below 3 gigahertz.[57] Additionally, the number of satellites operating in the 7-8 gigahertz band, commonly used by GEO satellites, has grown rapidly over the past two decades.[58] Since many satellites vie for this advantageous orbit (see Trend 1.5 below), there is an increased risk of accidental jamming.

Increased demand for bandwidth was apparent during the US-led invasion of Afghanistan in 2001, when the US military used some 700 megabytes per second of bandwidth, compared to about 99 megabytes per second during the 1991 US operations in Iraq.[59] 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.[60] The Wideband Global SATCOM 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.[61]

While crowded orbits can result in signal interference between satellites, new technologies are being developed to manage the need for greater frequency usage, allowing more satellites to operate in a closer proximity without interference (see Trend 1.5). Frequency hopping, lower power output, 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.[62]

There is also significant research being conducted on the use of lasers for communications, particularly by the US military. Lasers transmit information on much higher frequencies and have a very low beam-divergence, as opposed to less focused radio waves. These features allow higher bit rates and tighter placement of satellites to alleviate some of the current congestion and concern about interference. The US military Transformational Satellite Communications System proposes to use this technology, but it is experiencing budget cuts and delays and is not expected to be fielded before 2014. The planned US NeXt Generation Communications Program also aims to alleviate frequency demand by allowing several users to share one band of frequency, with their respective devices intelligently searching through the allocated band for unused portions for transmission[63] (see Space Support for Terrestrial Military Operations Trend 5.1).

Today, issues of interference arise primarily when two spacecraft 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."[64]

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."[65] 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.[66]

Originally adopted in 1994, the current version of the ITU Constitution[67] governs international sharing of the finite radio spectrum and orbital slots used to communicate with and house satellites in GEO. 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."[68] Military communications are exempt from the ITU 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 that can take years.[69] 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."[70]

Regional efforts are also underway to harmonize radio frequency utilization. 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.[71] ASEAN and the EU are also seeking to harmonize regulations in Asia and Europe respectively.[72]

TREND 1.5: Growing demand for orbital slots

Today's satellites operate in three basic orbital bands: LEO, Medium Earth Orbit (MEO), and GEO. There are approximately 850 operational spacecraft, approximately 36 percent of which are in LEO, six percent in MEO, 48 percent in GEO, and about 10 percent in either Highly Elliptical Orbit (HEO) or planetary trajectories.[73] HEO is increasingly being used for specific applications, such as early warning satellites. LEO is often used for remote sensing and earth observation, and MEO is home to critical navigation systems such as the GPS and Galileo system. Most communications and weather satellites are in GEO, as orbital movement at this altitude is synchronized with the Earth's 24-hour rotation, eliminating the need for expensive tracking receivers.

Prime GEO slots are located above or close to the equator to maximize the continuous communications footprint. 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;[74] these desirable slots are also optimal for the rest of the Americas. Similar limitations are true for all geographic regions.

The ITU Constitution states that radio frequencies and associate orbits, including GEO, "must be used rationally, efficiently and economically…so that countries or groups of countries may have equitable access to" both.[75] In the case of the GEO orbital slots registered by the ITU, the legal principle has been that such positions should be made available mainly on a first-come, first-served basis. To avoid radio frequency interference, GEO satellites are required to maintain at least two 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.[76] This means that only a limited number of satellites could occupy the prime equator (0 degree inclination) orbital path. In the equatorial arc around the continental US, there is room for an extremely limited number of 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.[77] 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 (DBS) to be spaced nine degrees apart, placing greater constraint on the availability of orbital slots in GEO.[78]

There are measures that can help reduce the problem of competition for orbital slots and mitigate signal interference. First, the US FCC two-degree spacing requirement between satellites (not including DBS) only applies to satellites that use the same frequency. Satellites with different frequencies can be spaced as little as one-tenth of a degree away from one another.[79] 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.[80] For example, the 91-92 degrees West slot in GEO houses a Brazilsat, two Galaxy satellites, and a Canadian Nimiq satellite.[81] Lastly, satellite operators have begun swapping or sharing orbital slots with other space actors in order to better respond to their operational needs.

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 has 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.[82]

TREND 1.1: Growing debris threats to spacecraft

2006: Chinese missile intercept increases population of catalogued space debris by over 10 percent in LEO

Previously unreported Chinese attempts to intercept a satellite with a ballistic missile on 7 July 2005 and 6 February 2006 culminated in the successful hit-to-kill explosion of an aging Chinese weather satellite on 11 January 2007 (see Space Systems Negation Trend 7.3).[83] The anti-satellite test took place in LEO at an altitude of approximately 850 kilometers, creating a vast amount of debris in popular orbits between 200 and 3,800 kilometers. At the time of writing, 1,337 pieces of debris larger than 10 centimeters have been catalogued by the US Space Surveillance Network (SSN), although the process is ongoing and the final count is not yet available.[84] It is estimated that 40,000 pieces of untracked debris between one and 10 centimeters remained in orbit after the test.[85] Due to the high altitude of the debris, much of it will remain a threat to spacecraft for decades or longer. The debris threatens spacecraft in LEO, where almost half of all satellites operate.

The event is being described as one of the worst man-made debris-creating events to date. It will have created roughly the same amount of debris as the last US kinetic ASAT test in the 1985, given that both tests were aimed at weather satellites of approximately the same size (much of the large debris from the 1985 test could not be tracked at the time, given the limited resolution of the SSN).[86] However, the US test in 1985 took place at an altitude of approximately 550 kilometers, so most of the debris returned to Earth atmosphere in a relatively short period of time. The high altitude of the Chinese test contributes to the severity of the event.

2006: Record year for satellite fragmentation; increase in annual production of space debris

At the end of December 2006, the number of large and medium-sized objects (>10 cm) in orbit catalogued by the US SSN stood at 9,948 (prior to the Chinese ASAT test).[87] This number represents an increase of 521 objects or 5.52 percent when compared with yearend data for 2005.[88] A record nine cases of satellite fragmentation were observed in 2006 – the highest number since 1993. Most of these events created only short-lived debris (see Figure 1.5). Two Russian Proton motor breakups brought the total number of breakups associated with this type of motor since 1984 to 35. Of considerable concern was the unexpected fragmentation of a US Delta-4 second stage just prior to a controlled re-entry burn on 4 November 2006. The cause is not known but is being investigated.[89]

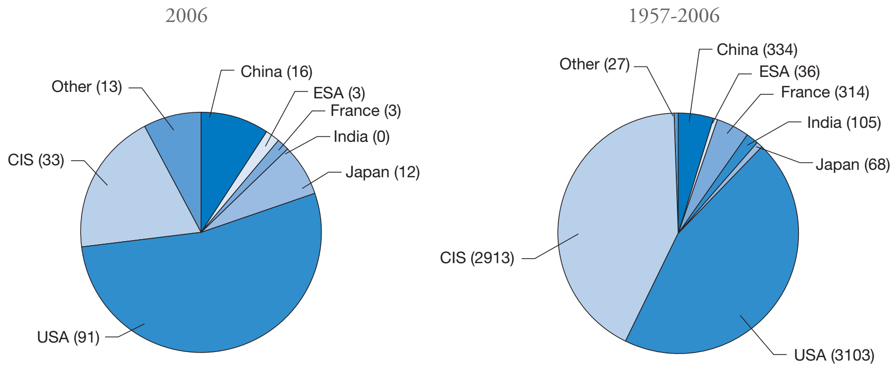
Figure 1.5: Satellite breakups in 2006[90]

Date	Spacecraft	Estimate of large debris
May 2006	20-year-old Soviet rocket	50 (most short-lived)
June 2006	Russian Proton motor	130+
August 2006	Japanese H-2A second-stage rocket	21 (short-lived)
August 2006	Russian Molnya upper stage	10 (short-lived)
September 2006	Russian Proton motor	7+
November 2006	Russian Cosmos 2423 detonated	28 (short-lived)
November 2006	US Delta-4 second stage	62+ (short-lived)
December 2006	17-year-old US Delta-2 second stage	62+ (short-lived)
December 2006	Japanese H-2A second-stage rocket	< 20 (short-lived)

One debris-related collision also took place in 2006, causing a Russian telecommunication satellite to shutdown on 29 March 2006. Although the impact caused the spacecraft to lose orientation and rotation, it was successfully moved to a graveyard orbit.[91]

Of the total increase in space debris in 2006, 171 pieces were created by launches. The total launch-related debris currently in orbit stands at 6,900, of which US launch activity accounts for 45 percent and CIS launch activity for 42 percent (see Figure 1.6). 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 altitude. There is also a concentration of debris in GEO and to a lesser extent in MEO.

Figure 1.6: Number of pieces of debris created by launching state[92]



The CIS refers to Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan, and Ukraine. The figures exclude the Chinese ASAT test.

2006: New NASA policy will result in temporary increase in space debris in LEO

The jettisoning of a golf ball off the International Space Station (ISS) in 2006 coincided with a new policy proposal from NASA to intentionally release unneeded gear from the ISS, which will take effect if approved by the other members of the ISS. According to this policy, objects would be pushed off the rear of the ISS in a way that minimized the amount of time that they would spend in orbit, eliminating the possibility that released objects might collide with the station. Objects that could be released from the ISS are those that are unlikely to break up before re-entry (and therefore unlikely to create additional debris), and those that will probably not survive re-entry and so not cause damage on the ground. NASA has identified four types of objects that do not meet these criteria, but will nonetheless qualify for jettisoning: those that would pose a danger to the ISS if kept onboard, those that would pose a danger to a space vehicle if it were to be sent back to Earth, items for which retrieval from the station is time consuming, and items designed to be jettisoned.[93] The policy will cause temporary increases in debris at very low altitudes.

2006: New research finds inevitable increase in space debris

New research by NASA scientists has shown that the orbital debris in LEO will inevitably increase, even in the absence of new launches. The evolution of pieces of debris in LEO that are 10 centimeters or larger was projected over the next 200 years with the assumption that no new debris-producing launches or in-space debris-disposal maneuvers would take place. The study found that the debris population would remain stable over the next 50 years, but would begin to increase beyond 2055. Debris-debris collisions would create most of the debris, but atmospheric drag and solar radiation would also be factors. The study foresees a threefold increase in the number of medium- to large-sized debris within the next 200 years, increasing the probability of collision tenfold. These numbers underestimate what will occur in reality, since debris-producing launches will continue.[94] In the absence of remediation technologies, efforts to mitigate man-made debris will not address this long-term problem.

2006: Pursuit of debris remediation technologies continues, but capabilities remain remote

To date no effective technical means to remove space debris exists. Nonetheless, interest in the development of electromagnetic tethers that could be deployed after a satellite becomes non-operational continued in 2006. Space tethers are essentially cables made of conductive material that are attached to a satellite and through which electric current passes. The motion of the cable in the Earth's magnetic field provides propellant-free propulsion for orbital objects. 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 if in LEO or to raise the orbit, if in GEO.[95] In October 2006 the IADC issued a final report assessing the potential benefits and risks of using such a mechanism to combat space debris and made several recommendations based on a five-year study.[96] It concluded that while "electrodynamic tethers have strong potential to become effective mitigation measures…various problems are still to be solved before this technique can be practically adopted."[97] There are also concerns that the technology could be used against uncooperative satellites for space negation purposes.

On 31 May 2006, the US DOD held a Preliminary Design Review for the Large Area Debris Collector (LAD-C). The LAD-C is a 10 m^2 aerogel and acoustic sensor system that will be used on the ISS to collect and catalogue small debris. It will record impact time, location, and strength using acoustic techniques. The LAD-C will provide a better understanding of the characteristics and possible sources of the LEO debris population. It is currently scheduled for launch in 2008, and is expected to deploy for a period of one or two years, after which it will be returned to Earth.[98]

Space security impact

Developments in space debris had a mixed impact on space security in 2006. It is clear that the population of large, threatening space debris is growing at an increasing rate, both through human activities in space and the natural forces of the space environment. On the other hand, developments in debris mitigation technology such as space tethers and the space elevator could potentially have a positive effect in the future by reducing the amount of space debris. However, the sufficiency and cost effectiveness of these mitigation technologies have yet to be proven.

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

2006: Space debris mitigation guidelines drafted at UN COPUOS

The Space Debris Working Group of the Scientific and Technical Subcommittee of COPUOS drafted space debris mitigation guidelines in 2006 consistent with those of the IADC. The draft document "UN COPUOS STSC Space Debris Mitigation Guidelines" presents general recommendations in the form of seven guidelines to be implemented on a voluntary basis through national legislation and protocols (see Figure 1.7). Of particular interest is the avoidance of *intentional destruction and other harmful activities* in space. At the time of writing, these guidelines had been unanimously accepted by the member states of the STSC, but still had to be officially adopted by the COPUOS Plenary, the UN Fourth Committee, and finally the UN General Assembly. It is anticipated that these approvals will take place by the fall of 2007.

2006: Debris mitigation continues to be a priority of the US National Space Policy and the Chinese White Paper on Space Activities

In 2006 the US updated its National Space Policy for the first time since 1996. Consistent with the 1996 version, this new policy recognizes the risks posed by space debris and affirms that the US will "seek to minimize the creation of orbital debris by government and non-government operations in space." To this end, departments and agencies must continue to follow cost-effective US Orbital Debris Mitigation Standard Practices. Licensing procedures followed by the Secretaries of Commerce and Transportation must "continue to address orbital debris issues," and the US "shall take a leadership role" to promote the adoption of debris mitigation policies and practices on an international level.[99] Similarly, China released a White Paper entitled "China's Space Activities in 2006" in which it reports actively participating in debris mitigation mechanisms and policy efforts at an international level.[100] It was released prior to the Chinese missile intercept (see Trend 1.1).

Figure 1.7: Summary of the UN COPUOS STSC Space Debris Mitigation Guidelines[101]

UN COPUOS STSC Space Debris Mitigation Guidelines
1. Limit debris released during normal operations
2. Minimize the potential for breakups during operational phases
3. Limit the probability of accidental collision in orbit
4. Avoid intentional destruction and other harmful activities
5. Minimize potential for post-mission breakups resulting from stored energy
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

Space security impact

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 international implementation, verification, or compliance measures. While debris mitigation procedures are on the verge of being accepted worldwide, these policies may be insufficient to combat the growing debris problem in the long term without additional efforts to remove debris, given natural increases in space debris caused by the space environment.

TREND 1.3: Space surveillance capabilities to support collision avoidance slowly improving

2006: US space situational awareness capabilities hindered by delays and ongoing restricted data sharing

US efforts to expand its space surveillance system in 2006 suffered from funding cuts and program delays. The US Air Force (USAF) announced that two of its three Space Fence very high frequency radar surveillance systems will be deployed internationally; however initial operations have been delayed to 2013 or 2014.[102] Moreover, in December 2006 the DOD indicated significant funding cuts for future upgrades to the system to improve its detection capability from objects 30 cm in diameter and larger to those as small as five centimeters. The planned funding cuts have prompted a revisit of the program schedule that could result in further delays.[103] Similarly, while some progress on the Space-Based Surveillance System (SBSS) continued in 2006 with the completion of a key risk reduction step for the initial pathfinder satellite, its launch has been delayed to 2009 and the remaining four satellites necessary to complete the system are currently planned for launch only in 2013-14.[104] The system would enhance the capabilities of the Space Fence and the SSN by providing surveillance of objects in GEO. In 2006 the DOD also cancelled the Orbital Deep Space Imager program, intended to develop satellites that would monitor other satellites and objects in GEO, due to budgetary constraints.[105]

While both the SBSS and the Orbital Deep Space Imager are relevant to the US space control mission (see Space Systems Negation Trend 7.2), delays and cancellations also significantly hinder much needed capabilities to accurately track and monitor space debris and other objects in GEO. This capability gap could be partially filled by Canada's SAPPHIRE satellite, scheduled for launch by 2010. Officially designated for the Canadian Department of National Defence, SAPPHIRE will also provide space-based surveillance of satellites and space debris in GEO for the US SSN.[106]

Further, traditional US willingness to provide space surveillance data to other governments and commercial firms has been challenged over the past several years – both for cost reasons and from concerns about satellite security. At a September 2006 conference, co-sponsored by the Center for Defense Information and the US Air Force Academy's Center for Space and Defense Studies, experts expressed concerns with both the capabilities of SSN and the processes for disseminating data from that network.[107]

2006: Other actors continue to pursue independent space situational awareness capabilities

Though little public information is available on Russia's Space Surveillance System, in November 2006 Russia's Space Forces announced plans to expand the detection range of the Okno space-monitoring center. The tracking precision and servicing period will also be enhanced through the modernization of electronic equipment. The complex is primarily set up to detect objects at altitudes ranging from 2,000 to 40,000 kilometers.[108]

European states continued to develop independent space surveillance capabilities in 2006. Although there is still not an integrated European network, option studies are ongoing and a formal proposal is expected in 2008.[109] Moreover, the ESA has defined space surveillance as one of three main security priorities.[110] France's GRAVES space surveillance radar was fully operational as of 22 December 2005. The system is capable of monitoring space objects, including orbital debris and satellites in LEO up to 1,000 kilometers in altitude, and can follow more than a quarter of all satellites, particularly those that France considers "the most threatening" and those for which the US does not publish orbital information.[111] France has 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.[112] France is now able to maintain a satellite database of approximately 2,000 space objects. The UK's British National Space Centre (BNSC) awarded two contracts to Space Insight in 2006 to develop a new space surveillance system to map large areas of the sky quickly. This method is different from the conventional time-consuming method of detecting individual space objects[113] and could provide greater European space surveillance capability.

Space security impact

International efforts to improve space surveillance and space situational awareness capabilities in 2006 could 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 continued drive for independent space tracking systems has dual-use applications for space negation purposes. While most states are developing independent capabilities to supplement data collected by the SSN, the extent to which this is driven by a desire for independent, national capabilities rather than a sense of collective responsibility is unclear. Ongoing limitations on surveillance of GEO and data sharing continue to pose challenges for space security.

TREND 1.4: Growing demand for radio frequencies

2006: Substantial decrease in radio frequency interference cases reported

According to the Satellite Users Interference Reduction Group, there were only 305 satellite radio frequency interference incidents reported in 2006, a significant decline from the 1,282 reported incidents in 2005.[114] Of these events 17 percent were caused by equipment malfunction and 19 percent by human error; less than one percent of the interference occurrences were caused by terrestrial services. Only 14 percent occurred during cross-polarization – when satellite dishes are being aligned to receive signals from the satellite – and adjacent satellites were responsible for only four percent of the incidents, suggesting the ongoing ability of the international community to manage use of the radio frequency spectrum. Almost 40 percent of all cases were classified as unknown; however, most of these are attributed to operator errors that were quickly corrected.

2006: Continued ability to manage growing bandwidth demand, but key technologies behind schedule

The dramatic increases in military satellite telecommunication usage (see Space Support for Terrestrial Military Operations) as well as the growth in digital media have increased pressure on frequency availability. In June 2006, 101 states signed an international treaty in Geneva to replace traditional analytical radio and television broadcasts with digital by 2015. This agreement will promote global connectivity and provide remote communities with modern communication technologies. Implementation of this treaty is also likely to significantly increase civil and commercial satellite bandwidth demand worldwide,[115] while military demand continues to rely on commercial capabilities (see Commercial Space Trend 4.3). Efforts to manage this growing demand continued in 2006, but key mitigating military technologies are behind schedule.

Following a 2005 European Commission report on the need to coordinate European spectrum policy, plans were announced in 2006 to harmonize its regulatory framework for satellite communications, allowing for better allocation of the frequency spectrum for all users. To promote its satellite communications sector, the EU is funding a newly inaugurated industry-led platform called the Integral Satcom Initiative, which will address a variety of satellite communications issues, including the promotion of a harmonized European regulatory framework.[116] A coordinating process is underway in Asia as well.

European concerns were raised in 2006, however, when China announced that the planned "Compass" satellite navigation system may use the same military frequencies reserved for Galileo's encrypted service, and perhaps the GPS military signal as well.[117] Military communications are exempt from the ITU Constitution that regulates frequency use. A similar dispute over frequency use by the US GPS and the EU Galileo system was resolved in 2004.

Several key US military projects that could enhance available bandwidth continued to experience delays in 2006. Boeing and Northrop Grumman successfully carried out tests in 2006 on new military satellite systems: the Wideband Global SATCOM (WGS) and the Advanced Extremely High Frequency (AEHF) system, which are expected to increase bandwidth availability for the US military and alleviate demands for commercial satellite bandwidth.[118] Although recent reports anticipate the launch of the first WGS in 2007 and the first AEHF in 2008,[119] both projects have experienced significant delays and cost overruns. Similarly, the Transformational Satellite Communications System (TSAT), which intends to use laser communications for higher data transmission at higher frequencies, has been postponed from 2012 to 2014 and its future is uncertain (see Space Support for Terrestrial Military Operations Trend 5.1).

Space security impact

Growing demand for radio frequency use may challenge the sustainability of broader access to and use of space in the future, particularly if new technologies do not keep pace. In 2006, however, continuing regional efforts to harmonize the allocation of radio frequencies contributed to the continued management of this limited resource. Moreover, the significantly lower number of reported interference incidents suggests ongoing success in international efforts to manage this challenge.

TREND 1.5: Growing demand for orbital slots

2006: Cooperation and competition in the allocation and use of orbital slots

In 2006 Kazakhstan became the 47th state to acquire a satellite when its telecommunications satellite KazSat-1 was launched with the assistance of the Russian company Khrunichev.[120] Arianespace has agreed to launch Vietnam's first satellite by 2008. The telecommunications satellite, VINASAT-1, will be built by Lockheed Martin.[121] 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.[122] As more states develop domestic satellite programs, limitations on orbital slots could pose a challenge to the space community; however, to date the regulatory procedures of the ITU adequately ensure fair and equitable access.

Direct Broadcast Satellites (DBS) serving the US are regulated by the FCC mainly in accordance with the rules agreed to at the ITU. In November 2006, the FCC supported US-based EchoStar's application to operate in the 86.5o West Latitude orbital location against opposition from Telesat Canada, which claimed that it would affect satellite service to 1.5-million Canadian consumers. In contrast to US DBS requirements, the EchoStar satellite will be less than nine degrees away from two Telesat DBS satellites, causing potential frequency interference. The FCC found that granting EchoStar's application was in the public interest, but imposed interference limits until operations are coordinated with adjacent satellites.[123] The dispute highlights the growing demand and competition for orbital slots and frequencies, particularly in GEO. According to EchoStar, it also underscores "the need for the Commission to initiate a rulemaking on the [reduced spacing] satellite issues to determine, among other things, whether the interference that may be caused by [reduced spacing] satellites into existing DBS networks would be acceptable…"[124] The FCC considered the potential for smaller satellite spacing in 2002 and is considering rules for processing future applications by non-US DBS providers.

Space security impact

Developments in 2006, including competition for GEO slots and radio frequencies, demonstrated the governance challenges associated with secure and sustainable access to and use of space. While the increasing number of states seeking to acquire satellites may allow greater access and use of space for some, the corresponding strain on the availability of orbital slots and the frequency spectrum may reduce the sustainability of space use. Nonetheless, cooperation mechanisms such as the ITU and the FCC continued to facilitate harmonious allocation of space resources in 2006.

Space Laws, Policies, and Doctrines

CHAPTER TWO

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 progressively expanded to include, among others, 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 nuclear weapons or weapons of mass destruction in outer space.

This chapter also assesses trends and developments related to space security-relevant multilateral institutions mandated to address uses of space, such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS), the Conference on Disarmament (CD), and the UN General Assembly (UNGA). While COPUOS tends to focus on commercial and civil space issues, the CD primarily addresses 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 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.

This chapter also examines the interplay between national space policies and military space programs. 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 Impact

National and international laws have a direct impact on space security since they establish key space security parameters such as the common access to space, prohibitions against the national appropriation of space and the placement of certain weapons in space, and the obligation to ensure that space is used for peaceful (i.e., 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 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 the framework necessary for the sustainable commercial use of space.

Multilateral institutions play an essential role in space security, providing a venue to discuss issues of collective concern, negotiate 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 to 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 between policy and space security varies, depending on 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 space capabilities, not only increasing the number of space actors with space assets, but also creating a greater 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. States that remain ambiguous on these points could also stimulate the development of policies, doctrines, and capabilities to counterbalance what a peer may, with a lack of evidence to the contrary, perceive as a threat. Furthermore, military doctrines that rely heavily on space can push other states to develop protection and negation capabilities to protect valuable space systems.

Key Trends

TREND 2.1: Development of legal framework for outer space activities

The web of national and international laws and regulations, and international treaties that govern the use of space has become gradually 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 among 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 (OST)

Often referred to as the *Magna Carta* of outer space, the OST represents the primary basis for legal order in the space environment, establishing outer space as a domain to be used by all humankind for peaceful purposes (see Figure 2.1).

Lack of definitional clarity in the OST presents several challenges for space security. The OST does not specify where airspace ends and outer space begins. This issue has been on the agenda of both the Legal and the Scientific and Technical Subcommittees of COPUOS since 1959, and remains unresolved.[2] Nonetheless, the prevailing view that has become part of state practice holds that space begins at 100 kilometers above the Earth.

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" purposes.[3] The interpretation initially favored by Soviet officials equated peaceful purposes with wholly non-military ones.[4] State practice over the past 40 years has generally supported the view that "peaceful" does mean "non-aggressive." Thus, while space assets have been used extensively to support terrestrial military operations, actors have stopped short of actually deploying weapons in space. 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.[5]

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 1	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	The UN Charter and 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 V	States are internationally responsible for national activities in outer space, including activities carried on by non-governmental entities.
Article IX	In the exploration and use of outer space, states shall be guided by the principles of cooperation and mutual assistance and shall conduct all their activities in outer space with due regard to the corresponding interests of all other state. 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 a launching state "is absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight."[8] If a launching state causes damage to another space object, it is liable only if it is at fault for causing the damage. However, liability for damage caused in space is more difficult to establish. The Convention reiterates that state parties remain responsible for the activities of their national 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 current definition of the term "launching state," which does not include such actors.

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. The benefits of this central registry include effective management of space traffic, enforcement of safety standards, and attribution of liability for damage. Furthermore, it acts as a space security confidence-building measure by promoting transparency.

A lack of timelines for compliance remains a shortcoming of 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.[9] 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.[10] The Moon Agreement is not widely ratified and lacks support from major space powers.[11] States continue to object to its provisions regarding an international regime to govern the exploitation of the Moon's natural resources. Furthermore, 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.

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 responsible 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, reflecting the conviction of the international community on these issues.

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.

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).[12] 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.[13] Starting in 1995 the US and Israel consistently abstained from voting on the resolution, and the US cast the first negative vote against it in the UNGA in 2005.[14]

Figure 2.3: Signature and ratification of major space treaties

Treaty	Date	Ratifications	Signatures
Outer Space Treaty	1967	98	27
Rescue Agreement	1968	91	25
Liability Convention	1972	87	25
Registration Convention	1975	48	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 agreement, has been a recognition of the legitimacy of space-based reconnaissance, or National Technical Means (NTMs), as a mechanism of treaty verification, and agreement not to interfere with them.[15] 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."[16] A summary of the key space security-relevant provisions of these agreements is provided in Figure 2.4.

Other laws and regimes

Coordination among participating states in the Missile Technology Control Regime (MTCR) adds another layer to the international regulatory framework.[28] 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 Trend 4.3).[29] 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.[30] To increase transparency and reduce mistrust among subscribing states, it introduces confidence-building measures such as the obligation to announce missile launches in advance.

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[17]
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[18]
Hotline Modernization Agreement (1973)*	Sets up direct satellite communication between the US/USSR[19]
Anti-Ballistic Missile Treaty (1972)*†	Prohibition of space-based anti-ballistic missile systems and interference with national technical means of verification[20]
Environmental Modification Convention (1977)	Bans, for use as a weapon, modification techniques having widespread, long-lasting, or severe effects on space[21]
Strategic Arms Limitation Treaty II (1979)*	Acceptance of, and prohibition of interference with, national technical means of verification Prohibits fractional orbital bombardment systems (FOBS)[22]
Launch Notification Agreement (1988)*	Notification and sharing of parameters in advance of any launch of a strategic ballistic missile[23]
Conventional Armed Forces in Europe Treaty (1990)	Acceptance of, and prohibition of interference with, national and multinational technical means of verification[24]
Strategic Arms Reduction Treaty I (1991)*	Acceptance of, and prohibition of interference with, national technical means of verification[25]
Intermediate-Range Nuclear Forces Treaty (1997)	Acceptance of, and prohibition of interference with, national technical means of verification[26]
Memorandum of Understanding establishing a Joint Data Exchange Center (2000)*	Exchange of information obtained from respective early warning systems[27]
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
† US withdrew according to the terms of the treaty in 2002

Finally, the treaties that 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.[31] 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 these space activities in accordance with the OST, which establishes state responsibility for the activities of national and nongovernmental entities.[32] 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.[33]

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.[34]

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 would have banned the orbiting of objects carrying weapons of any kind and the installation of such weapons on celestial bodies or in outer space. 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.[35]

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.[36] 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."[37] 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.

In 2005 the UNGA adopted a resolution sponsored by Russia entitled "Transparency and confidence-building in outer space activities," inviting states to inform the UN Secretary-General on transparency and confidence-building measures, and reaffirming that "the prevention of an arms race in outer space would avert a grave danger to international peace and security."[38] The United States registered the only vote against the resolution and Israel the only abstention.

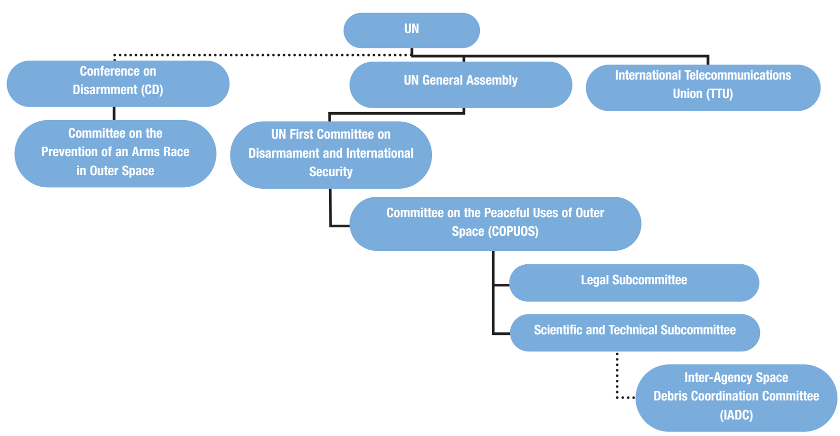
Nongovernmental organizations (NGOs) have also contributed to this dialogue on gaps in the international legal framework. For example, the Union of Concerned Scientists drafted a model treaty banning ASATs (1983).[39] More recently, the Henry L. Stimson Center proposed a code of conduct (2003) on dangerous military practices in space.[40] Since 2002, the UN Institute for Disarmament Research has periodically convened expert meetings to examine space security issues and options to address them.[41]

TREND 2.2: COPUOS remains active but the Conference on Disarmament has been unable to agree on an agenda 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.[42] There are currently 67 Member States of COPUOS, which works by consensus. 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, which provided the basis for those drafted by the COPUOS Scientific and Technical Subcommittee in 2005.[43] Debate to revisit the mandate of COPUOS to include all issues affecting the peaceful uses of outer space, namely those pertaining to militarization, has not reached consensus. The United States in particular emphasizes a strong distinction between peaceful uses and non-armament.[44]

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, driven by perceived gaps in the OST that include its lack of verification or enforcement provision and failure to expressly prohibit conventional weapons in outer space or ground-based ASATs. In

1982, The Mongolian People's Republic put forward a proposal to create a committee to negotiate a treaty to that effect.[45] 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."[46] 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.[47]

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 reverse priorities, with a resulting stalemate on both issues. 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.[48] 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, which received support from China in 2003, leaving only the US in disagreement. In 2004, several states called for the establishment of a CD expert group to discuss the broader technical questions surrounding space weapons, but there is still no consensus on a program of work. Since 2005 the CD has been advancing discussions on space security themes through informal sessions hosted by delegates.

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 also emphasizing economic development. Virtually all space actors underscore the importance of international cooperation in their space policies; however, it is often delineated by national security concerns.

The US has the most to offer to international cooperative space efforts. While perhaps the least dependent upon such efforts to achieve its national space policy objectives, the US National Space Policy nonetheless sets a goal to "encourage international cooperation with foreign nations and/or consortia on space activities that are of mutual benefit and that further the peaceful exploration and use of space," as well as to "advance national security, homeland security, and foreign policy objectives."[49] Such cooperation is particularly linked to space exploration, space surveillance, and Earth-observation. The US also aims to build an understanding of, and support for, US national space policies and programs and to encourage the use of US space capabilities and systems by friends and allies."[50]

Russia is deeply engaged in cooperative international space activities, arguing that international cooperation in space exploration is more efficient than breakthroughs by individual states.[51] 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.[52] Russia is also a major partner of the European Space Agency and is participating in the Galileo navigation system.[53] Russia's other key partners on space cooperation are China and India, both of which participate in GLONASS (see Civil Space and Global Utilities Trend 3.3 and 3.4).[54] Russia has also undertaken cooperative space ventures with Bulgaria, Canada, France, Germany, Hungary, Israel, Pakistan, and Portugal on various occasions.[55] Thus, like the US, Russian space cooperation activities have tended to support broader access and use of space. Nonetheless, Russian policy also aims to maintain Russia's status as a leading space power, as indicated in the Federal Space Program for 2006-2015, which significantly increased the resources of the Russian Federal Space Agency (Roscomos).[56]

China declares a commitment to the peaceful use of outer space in the interests of all mankind, linking this commitment to national development and security goals, including protecting China's national interest and building the state's "comprehensive and national strength."[57] While China actively promotes international exchanges and cooperation, it has stated that such efforts must encourage independence and self-reliance in space capabilities.[58] The Chinese White Paper on Space Activities 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.[59] In the spirit of these principles, 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.[60] China has also pursued space cooperation with 13 states, and is collaborating with Brazil on a series of Earth resources satellites.[61]

India is a growing space power that has pursued international cooperation from the inception of the Indian Space Research Organization (ISRO), although its mandate remains focused on national priorities. India has signed MOUs with Canada, China, the European Space Agency (ESA), France, Germany, Hungary, Indonesia, Mauritius, Norway, Russia, Sweden, Syria, the Netherlands, Ukraine and the US. India also provides international training on civil space applications through the Indian Institute of Remote Sensing (IIRS) and the Centre for Space Science and Technology Education in the Asia Pacific Region.[62]

In Europe, the ESA facilitates European space cooperation by providing a platform for discussion and policymaking for the European scientific and industrial community.[63] Many see this cooperation as one of the most visible achievements of European cooperation in science and technology. Historically, Europe lacked the resources to meet its stated space policy, which led to the establishment of strong cooperation with the larger space powers, specifically the US and Russia. In addition, France, Germany, Italy, and the UK all have extensive cooperative ventures with the US, Russia, and, to a lesser extent, Japan and others. 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. In 2005, however, the European Commission (EC) dedicated more than $5-billion to "Security and Space" programs for 2006-2013 and doubled its budget for space-related research programs.[64] Autonomy is also a goal of European national space policies, as exemplified by the Ariane launch and Galileo navigation programs.

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 major space powers, 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."[65] 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.[66] There is currently an active debate within the US on how best to assure the security of vulnerable domestic space 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.[67] The 2004 USAF *Counterspace Operations* doctrine document makes explicit mention of military operations conceived "to deceive, disrupt, deny, degrade, or destroy adversary space capabilities."[68]

Others in this debate advocate enhanced protection measures, but oppose the deployment of weapons in space.[69] Much official US military space doctrine has remained focused primarily on force enhancement, as reflected in the US DOD 1999 *Space Policy*.[70] 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.[71]

Interest in developing an anti-ballistic missile system in the US has fuelled discussion and plans for space-based interceptors and space-based lasers. Most notable was President Reagan's Strategic Defense Initiative of 1983. 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."[72] While not explicitly mentioning particular space-based systems, the 2006 *National Space Policy* calls on the Secretary of Defense to provide space capabilities to support "multi-layered and integrated missile defenses."[73]

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.[74] Therefore, a basic Russian national security objective is the protection of Russian space systems, including ground stations on its territory.[75] These concerns derive from Russia's assessment that modern warfare is becoming increasingly dependent on space-based force enhancement capabilities.[76] 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."[77] 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.[78] The second priority is upgrading 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.[79] 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.[80] 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 against any country that attempts to deploy weapons in space.[81]

China's military space doctrine, should it exist, is not made public. China's 2006 White Paper on Space Activities identifies national security as a principle of China's space program.[82] 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.[83] Although media reports consistently speculate on China's military space capabilities and intentions, 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.[84] Nonetheless, China demonstrated an ASAT capability on 11 January 2007, which has raised international concerns about the aims and intentions of the Chinese space program.

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.[85] While most European space capabilities have focused on civil applications, there is an increasing awareness of the need to strengthen dual-use capabilities. In the 2005 "Report of the Panel of Experts on Space and Security" EU experts concluded that "Europe must establish a new balance between civil and military uses of space" to effectively protect its borders in a changing security environment, although political support for this recommendation is unclear.[86] 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.[87] In addition, at the third EC Space Council Meeting in November 2005, elements of the space policy, including the Global Monitoring for Environment and Security (GMES) initiative, were confirmed as priorities.

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.[88] 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.[89] UK military space doctrine calls for greater satellite use for communications and intelligence. For its part, the ESA has traditionally focused on civil uses of space, a role mandated by the reference in its statute to "exclusively peaceful purposes."[90]

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.[91]The Indian Air Force is also working towards the creation of an Aerospace Command, intended to make "effective use of space-based assets for military needs."[92] 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.[93]

TREND 2.1: Development of legal framework for outer space activities

2006: Chinese missile satellite-intercept and US foreknowledge fail to invoke the Outer Space Treaty

Previously unreported Chinese attempts to intercept a satellite with a ballistic missile on 7 July 2005 and 6 February 2006 culminated with the successful hit-to-kill explosion of an aging Chinese weather satellite on 11 January 2007, creating a massive cloud of debris in outer space.[94] In the immediate aftermath of the event, international leaders expressed concern, but did not call it 'illegal' according to international law.[95] Specifically, the US called it "inconsistent with the spirit of cooperation that both countries aspire to in the civil space area" and the UK stipulated that it "did not believe the test contravened international law, but was concerned by the lack of consultation."[96] Only Japan expressed the opinion that the event was not compliant with international law.[97] The non-armament provisions of the OST are limited to the prohibition of the placement of nuclear weapons or other weapons of mass destruction in space (Article III) and the testing of weapons or military maneuvers on the Moon and other celestial bodies (Article IV). Nonetheless, the OST stipulates that states "shall undertake appropriate international consultations" before conducting an action that could potentially be harmful or interfere with the activities of another state in outer space, which China neglected to do despite the significant amount of dangerous space debris created by the incident. Neither the US nor the USSR/Russia held international consultations prior to their anti-satellite tests during the Cold War.

The OST also provides for a state to request consultation if it believes that the activities of another state will be harmful. The US apparently neglected to request a consultation with China despite intelligence of the two failed attempts to intercept a satellite and signs of preparation for the third, successful attempt; however, details of US intelligence and actions are not public.[98] Overall, while the Chinese interception of a satellite may not be deemed by some states to have breeched international law, it calls into question the spirit with which the Outer Space Treaty is being implemented.

2006: Continued polarization in PAROS debate at the UNGA

The negative vote by the US against the PAROS resolution in the UNGA First Committee, first observed in 2005, was repeated during the 61st session of the UNGA in 2006. The resolution passed with a vote of 166 in favor to one against, with two abstentions (Israel and Côte d'Ivoire).[99] At the plenary session of the UNGA, the resolution again passed with a vote of 178 in favor to one against (US), with Israel abstaining, signifying continued strong international support for the resolution.[100] US opposition to the PAROS resolution is consistent with the 2006 revised US National Space Policy in which the Bush administration opposes the development of new legal regimes or other restrictions pertaining to space[101] (see Trend 2.3). The US has consistently held the position that there is no arms race in space, and that the existing multilateral arms control regime adequately ensures the non-weaponization of outer space.[102]

2006: Space security proposals first tabled in 2005 still under consideration

In 2005, Russia and Sri Lanka sponsored draft resolutions in the UNGA First Committee on measures to promote transparency and confidence-building in outer space. Pursuant to those resolutions, in 2006 the UN Secretary-General invited member states to express their views on the advisability of further developing international outer space transparency and confidence-building measures in the interest of maintaining international peace and security, and promoting international cooperation and the prevention of an arms race in outer space. Several states, including Canada, China, Cuba, Iraq, Japan, Mexico, Mongolia, and the Russian Federation submitted written replies expressing support for the development of those measures and encouraging further dialogue on the issue.[103] The government of Canada indicated that some transparency and confidence-building measures already exist in international law and in states' multilateral commitments. China reaffirmed its long-held view that transparency and confidence-building measures are only transitional to the negotiation and adoption of international legal instruments having the binding force of law.[104]

Russia again introduced a draft resolution on transparency and confidence-building measures in outer space activities during the 61st session of the UNGA, urging all member states to submit concrete proposals on the said measures to the UN Secretary-General before the next session of the Assembly, and requesting that the Secretary-General submit a report on those proposals at the Assembly's next session.[105] Russia asserted that in substance the draft resolution did not in any way limit the legal right of states to self-defense, or the peaceful use of outer space.[106] The resolution passed in the First Committee with only the US voting against it and Israel abstaining. The issue is likely to be given further consideration during the 2007 sessions of the UNGA.

2006: COPUOS Legal Subcommittee discusses matters related to space security

Although no new space treaties were negotiated or adopted during the year under review, the Legal Subcommittee of COPUOS held deliberations on a number of issues related to space security. The deliberations covered matters such as the status and application of the five existing United Nations treaties on outer space, the character and utilization of the geostationary orbit without prejudice to the role of the International Telecommunication Union (ITU), and the review and possible revision of the Principles Relevant to the use of Nuclear Power Sources in Outer Space.[107] A common theme throughout the deliberations was the extent to which the existing international regime prevents the weaponization of space. Views were divided on the issue. Some delegations advocated the development of a universal comprehensive convention on space law as a means of addressing perceived gaps in the current regime, while others argued that the existing regime is sufficient to the task.[108]

Space security impact

The majority of states remained committed to expanding the international governance framework for outer space in 2006, but continued polarization among key international players on PAROS and transparency and confidence-building measures could have a negative impact on space security. Developments in 2006 continue to indicate that there is no clear way forward on these issues, despite the importance that states attribute to space security. Moreover, the Chinese ASAT calls into question the spirit with which international laws are being implemented.

TREND 2.2: COPUOS remains active but the Conference on Disarmament has been unable to agree on an agenda since 1998

2006: Continued stalemate on proposal to expand COPUOS mandate

Debate on expanding the COPUOS mandate to introduce additional topics, potentially including the militarization of space, remained polarized in 2006 during the 49th session. While some states expressed strong support for the proposal to include all issues related to the peaceful uses of outer space, including militarization, the US maintained the view that "COPUOS had been created exclusively to promote international cooperation in the peaceful uses of outer space and that disarmament aspects of outer space were more appropriately dealt with in other forums such as the General Assembly and the Conference on Disarmament."[109] Nonetheless, the Committee decided to retain the issue on the "ways and means of maintaining outer space for peaceful purposes" as a matter of high priority on the upcoming 2007 agenda.[110]

2006: Recommended guidelines on space debris mitigation developed by COPUOS Scientific and Technical Sub-committee

During informal meetings held in February 2006, the COPUOS Scientific and Technical Sub-committee Working Group on Space Debris approved a revised draft text of a preliminary document on space debris mitigation and also recommended voluntary implementation by all member states and international organizations to the greatest extent possible. The progress report to COPUOS acknowledged existing debris mitigation guidelines developed by the Inter-Agency Space Debris Coordination Committee, but asserted that the existence of high-level guidelines with wider acceptance among the global space community would provide greater benefits and utility to all stakeholders.[111] Accordingly, the recommended guidelines were based on the technical content and basic definitions of those developed by the IADC. They also took into account provisions of UN treaties and principles on outer space.[112] It was agreed that the draft guidelines should be circulated at the national level to facilitate approval at the 44th session in 2007 (see The Space Environment Trend 1.2).[113]

2006: Structured discussions held on space security issues in CD despite continuing inability to agree on formal Programme of Work

In 2006 the CD remained unable to achieve consensus on an agenda, thus preventing formal progress on the PAROS issue.[114] Nonetheless, a series of focused debates on PAROS were held during both formal and informal CD sessions.[115] On 8 June 2006 a formal plenary meeting of the CD was held to consider two issues: 1) the importance of PAROS and 2) the scope and basic definitions of a future international agreement to prevent the placement of weapons in outer space and the use of force against outer space objects. A series of plenaries followed, with discussions ranging from transparency and confidence-building measures in outer space to debates on new weapons of mass destruction.[116] These discussions took place with the unanimous support of all the principal space actors, including the US. Structured debate sessions on PAROS were based on several working papers submitted to the CD by member states. Russia and China jointly presented working papers on definition issues regarding the weaponization of outer space,[117] existing international legal instruments,[118] and international transparency and confidence-building measures.[119] Canada also introduced a working paper analyzing existing constraints on weapons and activities applicable to PAROS.[120]

During the structured discussions on PAROS, several states, including Belarus, Canada, China, the Democratic People's Republic of Korea, Germany, India, South Africa, Sweden, Syria, as well as EU members, expressed the view that conditions were ripe for the negotiation of a new legal instrument on PAROS, and that an ad hoc committee on PAROS should be established in the CD to do the substantive work.[121] Russia suggested three obligations to be included in any future treaty on prevention of outer space weaponization: 1) not to place weapons in outer space; 2) not to resort to the threat or use of force against outer space objects; and 3) not to assist others in doing either of the former.[122] Although the UK expressed basic support for PAROS it cautioned that it does not believe there is international consensus on the need for further legal treaties or codification. Representatives from Egypt and New Zealand took the PAROS issue further by expressing the need to de-militarize outer space.[123] The US maintained the position that the existing multilateral outer space regime adequately addresses the issue of PAROS and opposed the creation of an ad hoc committee to carry out substantive work on the issue.[124]

Space security impact

The year 2006 witnessed unprecedented cooperation and support by the principal space actors to hold discussions on space security issues within international institutions. Despite these discussions, the continued inability of the CD to reach consensus on a formal program of work raises doubts about the ability of these discussions to break the PAROS impasse. The drafting of space debris mitigation guidelines at the Scientific and Technical Sub-committee of COPUOS has the potential to enhance space security, but only insofar as states voluntarily apply them through national measures because they are not legally binding under international law.[125]

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

2006: New space policies in the US and China; European space policy expected in 2007

On 6 October 2006 a 10-page unclassified version of a new US National Space Policy was publicly released. The new policy declares that freedom of action in space is as important to the US as air and sea power. The document is similar in text to its 1996 predecessor, with a few significant exceptions. The new policy declares that "the US will oppose the development of new legal regimes or other restrictions that seek to prohibit or limit US access to or use of space; and that proposed arms control agreements or restrictions must not impair the rights of the US to conduct research, development, testing, and operations or other activities in space for US national interests."[126] It further states that the US "considers space capabilities – including the ground and space segments and supporting links – vital to its national interests"[127] and declares that "the United States will: preserve its rights, capabilities, and freedom of action in space; dissuade or deter others from either impeding those rights or developing capabilities intended to do so; take those actions necessary to protect its space capabilities; respond to interference; and deny, if necessary, its adversaries the use of space capabilities hostile to its national interests."[128]

Rather than charting a new course for the US, however, the 2006 National Space Policy appears to reflect changes that have already taken place in the implementation of US space policy. While the new policy appears to be more focused on national security concerns than its predecessor, it does identify new areas for military cooperation with foreign entities, in particular the sharing of intelligence and capacity for space situational awareness. Moreover, it maintains the tradition of US cooperation on peaceful uses of outer space, including space exploration, space surveillance, and Earth observation systems.[129]

Reacting to the new US policy the deputy head of the Russian Federal Space Agency, Vitaliy Davydov, declared that the US policy is the first step towards a serious escalation of the military confrontation in space and suggested that Russia has the capability to also "roll out certain military elements into outer space."[130] The White House insists that the new policy does not call for the development or deployment of weapons in space.[131] Nonetheless, Robert Joseph, then US Under Secretary of State for Arms Control and International Security, stated in a speech at the George Marshall Institute on 13 December 2006 that the US does not preclude the option of deploying weapons in space in the future.[132]

China's 2006 White Paper on Space Activities stresses the importance of international cooperation and exchanges, but also suggests that China intends to be a major competitor in the space industry. The Paper also links China's space activities to its national interests and "comprehensive national strengths."[133] Emphasis is placed on the importance of independence and self-reliance in space capabilities with the stipulation that international exchanges must operate on the basis of equality, mutual benefit and common development.[134] The document was drafted under the guidance of the Chinese National Space Administration (CNSA), however, and reports solely on China's civil space activities and ambitions. There is no mention of the role of the People's Liberation Army (PLA) in the Chinese space program, although brief reference is made to defense and security.

Progress was made in 2006 on European Commission efforts to adopt a new European Space Policy. In June 2006 Members of Parliament from 10 European countries met in Brussels under the aegis of the European Inter-parliamentary Space Conference (EISC) to discuss European space policy, emphasizing international cooperation, space applications, and education.[135] According to media reports, the policy was to be released at the next meeting of the European Space Council in May 2007. In September 2006, a conference on space, defense, and security was organized by the EISC and the Assembly of the Western European Union (see Trend 2.4).

Space security impact

Increased emphasis on national security aspects of space in 2006 and continued disagreements over the balance between international cooperation and national interests indicate a growing tension regarding space use and access. However, in general, states continued to promote international cooperation on the peaceful uses of outer space. Insofar as cooperation promotes transparency and confidence-building among space-faring states, this trend can be expected to exert a positive influence on space security.

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

2006: US, China, Japan, Israel, India, and the EU place greater emphasis on national security space applications

The number of states emphasizing the security uses of space in national policies continued to increase in 2006. The US National Space Policy declares that freedom of action in space is as important to the US as air and sea power (see Trend 2.3).

On 29 December 2006 China released a White Paper entitled *China's National Defense in 2006*.[136] The document stresses "informationization" as a key strategy in the modernization of the PLA. It further identifies reaching the "strategic goal of building informationized armed forces capable of winning informationized wars by the mid-21st century" as a key step in this process.[137] Despite the crucial role that space plays in the efficient collection and relay of information, there is no express mention of the use of outer space for national defense purposes. Nonetheless, in contemporary Chinese military science, the military use of space is inextricably linked to attaining comprehensive national military power.[138] Accordingly, the White Paper has been described as a continuation of China's tradition of military secrecy and criticized as "being rich in generalities about China's good intentions but sparse in specifics about its capabilities."[139] Although the White Paper does assert an international security strategy based on developing cooperative, non-confrontational, and non-aligned military relations with other states, China's 11 January 2007 ASAT test has raised questions about the extent and nature of China's military space program. The US-China Economic and Security Review Commission released a report in November 2006 accusing China of developing cyber-warfare capabilities as part of its informationized warfare strategy, although it contained no evidence of state-sponsored activities.[140]

The ruling Liberal Democratic Party in Japan formulated a bill for a new basic space law, which it plans to submit to the legislature for adoption. Presently, under a strict interpretation of the 1967 Outer Space Treaty contained in the 1969 Parliamentary (Diet) Resolution adopting the Law on the Establishment of the National Space Development Agency (NASDAct), Japan's use of space is limited to non-military purposes. If passed, the new bill will relax existing regulations and allow the Japanese government to carry out space activities for non-aggressive military and/or defense purposes, such as the development, launching, and operation of reconnaissance satellites by the Defense Ministry.[141] In fact, since 2003 Japan has had in orbit reconnaissance satellites, commonly described as non-military since they fall under the control of a special Cabinet committee and not the Ministry of Defense.[142]

In February 2006, the Israeli government ended years of heated debate by announcing that the Israeli Air Force, rather than the Military Intelligence Unit, will be given sole responsibility for all military activities in space as well as responsibility for designing and operating the nation's future satellites. The Air Force will now be known as the Israel Air and Space Force (IASF) and its mission will be to operate in the air and space arena for purposes of defense and deterrence.[143] Israeli officials publicly contemplated jamming commercial, third-party satellite signals during the war with Lebanon, although they acknowledged that it was against international law (see Space Systems Negation Trend 7.1).[144] The US was the first state to claim a potential willingness to interfere with third-party satellites in US Air Force Doctrine Document 2-2.1.[145]

In India, the establishment of a joint space weapons command was turned down by the Defence Ministry in 2006, but the country's military plans for space will be charted over the next year in a concept paper by the Defense Ministry's Integrated Defense Staff.[146] India still intends to establish what it calls an Aerospace Command, although the planned mandate remains vague.[147] That some experts in India are anticipating a more significant military role for space is suggested in the November 2006 publication *Space: The Frontiers of Modern Defence* published by India's Center for Air Power Studies. The introduction makes the following observations: "As we move forward in the 21st century it is inevitable that space will become another medium of warfare besides assuming the important role of protecting the country's commercial assets in this medium."[148]

In September 2006, the Western European Union Assembly and the EISC, in association with the ESA, France's *Centre National d'Etudes Spatiales* (CNES), and Arianespace, jointly held a conference on space, defense, and European security. The conference discussed the longstanding issue of a Space Policy for Europe, in particular the application of the space sector to European security and defense, and the industrial and technological capabilities required to achieve such a policy. The director of the ESA concluded that the conference had affirmed the importance of space for Europe and had provided valuable input toward the impending European Space Policy.[149] The conference concluded with general agreement that European defense must have a space dimension and urged Europe to take advantage of the dual-use nature of space.[150] In a related development, the EU Transport Commissioner, Jacques Barrot, proposed in October 2006 that Europe should consider using its Galileo navigation system for military purposes to recover escalating costs.[151] The extent to which these military-related policy discussions and recommendations are factored into the European Space Policy will not be known until it is released in 2007.

Space security impact

In 2006 there was a clear continuation of the increased focus on the security uses of space by a growing number of actors. This development may have both positive and negative effects on space security. Whereas the security benefits of sustainable access to and use of outer space can have a positive benefit on space security, doctrines intended to serve national interests by developing negation capabilities may eventually threaten that security. Comments on future conflicts in space by Indian officials, while not reflecting official state policy, and the Chinese ASAT test 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 Aviation and Space Agency, and the European Space Agency (ESA), and missions such as 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, through the launch capability of other actors, facilitate space access for countries without launch capability.

The chapter examines trends and developments in civil space for each space actor. The chapter also reviews 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 that 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. An example of a global utility is the US Global Positioning System (GPS).

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 Impact

Civil space programs can affect 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 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 can also be 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 Trend 7.2 and Space-Based Strike Systems Trend 8.2).

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 that 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. On the other hand, competition for access to and use of space resources in the longer term, particularly on the moon, could generate tensions between space powers.

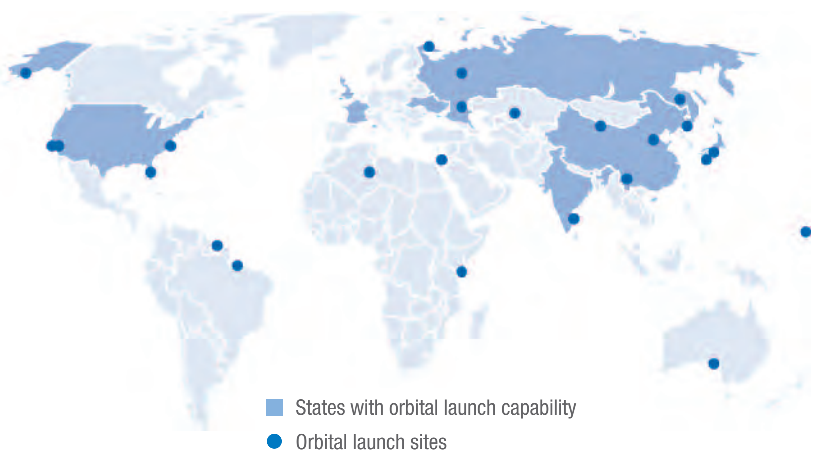
Key Trends

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 therefore under the present definition has demonstrated an orbital launch capability. Kazakstan, Brazil, South Korea, and Iran are also developing launch vehicles.

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

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



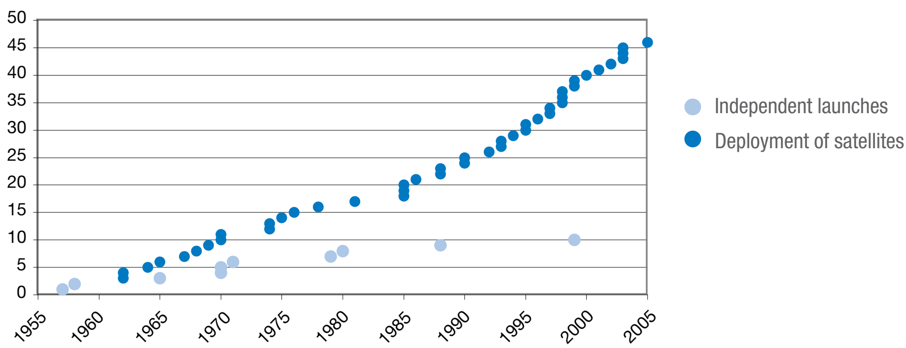
There are a further 18 actors that have sub-orbital capability, which is required for a rocket to enter space in its trajectory, but not achieve an orbit around the Earth. These actors are Argentina, Australia, Brazil, Canada, Germany, Iran, Iraq, Italy, Libya, North Korea, Pakistan, Saudi Arabia, South Africa, South Korea, Spain, Sweden, Switzerland, 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 2006, a total of 47 actors had accessed space, either with their own launchers or those of others. 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. Since the early 1990s, Surrey Satellite has assisted seven states (Algeria, Malaysia, Nigeria, Portugal, South Korea, Thailand, and Turkey) in efforts to build their first civil satellites.[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 states that have conducted manned launches 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[9]

Civil expenditures on space continue to increase in India and China, while decreases in the US, the EU, and Russia have begun to rebound. There was growth of about five percent per annum in real terms in the budget allocated to the Indian civil space program over the decade 1990-2000, for a total increase of over 60 percent.[10] 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.[11] 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.[12] Both budgets have begun to increase modestly since 2001. The NASA budget has increased annually at a rate of three to four percent since 2004 when President George W. Bush released the *Vision for Space Exploration*, which contains a renewed focus on human space flight.[13] The ESA budget was increased by 10 percent in 2005.[14] It is now steady at approximately $3.5-billion per year.

The USSR/Russia was the most active civil space actor from 1970 to the early 1990s, when sharp funding decreases led to a reduction in the number of civil missions. By 2001 the number of Russian military, civil, and commercial satellites had fallen from over 180 during the Soviet era to 89. The budget had been reduced to $309-million, or about 20 percent of its 1989 levels, which is less than the cost of a single launch of the US Space Shuttle.[15] This steady decline was reversed in 2005, however, when Russia approved a 10-year program with a budget of approximately $11-billion.[16] This budget may not provide an entirely accurate reflection of the status of Russian civil space capabilities, since even with a budget less than a tenth of NASA's, Russia launches more civil satellites than any other state.

Although a relative newcomer to space, China has the "fourth largest satellite space program" and the "fastest growing launch rate of any space-faring power," launching 39 satellites (eight of which were military) between 1996 and 2006, 75 percent in the last five years.[17]

Microsatellites

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 but at a 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 technology enabled 'smaller, faster, cheaper' space missions.

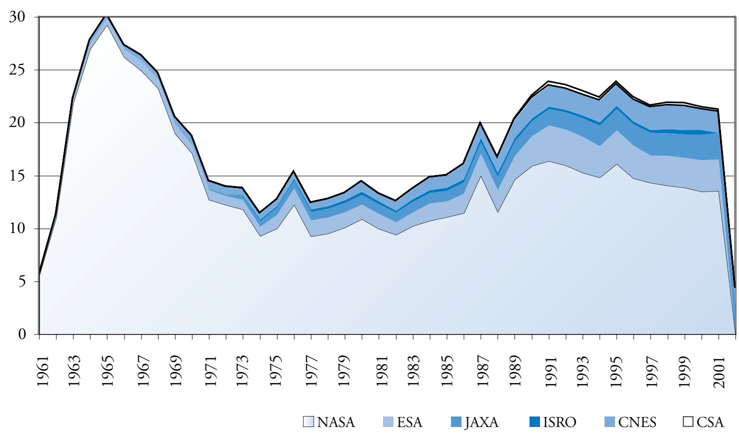
Microsatellites are now increasingly used for civil missions, including, for example, the multinational Disaster Monitoring Constellation and France's joint military-civil Myriade series of microsatellites.xvii These developments have enabled European actors, China, and Japan to expand their civil programs to the point where they now together equal the US or Russia's civil efforts. In 2004 China established the world's largest microsatellite industry park.[19] Furthermore, 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 out about 100 missions with a capacity of three humans on each flight. The 2006-2015 Federal Space Program maintains an emphasis on human space flight, featuring ongoing development of a reusable spacecraft, the Kliper, to replace the Soyuz vehicle, and completion of the Russian segment of the ISS.[20]

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. In the 1970s, the US initiated the Space Shuttle, which is 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.[21]

Figure 3.3: Historic annual civil space agency budgets of major space agencies (billion 2001 dollars)[22]



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.[23] In 2004 it launched an ambitious plan to develop a manned space station in Earth orbit within 15 years.[24] 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 was temporarily the only actor performing regular manned missions, with its Soyuz spacecraft providing the only lifeline to the International Space Station (see Figure 3.4).

Other civil programs are also turning to human spaceflight. In 2005 JAXA released its 20-year vision statement, which includes expanding its knowledge of manned space activities aboard the ISS as well as developing a manned space shuttle by 2025.[25] The ESA also has a long-term view to send humans to the Moon and Mars through the Aurora program. For an overview of historical civil space budgets, see Figure 3.3.

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.[26]

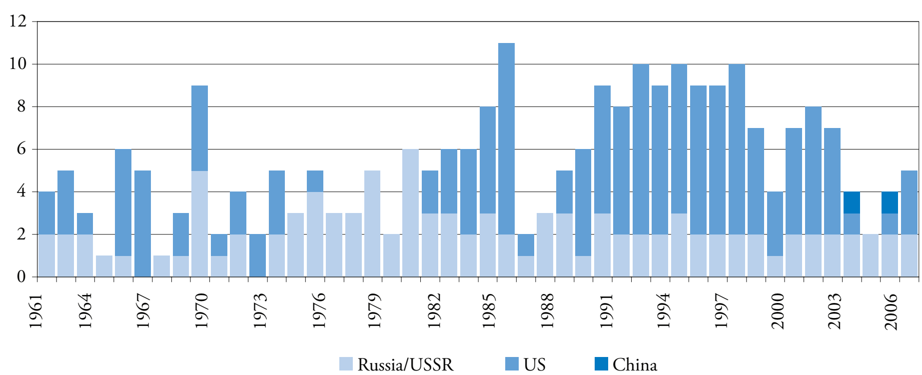
A Russian space agency (Rossyskoe Kosmicheskoe Agenstvo) was established in 1992, and has since been reshaped into the Russian Aviation and Space Agency (Rosaviakosmos). While this new agency has more centralized powers than previous organizations, most work is still completed by design bureaus, now integrated into "Science and Production Associations" (NPOs) such as NPO Energia, NPO Energomash, and NPO Lavochkin. This continued decentralization of civil activities makes obtaining accurate comprehensive budget figures for Russian civil space programs difficult.[27] It is known that, in 2002, the Russian government contributed about $265-million to the Russian Aviation and Space Agency.[28]

In 1961, France established its national space agency, the Centre National d'Études Spatiales (CNES), which remains the largest of the EU national-level 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 in 1975 into ESA, which is the principal space agency of the region today. Most ESA funding is provided by a small group of states with active national space programs. Between 1991 and 2000, Germany and France regularly provided between 40 and 50 percent of the ESA budget.[29]

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 $2-billion per year.[30]

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.[31] India's civil space agency, the Indian Space Research Organisation (ISRO), 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.

Figure 3.4: Number of manned launches[32]



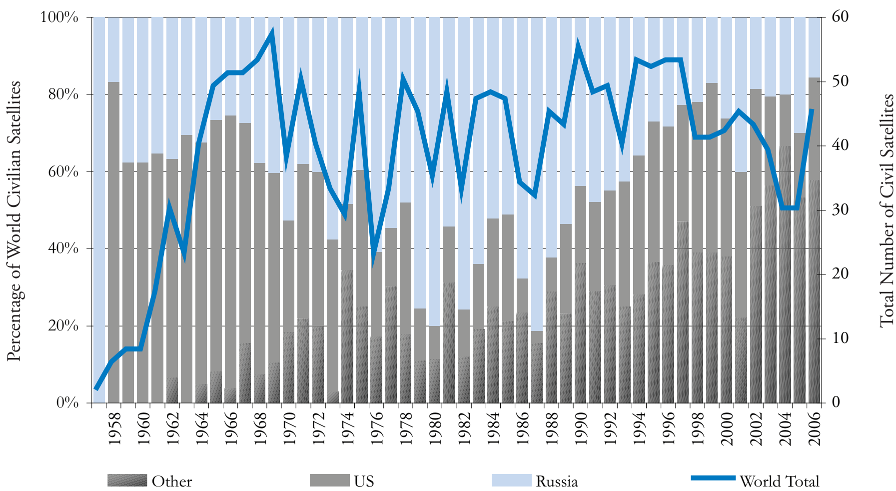
New directions for civil programs

A growing number of civil space projects are now also explicitly focused on social and economic development objectives. ISRO has developed 10 communications satellites that provide tele-education and telehealth applications, and nine remote sensing satellites to enhance agriculture, land, and water resource management and disaster monitoring.[33] In 2000, Malaysia launched Tiungsat-1, a microsatellite that included several remote sensing instruments for environmental monitoring. In 1998, Thailand and Chile together launched TMSat, the world's first 50-kilogram microsatellite to produce high-resolution, full color, multispectral images for monitoring the Earth, and FASat-Bravo, a microsatellite to study depletion of the ozone layer.[34] African states such as Algeria, Egypt, Nigeria, and South Africa have built, or are in the process of building, satellites to support development.

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 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."[35]

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 increased employment and economic growth.[36] Recent examples of these spin-offs from NASA's programs include scratch resistant lenses, virtual reality equipment, more efficient solar cells, microlasers, advanced lubricants, and programmable pacemakers.[37] Figure 3.5 shows civil space launches over time.

Figure 3.5: World civil satellites, including manned space missions[38]



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

Due to the huge 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.[39] From 1995 to 1998, there were nine dockings of the US Space Shuttle to the MIR space station, with various crew exchanges.[40] 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 Aviation and Space Agency, ESA, JAXA, and the Canadian Space Agency. Brazil participates through a separate agreement with NASA. The first module was launched in 1998; the station is still under construction. By 2006, 58 launches had carried components, equipment, and astronauts to the station.[41] The ISS is projected to cost $129-billion.[42]

Space-based global utilities, discussed in more detail in Trend 3.4, represent another area of international cooperation. The EU Galileo satellite navigation system is a partnership between the EU and the ESA and includes several international partners.[43] Algeria, China, Nigeria, Spain, Thailand, Turkey, Vietnam, and the UK are collaborating on the Disaster Monitoring Constellation. The project, initiated by China, foresees the deployment of 10 dedicated microsatellites, five of which have been deployed to date.

Another recent international civil space initiative is the Global Earth Observation System of Systems (GEOSS), which has the goal of "establishing an international, comprehensive, coordinated and sustained Earth Observation System."[44] 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.[45]

The nature of international space cooperation has changed since the end of the Cold War, as many 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.[46] However, increased cooperation has been hindered by export control issues, particularly in the US (see Commercial Space Trend 4.3).

TREND 3.4: Continued growth in global utilities as states seek to expand applications and accessibility

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, and generated sales revenue of $6.2-billion in 1999[47] and $21.8-billion in 2005.[48] Key global utilities such as GPS and weather satellites were initially developed by military actors. Today these space applications are indispensible to the civil and commercial sectors as well.

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 determine its location, accurate within 20 meters depending on the precision of available signals. 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 military allies.

Commenced 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 its total market. In 1999, the GPS industry employed 30,000 people. The commercial air transportation industry, which carried about 1.6-billion passengers in 2000, relies heavily on the GPS.[49] 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.[50]

The Russian GLONASS system uses principles that are similar to those used in 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.[51] The first GLONASS satellite was orbited in 1982, and the system became fully operational in 1996, with accuracy similar 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.[52] GLONASS operates a Standard Precision service available to all civilian users on a continuous, worldwide basis and a High Precision service available to all commercial users as of 2007.[53] Russia has extended cooperation on GLONASS to China and India. To augment the GPS India is also developing a civilian satellite navigation system called GAGAN (GPS and GEO Augmented Navigation) or SBAS (Space-Based Augmentation Systems), which will be a low-cost system using seven geostationary satellites and ground-based systems to provide greater coverage of the Indian sub-continent.[54] The first payload is scheduled for launch in 2007.

China, Japan, and the EU are all engaged in the research and development of additional satellite navigation systems.[55] The Chinese Beidou system has been under development since the late 1990s and currently has three 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.[56]

Japan has begun developing the Quazi-Zenith Satellite System (QZSS), which is to consist of three satellites interoperable with GPS in Highly Elliptical Orbit to enhance regional navigation over Japan.[57] The first satellite is scheduled for launch in 2009-2010.

Perhaps most significantly, the EU and ESA are jointly developing the Galileo navigation system, which is planned to consist of 30 satellites in a constellation similar to that of 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.[58] 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.[59] The Galileo project has been opened to international partners to support the development of the system; by 2006 these included Israel, Ukraine, India, Morocco, Saudi Arabia, and South Korea. Russia has agreed to launch Galileo satellites. China's partnership status was clarified in 2004, when it was announced that China would not be granted access to the secure Public Regulated Service government channel.[60]

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 a solution 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.[61] Galileo will offer Open Service, commercial service, safety-of-life service, search-and-rescue service, and an encrypted, jam-resistant, publicly regulated service reserved for public authorities that are responsible for civil protection, national security, and law enforcement.[62] The project is currently in its testing phase, but is already over budget; the completion date has been extended from 2008 to 2011.[63]

Earth Observation

Earth observation satellites are used extensively for a variety of functions, including weather forecasting; 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.

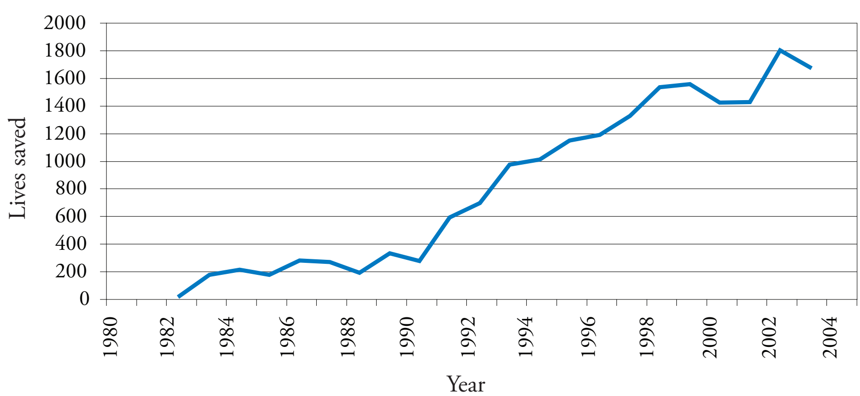
The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) has launched eight satellites into GEO since 1972 to provide meteorological data for Europeans. Similarly, the US National Oceanic and Atmospheric Administration (NOAA), founded in 1970, has launched over 34 satellites to provide US meteorological services.[64] 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.[65] In 2005, 61 states supported by 40 international organizations agreed to a 10-year implementation plan for GEOSS, which is designed to bring together and make compatible existing and new hardware and software in order to supply data and information at no cost.[66]

Space has become critical for measuring climate change. Several countries, including Algeria, China, Nigeria, Vietnam, Thailand, Turkey, Spain, and the UK, are collaborating on the Disaster Monitoring Constellation to deploy 10 microsatellites dedicated to this use.[67] There are currently five in operation.

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).[68] This figure is double that of 1996. Currently COSPAR-SARSAT operates 12 satellites.[69]

Figure 3.6: Lives saved annually by COSPAS-SARSAT[70]

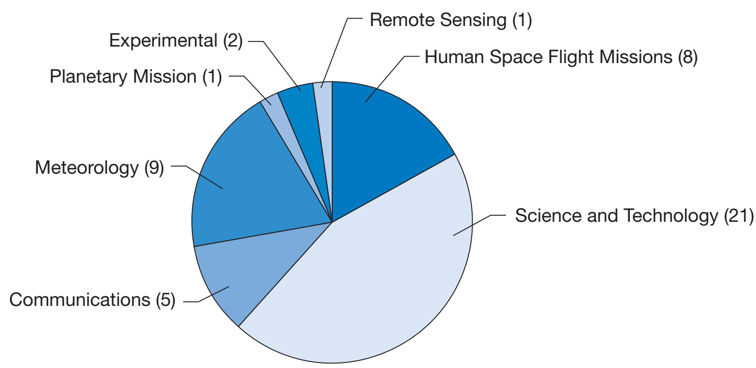


TREND 3.1: Growth in the number of actors gaining access to space

2006: Global progress in space access, launch, and propulsion technologies

In 2006, 47 civil spacecraft were successfully launched, up from 24 in 2005, indicating a slight increase in civil space access (see Figures 3.7 and 3.9).

Figure 3.7: Civil space launches in 2006



With the Russian launch of KazSat-1 on 17 June 2006 aboard a Proton Rocket, Kazakhstan became the 47th nation to own a satellite.[71] The satellite will provide communications services to numerous entities in the region, including Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, and parts of Russia. After this successful collaboration, Russia and Kazakhstan plan to work together on the launch of Kazakhstan's next satellite, KazSat-2.[72] Other plans for satellite launches in the short term demonstrate the growing importance of access to space in the developing world. Egypt's first scientific satellite is scheduled for 2007, and the launch of Indonesia's first domestically produced satellite is planned for late 2008.[73] Belarus has indicated plans for a second attempted launch of its first satellite following the failed July 2006 launch of its BelKa remote sensing satellite.[74] Nigeria has also announced the construction and future launch of its first telecommunications satellite in 2007.[75] South Africa intends to launch its first microsatellite from Russia, following cabinet approval for the creation of the South African Space Agency.[76]

The continued development in 2006 of launch vehicle technology could facilitate future space access. The ESA registered several successes in the development of its Vega small satellite launcher. The November 2006 successful test of its first-stage P80 motor will be followed by several more tests for the second- and third-stage motors. The ESA has tentatively scheduled the first voyage of the Vega launcher for 2008.[77] In partnership with the Australian National University, the ESA has also successfully tested early developments for a new ion engine design[78] South Korea plans to inaugurate its first launch vehicle in 2007 or 2008. The Korea Space Launch Vehicle (KSLV-I) will be capable of launching payloads up to 100 kilograms into LEO, allowing greater independence and growth for the Korean Aerospace Research Institute's (KARI) space program.[79]

Significant launch failures in 2006 include the 26 July 2006 Dnepr launch vehicle explosion, which destroyed 20 microsatellites from seven countries – mostly manufactured by universities. This incident was a major setback for many low-cost space efforts. On 10 July an Indian launch vehicle with an ISRO-developed civil communications satellite failed and hindered Indian efforts to become one of the few states with a heavy-payload launch capability to GEO.[80]

Space security impact

The growing number of developing countries gaining access to and using space is an encouraging sign for space security as it increases the number of country stakeholders with an interest in the secure and sustainable access to space. Nonetheless, this increase in access could also allow for proliferation of military or dual-use capability spacecraft and greater debris creation, which might have a negative impact on space security. Moreover, despite the growing number of national stakeholders in space, most activity is by a small group of countries, which continue to have the largest impact on space security.

TREND 3.2: Changing priorities and funding levels within civil space programs[81]

2006: A balance of strong and modest budget growth across space actors

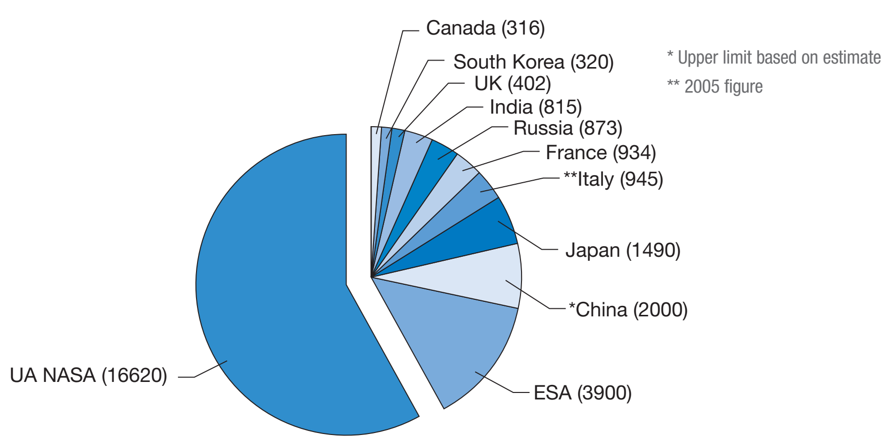
Budgets generally increased for civil space agencies in 2006, although some at higher rates than others. ISRO saw the greatest proportional increase in funding at 35 percent, with a 2006-2007 budget of $815-million.[82] In response to severe under-funding from 2001-2005, the Russian Federation's Federal Space Agency's annual budget grew by $180-million in 2006 to approximately $873-million, approved under a five-year plan.[83] The ESA reported a budget of approximately $3.5-billion in 2006.[84] KARI reportedly had a budget of approximately $320-million, with expectations that this number would grow in the future.[85] The Japanese Parliament approved a 2006 budget for JAXA of $1.49-billion; the proposed 2007 budget is $1.52-billion.[86]

The United States continues to dominate the world in civil space spending. However, the new Democratic-controlled Congress determined that it would enact "continuing resolution" bills rather than pass any currently unfinished spending legislation. Consequently, NASA's funding for FY 2007 will remain at $16.62-billion, short of its request for $16.97-billion.[87] Nonetheless, NASA continues to account for more dollar-for-dollar expenditures than all other major space powers combined (see Figure 3.9).

Chinese officials have been quoted as saying that the Chinese space budget is as low as $500-million. Media sources place the budget closer to $2-billion. While it is safe to speculate that it falls somewhere between these two figures, there is no reliable evidence.[88]

Signaling its dedication to increasing the use of space for national development purposes, South Africa announced that it will create a national space agency, although a budget is not yet available.[89]

Figure 3.8: Civil space budgets in 2006 (Millions USD)



2006: Civil space agencies focus efforts on lunar exploration and manned missions

On 4 December 2006 NASA announced its new strategy for lunar exploration. This strategy will begin with a planned 2008 launch of an unmanned lunar probe, which will be used to study, analyze, and map the lunar surface in preparation for further exploration.[90] Future plans include human return to the moon, and a permanent human presence on the lunar surface.[91] This announcement followed a report in March 2006 that $3-billion will be cut from NASA's space science budget over the course of three years, reflecting a shifting priority towards human space flight.[92]

In 2006 Russia announced that its short-term lunar plans include the launching of a number of small spacecraft in 2007, followed by a robotic lander in 2012. Russia also plans a manned mission to lunar orbit during this time, followed by possible construction missions to the lunar surface.[93] Integral to the Russian plans is the successful development and construction of a new craft to succeed its current Soyuz spacecraft, which was approved in 2005.[94]

China also identified lunar exploration as a priority. The Chinese National Space Administration (CNSA) has announced plans to have a satellite Chang'e-1 in lunar orbit by September 2007. Its long-term lunar aspirations include a robotic lander and possible manned missions.[95]

ISRO continued with plans to conduct a major lunar mission, Chandrayaan-1, now scheduled for mid-2008. Other space agencies participating in this venture include NASA and the ESA, which have designated several payloads for the launch.[96] ISRO received approval for a fully funded manned space program in 2006, hoping to become the fourth country to launch a human into space.[97]

In 2006 the ESA successfully completed its SMART mission, which crashed a spacecraft into the lunar surface, from which numerous scientific tests were conducted. Prior to its final demise on the lunar surface, the probe was used to test new technologies and carry out mapping missions of the Moon.[98] The ESA has also established a framework of exploration for the Moon and Mars through its *Aurora* program.[99]

Space security impact

The announcements of the past year have demonstrated renewed interest in large-scale space projects, particularly lunar exploration. These projects offer opportunities for both international cooperation and competition. Recent trends suggest that progress on these projects will be predominantly cooperative, but the extent to which they are influenced by strategic concerns could fuel tensions in space. Nonetheless, it remains to be seen if these long-term goals will be accompanied by the necessary investments. Until it becomes clear if and how lunar exploration will unfold, its impact on space security will remain limited.

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

2006: Continuing international civil space cooperation

The trend of international civil space cooperation continued in 2006 with the signing of several significant bilateral and multilateral agreements and the completion of joint missions. Russia and the ESA agreed to collaborate in areas of specific mutual interest such as communications and new technology.[100] The ESA has also signed an agreement with Russia to investigate the design of a new spacecraft to replace the current Soyuz craft. Over the next two years Russia, the ESA, and possibly Japan will explore the craft's development and feasibility. Russia and China have agreed to collaborate on a mission to Mars, and have also discussed the possibility of cooperating on future lunar exploration missions.[101] Russia signed agreements with South Korea and Malaysia to send astronauts from those countries to the ISS.[102] Russia has also entered into new space launch agreements with France and sought closer space ties with South Africa.[103]

In September NASA collaborated with the ESA and JAXA on a successful project that sent the Hinode satellite to monitor the sun.[104] NASA also collaborated with Taiwan to launch six microsatellites in April.[105] There were some indications of future contact between the civil space activities of China and the US when NASA Chief Administrator Michael Griffin visited China in September 2006. Substantial cooperation on major projects such as the ISS and lunar/Martian exploration missions is not evident in the short term.[106]

ISRO and NASA signed a major agreement of cooperation in March 2006, with a focus on technology exchange and cooperation in areas such as exploration, satellites, and earth sciences. India and Russia have committed to joint use of, and cooperation in, the Russian GLONASS navigation project.[107] ISRO has also entered into agreements with Malaysia and Israel to collaborate on launch facilities and technology exchange.[108]

ESA expanded its network of partners to include Romania as a "Cooperating State," joining the Czech Republic and Hungary, which were so designated in 2003.[109] EUMETSAT and the US NOAA entered into an agreement in February 2006 to ensure the continued flow of meteorological information during times of crisis or war.[110] Estonia and Croatia also joined the EUMETSAT organization.[111] Deals were finalized to include South Korea and Morocco in the European Galileo navigation satellite program.[112] The EU has also been seeking stronger cooperation for its Global Monitoring of Environment and Security (GMES) project and hopes to have services running by 2008 as part of its pilot phase.[113]

In October a white paper titled "China's Space Activities in 2006" stated that China has signed 16 international space cooperation agreements with 13 different countries, space agencies, and international organizations over the past five years.[114] It claims that in the next five years China will work with Pakistan, Nigeria, and Venezuela to develop and launch satellites. China has agreed to help Pakistan develop space technology and to launch three earth observation satellites. China and Nigeria agreed on a loan of $200-million for Nigeria's communication satellite project, NigComSat-1, which has been re-scheduled for launch from 2006 to 2007.[115] China's cooperation with Venezuela builds on memoranda of understanding signed in 2005.[116]

Space security impact

Growing cooperation and collaboration between major and less developed space powers enhance space security by providing partner countries with greater access to space through shared resources and technology. Larger networks of cooperation could also result in greater transparency of space activities, mitigating uncertainties or mistrust that may arise as more countries gain access to space. There is a risk, however, that sensitive military technologies will proliferate. Moreover, there are some indications that this cooperation is following strategic geo-political concerns that could fuel tensions and rivalries in space.

TREND 3.4: Continued growth in global utilities as states seek to expand applications and accessibility

2006: Advances in US, Russian, Indian, Chinese, and European satellite navigation systems

The US Air Force-managed GPS system launched its second and third GPS IIR-M satellites in September and November 2006 as part of a modernization program initiated in 2005.[117] This number was down from the three or four launches previously planned for 2006. Launch of an IIF satellite, which will be the first to carry a third civilian signal, has been postponed to 2008. The final stage of the modernization process, GPS-3, has been rescheduled from 2009 to 2013 following a series of budget cuts and restorations.[118] Russia launched three additional GLONASS navigation satellites at the end of 2006, bringing the constellation to a total of 19 spacecraft, 14 of which were operational.[119] Officials claim that it will be completed with the launch of five more satellites in 2008.[120] Civilian and commercial restrictions are to be lifted.[121]

India announced plans to develop an independent regional satellite navigation system. Called the Indian Regional Navigation Satellite System (IRNSS), it will consist of a seven-satellite constellation independent of India's current involvement in the ESA's Galileo project and Russia's GLONASS.[122] This new system is also different from India's GAGAN system, which seeks to increase and improve the efficiency of currently available GPS signals used by the Indian aviation industry.[123] Although GAGAN completed preliminary testing with Raytheon in July 2006, the first satellite has yet to be completed and the system will not be operational before 2009.[124] China announced in 2006 that it will extend its regional Beidou system into a global system called Compass or Beidou-2 for military, civilian, and commercial use.[125] The global system is planned to include five satellites in GEO and 30 in MEO. The initial regional system is expected to provide service in 2008; it included three satellites at the end of 2006.

The first signals from the Giove-A prototype Galileo navigation satellite were received in January 2006. The launch of Giove-B was pushed back to 2007.[126] The ESA completed deals with South Korea and Morocco, confirming their involvement with the Galileo project.[127] By 2006 Galileo was already $513-million over budget and still in the testing phase. The operational date has moved from 2008 to 2011. The future of the system is unclear.

2006: Weather and climate change are priorities for earth observation satellites, but security concerns place restrictions on data distribution

Civil space applications are increasingly being used for natural disaster mitigation. Following a successful launch of a Fengyun satellite in December, China announced long-term plans for further meteorological satellites.[128] China also intends to launch three Earth observation satellites in 2007 to better manage environmental calamities across its large territory.[129] In April 2006 NASA successfully launched its CALYPSO and CloudSat missions, which were sent to examine and monitor the Earth's weather and climate. The satellites will also be used to study meteorological activity in an effort to better forecast weather and predict climate change.[130] On 15 April a Minotaur-1 rocket launched a constellation of six Taiwanese remote sensing satellites as part of the COSMIC project with the US.[131]

In a significant shift of policy regarding weather satellites, distribution of the data collected by EUMETSAT's constellation of MetOp meteorological satellites will be restricted by security concerns. A 2006 agreement between EUMETSAT and the US NOAA will create a 'data denial list' stipulating agencies that are restricted from accessing data from the MetOp satellites. This agreement comes as the US DOD and NOAA merge their weather satellites, giving the DOD a vested interest in any agreements made with EUMETSAT. The satellites will be under EUMETSAT control but subject to US requests to restrict third party access.[132] On 19 October 2006 Europe launched its MetOp-A satellite, the first of the EUMETSAT Polar System. Data from this satellite will be used for climate and environmental monitoring, as well as more accurate weather forecasting and disaster mitigation. A total of three MetOp satellites will be launched sequentially, providing service until 2020.[133]

Space security impact

The proliferation of and increased access to navigation systems should have a positive effect on space security by involving an ever-widening community of stakeholders and redundancy of capabilities. Some states have expressed concerns, however, that the information gathered by these systems can threaten national security if not properly protected.[134] Furthermore, given the capabilities of navigation satellites, these systems can serve dual-use functions for space systems negation and space-based strike capabilities, and for improving the accuracy of missiles and other munitions. These concerns are compounded by the development of regional and independent systems. Restriction of data from Earth observation satellites demonstrates the growing securitization of civilian space applications. In particular, the agreement between NOAA and EUMETSAT is an important policy shift that may lead to the creation of barriers to international cooperation in the future, and possibly hinder the ability of all states to enjoy the benefits of space.

Figure 3.9: Civil spacecraft launched in 2006 (by owning state)[135]

COSPAR	Launch Date	Launch Vehicle	Satellite Name	Launch State	State	Primary Function	Primary Manufac.	Orbit Type
2006-015A	4/26/06	Chang Zheng 4B	Yaogan 1 *	China	China	Remote sensing	-	LEO
2006-035A	9/9/06	Chang Zheng 2C	SJ-8	China	China	Biology	CAST	LEO
2006-046A	10/23/06	Chang Zheng 4B	SJ-6/2A *	China	China	Experimental (SIGINT)?	SISE/ Shangha	LEO
2006-046B	10/23/06	Chang Zheng 4B	SJ-6/2B *	China	China	Experimental (SIGINT)?	SISE/ Shangha	LEO
2006-048A	10/28/06	Chang Zheng 3B	Xinnuo 2	China	China	Telecoms	CAST	GEO
2006-053A	12/8/06	Chang Zheng 3A	Feng Yun 2D *	China	China	Meteorology	SISE/ Shangha	GEO
2006-044A	10/19/06	Soyuz-2-1A	METOP 2	Russia	ESA	Meteorology	Astrium	LEO
2006-016B	4/28/06	Delta 7420-10C	Calipso	USA	France	Science	CNES	LEO
2006-063A	12/27/06	Soyuz-2-1B	COROT	France	France	Astronomy	Alcatel/Cann	LEO
2006-014A	4/25/06	Start-1	EROS B	Russia	Israel	Imaging	IAI	LEO
2006-041F	9/22/06	M-V	HIT-SAT	Japan	Japan	Telecoms	HokkaidoIT	LEO
2006-005C	2/21/06	M-V	CUTE-1.7-APD	Japan	Japan	Telecoms	TITech	LEO
2006-041D	9/22/06	M-V	SSSAT	Japan	Japan	-	ISAS?	LEO
2006-002A	1/24/06	H-IIA 2022	Daichi	Japan	Japan	Imaging	NASDA/ Tsukub	LEO
2006-004A	2/18/06	H-IIA 2024	MTSAT-2	Japan	Japan	Meteorology	MELCO	GEO
2006-005A	2/21/06	M-V	Akari	Japan	Japan	Astronomy	ISAS	LEO
2006-005B	2/21/06	M-V	SSP	Japan	Japan	Technology	ISAS	LEO
2006-041A	9/22/06	M-V	Hinode	Japan	Japan	Astronomy	MELCO	LEO
2006-043C	10/13/06	Ariane 5ECA	LDREX-2	France	Japan	Technology	JAXA	GEO
2006-059A	12/18/06	H-IIA 204	Kiku-8	Japan	Japan	Telecoms	MELCO/NEC	GEO
2006-022A	6/17/06	Proton-K/DM-2M	Kazsat	Russia	Kazakh	Telecoms	Krunichev	GEO
2006-009A	3/30/06	Soyuz-FG	Soyuz TMA-8	Russia	Russia	Human	Energiya	LEO

COSPAR	Launch Date	Launch Vehicle	Satellite Name	Launch State	State	Primary Function	Primary Manufac.	Orbit Type
2006-013A	4/24/06	Soyuz-U	Progress M-56	Russia	Russia	Human	Progress	LEO
2006-019C	5/26/06	Shtil'-1	COMPASS-2	Russia	Russia	Science	Makeev	LEO
2006-021A	6/15/06	Soyuz-U	Resurs-DK	Russia	Russia	Imaging	TsSKB	LEO
2006-025A	6/24/06	Soyuz-U	Progress M-57	Russia	Russia	Human	Progress	LEO
2006-040A	9/18/06	Soyuz-FG	Soyuz TMA-9	Russia	Russia	Human	Energiya	LEO
2006-045A	10/23/06	Soyuz-U	Progress M-58	Russia	Russia	Human	Progress	LEO
2006-031A	7/28/06	Rokot	Arirang-2	Russia	South Korea	Imaging	KARI	LEO
2006-011F	4/15/06	Minotaur	COSMIC 6	USA	Taiwan	Science	OSC-Germanto	LEO
2006-011E	4/15/06	Minotaur	COSMIC 5	USA	Taiwan	Science	OSC-Germanto	LEO
2006-011D	4/15/06	Minotaur	COSMIC 4	USA	Taiwan	Science	OSC-Germanto	LEO
2006-011C	4/15/06	Minotaur	COSMIC 3	USA	Taiwan	Science	OSC-Germanto	LEO
2006-011B	4/15/06	Minotaur	COSMIC 2	USA	Taiwan	Science	OSC-Germanto	LEO
2006-011A	4/15/06	Minotaur	COSMIC 1	USA	Taiwan	Science	OSC-Germanto	LEO
2006-001A	1/19/06	Atlas V 551	New Horizons	USA	USA	Planetary	APL	Planet.
2006-008C	3/22/06	Pegasus XL	ST-5 AFT	USA	USA	Science	NASA GSFC	MEO
2006-008B	3/22/06	Pegasus XL	ST-5 MID	USA	USA	Science	NASA GSFC	MEO
2006-008A	3/22/06	Pegasus XL	ST-5 FWD	USA	USA	Science	NASA GSFC	MEO
2006-016A	4/28/06	Delta 7420-10C	Cloudsat	USA	USA	Science	Ball	LEO
2006-018A	5/24/06	Delta 4M+(4,2)	GOES 13	USA	USA	Meteorology	Boeing/ES	MEO
2006-028A	7/4/06	Space Shuttle	Discovery (STS-121)	USA	USA	Human	BNA/ Palmdale	LEO
2006-036A	9/9/06	Space Shuttle	Atlantis (STS-115)	USA	USA	Human	BNA/ Palmdale	LEO
2006-047B	10/26/06	Delta 7925-10L	STEREO B	USA	USA	Science	APL	Solar
2006-047A	10/26/06	Delta 7925-10L	STEREO A	USA	USA	Science	APL	Solar
2006-055A	12/10/06	Space Shuttle	Discovery (STS-116)	USA	USA	Human	BNA/ Palmdale	LEO
2006-058C	12/16/06	Minotaur	Genesat-1	USA	USA	Biology	NASA ARC/ SCU	LEO

*Suspected by some western experts to also serve military use[136]

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 that 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 that 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. Recently, overcapacity has driven down the cost of commercial space launches. Increased competition and technological innovations, such as the development of so-called piggyback launches of small, secondary payloads, also exert a downward pressure on prices and create a corresponding increase in the number of commercial space actors.

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 and by adopting enabling policies and regulations. 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 primarily through domestic and international export controls.

Several states have begun to consider commercial space as 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 Impact

The commercial space sector bears directly on space security considerations as it provides several actors with launchers with which to access space. Commercial activity provides much of the satellite and ground station manufacturing capability, enabling actors to operate entire space systems. Commercial space services also provide individual consumers with one of the most direct ways to use space.

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 number of 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 transparency and trust through international collaboration. Additionally, the development of the space industry could influence international space governance. To thrive, sustainable commercial markets require a framework of laws and regulations on 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, lead to greater competition for scarce space resources such as orbital slots and radio frequencies. Commercial actors could undermine global priorities 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 the global commercial space 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, followed by a rebound in 2005. Recent trends include significant growth in profits from satellite services, but a decline in profits in the manufacturing and launch sectors. The satellite services sector has tripled in size since 1996, generating $52.8-billion in revenues in 2005, or 60 percent of the commercial satellite sector's $88.8-billion total revenues (see Figure 4.1).[2]

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.[3] Satellite industry revenues were first reported in 1978, when *US Industrial Outlook* published 1976 Communication Satellite Corporation operating revenues of almost $154-million.[4] By 1980, it is estimated that the worldwide commercial space sector already accounted for $2.1-billion in revenues,[5] and by 2005, the sector had collected $88.8-billion.[6] Not yet included in industry revenue totals is the nascent space tourism industry. The growing commercial use of satellite positioning services is part of this increasing demand.

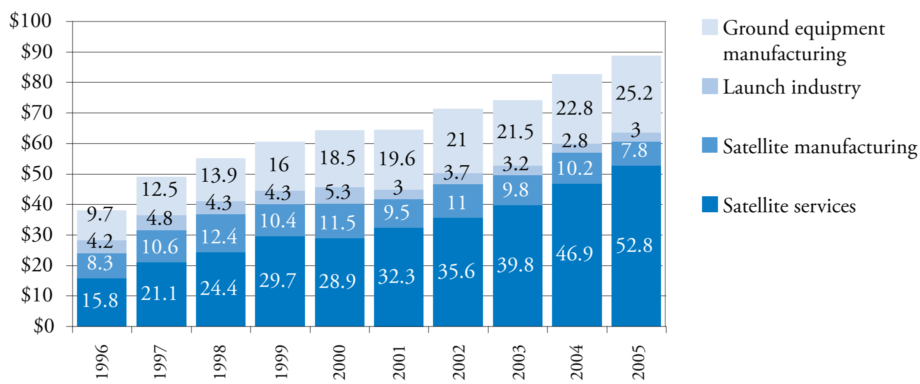
A number of new companies were founded in the 1980s to take advantage of anticipated growth in the space telecommunications services sector. This sector was deregulated in many countries during the 1990s, and previously government-operated bodies, such as the International Maritime Satellite Organization (Inmarsat) and the International Telecommunications Satellite Organization (Intelsat), were privatized in 1999 and 2001 respectively.[7] PanAmSat, New Skies, GE Americom, Loral Skynet, Eutelsat, Iridium, EchoStar, and Globalstar were some of the prominent companies to emerge during the 1990s. Hughes also entered the market with DirecTV, a new satellite television broadcast system.

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 costs of both communications equipment and launches. Current major satellite telecommunications companies include SES Global, Intelsat, Eutelsat, and Telesat Canada.[8]

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. The number of commercial satellite launches dropped from a peak of 38 in 1999 to 16 in 2001 and has not fully recovered.[9] Revenue from commercial satellite launches peaked at $5.3-billion in 2000, but has since leveled around $3-billion annually.[10] Despite the persistent overcapacity of the space-launch market, estimated at roughly 70 percent, there has been a consolidation of space launch prices since 2004[11] (see Trend 4.2). Since 2002, 80 percent of commercial launches have been to Geosynchronous Orbit (GEO), reflecting the growing demand for telecommunications services.[12]

After a record high of $12.4-billion in revenue in 1998, satellite manufacturers worldwide collected only $7.8-billion in 2005, a drop of about 36 percent. Revenue is uneven across government and commercial launches. The estimated value of government payloads was 71 percent of total revenues in 2005, while commercial payloads were still only 29 percent.[13]

Figure 4.1: World satellite industry revenues by sector (billion)[14]



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

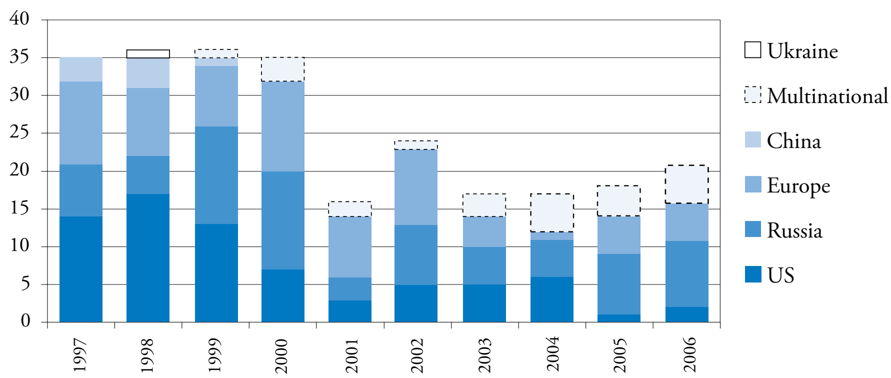
Space Launches

A commercial launch is defined as one in which at least one satellite payload's launch was contracted internationally, so that, in principle, a launch opportunity was available to any capable launch services provider.[15] 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 2006.[16] 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."[17]

Commercial space access grew significantly in the 1980s. At that time, NASA viewed its provision of commercial launches more as a means to offset operating expenses than as 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 ban of commercial payloads on the Space Shuttle following the 1986 Challenger Shuttle disaster encouraged further commercial launch competition. The Ariane launcher, developed by the French in the 1980s, captured over 50 percent of the commercial launch market during the period 1988-1997.[18] The Chinese Long March and the Russian Proton rocket entered the market in the early and mid-1990s. The Long March was later pressured out of the commercial market due to "reliability and export control issues."[19] China has opened the possibility of reentering the commercial space flight market.[20] Today, Ariane, Proton, and Zenit rockets dominate the commercial launch market.

Figure 4.2: Worldwide Commercial Orbital Launches (1997-2006)[21]



Japanese commercial efforts have suffered from technical difficulties and its H-2 launch vehicle was shelved in 1999 after flight failures.[22] Although the H-2 was revived in 2005, Japan lags behind Russia, Europe, the US, and China in global launches.[23] 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.[24]

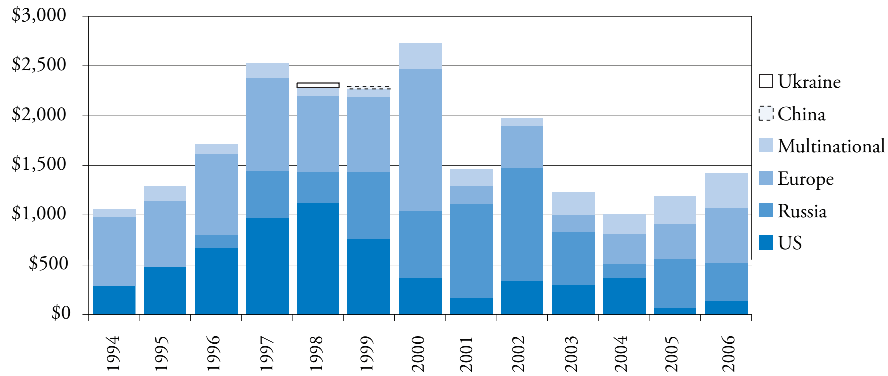
Today's top commercial launch providers include Lockheed Martin and Boeing Launch Services in the US, Arianespace in Europe, Energia in Russia, and two international consortia – Sea Launch and International Launch Service (ILS).[25] Sea Launch, comprised of Boeing (US), Aker Kvaerner (Norway), RSC-Energia (Russia), and SDO Yuzhnoye/PO Yuzhmash (Ukraine), launches from a sea-based platform located on the equator in the Pacific Ocean.[26] ILS was established as a partnership between Khrunichev State Research and Production Space Center (Russia), Lockheed Martin Space Systems (US), and RSC-Energia (Russia). In 2006 Lockheed sold its share to US Space Transport Inc. New commercial launch vehicle builders such as Space Exploration Technologies (SpaceX) are seeking to compete by providing cheaper, reusable launch vehicle designs.

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 – 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 smaller satellites on small launchers such as the Cosmos rocket. Emerging technologies such as air-launch vehicles and hypersonic "scramjet" engines may lead to further cost reductions of space launch into LEO.[27]

Launcher competition and new launch techniques have supported a decrease in space access costs. In 2000 payloads could be placed into LEO for as little as $5,000 per kilogram.[28] 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,[29] with prices consolidating.[30]

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. Forty-seven states have now accessed space; almost all have been enabled in some way by the commercial sector.

Figure 4.3: Commercial space launch revenues (million)[31]



Commercial Satellite Imagery

Until a few years ago, only a government could gain access to satellite imagery; today any individual or organization with access to the Internet can use these services through Google Maps, Google Earth, and Yahoo Maps programs.[32] Companies such as Surrey Satellite Technology Ltd. and SpaceDev have commercialized private research in the area of space and satellite technologies. There are currently seven companies in Canada, France, Germany, Israel, Russia, and the US providing commercial satellite imagery. The resolution of the imagery has become progressively more refined and affordable. In addition to photoreconnaissance, companies such as InfoTerra are planning to offer synthetic aperture radar images at one meter in resolution. A growing consumer base is driving up revenues. Global commercial satellite remote sensing revenue totaled $1.12-billion in 2005 – an 18 percent increase over 2004.[33] Security concerns have been raised, however, due to the potentially sensitive nature of the data (see Trend 4.3).

Space Tourism

An embryonic space tourism industry continues to emerge, seeking to capitalize on advanced, reliable, reusable, and relatively affordable space launch technology. 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 authority of the Federal Aviation Administration (FAA) over suborbital space tourism in the US, allowing it to issue permits to private spacecraft operators to send customers into space.[34]

The space tourism industry is generating a larger commercial market for space services. By 2005, three suborbital space tourists had flown, all on the Russian Soyuz, and Space Adventures had taken deposits for over 100 space flights.[35] In June 2004, SpaceShipOne, developed by US Scaled Composites, became the first private manned spacecraft.[36] There are now 19 suborbital launch vehicles under development, primarily for the space tourism market.[37] This market is also generating commercial investment in space infrastructure. Bigelow Aerospace has announced plans to build a privately owned, inflatable in-space platform.[38]

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

Governments have played an integral 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. Full state ownership of space systems has now given way to a mixed system in which many larger commercial space actors receive significant government contracts and a variety of government subsidies. 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. It is expected, however, that military-commercial interdependence will continue to underwrite growth in the commercial space sector.[39]

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.[40] In 2002, the US Air Force requested $1-billion in subsidies from Congress for the period 2004-2009 for Lockheed Martin's Atlas 5 and Boeing's Delta 4 development as part of the Evolved Expendable Launch Vehicle (EELV) program.[41] To maintain the financial feasibility of the program, the 2005 Space Transportation Policy requires the Department of Defense (DOD) to pay the fixed costs to support both companies until the end of the decade.[42] The US Air Force accordingly announced that it will divide its planned 23 EELV missions between the two companies rather than force price-driven competition.[43]

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.[44] The program 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.[45] It also supports a continued relationship with Russia to launch the Soyuz from the Kourou launch site in French Guiana.

Russia's commercial space sector maintains a close relationship with its government, receiving contracts and subsidies for the development of the Angara launcher and launch site maintenance.[46] The Russian space program receives subsidies from the US in the form of contracts for 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 Russian media, the Russian space industry was to receive only $38-million in subsidies in 2003, not enough to cover existing debts or ISS commitments.[47]

Commercial Satellite Positioning

Initially intended for military use, satellite navigation has emerged as a key civilian utility with a strong commercial market. The US government first promised international civilian use of its planned Global Positioning System (GPS) in 1983 following the downing of Korean Airlines Flight 007 that strayed over Soviet territory, and in 1991 pledged that it would be freely available to the international community beginning in 1993.[48] US GPS civilian signals have dominated the commercial market, but new competition is emerging from the EU's Galileo system, which is specifically designed for civilian and commercial use, and Russia's GLONASS.[49] China's regional Beidou system may also be available for commercial use by 2008.[50]

The commercial satellite positioning industry initially focused on niche markets such as surveying and civil aviation, but has since grown to include automotive navigation, agricultural guidance, and construction.[51] The crux of revenues to the commercial satellite positioning industry is sales of ground-based equipment. In the mid-1990s, sales to commercial users first outpaced military buyers.[52] The commercial GPS market continues to grow with the introduction of new receivers that integrate the GPS function into other devices such as cell phones, making it a mainstream electronic.[53] In 2005, global GPS revenues were estimated at $21.8-billion.[54]

Insurance

Governments play an equally important role in the insurance sector, in which 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 was about seven percent of the satellite and launch vehicle value. Since 1998, however, a 146 percent rise in the number of on-orbit anomalies has forced a 129 percent increase in insurance premiums.[55] 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 overreacting. In 2002, the space insurance industry paid out $830-million in claims while it collected just $490-million in premiums.[56]

Revenues have since stabilized with increasing premiums and few payouts, resulting in 2005 profits of $880-million.[57] Since 2004, launch premium rates have stabilized at around 20 percent but terms have become more restricted. Insurers do not generally quote premiums more than 12 months prior to a scheduled launch and in-orbit rates are usually limited to one-year terms.[58] Insurance exclusions for events such as terrorism have also been implemented.[59] Consequently, the cost of space access has increased.

With the advent of space tourism, the space insurance industry may expand to cover human space flight. In the US, the FAA requires commercial human spacecraft operators to purchase third-party liability insurance, although additional coverage is optional. The first two space tourists both purchased policies for training, transportation, and time spent in space.[60]

In 1988, the US Congress amended the 1984 Commercial Space Launch Act to include an indemnification authority limiting the maximum payout by launch insurance providers to $500-million, covering basic damage costs in the event of structure or payload failures. The Act provided for Congress to appropriate up to an additional $1.5-billion to cover excess liabilities beyond the required insurance.[61] The US Commercial Space Act of 2003 represented the third extension of this provision, to 31 December 2007, to give Congress time to re-evaluate proposed changes to the regime.[62] 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.[63] 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 technology, and many civil and commercial satellites contain advanced capabilities with potential military applications. Dual-use concerns have led states to develop national and international export control regimes aimed at preventing proliferation. The regime most pertinent to commercial space security considerations is the Missile Technology Control Regime (MTCR).

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 collaborating on a voluntary basis to coordinate the development and implementation of common export policy guidelines.[64] The 34 members of the MTCR include Australia, Brazil, Canada, France, Germany, Japan, Russia, South Korea, the UK, and the US, with China formally expressing interest in becoming a member in 2003.[65] However, export practices differ among members. Although the American "Iran Nonproliferation Act" of 2000 limited the transfer of ballistic missile technology to Iran, for example, Russia is still willing to provide such technology under its Federal Law on Export Control.[66] 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.[67]

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 led to allegations about the transfer of sensitive US technology to China by aerospace companies Hughes and Loral. Concerns sparked the transfer of jurisdiction over satellite export licensing from the Commerce Department's Commerce Control List to the State Department's US Munitions List (USML) in 1999.[68] 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 (ITAR) 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."[69] 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."[70] Recently, European satellite firms have been developing 'ITAR free' satellites that use no US components and thus avoid all ITAR restrictions.[71]

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.[72] In 2001 the French Ministry of Defense prohibited open sales of commercial Spot Image satellite imagery of Afghanistan.[73] Indian laws require the "scrubbing" of commercial satellite images of sensitive Indian sites.[74] 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.[75] Analysts note, however, that competition among increasing numbers of commercial satellite imagery providers may eventually make shutter control prohibitively expensive.[76]

Commercial space systems as critical infrastructure

Space systems, including commercial systems, are increasingly viewed as national critical infrastructure and strategic assets. During the overcapacity of the 1990s, the US military began employing commercial satellite systems for non-sensitive communications and imagery applications. During Operation Enduring Freedom in 2001, the US military used 700 megabytes per second of bandwidth, 75 percent of which was from commercial systems.[77]

The US DOD is the single largest customer for the satellite industry. By November 2003, it was estimated that the US military was spending more than $400-million each year on commercial satellite services.[78] 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.[79] 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.[80]

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 needs.[81]

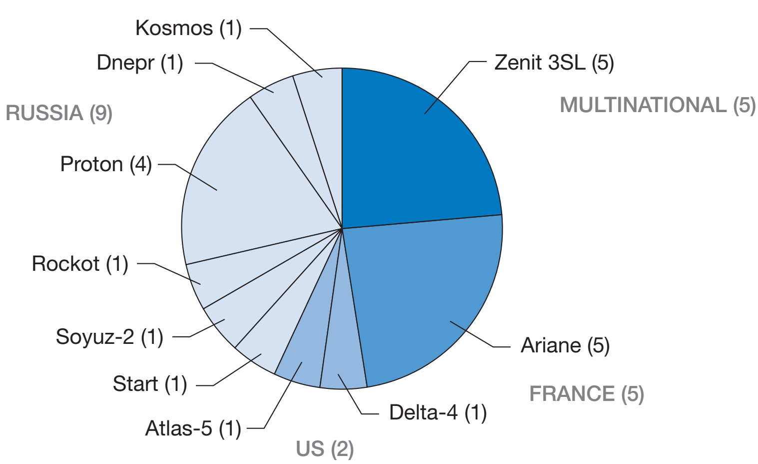
TREND 4.1: Continued overall growth in global commercial space industry

2006: Growth in commercial space industry largely driven by expanding consumer base

The commercial space industry is rebounding from a previous low with increasing revenues in the launch, services, and manufacturing sectors. Demand for commercial space transportation services, which are directly linked to activities in the global satellite market, increased in 2006.[82] Of the 63 successful orbital launches in 2006, 21 were commercial launches,[83] an increase over 2005 when 17 of 55 launches were commercial.[84] Russia continued to lead the industry with nine successful launches (Figure 4.4).[85]

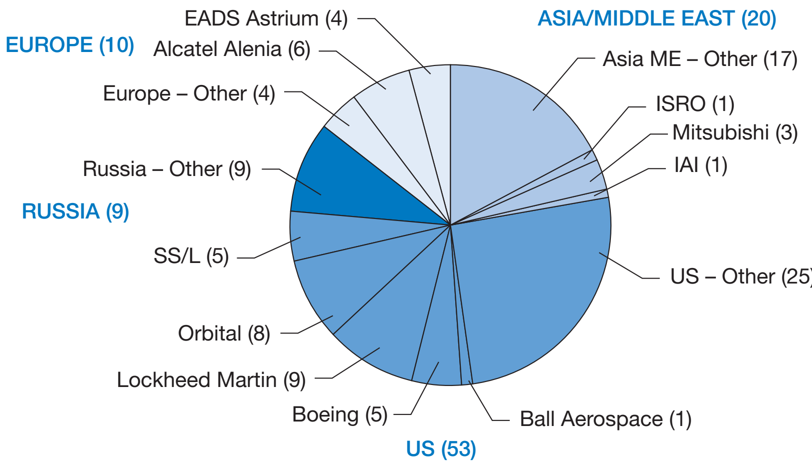
While government payloads still account for the majority of launch revenues, the proportion of commercial customers and revenues is increasing.[86] Of the 21 commercial launches in 2006, 16 went to GEO – the highest number since 2002, reflecting the growing demand for telecommunications services.[87] Launch revenues in 2006 hit their highest point since 2002, increasing 20 percent over 2005.

Figure 4.4: Commercial launches in 2006 by launch vehicle[88]



Satellite services account for more than 60 percent of total satellite industry revenues and are steadily increasing.[89] Individual consumers represent a significant portion of this growth. Demand for Direct Broadcast Services (DBS) drives most revenue for satellite services, followed by Fixed Satellite Services (FSS) for communications and broadcasts and Mobile Satellite Services (MSS). Revenue in the ground equipment sector is also increasing, largely due to the strength of end-user equipment sales, particularly for consumer services such as satellite radio and direct TV.

Figure 4.5: Manufacturers of satellites launched in 2006[90]



The commercial remote sensing sector is also expanding due to new market opportunities.[91] Governments worldwide continue to constitute the major source of demand for commercial remote sensing services, but new markets are emerging as more civil and commercial applications are introduced.[92] Following 2005 deals to create Internet mapping portals between Google and DigitalGlobe, and Microsoft and Orbimage Inc., Yahoo signed a deal with GeoEye (Orbimage Inc. and Space Imaging) in 2006 to acquire remote sensing imaging for its MapQuest program.[93]

The commercial GPS market also continues to grow, with the introduction of new devices marketed to individual consumers. Handheld GPS equipment, which often integrates the GPS function into other electronics, is increasing demand for what was once a technology used primarily by government and large businesses.[94]The market for these converged devices is just starting to accelerate in the U.S., but has been strong in Europe and Japan for several years.[95] Sales of satellite navigation devices in Europe, the Middle East, and Africa "have doubled in the past year" and a significant increase in GPS-enabled Location Based Services subscribers is expected in the coming years.[96] Consumer demand is also increasing for dedicated portable navigation devices.[97]

More satellite launches and a growing satellite services sector have a direct impact on the manufacturing industry. US satellite manufacturers dominated the industry in 2006, manufacturing 59 percent of all satellites launched, followed by Asian companies at 24 percent (see Figure 4.5). The five major manufacturers of commercial communications satellites are Alcatel Alenia Space, Boeing Satellite Systems, EADS Astrium, Lockheed Martin, and Space Systems/Loral. Newcomers NPO Prikladnoy Mekhaniki (Russia) and the Indian Space Research Organization (ISRO) are expected to make an impact in the future.[98] In 2006 Alcatel Alenia Space signed contracts to construct 57 new satellites, giving it approximately one-third of the manufacturing market for communications and observation/science satellites.[99]

2006: Continued privatization and consolidation in commercial sector

Privatization and consolidation continued in the commercial space sector in 2006. Private equity firms now hold "controlling stakes and other significant equity positions in some of the largest satellite operators in the world," and consolidation among satellite operators "is occurring as operators are seeking complementary markets and services to offer global solutions."[100] An overview of major industry consolidations in 2006 is available in Figure 4.6.

Figure 4.6: Major space industry consolidations in 2006[101]

Sector	Companies	Activity	New Company	Value
Remote sensing	Orbimage and Space Imaging	Acquisition	GeoEye	$58.5 million
Communications	SES Global and New Skies Satellites	Acquisition	SES Global	$1.2 billion
Communications	Intelsat and PanAmSat	Acquisition	Intelsat	$3.42 billion
Communications	Alcatel and Lucent	Acquisition	Alcatel-Lucent	$11 billion
Launch	Rocketplane, Ltd. and Kistler Aerospace Corporation	Merger	Rocketplane-Kistler	N/A
Launch	Boeing and Lockheed Martin	Joint Venture	United Launch Alliance	$530.7 million

These consolidations have changed the face of the space industry: GeoEye is now one of only two US satellite remote sensing companies, along with DigitalGlobe;[102] Intelsat is now the world's largest fixed satellite services provider, with a fleet of 51 satellites;[103] and the United Launch Alliance consolidates US government launches on the Delta and Atlas vehicles under one company.[104] It is not yet clear what affect these developments will have on overall worldwide industry demand.[105] While the consolidations in the remote sensing and communications sector represent a drive for expanding business opportunities, mergers in the US launch industry represent market failures and restricted competition (see Trend 4.2).

In a break with the trend to consolidate, Lockheed Martin finalized the sale of its interests in ILS and Lockheed Khrunichev Energia International, Inc. to Space Transport, Inc., in October 2006. This concludes the cooperative arrangement between the companies for the joint sale, marketing, and launch support of Lockheed's Atlas and Khrunichev's Proton and Angara launchers.[106] The former allies will now compete in the commercial launch market, with Lockheed marketing and selling commercial launch services through Lockheed Martin Commercial Launch Services, Inc. and ILS continuing to market and sell the Angara and Proton launchers.

Space security impact

Continued growth in the commercial space sector, driven by increasing investment in commercial space and growing consumer demand for space services, suggests that there is overall confidence in the security of space and the ability of both companies and consumers to continue to rely on space resources. Competition for limited space resources such as orbital slots and the associated frequencies, however, may create future tensions if demand exceeds supply. In this case, further consolidation of the space industry may provide greater space security if streamlined operations are translated into a more efficient use of resources. Less competition in the commercial launch market, however, may negatively affect space security by reducing capacity and driving up the cost of access to space.

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

2006: Indications of launch costs beginning to rise

Following a steady decrease in launch costs to both LEO and GEO in the 1990s, prices consolidated and there are indications that they have now begun to rise. In 2006, commercial launch revenues hit their highest point since 2002 with an increase of 20 percent over 2005, reflecting the joint trends of higher demand for launches to GEO and higher launch costs. These figures are only beginning to reflect the rising costs to access space, however, as most launches in 2006 were ordered prior to the price increases of 2005 and 2006.[107] The commercial launch market has shifted away from the trend of low demand and high capacity, which had kept prices low. The launch failure of the Indian Geosynchronous Satellite Launch Vehicle (GSLV) on 10 July 2006, one of the few vehicles with a heavy-payload launch capability to GEO,[108] combined with high demand and the lack of new entrants to the market, may push prices higher.

2006: US struggling to maintain commercial launch market share

The US continued to lose commercial launch market share to Europe and Russia in 2006, providing only two of the 21 commercial launches (see Trend 4.1). This decline is partly due to a decrease in demand for commercial launches to LEO.[109] A report commissioned by the FAA in 2006 indicates that the success of the US commercial launch industry is viewed as "beneficial to national interests,"[110] as indicated by government initiatives in 2006 to buoy the industry. The merger of Boeing's Delta and Lockheed Martin's Atlas heavy-launch services into the United Launch Alliance, which began operations on 1 December 2006, represents a significant failure in the US commercial launch market. The joint venture was supported by DOD, which feared that the low number of launches per year would drive one of the companies out of business, leaving DOD dependent on one type of rocket.[111] The merger formalizes the de facto monopoly created in 2005 when the US Air Force announced that it would forgo price-driven competition for launches by dividing its Evolved Expendable Launch Vehicle (EELV) missions between the Delta-4 and Atlas-5 rockets.[112] The companies claim that the merger will save the government $100-million to $150-million a year; however, the loss of competition may outweigh any economic benefits.[113]

The merger of Rocketplane, Ltd. and Kistler Aerospace Corporation also consolidates competition in the US commercial launch market. However, new opportunities are emerging in the wake of the Space Shuttle retirement in 2010, which will create a temporary service gap to the ISS. On 18 August 2006 NASA selected two companies to share $500-million available in financing through the Commercial Orbital Transportation Services (COTS) program to promote commercial participation in space.[114] SpaceX, which will receive $278-million, and Rocketplane-Kistler, which will receive $207-million, both signed Space Act agreements "to develop and demonstrate the vehicles, systems, and operations needed to support a human facility such as ISS."[115]

Hopes for a new, competitive American commercial space launcher were temporarily dashed when the first Falcon-1 launch attempt by SpaceX failed on 24 March 2006 due to a fuel leak.[116] Falcon-1 aims to provide commercial launch services at an estimated launch price of just $6.7-million. It is part of a 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.

2006: Commercial activity continues in space tourism, but remains a distant proposition

On 18 September 2006 Anousheh Ansari became the fourth space tourist when she visited the International Space Station on board a Russian Soyuz capsule at a cost of $20-million.[117] The potential for space tourism as an industry was recognized in the *California Space Enterprise Strategic Plan 2007-2010*, which noted that suborbital space tourism is an estimated $1-billion worldwide market.[118] Space Adventures Ltd. is the leading space tourism company, and the only one to have successfully launched clients into space.

The industry received a boost from several new initiatives in 2006. On 20 July 2006 the ESA, under the auspices of its General Studies Programme, announced the "Survey of European Privately-funded Vehicles for Commercial Human Spaceflight" to support the emergence of a European space tourism industry.[119] Bigelow Aerospace launched its Genesis I inflatable module prototype to LEO;[120] to date, Bigelow has spent over $75-million in the development of human-habitable modules.[121] Several planned international spaceports are receiving support.[122] New Mexico announced support for the development of the Southwest Regional Spaceport to support Virgin Galactic,[123] and the Oklahoma Space Industry Development Authority was issued a license to operate a commercial spaceport at the Clinton-Sherman Industrial Airpark.[124]

But while the industry continues to face challenges – including a lack of international legal safety standards, high launch costs, and export regulations[125] – important liability standards are beginning to emerge. On 15 December 2006 the FAA released final rules governing private human spaceflight requirements for crew and participants. Launch vehicle operators are required to provide passengers with information related to safety and the general risks of space travel so that they can make "informed decisions" regarding their personal safety.[126] Final rules were also issued to facilitate FAA launch vehicle safety approvals.[127]

Space security impact

US government backing of its commercial space launchers indicates the centrality of the industry to sustainable access to space and the fragility of that access. While consolidations in 2006 may limit competition and reduce downward pressures on the cost of space access, government support may be necessary to maintain that access. The continuing development of a viable space tourism industry has yet to deliver sustainable, low-cost launchers. To be successful in the long term, space tourism must be accompanied by appropriate laws and regulations to ensure safety and to manage space traffic.

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

2006: Strong interdependence between military and commercial uses of space

Military-commercial interdependence continued in 2006. The US DOD continued to be the single largest consumer of commercial satellite bandwidth. Delays in programs to overhaul military satellite systems, including the Transformational Communications Satellite (TSAT) network, reaffirmed the military's dependence on commercial satellite communications.[128] These delays are now providing $1-billion a year in revenues for commercial broadband satellite services alone.[129] Indeed, "DoD estimates that commercial satellite systems are providing over 80 percent of the satellite bandwidth supporting Operation Iraqi Freedom."[130] In response, DOD is examining ways to facilitate satellite service procurement by studying different acquisition methods.[131] This would provide a more long-term, strategic partnership between DOD and its commercial providers.

In 2006 US DOD continued to be a significant consumer of commercial satellite imaging services. The National Geospatial-Intelligence Agency awarded contracts to DigitalGlobe ($24-million), Space Imaging ($24-million) and Orbimage ($12-million) to procure high resolution satellite imaging in 2006.[132] Yet national security concerns also placed constraints on commercial providers of satellite imagery in 2006. In response to detailed satellite images of what the Indian government referred to as strategic locations that were made available on Google Earth, the company was asked to mask or blur these images. Similar policies exist in many other countries including Australia, Russia, South Korea, Thailand,[133] and Israel.

The US government has recognized the increasing commercial uses of its GPS technology and is taking steps to support the market. In January 2006 the new LC2 signal, an upgrade to the GPS system "designed specifically for commercial users," became available. The LC2 signal is stronger in "cities, indoors and other areas where current signals are difficult to receive."[134] Russia, China, and ESA are also becoming more active in the commercial satellite positioning market (see Civil Space and Global Utilities Trend 3.4).

2006: Trade restrictions irritate but do not inhibit the commercial space industry

The US International Traffic in Arms Regulations (ITAR) remained a contentious issue in 2006. US aerospace industry groups, trade associations, and foreign companies claim that the restrictive export controls placed on space technology hinder global competition.[135] In its 2006 Commercial Space Transportation Forecasts, the FAA also pointed to ITAR as a source of difficulty for the US commercial space industry, claiming that it "is hampering U.S. satellite suppliers and launch vehicle providers," and "caused both delays and cancellations of programs."[136] ITAR has also been cited as a cause of unsafe business practices by the NASA Mishap Investigation Board, which placed partial blame for the failure of the DART mission on the failure of the US prime contractor and a British parts supplier to hold open discussions (the report itself was redacted because it contained satellite navigation data covered by ITAR).[137] To ease ITAR constraints, however, the US government has recently shown a willingness to facilitate international cooperation on a deal-by-deal basis, as evidenced by one agreement with India that would allow it to bid on commercial launches of US satellites and another that could streamline the ITAR process for transfer of technology to India.[138]

While US companies view ITAR as inhibiting their ability to compete internationally, the European satellite industry claims to be disadvantaged by the DOD-supported US industry.[139] Industry statistics as a whole fail to provide clear evidence to support either side. In 2006 US companies dominated the space manufacturing market while Europe and Russia led the commercial launch market (see Trend 4.1). The effects of ITAR and other security-related trade restrictions on the commercial space industry are not clear.

2006: National space policies continue to link the commercial space industry to national security

In 2006, the US identified the enabling of "a dynamic, globally competitive domestic commercial space sector in order to promote innovation, strengthen U.S. leadership, and protect national, homeland, and economic security" as a fundamental goal of its revised National Space Policy.[140] Similarly, China's 2006 White Paper on Space Activities clearly integrates its domestic space industry into its national space strategy and the country's overall national development strategy.[141] This suggests that both the US and Chinese governments will continue to play a strong role in supporting their domestic space industries against international competition, as evidenced by US government support for its commercial launch industry (see Trend 2.2).

Space security impact

The strong relationship between military and commercial uses of space, and the security dimensions of many commercial services, has a complex impact on space security. In 2006 the blurred distinction between military and commercial assets both created and constrained market opportunities and, by extension, the free access to and use of space. Increasing military needs for commercial satellite frequencies could stress this resource and impinge on civilian and commercial access. Similarly, the security implications of commercial space technology continued to pose obstacles to commercial space initiatives that might increase access to space; but they also provided a strong rationale for key governments to continue to support these initiatives in their national space doctrines.

Figure 4.7: Commercial spacecraft launched in 2006, by owning state

COSPAR	Launch Date	Launch Vehicle	Satellite Name	Launch State	State	Primary Function	Primary Manufac.	Orbit Type
2006-043B	10/13/06	Ariane 5ECA	Optus D1	France	Australia	Telecoms	Orbital	GEO
2006-007A	3/11/06	Ariane 5ECA	Hot Bird 7A	France	France	Telecoms	Alcatel	MEO
2006-032A	8/4/06	Proton-M/Briz-M	Hot Bird 8	Russia	France	Telecoms	Astrium/Toul	GEO
2006-010A	4/12/06	Zenit-3SL	JCSAT 9	USA/Ukraine	Japan	Telecoms	LMCSS/ Sunnyv	GEO
2006-033A	8/11/06	Ariane 5ECA	JCSAT 3A	France	Japan	Telecoms	LMCSS	GEO
2006-012A	4/20/06	Atlas V 411	Astra 1KR	USA	Luxem-bourg	Telecoms	LMMS/ Sunnyv	MEO
2006-056A	12/11/06	Proton-M/Briz-M	Measat 3	Russia	Malaysia	Telecoms	Boeing	HEO
2006-020A	5/27/06	Ariane 5ECA	Satmex 6	France	Mexico	Telecoms	Loral	GEO
2006-006A	2/28/06	Proton-M/Briz-M	Arabsat 4A (BADR-ONE)	Russia	Saudi Arabia	Telecoms	Astrium	HEO
2006-051A	11/8/06	Proton-M/Briz-M	Badr 4	Russia	Saudi Arabia	Telecoms	Astrium	GEO
2006-020B	5/27/06	Ariane 5ECA	Thaicom 5	France	Thailand	Telecoms	Alcatel	GEO
2006-003A	2/15/06	Zenit-3SL	Echostar 10	USA/Ukraine	USA	Telecoms	LMCSS/ Sunnyv	GEO
2006-023A	6/18/06	Zenit-3SL	Galaxy 16	USA/Ukraine	USA	Telecoms	Loral	GEO
2006-029A	7/12/06	Dnepr	Genesis-1	Russia	USA	Human	Bigelow	LEO
2006-043A	10/13/06	Ariane 5ECA	DirecTV 9S	France	USA	Telecoms	Loral	GEO
2006-049A	10/30/06	Zenit-3SL	XM Radio 4 (Blues)	USA/ Ukraine	USA	Telecoms	Boeing/ES	GEO
2006-054B	12/8/06	Ariane 5ECA	AMC 18	France	USA	Telecoms	LMCSS/ Sunnyv	MEO
2006-054A	12/8/06	Ariane 5ECA	WildBlue 1	France	USA	Telecoms	Loral	GEO

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 are used to support terrestrial military operations. This includes warning, communications, intelligence, surveillance and reconnaissance (ISR), meteorology, as well as navigation and weapons guidance applications.

Extensive military space systems were developed by the US and the USSR during the Cold War. Satellites offered an ideal vantage point 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. Satellites also offered the first credible means for arms control verification, leading President Johnson to recognize that fears of a missile gap between the US and the Soviet Union were greatly overstated. The space age opened new chapters on the development of reconnaissance, surveillance, and intelligence collection capabilities through the use of satellite imagery and space-based electronic intelligence collection. In addition, satellite communications provided extraordinary new capabilities for real-time command and control of military forces deployed throughout the world.

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, integrating them into virtually all aspects of military operations 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.

At present, the US leads in the development of space systems to support military operations, accounting for 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, although this situation is changing.

This chapter identifies the development of the military space capabilities of the US and Russia as a distinct space security trend. It also examines the efforts of a growing number of other states that have begun to develop national space systems to support military operations and their rapidly expanding capabilities, primarily in the areas of surveillance and communications. It does not examine military programs pertaining to space systems protection or negation, or space-based strike capabilities, which are described in their respective chapters.

Space Security Impact

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. The increased use of space has also led to greater competition for scarce space resources such as orbital slots and, in particular, radio frequencies. 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 play an important strategic and increasing tactical role in the terrestrial military operations of certain states. In most cases, space systems have augmented advanced states' military capabilities through enhancing 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 have driven an increasing dependence on space, particularly by the major space-faring states.

An increasing number of state actors are integrating space capabilities and space-derived information into their day-to-day military planning. This can have a positive effect by increasing the collective vested interest in space security. The use of space to support terrestrial military operations can also have a negative impact on space security if potential adversaries, viewing space as a new source of military threat or as critical military infrastructure, develop space system negation capabilities to neutralize the advantages of those systems.

As space systems that support military operations are seen as vulnerable, actors acquire greater incentives to protect them by developing space system protection and negation capabilities, which may lead to an arms escalation dynamic. Concern has been expressed that extensive use of space in support of terrestrial military operations blurs the notion of "peaceful purposes" as enshrined in the Outer Space Treaty, but state practice over the past 40 years has generally accepted these applications as peaceful insofar as they are not aggressive in space (see Space Laws, Policies, and Doctrines Trend 2.1). Space has been militarized since the first satellite, Sputnik, was placed into orbit. Of concern here is not whether militaries should use space, but rather how the use of space by militaries improves or degrades the security of space.

Key Trends

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

During the Cold War, the US and USSR developed military space capabilities at a relatively equal pace. The collapse of the USSR, however, 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 by 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 more integrated with the military. 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 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 2005, the US had approximately 130 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 by all indications is the actor most dependent on its space capabilities. By comparison, Russia is believed to presently have some 60 operational military satellites in orbit.[3]

SATCOM

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 of these systems, 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 begin in 2008 to replace current Milstar satellites with Advanced Extremely High Frequency (AEHF) satellites, which are designed to provide assured strategic and tactical command and control communications worldwide.[4] By 2014 the US hopes to deploy the Transformation Satellite Communications System (TSAT) to provide high-speed internet-like information availability to the military using laser communications.[5] Both programs have experienced cost increases, funding cuts, and re-scheduling. The need for high-speed, high-volume data transmission capability is critical to meet current and future demand, particularly as the use of applications such as unmanned aerial vehicles (UAV) increases.

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 nine satellites in GEO. A planned follow-on to this system, the Advanced Wideband System (AWS), is 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 Global SATCOM (WGS) 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]

Earth Observation/Early Warning/Intelligence

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. 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.[8] The US plans to replace the DSP system with the Space Based Infrared System (SBIRS) to provide advanced surveillance capabilities for missile warning and missile defense.[9] However, SBIRS is currently over budget, behind schedule, and may be replaced. The anticipated US Space Tracking and Surveillance System (STSS) is intended to work with SBIRS to support missile defense responses (see Space Systems Protection Trend 6.1 and Space Systems Negation Trend 7.2).

Corona, the first US optical reconnaissance satellites, were launched as early as 1959, with the Soviets following suit by 1962.[10] 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.[11] Gradually, resolution of these cameras was improved from about 10 meters to less than a meter. While the exact resolution of today's imaging satellites remains classified, the US is generally thought to have optical satellites with resolutions as precise as 10 centimeters.[12] As early as 1976, the US began to fit its imaging satellites with charge coupled devices that took digital images, which could be transmitted back to Earth via radio signal, providing near-real-time satellite imagery.[13] Open sources information suggests that the US currently operates between eight and 10 imagery intelligence satellites through two optical systems known as Crystal and Misty, and one synthetic aperture radar system known as Lacrosse. The US operates between 16 and 25 signals intelligence (SIGINT) satellites in four separate systems – the Naval Ocean Surveillance System, Trumpet, Advanced Orion, and Vortex. [14]

The US military also uses commercial imagery services from DigitalGlobe and GeoEye (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 several dual-use civilian-military meteorology spacecraft, including the Geostationary Operational Environmental Satellite and the Polar-orbiting Operational Environmental Satellite.[15]

Figure 5.1: Characteristics of key US military space systems[16]

Current programs	Function	Orbit	Constellation	Future planned systems
Defense Satellite Communications System III	Communications	GEO	9	Advanced Wideband (2009)
Military Satellite Communication System (Milstar)	Communications	GEO	5	Advanced Extremely High Frequency (2008); Transformational Satellite Communications System (TSAT) (2014)
Interim Polar Satellite Program	Communications	GEO	2	Enhanced Polar System (2014)
UHF Follow-on Satellite	Communications	GEO	8	
Satellite Data System	Communications	GEO	4	Wideband Global SATCOME (2007); Mobile User Objective System (MUOS) (2009)
Defense Meteorological Satellite Program	Weather	LEO	6	
Global Positioning System	Navigation	MEO	31	
Defense Support Program	Early Warning	GEO	4-8	Space Based Infrared System (2008); Alternative Infrared Satellite System; Space Tracking and Surveillance System (2007)
N/A	Tactical Warning			Space Radar (2015)
Crystal	Imaging	LEO	4	
Lacrosse	Imaging	LEO	3	
Misty	Imaging	LEO	1	
Naval Ocean Surveillance System (NOSS)	SIGINT	LEO	15	
Advanced Orion (Mentor)	SIGINT	GEO	3	
Vortex (Mercury)	SIGINT	GEO	2	
Trumpet (SB-WASS)	SIGINT	HEO	3	

Navigation

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 GPS 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 Trend 3.4).

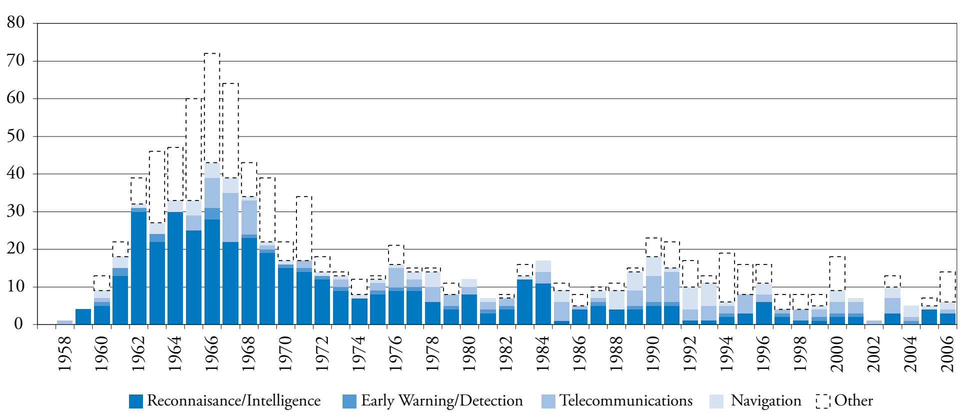
Launch

Since 2003, the US Air Force (USAF) has promoted Operationally Responsive Spacelift (ORS), which aims to reduce satellite costs and deployment time of satellites from years or months to days. Such savings could be made possible by new launch capabilities, combined with miniaturization technologies that have dramatically increased the "capability per kilogram on orbit" equation for satellites, and by having ground satellite spares ready to be launched.[17] These ORS efforts seek the capability to replace US satellites on short notice,[18] 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 satellite series are intended for ORS demonstration, weighing just 110 kilograms and combining existing military and commercial technologies such as imaging and communications with new commercial launch systems to provide "more rapid and less expensive access to space."[19] The satellites are controlled directly by deployed US commanders.[20]

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 could be used for both commercial and government purposes.[21] To meet future government requirements, both the Lockheed Martin Corporation and the Boeing Company are pursuing Heavy Lift launch capability under the EELV program. In 2004 Boeing tested the Delta-4 Heavy, which, despite some difficulties, is expected to provide lift capacity for 13,130 kilograms into GEO.[22] Lockheed's Atlas-5 Heavy is described as "available 30 months from order," but there are no specific launch plans.[23]

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 capabilities (see Space Systems Protection and Space Systems Negation).[24]

Figure 5.2: US military space launches (1957-2006)[25]



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 Russian spacecraft have now exceeded their designed lifespan.[26] Some of Russia's more critical systems have, however, been maintained and upgraded over the years.

SATCOM

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.[27] 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.[28] 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, potentially augmenting the military satellite system.[29] There are indications that maintenance of the Strela and Raduga systems will remain a priority for Russia.[30] Molniya-1 and -3 satellites are in Highly Elliptical Orbits (HEO) and serve as relay satellites for both military and civilian use. They are being replaced by the Meridian satellite system over the course of the next few years.[31]

Earth Observation/Early Warning/Intelligence

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 only one of these satellites is operational today.[34]

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.[35] Russia's optical imaging capabilities have declined since the Cold War. The three Russian photo electronic reconnaissance systems in operation today are the Yantar, Arkon, and Orlets/Don systems, which received new satellites in 2006, 2002, and 2006 respectively. Russia will reportedly orbit a constellation of high-resolution space radars in the next few years, using Arkon-2 and Kondor-E satellites. The Arkon-2 satellite will provide photos with resolution of up to one meter while the Kondor-E satellite will have multirole radar that provides high-resolution images along two 500-kilometer sectors to the left and right of its orbit.[36] 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.

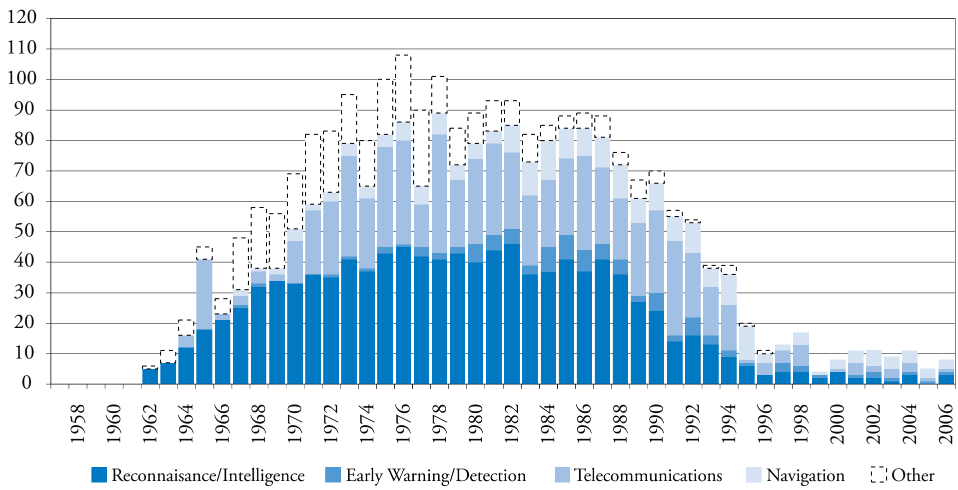
Navigation

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 operating, with an accuracy of about 100 meters.[37] 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.[38] With a full constellation, the navigational system is supposed to have resolution comparable to that of the GPS.[39] By December 2006 there were 19 GLONASS satellites in orbit, 14 of which were in operation (see Civil Space and Global Utilities Trend 3.4).[40]

Launch

As noted in Figure 5.3, Russia has tended to maintain an average annual satellite launch rate slightly higher than that of the US. This has not been sufficient, however, to keep its military space systems fully operational since they have shorter life spans and 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.[41] In 2004 Russia stated that it would focus on "maintaining and protecting" its fleet of satellites and developing satellites with post-Soviet era technology.[42]

Figure 5.3: USSR/Russia military space launches (1957-2006)[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. In 1995 France and Chile both launched dedicated military satellites.[45] Traditionally, military satellites outside of 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 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, acquire existing satellites from others, or purchase data and services from other satellite operators.[46]In the Cold War, states allied with either the US or the USSR benefited from their capabilities. Today, however, declining costs for space access and the proliferation of space technology enable more states to develop and deploy military satellites, usually relying on the launch capabilities and manufacturing services of others states or the commercial sector.

Europe

European states have developed a range of space systems to support military operations, with France having the most advanced and diversified independent military space capabilities.

Traditionally, European states have not had separate military and civil space budgets. Current total European space military spending is estimated at $1.35-billion.[47]

France initiated the Helios observation satellite system in LEO; however, today the Helios-1 and 2 are reportedly used by members of the highly classified Besoin Operationnel Commun (BOC), which provides the framework for space systems cooperation between the ministries of defense in France, Germany, Italy, Spain, Belgium, and Greece.[48] The program should provide imagery until 2013, with each satellite expected to have a minimum five-year lifespan.[49] The French Ministry of Defense procurement agency (DGA) manages the program, retaining direct control over the management of the ground segment while delegating the space segment responsibility to the French space agency, the Centre National d'Etudes Spatiales (CNES).

France further intends to launch the first of two high-resolution dual-use optical imaging satellites, known as Pleiades, by 2008.[50] In 2004, France launched a constellation of four SIGINT satellites know as Essaim and in 2006 it launched the Syracuse 3A, the first of a new generation of communications satellites for the French military. It has been described as "the cornerstone in a European military Satcom system."[51] France plans to launch two Spirale early-warning microsatellites for a probative research and technology demonstration program in 2008.[52] France maintains the dual-use Telecomm-2 communications satellite and the military Syracuse-2 system.[53]

Other European military space systems include the UK's constellation of three dual-use Skynet-4 UHF and Super High Frequency (SHF) communications satellites in GEO.[54] It began work in 1998 to develop four Skynet 5 military communications satellites.[55] In 2005 it launched an imagery microsatellite TopSat, built by Surrey Satellite Technology Ltd. Spain launched the communications satellite XTAR-EUR in 2005. Spain also operates the dual-use Hispasat system, which provides X-band communications to the Spanish military. By 2007 Germany plans to launch five SAR-Lupe high-resolution radar satellites, which will deliver radar images to the German Armed Forces.[56] 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.[57] Italy's Sicral military satellite provides secure UHF, SHF, and EHF communications.[58]

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 2012. 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.[59]

The Galileo satellite navigation program, initiated in 1999 and jointly funded by the EU and the ESA, will provide location, navigation, and timing capabilities.[60] While Galileo is intended principally for civil and commercial purposes, it 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 changing military space priorities in Europe.

China

China does not maintain the same separation between civil and military space programs – officially its space program is dedicated to science and exploration.[61] 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.[62] 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.[63] 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."[64] Today China maintains three ZY series satellites in LEO for tactical reconnaissance and surveillance.[65] It is also believed to be purchasing additional commercial satellite imagery from Russia.[66] In 2005 China launched the Beijing-1 (Tsingshua-1) microsatellite, which is a civil Earth observation spacecraft that combines a multispectral camera with a high-resolution panchromatic imager and may also support the military.[67]

Western experts believe that Chinese military satellite communications are provided by the DFH series satellite, officially known as ChinaSat-22. Officially a civilian communications satellite, 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.[68] China also operates three Beidou regional navigational satellites designed to augment the data received from the US GPS system and to enable China to maintain navigational capability if the US were to deny GPS services in times of conflict.[69] Beidou may also improve the accuracy of China's intercontinental ballistic missiles (ICBMs) and cruise missiles.[70] 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.[71]

South Asia

India does not operate any dedicated military satellites, but it has one of the oldest and largest space programs in the world that has developed a range of indigenous dual-use capabilities. Space launch has been the driving force behind the Indian Space Research Organization (ISRO). It successfully launched its Satellite Launch Vehicle (SLV) to LEO in 1980, followed by the Augmented Satellite Launch Vehicle (ASLV), the Polar Satellite Launch Vehicle (PSLV) in 1994, and the Geostationary Satellite Launch Vehicle (GSLV) in 2004. During this time ISRO developed a series of civilian Indian Remote Sensing satellites and currently maintains a constellation of six satellites, several of which would be suitable for reconnaissance with resolutions up to one meter.[72] India also maintains the joint government/military Technology Experimental Satellite, which provides images with a resolution of between one and 2.5 meters.[73] In 2007 India plans to launch the Military Surveillance and Reconnaissance System, which will provide India with dedicated military satellite intelligence.[74]

Pakistan's space-based capabilities are significantly less advanced than India's. China launched Pakistan's Badar-1 multipurpose satellite in 1990 followed by the Russian-launched Badar-2 Earth observation satellite in 2001.[75] Pakistan plans to construct the Remote Sensing Satellite System (RSSS) to provide high-resolution satellite images to its military, but its status is unclear.[76] While India and Pakistan seem intent on developing space systems to support military operations, significant progress remains a longer-term objective.

East Asia

The commercial Superbird satellite system provides military communications for Japan, which also has two reconnaissance satellites – one optical and one radar – that were launched in 2003 following growing concerns over North Korean missile launches.[77] A second launch effort later in 2003 resulted in a high-profile failure of its domestically developed H-2 rocket.[78] Japan plans to have three intelligence satellites by 2007 and an advanced reconnaissance satellite by 2010.[79] 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.[80]

In December 2003, South Korea announced its intentions to increasingly use space for military purposes.[81] South Korea operates the civilian Kompsat-1 satellite with 6.6 meters imaging resolution, which is "sufficient for [military] mapping although not for military intelligence collection."[82] It also bought 10 Hawker 800 series satellites from the US, and has operated them for signals intelligence since 1999.[83] 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.[84] Taiwan has also announced plans to launch a $300-million reconnaissance satellite, but it is not clear if work has commenced. The planned system, named Follow-On RSS (Remote Surveillance Satellite), will be capable of producing images with 50 centimeters resolution. In the meantime, a Taiwanese official stated that military and security authorities will have to increase their reliance on images taken from their existing Formosa-2, which has a resolution of 1.8 meters.[85]

Middle East

Israel's programs reflect an interest in exploiting space systems in support of terrestrial military operations, including operational and tactical missions. Israel 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.[86] It frequently passes over Arab territory in the region. Its capabilities are augmented by the dual-use Eros-A imagery system with a resolution of roughly 1.8 meters.[87] The Israeli Ministry of Defense is managing five additional satellite programs intended to provide more advanced optical and radar imaging and secure communications for the military.[88] In 2005 Israel successfully tested the latest Shavit Space Launch Vehicle, intended to give Israel independent launch capabilities.[89]

Iran launched its first satellite, the Sina-1, in 2005 with the support of a Russian launcher. It has a resolution precision of approximately 45 meters. Although the satellite is intended to collect data on ground and water resources and meteorological conditions, the head of Iran's space program said that it is capable of spying on Israel.[90] Iran also has a nascent space launch vehicle program, which some speculate is linked to its development of intercontinental-range ballistic missiles and the Shahab-4 and Shahab-5.[91]

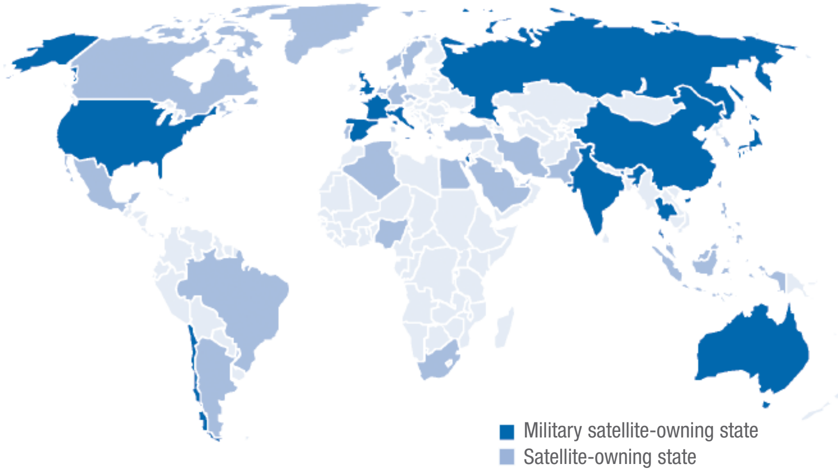
Australia

Until recently, the Australian defense forces used X-band facilities on satellites owned by the US and other allies.[92] In 2003, however, Australia launched the Defence C1 communications satellite. The satellite will be part of a new Australian Defence Satellite Communications Capability system, which will provide the country's defense forces with 18 beams satellite communications across Australia and throughout the Asia Pacific region in the X, Ka, and UHF radio frequency bands.[93]

Canada

Canada does not yet have a dedicated military satellite program, but uses commercial satellite communication, surveillance, and imaging services.[94] In June 2005, however, 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 ocean approaches.[95] The project will link to information from RADARSAT and other sources to produce high quality imagery for military as well as other applications.[96]

Figure 5.4: State's first dedicated military satellites and their function[97]



Year	State/Actor	Description
1958	US	Telecommunications experimental satellite
1962	USSR	Reconnaissance (optical)
1969	UK	Telecommunications
1970	NATO	Telecommunications
1975	China	Reconnaissance (optical)
1988	Israel	Telecommunications
1995	France[98]	Reconnaissance (optical)
1995	Chile	Telecommunications and reconnaissance (optical)
1998	Thailand	Telecommunications
2001	Italy	Telecommunications
2003	Australia	Telecommunications
2003	Japan	Reconnaissance (optical)
2006	Spain	Telecommunications
2006	Germany	Reconnaissance (radar)
2006	South Korea	Telecommunications

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

2006: The US is reassessing existing space programs, implementing budget cuts and considering less expensive alternatives

The US remained by far the dominant military space actor in 2006 in terms of both capabilities and spending. US space budgets, however, are facing considerable cuts and several major programs have significant cost overruns.[99] The focus is on meeting deadlines for projects that are underway.

Several programs progressed slowly in 2006. The USAF-managed GPS system launched its second and third GPS IIR-M satellites in September and November 2006 as part of a modernization program initiated in 2005; however, this number was down from the three or four launches previously planned for 2006[100] (see Civil Space and Global Utilities Trend 3.4). Boeing completed a series of tests on the first Wideband Global SATCOM satellite (WGS – previously known as the Wideband Gapfiller Satellite) in 2006, preparing it for launch in 2007, three years behind schedule.[101] When launched, the WGS will be the US military's highest capacity communications satellite, although it will be unprotected against jamming and nuclear effects. The goal of the program is to alleviate bandwidth shortfalls and reduce reliance on commercial bandwidth capacity in the near term until the Advanced Extremely High Frequency (AEHF) and Transformational Communications System (TSAT) programs become operational. Responding to ongoing delays in these programs, USAF contracted with Boeing in November 2006 to build a fourth satellite for the system, initially scheduled for launch in 2011, with options to procure two more. The fourth satellite is intended to have radio frequency bypass capability to provide support to airborne intelligence, surveillance, and reconnaissance platforms that require additional bandwidth.[102]

Other programs face greater obstacles. While the TSAT program progressed slowly in 2006, it faces an uncertain future. TSAT, aimed at providing the US military with secure, high data transmission laser communications and Internet-like services, completed a series of ground tests in 2006. The second phase of testing is scheduled for 2007,[103] but budget constraints could disrupt development. In 2006 the budget allocated to TSAT by the Air Force was cut to $867-million for the next fiscal year, far less than the $1.068-billion planned.[104] The total program cost is currently estimated at between $14-billion and $18-billion.[105] Moreover, it has faced technical challenges and only inter-spacecraft laser links are currently being planned.[106] These difficulties have led to schedule slippages: launch of the first reduced-capacity satellite is delayed to 2014 from 2009.

The AEHF program, intended to provide interim high-capacity, secure communications before TSAT becomes operational, also suffered budget cuts in 2006. Contradictory information has emerged about the future of this project, some of it suggesting that the USAF may eventually phase out the project in favour of TSAT.[107] The AEHF program is also over cost and behind schedule by 12 months – the launch of the first satellite is currently planned for 2008. The Department of Defense is expected to decide soon if it will proceed with TSAT as planned or add two additonal AEHF satellites to the three currently underway as a stop-gap measure.[108] Ongoing challenges with next-generation communications systems are posing problems for current and future bandwidth demand. Increased use of unmanned aerial vehicles (UAV) is straining both military and commercial capacity in places such as the Middle East; TSAT is expected to solve this problem.[109]

Another program facing uncertainty at the end of 2006 was the Space Based Infrared System (SBIRS), which is intended to meet the military's infrared space surveillance needs for missile warning and missile defense (see Space Systems Protection Trend 6.1). It has continued to experience growing costs, which are now in excess of $10-billion, far above the original $2-billion planned. Moreover, launch of the first satellite in GEO has been postponed from 2002 to 2008. In response, USAF has initiated what is supposed to be a simpler alternative, the Alternative Infrared Satellite systems (AIRSS).[110] It is not certain if the two programs will be integrated, or if SBIRS will be cut.

A report issued by the Government Accountability Office on 17 November 2006 brought increased attention to the ongoing cost overruns of several high-profile space acquisition programs, including SBIRS, WGS, and AEHF. It revealed that estimated costs for "major space acquisition programs have increased by about $12.2 billion from initial estimates for fiscal years 2006 through 2011," largely due to unrealistic cost estimates.[111] DOD concurred with the overall findings of the report and is reportedly taking actions to address these challenges.

Other programs that faced delays and cost overruns in 2006 include the National Polar Orbiting Operational Environmental Satellite System program, which has experienced cost increases of 25 percent and is currently under review,[112] and the Future Imagery Architecture (FIA) program. The FIA, which is intended to provide next generation reconnaisance capabilities, was put under review in 2006 and the DOD is considering the purchase of an interim capability in response to ongoing delays.[113] As well, it appears that the National Reconnaissance Office's (NRO) L-21 satellite, launched in December 2006, failed. The mission is classified, but later reports indicated that it was part of the testing of equipment intended for use on the FIA.[114] Another classified satellite, NROL-22, that was previously launched in June 2006, may or may not be part of the FIA reconnaissance program.[115]

2006: Progress and setback in US Operationally Responsive Spacelift (ORS)

On 16 December 2006 the US Air Force Research Laboratory's demonstrator TacSat-2 microsatellite was launched. Now renamed JWS D 1 (Joint Warfighting Space Demonstrator), it is a 415 kg technology mission that is to exhibit the tenets of responsive space concepts. It was operational within approximately 24 months of concept and launched six months after the contract was awarded. To date the mission is reported to be a success.[116] TacSat-2 provides both SIGINT and one-meter resolution imagery. The Air Force has longer-term plans for responsive space capabilities based on three main objectives: (1) Rapid Design, Build, Test with a launch-ready spacecraft within 15 months from authority to proceed; (2) Responsive Launch, Checkout, Operations to include launch within one week of a call-up from a stored state; and (3) Militarily Significant Capability to include obtaining images with tactically significant resolution provided directly to the theater.

US efforts for a reusable launch vehicle passed a milestone in 2006 with the first free glide flight test of DARPA's X-37A technology demonstration vehicle on 7 April, followed by additional flights on 18 August and 26 September. The vehicle is based on USAF's Space Maneuver Vehicle X-40A, first initiated in 1996. USAF subsequently announced in November 2006 that it will develop an X-37B Orbital Test Vehicle to further test reusable space vehicle technologies.[117] However, US responsive launch efforts were set back when the SpaceX Falcon-1 launcher failed 34 seconds after takeoff during its maiden flight on 24 March 2006, destroying the rocket and the DARPA FalconSAT-2 payload. Falcon-1 is scheduled for a second attempt in the first quarter of 2007.[118]

2006: Russia focuses on maintaining existing space assets and programs

In 2006, the first year of a 10-year federal space program, Russia increased its military space budget by as much as one-third compared with that for 2005, following a decade of severe budget cutbacks. Military space funding is also being allocated through the state armaments (defense and security) program for 2007-2015 and the special federal programs "Global Navigation System" and "Development of Russian Space Centers in 2006-2015."[119] Despite the recent growth in Russia's spending, capabilities will only gradually increase as there are significant investments required to upgrade virtually all parts of the military.

Russia launched eight military satellites in 2006 to maintain its reconnaissance, early warning, communications, and navigation capabilities. On 4 May a Kobalt-M (Yantar) type optical reconnaissance satellite, Cosmos 2420, was launched.[120] Cosmos 2421, a naval reconnaissance satellite, was launched on 25 June.[121] There were unconfirmed reports that Cosmos 2423, a military optical reconnaissance satellite of the Don type used to provide military and civilian imaging, launched in September, de-orbited in November.[122] Russian officials denied the claims and said that the satellite had completed its mission.[123]

Russian early-warning capabilities improved slightly with the 21 July 2006 launch of Cosmos 2422 aboard a Molniya M rocket. It is a new satellite of the US-KS early warning system known as Oko, and brings the constellation to four satellites, the minimum for operational status. It is complemented by one next-generation US-KMO satellite in GEO.[124] The system still does not provide global coverage, but is focused on the US. Military communications capabilities were also enhanced with the launch of the first Meridian satellite, intended to provide communications to ships and aircrafts in the Polar Regions, on 24 December 2006.[125] Meridian will replace the Molniya 1 satellites launched since 1954.[126] Russia also announced plans to restore the space-based component of its missile attack warning system (MAWS), and has recently increased MAWS funding.[127]

The GLONASS navigation constellation was increased in 2006 with the launch of three GLONASS M class satellites on 25 December aboard a Proton K rocket, designated Cosmos 2424, 2425, and 2426. The lifespan of these satellites is expected to be longer than that of their predecessors.[128] A fourth is scheduled for launch in 2007.[129] The GLONASS system currently has 19 satellites in orbit, 14 of which are operational. The system, which has been under development since 1982, is currently expected to reach its full constellation of 24 satellites by 2009-2010.

Space security impact

Even though the US remains the leader in military space technology it is experiencing significant project delays and budget cuts, which could have a. negative impact on space security by continuing to limit military bandwidth, maintaining pressure on the frequency availability, and delaying improvements in secure communications and space situational awareness. Conversely, these delays and cuts could improve space security by keeping US military systems at a steady state. Fewer new systems deployed may result in a reduction of the development of counterspace capabilities by potential US adversaries. However, upgrades to Russia's navigation, early-warning, and communications capabilities could be positive developments for space security by providing redundancy for the US GPS, more reliable and secure early-warning capabilities, and more secure satellite communications.

TREND 5.2: More states developing military space capabilities

2006: Regional tensions drive military space developments in Asia

Following a series of missile tests by North Korea in July 2006, Japan launched a one-meter resolution optical reconnaissance satellite on 11 September using a H-2A launcher. Officially called the Information Gathering Satellite (IGS) 3A, it joins two other reconnaissance satellites launched in 2003 – a fourth is scheduled for 2007. Japan is primarily interested in monitoring the Korean Peninsula, but the IGS 3A provides a scan of the entire planet at least once a day.[130] In 2006 Japan's ruling Liberal Democratic Party tabled a bill to relax restrictions on military space applications, which would allow the development of higher-grade military capabilities (see Space Laws, Policies, and Doctrines Trend 2.4).[131]

On 22 August 2006 Sea Launch launched South Korea's dual military/ commercial Koreasat 5 (Mugunghwa 5) communications satellite to replace Koreasat 2. This is a hybrid multiband satellite, which is part of South Korea's new high-capacity Spacecom System over the Asia-Pacific.[132] It will operate on the Ku band, the C band, and the military SHF band. Koreasat 5 is jointly owned by the French Agency for Defense Development (DGA) and South Korea's KT Corp. It will provide secure communications to South Korea's defense forces and support to KT's commercial satellite business.[133] On 28 July South Korea also launched the Kompsat 2 high Remote Sensing Satellite for Earth mapping.[134] Although a civilian spacecraft, its one-meter resolution could allow it to serve as a reconnaissance asset.[135]

In 2006 Taiwan's military released reconnaissance photos that it claimed depicted China's military buildup. Officials declined to comment on the source of the photos,[136] but they may have come from Taiwan's Formosa-2 research satellite, which has a 1.8-meter resolution. Chinese officials expressed concern that the Formosa-2 would support military purposes when it was launched in 2004.

2006: No dedicated military spacecraft launched by China but dual-use applications potentially expand its military space capabilities

On 12 September 2006 China launched the commercial communications satellite ZhongZing-22A (ChinaSat-22A) using the Long March 3A. Although officially designated as a commercial communications satellite owned by the China Telecommunications Broadcast Satellite, it is believed by some Westerners to also serve military communications needs.[137] It replaces the ZhongZing-22 (ChinaSat-22) launched in 2000, long believed to enable "theatre commanders to communicate with and share data with all forces under joint command" through C-band and UHF systems.[138]

China also launched the synthetic aperture radar (SAR) Remote Sensing Satellite-1 on 27 April 2006 under a civilian name Yaogan-1. The satellite is intended for "scientific experiment, survey of land resources, appraisal of crops and disaster prevention and alleviation."[139] While some Western sources also give the satellite a military designation, JianBing-5,[140] there is currently no evidence to suggest that it is being used for military purposes, although it could provide a military capability. Three Chinese Shi Jian experimental satellites were also launched in 2006, two of which (SJ-6/2A and SJ-6/2B) are suspected by some Western experts to be providing signals intelligence (SIGINT); however their official purpose is to measure the space environment.[141] SIGINT satellites are used to detect broadcast signals such as radios, as well as radars and other electronic signals. The third SJ satellite was a recoverable seed breeding satellite.

China's military space capabilities suffered a setback following the breakdown of the Sinosat-2 direct broadcast satellite. The mission was launched 29 October 2006 and failed on 8 November when its solar panels failed to deploy.[142] This was to be the first operational use of China's next generation Dongfanghong (DFH-4) spacecraft bus. Designated for commercial purposes, the DFH-4 direct broadcast system would have been adaptable for military purposes to distribute information on a battlefield.[143] DFH is the series of satellite also used for ChinaSat-22 and ChinaSat-22A.

China reaffirmed its committment to build a global satellite navigation system, the Beidou-2 or "Compass" system, expanding on the Beidou-1 regional system scheduled to be operational in Asia by 2008. The global system is planned to have five satellites in GEO and 30 in MEO to provide positioning accuracy within 10 meters for military, commercial, and civilian users. No details on the costs of the system have been made public.[144] It is unclear if this will affect China's stake in the EU-led Galileo navigation system, but the announcement of initial plans to use the same frequencies reserved for Galileo's encrypted service have raised European concerns.[145]

2006: Military space capabilities and cooperation boosted in Europe

Germany launched its first dedicated military reconnaissance satellite in 2006. The first of five all-weather synthetic aperture radar (SAR) high-resolution imaging satellites was launched on 19 December 2006 aboard a Russian rocket.[146] SAR-Lupe is part of a classified reconnaissance sharing agreement between Germany, France, Spain, Italy, Belgium, and Greece that includes France's high-resolution optical Helios-2A and Helios-2B (2008) and Italy's Cosmo Skymed radar satellites (2007).[147] In December Germany signed a contract with OHB-System AG to provide the technical interfaces necessary to operationalize this agreement.[148] In 2006 Germany, France, and Spain also advanced with military satellite communications systems. A procurement contract was signed with MilSat Services GmbH. The system will provide the German Armed Forces with a secure information network to assist its units on deployed missions.[149] The system, scheduled for operation in 2009, is part of Germany's concept for network-centric operations.

On 11 August 2006 France successfully launched a new-generation military communications satellite, Syracuse-3B, joining the Syracuse-3A launched in October 2005 to complete the Syracuse III system. Both satellites are based on a radiation-hardened version of the Alcatel Alenia Space's Spacebus. Their communication payloads operate in the SHF and EHF bands to provide Internet-like access to the military. The system also has jamming resistance features. It is now operational, providing permanent connections between military and government authorities in France and serving units deployed around the world using SHF and EHF bands.[150] Syracuse has been added to a list of systems including Britain's Skynet and Italy's Sicral, to provide the SHF capacity for NATO.

On 11 March 2006 Spain launched the military communications satellite Spainsat on board an Ariane 5 ECA rocket to service the Ministry of Defense. Spainsat carries a total of 13 wide-band, high-power X-band transponders and a Ka-band payload.[151]

2006: Europe considers dual-use of its space assets

The launch of the second Galileo navigation satellite prototype, the Giove-B, was postponed to early 2007 following a short circuit that occurred during its final testing.[152] The launch of the first satellite of the planned 30-satellite constellation is now planned for late 2008. Although the project is currently only in its testing phase, it is already over budget and the completion date has slipped from 2008 to 2011.[153] While funding has become an obstacle, its use is also a source of contention in Europe. Although intended for civilian use, there have been recent calls to use its dual-purpose capabilities for military applications, but all EU/ESA members do not share this view.[154]

The European Space Agency (ESA) has traditionally been restricted to working on projects designed exclusively for peaceful purposes; however it has begun to consider investing in dual-use security-related research. Space surveillance, Earth observation, and data-relay satellites have been identified as priorities.[155] Moreover, potential projects such as a global, European-coordinated space-surveillance system are being described in dual-use terms, with reference to "multiple" end-users.[156] Although end-users could potentially use ESA-developed applications for military purposes, the ESA itself would not be designing or operating military spacecraft.[157]

2006: New reconnaissance satellites in the Middle East

On 25 April 2006 Israel's ImageSat launched the high-resolution imaging Eros B satellite on a Russian launcher. The Eros-B is designed to capture black-and-white images at 70-centimeter resolution, which is sharp enough to discern objects of that size and larger. Its predecessor, Eros-A, collects images with 1.9-meter resolution.[158] Although owned and operated by ImageSat, through its Satellite Operating Partner Program Israel has secured shutter control (control and command) of the satellite over its region. Turkey's Air Force is planning to spend at least $200-million to buy and launch an electro-optical reconnaissance satellite with a resolution of 80 centimeters by 2011 under a program dubbed GOKTURK.[159] A competitive procurement process was underway in 2006.

2006: India begins work on Aerospace Command and Surveillance and Reconnaissance systems

India continued to plan the creation of a military Aerospace Command in 2006, but its exact composition and function are still vague.[160] This is part of a wider process that is seeing an increased role for military applications in India's space activities. The Military Surveillance and Reconnaissance system being built jointly by the civilian ISRO and the Defense Research and Development Organization (DRDO) is scheduled for operation in 2007. This system will incorporate the Cartosat-1 and -2 satellites and GLONASS with the ISRO-operated Technological Experiment Satellite, which has a remote sensing imaging resolution of 2.5-meters. Cartosat-2, an advanced remote sensing satellite with a resolution of one-meter, is scheduled for launch in 2007. India's Remote Imaging Satellite (Risat), scheduled for launch in 2007, will provide the country's first SAR microwave system capable of all-weather, day-and-night Earth imaging.[161] Like China, India asserts the civilian application of SAR capabilities, though it could support military purposes. India has not launched any dedicated military satellites to date; however, an operational Aerospace Command could potentially change this situation.

2006: Canada expanding miltary space applications

Canada continued to increase its access to military space applications in 2006. Successful negotiations were conducted to give Canada access to the US AEHF satellite system, scheduled to be operational by 2010.[162] When this system is combined with ground receivers, Canada will have its first access to dedicated military satellite communications The Canadian Forces have also announced plans for a low-cost ($27-million) Joint Space Support Project (JSSP) to acquire surveillance information for commanders in the field via direct in-theatre download of space imagery provided by commercial satellites such as Radarsat-2, scheduled for launch in 2007.[163] Funding approval for this project is expected in March 2007, with operations planned to begin in March 2009. The JSSP will use space situational awareness information gathered by the US Space Surveillance Network (SSN). These developments follow the 2005 creation of Project Polar Epsilon, a $52.1-million joint space-based wide area surveillance and support capability for Canada's Arctic and ocean regions.[164]

Space security impact

A growing number of states are using space to support military applications. While European countries are cooperating on military space capabilities, there is some evidence to suggest that the global trend may be towards development of independent, national systems. Even the European systems are, in fact, shared 'national' systems. Although greater redundancy of capabilities could enhance space security, there is also the potential for increased military tension and stronger intentions to use space for national military purposes. Increasing use of dual-use technologies for military applications demonstrates the growing difficulty of distinguishing military assets and targets from civilian. Moreover, such dual use may hamper international cooperation and trade as states try to limit the spread of such technologies.

Figure 5.5: Dedicated military spacecraft launched in 2006 (by owning state)[165]

COSPAR	Launch Date	Launch Vehicle	Satellite Name	Launch State	State	Primary Function	Primary Manufac.	Orbit Type
2006-033B	8/11/06	Ariane 5ECA	Syracuse 3B	France	France	Telecoms	Alcatel	GEO
2006-060A	12/19/06	Kosmos-11K65M	SAR-Lupe 1	Russia	Germany	Imaging-Radar	OHB	LEO
2006-037A	9/11/06	H-IIA 202	IGS Optical-2	Japan	Japan	Imaging	MELCO	LEO
2006-039A	9/14/06	Soyuz-U	Kosmos-2423	Russia	Russia	Imaging	Arsenal	LEO
2006-017A	5/3/06	Soyuz-U	Kosmos-2420	Russia	Russia	Imaging	Arsenal	LEO
2006-026A	6/25/06	Tsiklon-2	Kosmos-2421	Russia	Russia	Signals Intel.	Arsenal	LEO
2006-030A	7/21/06	Molniya 8K78M	Kosmos-2422	Russia	Russia	Early Warning	Lavochkin	HEO
2006-061A	12/24/06	Soyuz-2-1A	Meridian No. 1	Russia	Russia	Telecoms	NPO PM	HEO
2006-062C	12/25/06	Proton-K/DM-2	GLONASS-M	Russia	Russia	Navigation	Polyot	MEO
2006-062B	12/25/06	Proton-K/DM-2	GLONASS-M	Russia	Russia	Navigation	Polyot	MEO
2006-062A	12/25/06	Proton-K/DM-2	GLONASS-M	Russia	Russia	Navigation	Polyot	MEO
2006-007B	3/11/06	Ariane 5ECA	Spainsat	France	Spain	Telecoms	Loral	GEO
2006-024C	6/21/06	Delta 7925-9.5	USA 189	USA	USA	Technology	NRL	GEO
2006-024B	6/21/06	Delta 7925-9.5	USA 188	USA	USA	Technology	Lockheed	GEO
2006-024A	6/21/06	Delta 7925-9.5	USA 187	USA	USA	Technology	OSC	GEO
2006-027A	6/28/06	Delta 4M+(4,2)	USA 184	USA	USA	Signals Intel.	?	HEO
2006-042A	9/25/06	Delta 7925-9.5	Navstar GPS IIR-M2	USA	USA	Navigation	LMMS/VF	HEO
2006-050A	11/4/06	Delta 4M	DMSP 5D-3 F-17 (USA 191)	USA	USA	Metrology	LMMS/EW	SSO
2006-052A	11/17/06	Delta 7925-9.5	Navstar GPS IIR-M3	USA	USA	Navigation	LMMS/VF	MEO
2006-055J	12/10/06	Space Shuttle	ANDE-MAA	USA	USA	Science	NRL	-
2006-055F	12/10/06	Space Shuttle	ANDE-FCAL	USA	USA	Calibration	NRL	LEO
2006-055D	12/10/06	Space Shuttle	NMARS	USA	USA	Telecoms	USNA	LEO
2006-055C	12/10/06	Space Shuttle	RAFT1	USA	USA	Calibration	USNA	LEO
2006-055B	12/10/06	Space Shuttle	MEPSI 2A/2B	USA	USA	Technology	Aerospace	LEO
2006-057A	12/14/06	Delta 7920-10C	USA 193	USA	USA	Technology	UNK	LEO
2006-058A	12/16/06	Minotaur	Tacsat 2	USA	USA	Imaging	MicrosatSyst	LEO

CHAPTER SIX

Space Systems Protection

This chapter assesses trends and developments related to the research, development, testing, and deployment 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, such as anti-satellite (ASAT) systems, are considered protection measures by some. These capabilities are addressed by the Space Systems Negation and Space-Based Strike Systems 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 by 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.

The protection of satellites, satellite ground stations, and communications links 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 Trend 1.1.

Space Security Impact

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 microsatellites; (6) hit-to-kill anti-satellite weapons; and (7) high-altitude nuclear detonations (HAND).[1] Other potential threats include radiofrequency 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, and/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 available 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, if such attacks would seem to be both futile and costly.

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.

Because it is currently difficult to distinguish between satellite failures caused by environmental factors and deliberate attacks, some experts argue that greater space situational awareness is critical to improvements in space security.[2] There are, however, inherent dual-use concerns. Moreover, it is almost 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 mass 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 USSR/Russia lead in general capabilities to detect rocket launches, while US leads in the development of advanced technologies to detect direct attacks on satellites

The ability to distinguish space negation attacks from technical failures or environmental disruptions 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 in 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 space-based early-warning 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. The Oko system now provides coverage of US intercontinental ballistic missile fields, but with reduced reliability – capable of detecting massive attacks but not individual missile launches.[4]

The Oko system is complemented by an additional early-warning satellite in Geosynchronous Orbit (GEO), which is believed to be a next-generation US-KMO or Prognoz satellite capable of detecting missiles against the background of the Earth.[5] Russia began launching Prognoz in 1991. There have been up to six launches, but the program has been plagued by satellite malfunctions. Despite setbacks, Russia completed construction of a new command and control station in 1998.[6] The complete system would be composed of up to seven GEO satellites; only one is currently active.

The US military has always emphasized space protection as one of the key pillars of its space doctrine.[7] 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. By 2002, the DSP system had increased from four to seven GEO satellites, enhancing reliability by allowing certain areas to have additional satellite coverage.[8]

The US is now building the Space Based Infrared System (SBIRS) and the Space Tracking and Surveillance Systems (STSS) to replace the DSP satellites; however, both face ongoing delays, funding shortfalls, and cost overruns.[9] If completed, these systems would be capable of detecting and tracking ballistic missiles and potential ground-based kinetic-kill ASATs. The SBIRS constellation would consist of four GEO satellites, a spare satellite, and additional sensors on two classified HEO satellites.[10] A Lockheed Martin-Northrop Grumman team was awarded a $2.16-billion contract to build SBIRS in 1996. By September 2002, when the first launch was initially scheduled to take place, this contract was valued at $4.18-billion, not including the cost of three of the five GEO satellites.[11] Escalating costs led Congress to cut $27-million of the $66-million requested for FY2005 and to initiate a parallel program in 2006.[12] The first SBIRS satellite has yet to be launched. 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. China is also believed to have one Large Phased Array Radar for missile launch detection near Xuanhua in the west.[13] 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 up to 4,000 kilometers.[14] 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.[15]

Detecting ASAT attacks

Most actors have a basic capability to detect a ground-based electronic attack on their space systems, such as jamming, by sensing the interference signal of the attacker or detecting the loss of communications with the system under attack. Early warning for such attacks, however, remains a challenge. 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 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 by thermal sensors. Onboard 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 might prevent damage, depending on the sophistication of the attacker. Only US satellites are known to have such capabilities, and only Russia, France, Germany, 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. The US has been slowly augmenting this capability with the development of the Space Surveillance Telescope (SST), the Deep View radar, and the Large Millimeter Telescope and the Space Based Space Surveillance System (SBSS); however, these programs are generally under-funded and behind schedule. EU states have also discussed the feasibility of developing an independent space surveillance system (see The Space Environment Trend 1.3). 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.[16] 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 ongoing 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.[17] The US is also developing capabilities to detect electromagnetic interference on satellites 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, thus enabling timely deployment of defensive responses.[18] It began operation in 2005 with six fixed ground stations and three deployable ground segments.[19] Finally, the US Air Force is developing the Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) to shadow host satellites in orbit and monitor the surrounding space.[20] The first ANGELS launch is currently expected in 2009.

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, which 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.[21] 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: Protection of satellite ground stations is a concern, while the protection of satellite communications links is poor but improving

Protection of satellite ground stations

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 emphasized that the key threats to the commercial satellite fleet are those faced by ground facilities from computer hacking or possibly, but less likely, jamming.[22] Satellite communications can usually be restored, however, 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,[23] 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.[24] Responding to such concerns, in 2002 the US General Accounting Office recommended that "commercial satellites be identified as critical infrastructure" (see Commercial Space Trend 4.3).[25] The use of standardized protocols and communications equipment could allow alternative commercial ground stations to be brought online.

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 Trend 7.1).

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 that 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; (4) shielding and radio emission control measures that reduce the radio energy that can be intercepted for surveillance or jamming purposes; and (5) robust encryption onboard satellites.[26]

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 nullify or cancel the interference.[27] This last technique is considered the most comprehensive anti-jamming technique in existence.[28]

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.[29] Through its Global Positioning Experiments project, the US has demonstrated the ability of GPS airborne pseudo-satellites to relay and amplify GPS signals to counter signal jamming.[30] The US and several other countries are 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, the Apstar-4 communications satellite, in 2005.[31]

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 by 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 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.

Twenty-eight 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. Ten actors have developed an orbital launch capability; eight of these actors have demonstrated the capability to reach GEO. The fact that LEO can be reached in a matter of minutes, while GEO takes about a half-day to reach by completing a Hohmann transfer orbit, illustrates the unique protection dynamics associated with different orbits.[32] Not surprisingly, military systems are increasingly being placed into higher orbits such as Medium Earth Orbit (MEO) or GEO. Russia leads in use of HEO applications.

There are defender advantages in space: for example, the distances and speeds involved in satellite engagements can 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. Higher operational orbits also 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 almost impossible to provide physical hardening against such attacks because of the high relative velocities of objects in orbit. As previously discussed, however, 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 that 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,[33] but the extra fuel required might represent more than 10-20 percent of the satellite cost.[34]

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.[35]

In general, there is currently little redundancy of commercial, military, or civilian space systems. This is especially true of the space-based components, due to the large per-kilogram cost of launch. However, commercial satellites are 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, India, the European Space Agency (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, as the US and EU agreed to do in 2004 with the GPS and Galileo systems (see Civil Space Programs and Global Utilities Trend 3.4).[36]

Protection against nuclear attack

Since all current nuclear weapon states also have suborbital space access, the capability to carry out a HAND attack is within the capability of at least 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.[37]

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 and particularly vulnerable to radiation effects, 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.[38] 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 that 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 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 that protect systems from natural radiation events, such as solar flares. Generally, commercial satellites are not specifically protected from the EMP effects that would result from a HAND. Some commercial spacecraft components, however, 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.[39] 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.[40]

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.[41] 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 that 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 measures 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 continue to require higher power. 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, which can be damaged by lasers.[42] 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.[43] 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 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 ? = Unclear from open source literature

TREND 6.4: US and USSR/Russia lead in developing 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. 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 has also 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.[44] 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 that included plans for the rapid launch of military satellites to replace space assets lost in action.[45] A significant portion of Russia's current launches, however, are of other nations' satellites; Russia continues to struggle to maintain existing military systems in operational condition. Thus, in practice, little redundancy is leveraged through this launch capability.[46]

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

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."[47] Several programs address this concern, including the Falcon program.[48] Initial steps included a Small Launch Vehicle subprogram for a rocket capable of placing 100-1,000 kilograms into LEO on 24-hours notice for under $5-million; however, the program is ultimately linked to a long-term prompt global strike capability.[49]

Concepts for a US Space Maneuver Vehicle (SMV) or military space plane first emerged in the 1990s as a small, powered, reusable space vehicle, operating as an upper stage on top of a reusable launch vehicle.[50] Two technology demonstrators have been built, including the X-40 (US Air Force) and the X-37A (NASA/DARPA).[51] India is working on a similar design, the Reusable Launch Vehicle, but it is not anticipated before 2015.[52] The commercial space industry is contributing to responsive launch technology development through advancements with small launch vehicles, such as the Falcon-1 developed by Space Exploration Technologies (see Commercial Space Trend 4.2).

There is also increasing interest in the development of air-launched microsatellites, which could reduce costs and allow rapid launches as they do not require dedicated launch facilities. 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.[53] The Mikron rocket of the Moscow Aviation Institute's Astra Centre, introduced in 2002, was designed for launch from a MiG-31 and is capable of placing payloads of up to 150 kilograms into LEO.[54] The US has been using the Pegasus launcher, first developed by Orbital Sciences Corporation in 1990, to launch military small payloads up to 450 kg from a B-52 aircraft.[55]

The US is also pursuing technologies to recover from 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.

TREND 6.1: The US and USSR/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

2006: Upgrades on ballistic missile early warning in the US and Russia

Despite efforts in 2006 to operationalize the Space Based Infrared System (SBIRS), designed to replace the US Defense Support Program (DSP), the program remains over budget, behind schedule, and risks being replaced. If completed, it would provide all-weather warning of ballistic missile and rocket launches, track launch vehicles in flight, and determine when the payload has been released.[56] The first SBIRS infrared sensor was launched into HEO in June aboard a classified National Reconnaissance Office satellite.[57] The HEO orbit will allow it to detect missile and rocket launches in high latitude and Polar Regions. US Air Force officials reported that the sensor performed well during its initial checkout with targets of opportunity, such as the launches of the satellites in the US Defense Meteorological Satellite Program.[58] Testing of the sensor and other support computer algorithms are expected to lead to operational status in 2008.[59] Launch of the first GEO satellite has slipped from 2002 to 2008.[60] Moreover, due to cost and schedule overruns, the US DOD has cut the program to a maximum of three GEO satellites from four.[61]

In further response to repeated delays and cost overruns of SBIRS, the US Air Force initiated a parallel program in 2006: the Alternative Infrared Satellite System (AIRSS), supposedly designed to provide DSP-like functions with a simpler and cheaper design than SBIRS.[62] General Dynamics was awarded an initial contract of $23.3-million to support program research and development.[63] Officials suggested that technology developed for AIRSS could be integrated into the SBIRS program, but it could also replace it.

In 2006 Northrop Grumman received a $126.2-million contract modification to extend the Space Tracking and Surveillance System (STSS) program timetable and perform additional testing.[64] The program has been restructured and renamed several times since 2001, and has experienced significant cost growth.[65] It is designed to track missiles through space, differentiate missile warheads from decoys and debris, and provide targeting data for a missile defense interceptor. Two STSS satellites are currently expected to be launched in late 2007.[66] STSS has dual-use applications for space systems negation efforts and space-based strike capabilities.

Russia's new Voronezh meter-band early warning radar near Lekhtusi in the Leningrad Region was put online in 2006, closing a seven-year coverage gap in its northwestern region.[67] The new radar will enhance Russia's ability to detect warheads from intercontinental ballistic missiles. Another Voronezh-type radar, to be located in the Krasnodar Territory in southwest Russia, is currently scheduled for completion by 2007. Russia is also taking steps to improve its space-based early warning capabilities. It is believed that the Cosmos 2422 launched into HEO on 21 July 2006 was a US-KS (Oko) satellite designed to detect ballistic missile launches from US territory.[68] This would bring the Oko constellation to four satellites, complemented by one next-generation US-KMO satellite in GEO. Despite the additional satellite, the Oko system is operating below capacity and does not provide global coverage.[69]

Additional developments related to space situational awareness in the US, Canada, and Europe are covered in The Space Environment Trend 1.3.

2006: US continues work on on-orbit capabilities to detect attacks on satellites

The US is moving forward with its Autonomous Nanosatellite Guardian for Evaluating Local Space (ANGELS) program, which is intended to shadow a space asset and provide local on-orbit space situational awareness and anomaly characterization.[70] In 2006, the US Air Force Research Laboratory Space Vehicle Directorate awarded SpaceDev a $1.25-million contract to provide the preliminary design for ANGELS, and gave Lockheed Martin Space Systems an $8-million contract to provide engineering design and development support; a flight test is currently scheduled for late 2008 or early 2009.[71] The program has a budget of $20-million.[72] The program could have dual space negation implications, as ANGELS satellites will be able to maneuver to perform close proximity functions, although information in open literature does not indicate that it will have the capacity to significantly change orbit to target foreign satellites.

2006: Efforts to better identify satellite interference and responses

US STRATCOM announced that it has shifted its procedures to assume that all reported incidents of satellite disturbances are deliberate acts rather than abnormalities due to system failure or the space environment. Officials indicate that the change is intended to allow operators to "practice procedures that would come into play if an adversary tried to obstruct U.S. space operations."[73] The shift in assumptions is designed to create a sense of urgency in determining the source and attribution of interference events and improve response time. As a procedural change, it does not affect US policy or legal obligations regarding responses to interference, although the underlying premise of investigation has become more assertive.

China is reportedly upgrading its Xi'an Satellite Monitoring Center, which is the primary control center for China's network of 13 monitoring stations. With its telecommuting system, engineers are supposedly able to monitor and diagnose satellite malfunctions, eliminate harmful interference, and prevent purposeful damage to satellite communications links.[74] Upgrades to the center also include increased orbit determination and tracking capabilities, which can be used to support space negation activities (see Space Systems Negation Trend 7.2).

Several states acquired the services of a commercial provider of satellite interference data in 2006. The Japanese Space Communication Corporation (SCC) ordered a system for satellite communications interference identification from QinetiQ of the UK.[75] The system can reportedly identify and locate the source of radio interference. SCC will install the system in one of its two satellite control centers in Japan to help monitor the operation of the company's SUPERBIRD communications satellites. QinetiQ's services were also procured to transmit the 2006 World Cup from Germany, and a system was launched to provide service to European customers.[76]

Space security impact

Advancements of technology for space surveillance, missile early warning, and on-orbit situational awareness could improve space security by enhancing the transparency of space activities and facilitating threat evasion. These developments, along with improvements in satellite interference identification, may also help to bolster strategic stability by helping to distinguish accidental and environmental interference from deliberate attacks on critical space systems. Nonetheless, the nature of this impact will depend on whether information from surveillance, tracking, and early warning systems is shared, whether these systems are used to support space negation or space-based strike capabilities, and the response to satellite interference.

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

2006: Efforts to develop secure laser communications, but challenges remain

In 2006 Europe, Japan, and the United States each made some progress in the development of satellite laser communications. Building on previous success, the ESA successfully established a laser communication link between a satellite in GEO and a high flying aircraft in two separate flights as part of the French Ministry of Defense procurement agency's airborne laser optical link program.[77] On 7 June the Japanese OICETS satellite (Kirari) successfully maintained a three-minute laser communication link with a mobile ground station operated by the German DLR.[78] Further testing with ground stations and the Artemis satellite is expected.

Despite progress, the US Transformational Satellite Communication (TSAT) program demonstrates the ongoing challenges related to laser communications.[79] In March 2006 preliminary testing of the ground segment's laser communications terminal hardware was completed and it was able to maintain a laser link with a government reference terminal.[80] The Next-Generation Processor Router (NGPR), responsible for RF ground-to-satellite communication, also demonstrated interoperability with a reference ground terminal using the XDR+ anti-jamming waveform.[81] The five-satellite TSAT constellation was originally envisioned to employ laser links for all communications; however, only inter-spacecraft laser links are currently being planned.[82] The first reduced-capacity satellite is not expected to orbit until 2014, and the program continues to experience cost overruns and schedule delays (see Space Support for Terrestrial Military Operations Trend 5.1).

2006: United States Air Force to Establish Cyberspace Command

The US Secretary of the Air Force announced plans to establish the 8th Air Force as the new Air Force Cyberspace Command.[83] It will be responsible for the military's Internet and other computer networks, as well as the electromagnetic spectrum, and is expected to be operational by 2009. Its purpose is to defend computer networks against asymmetric threats and to counter the presence of online terrorist groups.[84] The inclusion of the entire electromagnetic spectrum within the definition of cyberspace means that satellite protection from directed energy weapons and communications jamming could fall within the purview of the cyberspace command. It remains to be seen how this development will affect space security.

Space security impact

Advancements in laser communication links could help to enhance space security in the future because they combine strong protection, high data transmission rates, and reduced instances of accidental jamming and cross-pollution of radio signals, reducing potential mistrust among space actors. The ability to direct a laser beam at another spacecraft, however, could have negative implications for space security if it is used for space negation purposes. The technology is still immature, so it is too early to determine its exact capabilities and uses. Similarly, the impact of the Air Force Cyberspace Command will not be fully discernable until it has become operational.

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

2006: Orbital Express space servicing architecture back on track

After almost being cancelled in 2005 due to cost overruns, the Orbital Express program was brought back on track in 2006 following cost control efforts and a successful system integration test. Developed by prime contractor Boeing with DARPA and NASA, Orbital Express aims to develop architecture for future automated on-orbit spacecraft servicing.[85] In 2006 preparations were made for an on-orbit demonstration of key technologies. The 1,090-kilogram Astro servicing craft and the 250-kilogram NextSat target satellite are scheduled for launch into LEO aboard an Atlas 5 on 8 March 2007.[86] Once in orbit, the two spacecrafts are intended to separate and conduct experiments on automated approach and docking, fuel transfer, and components exchange using a robotic arm mounted on Astro.[87] The cost of the Orbital Express program, initially estimated at $113-million in 2002, grew to $267.4-million for FY 2001-2007.[88] The program builds on the experiences of previous autonomous operations such as the US DART, XSS-10, and XSS-11; and Japan's Engineering Test Satellite-7. If successful, future spacecraft on-orbit servicing could extend the life of satellites and enable greater maneuverability.

2006: University of Florida and Honeywell are developing software-based protection for space assets

Engineers at the University of Florida and Honeywell are currently developing a new type of spacecraft computer system that is tolerant to radiation.[89] The new system, the Dependable Multiprocessor, utilizes commercial, off-the-shelf components and new software in a computer that is fault-tolerant and reconfigurable. Rather than using hardware to protect the computer from ionizing radiations, the Dependable Multiprocessor software detects and corrects for the errors generated by radiation and reconfigures the computer to bypass damaged parts if necessary.[90] It is scheduled to be launched in 2009 onboard Space Technology-8 spacecraft, as part of NASA's New Millennium program.[91]

Space security impact

On-orbit servicing is an enabling technology that could contribute to space security by allowing for close inspection of satellites and monitoring malfunctions as well as providing re-fuelling options that would allow satellites to maneuver more frequently to avoid threats. On-orbit spacecraft servicing technology could also serve dual negation purposes if aimed at uncooperative satellites. In the long term, software advances that can protect satellites against direct threats such as radiation could improve the accessibility of protection capabilities, particularly if they are more cost effective than current hardware solutions.

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

2006: Growing interest in rapid air launch capabilities

The US progressed in its attempts to develop a rapid air launch capability in 2006. The Small Launch Vehicle (SLV) portion of the DARPA/USAF Falcon project seeks to develop launch vehicles that can send a 450-kg payload into LEO on 24-hours notice for less than $5-million. AirLaunch LLC is developing the QuickReach rocket and SpaceX is working on the Falcon I to fulfill the Falcon requirements.[92] The QuickReach launcher is a two-stage liquid fuel rocket powered by LOX and propane.[93] The rocket is carried to high altitude by a large cargo aircraft such as a C-17 and released from the cargo bay at the launch point. Airlaunch LLC conducted two drop tests of the QuickReach rocket using inert Drop Test Articles that simulate the dimensions and weight of the actual launch vehicle. The tests were conducted on 14 June and 26 July 2006; engine tests were also completed in 2006.[94] A critical design review for the Quickreach was scheduled for November 2006 and an orbital test planned for 2009.[95] NASA is also interested in new rapid launch technology. In 2006 NASA Ames Research Center and AirLaunch LLC signed an agreement to collaborate on aircraft-launched space boosters.[96] While advancements are promising, the US is still far from having a launch-on-demand capability.

Other states are also attempting to develop rapid air-launch capabilities. Kazakhstan's KazCosmos announced plans to develop the Ishim air-launched rocket system based on the Soviet-era ASAT system, together with the Moscow Institute of Thermal Technology and the aircraft company MiG.[97] Work is to begin on 1 July 2007, with an anticipated completion date of 2010.[98] The system could be capable of launching a 160-kg payload into a 300-km circular orbit and a 60-kg payload into a 1,200-km circular orbit, with Polar and HEO orbits also possible.[99] The launch vehicle is envisioned to have three stages and to be carried to the launch area in the centerline pylon of the MiG-31. The rocket will be released from the carrier aircraft from an altitude of between 15 to 18 km at airspeeds between 2,120 and 2,230 km/hour.[100] The Kazakh government is financing this project and already plans to use the system to launch eight satellites. As this system would be based on ASAT technology, it would have obvious dual use for space negation purposes.

In 2006 the China Aerospace Science and Technology Corporation (CASC) announced plans to develop two launch vehicles that are capable of launching small payloads into Sun-Synchronous orbits.[101] One design is a three-stage air-launched rocket released from a modified H-6 bomber. The 13-ton booster will be capable of inserting a 50-kilogram payload into a 500-kilometer Sun-Synchronous orbit. Like the proposed Ishim system, it is based on military technologies that would have dual-use capabilities. CASC is also working on a new liquid-fuelled rocket capable of launching a 500-kilogram satellite into a 700-kilometer Sun-Synchronous orbit. Although not based on air launch technology, this Next Generation Small Launch Vehicle is supposed to emphasize rapid launch and environmental friendliness.

More experimental hypersonic aircraft also have the potential to offer cheap and rapid access to space by lifting payloads up to the edge of the atmosphere and then launching them into orbit with a small rocket. Australia, India, Japan, and the United States are currently conducting research on hypersonic technology. There were several noteworthy developments in 2006, which are covered in Space-Based Strike Systems Trend 8.2.

Space security impact

Efforts on more responsive, cheaper space lift capabilities in the US, Russia, and Australia could improve space security in the future by allowing faster recovery times following attacks or malfunctions and enabling greater redundancy of space assets. Although progress is being made on technology development, this capability has not yet been realized. It must be noted that air-launched technology has dual-use negation applications. Both the MiG-31 carrier craft and the launch vehicle are based on previous ASAT weapons and could also be employed for satellite interception, which would threaten space security. Moreover, air launches provide the opportunity for covert space launches, which could enable an actor to secretly orbit nefarious spacecraft, and could reduce transparency of space activities. It could also be argued that rapid space launch capabilities might encourage more aggressive behavior by actors that can quickly rebuild their own space systems.

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, which is 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 in the United States as the five Ds: deception, disruption, denial, degradation, and destruction.

Many space negation capabilities apply widely proliferated military equipment, technology, 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 that 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 well, space surveillance capabilities are required 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 weapon 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 the long-term effects of false radiation belts, which would have an adverse impact on many satellites in Low Earth Orbit (LEO).[2]

Space Security Impact

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 concerns about an arms race 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 progressively develop more destructive negation means 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 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 Laws, Policies, and Doctrines Trend 2.1). 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 that could potentially inflict widespread damage on other space systems and undermine the sustainability of space security. 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 carefully targeted space negation efforts may have a positive impact on space security if such efforts prevent the target actor from using space systems to inflict widespread, long-term damage to the space environment or otherwise prevent access to space.

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 the most likely space negation scenario. System sabotage; physical attack on the ground facility by armed invaders, vehicles, or missiles; 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 incidents of electronically jammed media broadcasts have been reported in recent years, including interruptions to 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 suggests that jamming capabilities are proliferating – 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 communications signals, was declared operational.[9] The US Space Control Technology 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 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* stated 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]

The US Space Surveillance Network is the primary provider of space surveillance data. It has limited capabilities to provide real-time data collection, however, and restrictions were placed on the distribution of the data in the 2004 Defense Authorization Act.[15] 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.[16] Space-based surveillance, demonstrated by the US in the late 1990s through the Space Visible Sensor experiment,[17] 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."[18] A "Pathfinder" SBSS satellite is set for launch in 2007.[19] 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."[20] However, funding issues have bedeviled efforts to improve US space surveillance. Further, traditional US willingness to provide space surveillance data to other governments and commercial firms has been challenged over the past several years – both for cost reasons and concerns about satellite security[21] (see Space Environment Trend 1.3).

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[22]

System	Actor	Dates	No. Intercepts	Description of program
Bold Orion air-	US	1959, single test	0	Air-launched ballistic missile passed launched ballistic missile within 32 kilometers of the US Explorer VI satellite
SAtellite INTerceptor (SAINT)	US (USAF)	1960-1962, idea abandoned in the late 1960s	0	Designed as a co-orbital surveillance system, the satellite could be armed with a warhead or 'blind' the enemy satellite with paint
Program 505	US (US Army)	1962-1964	1?	Nike-Zeus nuclear-tipped anti-ballistic missile system employed as an ASAT against orbital vehicles
Program 437	US (USAF)	1963-1975	1?	Nuclear-armed Thor ballistic missile launched directly into the path of the target
Co-orbital (IS) ASAT	USSR	1963-1972, 1976-1982	12?	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	0	Sary Shagan and Dushanbe laser sites reported to have ASAT programs
Air-Launched Miniature Vehicle	US (USAF)	1982-1987	1	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	1	Megawatt-class chemical laser fired at satellite to disable electronic though not sensors
Ground-Based Kinetic Energy ASAT	(US) US Army	1990-2004	0	Kinetic-kill vehicle launched from the ground to intercept and destroy a satellite
Medium-range ballistic missile-based kinetic energy ASAT	China (PLA)	2007-	1	Destroyed the Feng Yun 1C weather satellite

Conventional (kinetic hit-to-kill) weapons

Launching a payload to coincide with the passage of a satellite in orbit is the fundamental requirement for a conventional ASAT capability. Twenty-eight actors have demonstrated sub-orbital launch capabilities; 10 of this number have developed orbital launch ability. With tracking capabilities, a payload of metal pellets or gravel could be launched into the path of a satellite by suborbital rockets or missiles (for example a SCUD missile).[23] 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.

USAF Doctrine Document 2-2.1 outlines a set of "counterspace operations" designed to "preclude an adversary from exploiting space to their advantage … using a variety of permanent and/or reversible means."[24] 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.

The US Army invested in ground-based kinetic energy ASAT technology in the late 1980s and early 1990s. The small, longstanding Kinetic Energy (KE) ASAT program was terminated in 1993 but was later granted funding by Congress in FYs 1996 through 2005.[25] Congress appropriated $14-million for the KE ASAT for FY2005 through the Missile Defense Agency's (MDA) Ballistic Missile Defense Products budget.[26] It is part of an Applied Counterspace Technology testbed at Redstone Arsenal.[27]

The US has deployed a limited number of ground-based exoatmospheric kill vehicle (EKV) interceptors for ballistic missile defense purposes.[28] 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.[29] Some experts assess that, with limited modification, the EKV could act as an ASAT.[30] 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.[31] Russia has developed a long-range (350 kilometer) exoatmospheric missile, the Gorgon, for its A-135 anti-ballistic missile system.[32] The UK[33] and Chinese academic institutions are also exploring techniques for exoatmospheric interceptors.

As well, China is developing advanced kinetic ASAT capabilities, demonstrated by tests in 2005 and 2006 that culminated in the destruction of a Chinese weather satellite on 11 January 2007.[34] Russia continues to observe a voluntary ASAT test moratorium. The precise status of its ASAT system is not known, but it is most likely no longer operational.[35]

Nuclear weapons

A nuclear weapon detonated in space generates an electromagnetic pulse that is highly destructive to unprotected satellites, as demonstrated by the US 1962 Starfish Prime test.[36] 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.[37]

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.

Eight states are assessed to possess nuclear weapons: China, France, India, Israel, Pakistan, Russia, the US, and the UK. North Korea has an ongoing nuclear program.[38] Iran is suspected by many of pursuing a nuclear weapons program and has an active long-range missile program.[39]

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 and China. All states have access to low-powered lasers, which could be used to "dazzle" unhardened satellites in LEO, and many may already have the capability to use low-power lasers to degrade unhardened sensors on satellites in LEO.[40] 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,[41] suggesting that even a commercially available low-watt laser functioning from the ground could be used to "dazzle" or temporarily disrupt a satellite.[42] 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. Similarly, the USAF Starfire Optical Range at Kirtland Air Force Base in New Mexico is undertaking laser experiments that in the FY2006 budget request were characterized as aimed at ASAT as well as laser tracking applications.[43] Until 2004 the US was developing a Counter Surveillance/Reconnaissance System (CSRS) that employed lasers to temporarily disrupt surveillance satellites by dazzling their sensors.[44]

The Airborne Laser currently under development in the US is central to plans for future Boost Phase Ballistic Missile Defense.[45] The project achieved "first light" in 2004 in a ground-based test of the chemical oxygen iodine laser.[46] This technology is assessed by some experts to have ASAT capabilities; however, the Airborne Laser continues to suffer from serious technology challenges, schedule delays, and cost concerns within Congress.[47] China operated a high-power laser program as early as 1986 and is now believed to have multiple hundred-megawatt lasers.[48] Chinese researchers are also studying adaptive optics to maintain beam quality over long distances and the use of solid state lasers in space; both technologies could apply to ASAT applications.[49] 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 its small size, a space-mine microsatellite 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. At least 30 states have at some time employed microsatellites. In 2000 the partnership between China and Surrey Satellite Technology Ltd. of the UK saw the launch of the Tingshua-1 microsatellite and companion Surrey Nanosatellite Application Platform to test on-orbit rendezvous capabilities.[50] The ConeXpress Orbital Life Extension Vehicle being developed by Orbital Recovery is set to be the first commercial satellite that is specifically designed to rendezvous with a target satellite in GEO.[51] China, along with Algeria, Nigeria, Spain, Thailand, Turkey, Vietnam, and the UK, have pledged to contribute microsatellites to the Disaster Monitoring Consortium (see Civil Space Programs and Global Utilities Trend 3.4).[52] A number of states also employ microsatellites for scientific remote-sensing and surveillance, with no evidence of links to space negation 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 onboard optics. The USAF Experimental Spacecraft System (XSS) employs microsatellites to test proximity operations, including autonomous rendezvous, maneuvering, and close-up inspection of a target. For example, XSS-11 was launched in 2005 and flew successful repeat rendezvous maneuvers. The Missile Defense Agency (MDA) Near-Field Infrared Experiment (NFIRE), designed to provide support to ballistic missile defense, at one point was planning to employ a kill vehicle to encounter a ballistic missile at close range, with a sensor to record the findings. However, in 2005 MDA cancelled the kill vehicle experiment after Congress expressed concerns about its applicability to ASAT development.[53] Another missile defense technology currently under development that 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.[54]

Figure 7.3: Enabling capabilities of key actors for space-based kinetic-energy ASATs*

Capability	China	EU/ESA	France	UK	India	Israel	Japan	Russia	Ukraine	US
Space launch vehicles										
Land – Fixed[55]	X	X	X		X	X	X	X	X	X
Land – Mobile[56]	L		L	L	L	L		X	L	X[57]
Sea	L[58]							X[59,60]	X[61]	X[62]
Air								D[63]		X[64]
Space tracking (uncooperative)										
Optical (passive)	X[65]	X	X[66]	X[67]			X[68]	X[69]		X[70]
Radar	X[71]		X[72]	X[73]			X[74]	X[75]		X[76]
Laser[77]	X	X	X	X		X	X	X	X	X
Autonomous rendezvous										
Cooperative		D[78]						X[79]		D[80]
Uncooperative		D[81]						F[82]		D
Proximity operations										
Cooperative		D[83]								X[84]
Uncooperative		D[85]								X[86]
High-g, large-ΔV upper stages	X	X	X	L	D		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.[87] In 2005 the ASAT capability of maneuverable microsatellites was demonstrated when the DART unexpectedly collided with the target satellite and bumped it into a higher orbit.[88]

The Defense Advanced Research Projects Agency (DARPA) Orbital Express program will develop on-orbit refueling and reconfiguring – servicing necessary for maneuvering a space-based ASAT.[89] These programs make use of smaller, lighter components and are consistent with a growing US emphasis on responsive space programs.

On-orbit servicing is a key research priority for German and Canadian civil space programs and supporting commercial companies. The joint German-Russian-Canadian on-orbit servicing program, Technology Satellite for Demonstration and Verification of Space Systems, 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.[90] There is no evidence to suggest that these programs are intended to support space systems negation purposes, but the technologies could conceivably be modified for such application. Researchers at Chinese universities are analyzing on-orbit homing and rendezvous methods, although it is unclear whether the research is original and Chinese-initiated or merely a review of previously conducted foreign research.[91]

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

2006: Disruption of commercial satellite systems in Libya, Indonesia, and Lebanon

In 2006 commercial satellite systems were intentionally disrupted in several different instances. Cited as "one of the most persistent jamming events ever recorded in the commercial satellite sector," the jamming by Libyan nationals of Thuraya Satellite Telecommunications mobile satellite communications lasted more than six months.[92] The jamming ended when the government of the United Arab Emirates approached the Libyan government through diplomatic channels. The jamming was reportedly aimed at smugglers of cigarettes and other contraband into Libya, who were using Thuraya satellite phones; it had a much more far-reaching effect, causing the company to suffer revenue losses. In a further demonstration of the vulnerability of some commercial satellites, a group of Jakarta-based hackers collected data being transmitted by an older, unidentified commercial satellite. They did not use the data, but the incident demonstrates the ease with which some satellite systems can still be hacked.[93]

The potential for commercial satellites to be third-party targets during conflict was seen in the 2006 Israel-Lebanon war, when Israel tried, but failed, to jam the Al-Manar satellite channel transmitted by the Arab Satellite Communications Organization (ARABSAT). Israel refrained from directly jamming the satellite, which serves 200 million viewers through different services, but rather expressed an interest in developing an ability to selectively jam specific transmissions.[94] Although Israeli officials acknowledged that jamming communications satellites is against international law, the strategy remains appealing during wartime. The US was the first state to claim a potential willingness to interfere with third-party commercial satellites in US Air Force Doctrine Document 2-2.1.[95]

2006: Growing interest in ionosphere reconfiguration

USAF is funding a project that seeks to use plasma to reconfigure a part of the ionosphere.[96] The modified ionosphere would have different radio frequency properties, selectively blocking out radio transmission in an area while the surrounding areas are unaffected. The Microwave Ionosphere Reconfiguration Ground-based Emitter (MIRAGE) project would employ microwave transmitters on the ground and a small rocket to dispense chaff into the air at an altitude of 60-100 km.[97] About one liter of plasma is generated by the microwave-chaff interaction, changing the number of electrons in that portion of the ionosphere. The first phase of MIRAGE was recently completed by Research Support Instruments.[98] Atmosphere modification could be used as a method to conduct ground-based negation. Because it would not directly interfere with satellite communication, this type of disruption would be difficult to detect by conventional means or to distinguish from a normal atmospheric event. Currently this type of temporary, ground-based space negation is a technology of interest. At least one Chinese academic paper has been written about the potential of plasma negation efforts; however, there is no evidence at this time that the Chinese government is pursuing such technologies.[99]

Space security impact

Ongoing efforts to develop ground-based electronic negation capabilities would detract from space security by threatening actors' use of space assets, although temporarily and without causing long-term damage to the space environment. The potential deception with which such negation methods could be carried out might also contribute to insecurity by blurring the lines between satellite malfunction, environmental interference, and deliberate jamming, and so reducing transparency. The willingness of some actors to interfere with third-party commercial satellites demonstrates the threat to the secure and sustainable access to, and use of, space for all actors. This vulnerability is not matched by an equivalent trend in protection of commercial satellite systems, or development of international law.

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

2006: US cuts and Chinese advances in space situational awareness capabilities

Plans announced early in 2006 to upgrade the Air Force Space Fence radar portion of the Space Surveillance Network (SSN) to provide faster search and greater resolution capabilities appear to have been thwarted in December when the DOD announced significant funding cuts to the program (see The Space Environment Trend 1.3). While the Space Fence radar is primarily used to track space debris, the upgrades would have also increased its ability to track microsatellites in high orbits. Progress on the Space Based Surveillance System (SBSS) continued in 2006 with the completion of a key risk reduction step for the initial pathfinder satellite, but its launch has been delayed to 2009 and the remaining four satellites necessary to complete the system are currently planned for launch only in 2013-14.[100] The system would enhance the capabilities of the Space Fence and the SSN by providing surveillance of objects in GEO. Finally, in 2006 DOD cancelled the Orbital Deep Space Imager program, intended to develop satellites that would monitor other satellites and objects in GEO, citing budgetary constraints.[101] Both the SBSS and the Orbital Deep Space Imager programs are important components of US space control efforts.

China is reportedly upgrading its Xi'an Satellite Monitoring Center, which is the primary control center for China's network of 13 monitoring stations. Upgrades include increased orbit determination and tracking capabilities of domestic and foreign satellites, which could be used to target negation activities against space-based assets.[102] In 2006 Chinese researchers also continued to work on target-tracking technologies that may be used as key components for an advanced space tracking system. Present basic research involves obtaining greater tracking precision and real-time accuracy.[103] China's tracking and target capabilities were demonstrated by the Chinese ASAT test on 11 January 2007 (see Trend 7.3). The satellite was tracked and targeted from the Xi'an Satellite Monitoring Center.[104]

Space security impact

Ongoing efforts to develop space surveillance systems can have a positive impact on space security by increasing the ability of actors to safely operate in space, enhancing transparency of outer space activities, and providing a redundancy of capabilities. In this sense, program cuts and delays in the US detract from space security. On the other hand, the potential for such capabilities to support deliberate attacks against satellites and other space objects is demonstrated through the centrality of space surveillance to US ballistic missile defense and its role in the successful Chinese ASAT test (see Trend 7.3).

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

2006: China tests direct ascent missile against own satellite

Previously unreported attempts by China to intercept a satellite with a missile on 7 July 2005 and 6 February 2006 culminated in a successful intercept on 11 January 2007.[105] The target was the retired Feng Yun 1C (FY-1C) weather satellite, launched in 1999 into a Sun-Synchronous orbit with an altitude of 850 kilometers.[106] Reports indicate that the missile was launched from the Xichang Space Center, or a site close to it. The FY-1C was moving south at the time of the collision, when the kill vehicle collided with it at high velocity. The booster that delivered the kinetic kill vehicle is believed to be based on a medium-range ballistic missile, possibly the DF-21.[107] A massive cloud of large and small debris was ejected into popular LEO, GEO, and sun-synchronous orbits. China is the third country to successfully carry out a kinetic hit-to-kill intercept of a satellite. It demonstrates the country's advanced tracking, targeting, and precision guidance capabilities in space, as well as its ability to use those technologies for space negation purposes. In response to concerns expressed by many states, Chinese authorities maintain that the test was "not targeted at any country and will not threaten any country."[108] See The Space Environment Trend 1.1 and Space Laws, Policies, and Doctrines Trend 2.1 for further coverage.

2006: Chinese laser illuminates US satellites

In 2006 China reportedly used a ground-based laser to illuminate an American reconnaissance satellite flying over Chinese territory. The previously unreported incidents were acknowledged by the director of the National Reconnaissance Office, Donald Kerr, in October 2006. Details were not provided regarding the satellites involved or the number of incidents.[109] It is difficult to verify from publicly available sources the nature of the laser beam (power level, continuous versus pulsed, etc.), the physical effects on the spacecraft, or the intent behind the illumination.[110] Laser illumination at very low powers is used for satellite laser ranging as part of routine space surveillance. There is no international agreement prohibiting one state from using laser ranging on another state's satellites.[111] The laser did appear to have an effect on the satellites and the incidents were detected after operators noticed occasional and sudden declines in satellite performance when passing over China.[112]Gen. James Cartwright, Commander of US Strategic Command, denied that there is clear evidence of Chinese intentions to interfere with US space assets.[113] Nonetheless, the ability to illuminate satellites in orbit with a laser beam demonstrates Chinese advances in laser, satellite tracking, and optics technology. High power lasers could conceivably blind the sensitive optics in imagery satellites, although a case could be made that the laser system is only intended to prevent Chinese ground assets from being imaged. No official Chinese statements have been released.

2006: Progress on high energy lasers in the US and basic laser research in China

The US is developing a range of High Energy Laser (HEL) capabilities that are potentially capable of reaching space-based targets, seeking to make them more powerful and more accurate. In 2006, Northrop Grumman and Textron System were chosen by the US Army Space and Missile Defense Command to develop the third phase of a high-powered solid state laser system under the Joint High Power Solid State Laser (JHPSSL) program.[114] The contracts, valued at $56.68-million and $30-million respectively, call for the development and laboratory demonstration of a 100-kilowatt laser by 2009. Under a previous phase of the program, Northrop Grumman successfully tested a 27-kilowatt solid state laser for 350 seconds – 25 kilowatts for 300 seconds are the approximate requirements needed for heat-to-kill effects on satellites in LEO. Long-term goals of the program include "precision strike for airborne platforms."[115] Development of the US Airborne Laser Aircraft continued in 2006 with the successful testing of the megawatt-class Chemical Oxygen Iodine Laser and the integration of the beam control/fire control system and two solid state illuminator lasers onto a modified 747 aircraft.[116] The potential and limits of these programs for space-based applications are discussed in Space-Based Strike Systems Trend 8.2.

The US is also increasing the accuracy and range of its laser technology. In 2006 Northrop Grumman successfully demonstrated the continuously pulsed, solid state Strategic Illuminator Laser.[117] This illuminating laser can be used to enhance the precision of other laser systems by providing target tracking and improving beam quality through the atmosphere. In 2006

Boeing completed a $20-million contract with USAF to develop the Aerospace Relay Mirror System (ARMS), which is a half-scale prototype of a strategic mirror relay system.[118] Mirror relays can extend the range of lasers beyond line-of-sight. In the summer of 2006 a crane-mounted ARMS successfully relayed a sub-kilowatt beam from a ground laser to a target located two miles away.[119] The Air Force plans to use the hardware as a permanent test bed for laser relay technology development.

The ASAT implications of laser programs were highlighted in 2006 during the US budget process for FY2007. The initial DOD request included $5.7-million to test fire a laser at a satellite in LEO from the Starfire Optical Range.[120] These funds were denied by the House Armed Services Committee, which noted its applicability as an anti-satellite weapon and instructed that funds not be used to develop or demonstrate such capability. Funding for the test was later restored in conference with the Senate, after USAF officials provided background that denied any intent to test Starfire as an ASAT.[121] The Starfire program is only a fraction of total DOD spending on laser weapon technology,[122] but demonstrates the ongoing debate in the US about the potential negative repercussions of ASAT weapons and ongoing resistance to using them.

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. In 2006 research in China continued on atmospheric effects on laser propagation and laser Doppler radar for detecting space targets.[123] Laser communication in space and the damaging effects of high energy laser weapons on ballistic missiles were also studied.[124] Over 30 states continue to have foundational elements for developing laser ASAT such as high-powered lasers, high-quality optics, satellite tracking, and precision telescope pointing and tracking. As demonstrated by the 1997 MIRACL test, even low-powered lasers can damage satellites.

2006: North Korea attempts ballistic missile launch and nuclear test

North Korea attempted a test launch of its Taepodong-2 intercontinental ballistic missile (ICBM) in July 2006. The missile failed 42 seconds into its flight and crashed into the Sea of Japan.[125] The test was followed by five short-range missile tests and one medium-range test.[126] The Taepodong-2 missile is thought to be able to reach the continental United States with a small payload, and thus would have sub-orbital launch capability. In October North Korea attempted to detonate a plutonium implosion nuclear device.[127] The device appears to have fizzled, with the estimated yield less than one kiloton.[128] Air sample testing did confirm, however, that the explosion was nuclear and not simulated with conventional explosives, as some initially believed.[129] While North Korea is pursuing prerequisite technologies for a HAND device, there are no indications that the country is pursuing a discrete HAND capability.

Space security impact

Ongoing progress in the development of ground-based direct energy and kinetic-kill space negation technologies has a negative impact on space security. The demonstration of a Chinese ASAT highlights the many challenges posed by space negation capabilities to the secure and sustainable access to and use of space. These challenges include the creation of deadly space debris, the ability to permanently destroy another actor's space assets, the tensions and misperceptions that are generated, and the perceived gaps in an international legal framework that does not adequately manage these challenges. While direct energy (laser) ASAT technologies may limit the creation of space debris and provide temporary and reversible effects, many of the same challenges remain, as evidenced in the ongoing reticence of some US lawmakers to allow testing of these capabilities.

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

2006: US exploring potential space-based negation technologies with microsatellites in GEO

On 21 June 2006 a Delta II rocket launched a pair of Microsatellite Technology Experiments (MiTEx) satellites with an attached Naval Research Laboratory (NRL) upper-stage transfer motor into an unknown geostationary transfer orbit.[130] The MiTEx satellites are technology demonstrators for the Microsatellite Demonstration Science and Technology Experiment Program (MiDSTEP) sponsored by DARPA, the US Air Force and the US Navy.[131] A major goal of the MiTEx demonstrations is to assess the potential of small satellites in GEO for defense applications.[132] The MiDSTEP program, as described in the DARPA FY2007 budget estimate, integrates a variety of advanced technologies into microsatellites that can operate as high as GEO orbits. These technologies include lightweight optical space situation awareness sensors, lightweight power, chemical and electrical propulsion systems, and active radio frequency sensor technologies. The unclassified budget of $7-million dollars in FY2006 and a request for $8-million in FY2007 is modest;[133] however, this program could also be funded through classified accounts.

While there is little public information available to verify the intent of the MiDSTEP program, the stated technologies could have ASAT applications.[134] The experimental NRL upper-stage motor has solar panels, high performance delta-V motors, long lifetime attitude control thrusters, a high performance star tracker, and large capacity fuel tanks.[135] It is thought to possess greater capability and have a longer lifespan than is required to transfer a pair of microsatellites to GEO, and could potentially be designed to maneuver for close proximity operations with other satellites. Potential uses include passive reconnaissance missions or more hostile negation efforts to interfere with, or even damage satellites.[136] Moreover, these activities could be done discreetly, as currently only the US SSN can reliably detect the MiTEx satellites in GEO, given their small size. The known technology demonstrations are not very different from previous programs such as the XSS or DART, but much is unknown.[137]

2006: US DOD renews funding requests for potential space-based negation capabilities

The US MDA and USAF are seeking funding for several programs that could potentially yield space-based ASAT and strike capabilities.[138] MDA requested funding in the FY2007 budget for space programs that include the Space Based Interceptor Test Bed, the Near Field Infrared Experiment (NFIRE), and several small satellite programs that involve the development of distributed sensing and propulsion technologies and the use of microsatellites as practice targets for ballistic missile interceptors. These programs are discussed in further detail in the chapter on Space-Based Strike Systems, but they also have space negation applications.

USAF has requested funding for a follow-on XSS mission.[139] The FY2007 budget requested $26.6-million to complete the bus and payload for the next XSS satellite, to perform environmental testing, and to begin integration with the launch vehicle.[140] The XSS-11 spacecraft was launched in 2005 and continued to demonstrate proximity operations and autonomous rendezvous capabilities in low earth orbit (LEO) in 2006.[141] Like the MiTEx satellites, such technology could be used for passive reconnaissance missions or hostile negation efforts. The spacecraft was scheduled for de-orbit after depleting its fuel supply in 2006.

The capabilities described in this section are all in the early phase of development, and potential systems based on a combination of these capabilities are far from operational.

Space security impact

Developments in 2006 demonstrate the growing blur between space protection and space negation technologies and capabilities, particularly with advancements in space-based operations using low-cost, small, lightweight spacecraft. On the one hand, these capabilities can enhance actors' use of space by facilitating space-based surveillance for more accurate diagnoses of satellite malfunction or information-gathering on other, potentially hostile spacecraft. They can also support in-orbit satellite servicing to extend the lifespan of spacecraft and provide safer de-orbiting options. Conversely, the capabilities being developed by these microsatellite programs clearly have dual ASAT applications that can be used to disrupt, deny, or destroy other actors' space systems. Some space security experts fear that these programs could create space negation "facts in orbit." To date, however, the capabilities being tested are latent, as they have not been used for space negation purposes.

CHAPTER EIGHT

Space-Based Strike Systems

This chapter assesses trends and developments related to the research, development, testing, and deployment of space-based strike capabilities and systems. Space-based strike systems operate 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 strike capabilities, often referred to as anti-satellite (ASAT) weapons, are addressed in the Space Systems Negation chapter. Space systems that support Earth-based strike capabilities, such as reconnaissance satellites, are addressed in Space Support for Terrestrial Military Operations.

Mass-to-target strike systems collide with a target, damaging it through the combined mass and velocity impact of the weapon, or hit a target with inert or explosive devices. One mass-to-target 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 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 strike systems, 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 space-based strike system is the US Space-Based Laser (SBL) concept 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. The Missile Defense Agency (MDA) canceled the SBL program in 2000, although some work on the concept may be ongoing in the classified realm.[1]

While no space-based strike systems have yet been tested or deployed, the US and the former USSR devoted considerable resources to the development of key space-based strike 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 space-based strike programs, this chapter also assesses efforts of space actors to develop key technologies required for space-based strike capabilities, even if they are not being pursued for that purpose. It is generally accepted that only the most advanced space-faring states could overcome the technical hurdles to deploy effective space-based strike systems in the foreseeable future.

Space Security Impact

Space-based strike systems can have a direct impact on all aspects of space security. An actor with a space-based strike 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 strike systems may also be capable of attacking satellites, they could be used to restrict or deny the use of space assets.

The deployment of a space-based strike system 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.[2] It would 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 strike systems would most likely encourage the development of ASAT weapons and legitimize attacks on space assets in self-defense. Certain normative restrictions and moratoria upon such attacks could be undermined. For rapid response times, strike systems would have to be placed in low earth orbit, making them vulnerable to attack.[3] Further, the testing and deployment of ASAT systems in response to space-based strike installations could generate space debris, undermining the sustainable use of space for all actors over the longer term (see The Space Environment Trend 1.1).

Some have argued that space-based strike capabilities may be necessary to protect space systems from attack.[4] Indeed, the protection of satellites and the missile defense potential of space-based strike systems are two of the most commonly cited justifications for their development. As noted in Space Systems Negation, it has been argued that these systems could be used to protect the security of space assets against space negation attacks that might inflict long-term and disproportionate damage to the space environment or otherwise deny access to space.

Key Trends

TREND 8.1: While no space-based strike systems have been tested or deployed, the US is continuing the development of a space-based interceptor for its missile defense system

There have been no known integrated space-based strike systems tested or deployed.[5]

The most advanced space-based strike effort 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; it would de-orbit after flying only a fraction of one orbit, destroying an Earth-based target.[6] FOBS, as such, was not an space-based strike system, although it demonstrated capabilities that could be used in the development of an orbital bombardment system. A total of 24 launches, of which 17 were successful, were undertaken between 1965 and 1972 to develop and test the USSR FOBS system.[7] It was phased out in January 1983 to comply with the Strategic Arms Limitation Treaty II, under which deployment of FOBS was prohibited. It is not publicly known whether nuclear weapons were orbited through the FOBS efforts.

The US and USSR both pursued development of energy-to-target space-based strike 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), although the effort was ultimately unsuccessful and abandoned. The US also performed a Relay Mirror Experiment in 1990, which tested ground-based laser re-directing and pointing capabilities for the SBL.[8] 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.[9]

The USSR's neutral particle beam experiments were reportedly halted in 1985. The US SBL program was cancelled in 2000, and the SBL office closed in 2002.[10] Although indirect research and development continue through the US MDA, the technology for the SBL does not exist.[11] For example, over $120-million was allocated to Department of Defense (DOD) Directed Energy Programs in FY2003,[12] and other larger classified budgetary programs are suspected of continuing work on space-based directed energy technologies.[13]

Under SDI in the 1980s, the US invested several billion dollars in research and development of a space-based strike concept called Brilliant Pebbles. While the SDI never developed or deployed a fully operational system, the US did test some propulsion and targeting subsystems for Brilliant Pebbles. Research and development efforts in the US for space-based strike capabilities declined in the 1990s, but have been revived since 2000 through the SBI. SBI continues to be the most substantial space-based strike research and development program today. The current 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."[14] It has been succeeded by the US Air Force's Experimental Spacecraft System (XSS) with the objective to develop and demonstrate the capabilities of various microsatellite technologies, although the program has no direct relationship to MDA's SBI program (see Space Systems Negation Trend 7.4). The US Near-Field Infrared Experiment (NFIRE), scheduled for launch in 2007, is projected to include many of the key capabilities required for an SBI, including appropriate sensors, propulsion, and guidance units.[15] 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. This mission has been revised several times.[16] Under none of these revisions has the kill vehicle included the propulsion unit required for homing in on a missile, so it cannot be called an integrated space-based strike system. 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.[17]

Longer-term US plans include the deployment of an SBI testbed with initial experiments planned for 2010-2011.[18] While such a system would have limited operational utility, it could constitute the first deployment of a space-based strike system. A summary of completed and planned US space-based strike-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	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

Since its first appearance on the budget in FY2004 under the Ballistic Missile Defense Interceptor Program, the allocation for SBI has been scaled back financially and the timeline has been extended. The budget request in FY2004 was $14-million with initial tests scheduled for 2008. By FY2005 initial experiments had been pushed back to 2010-2011. The amount of funding requested has dropped sharply, from $1.5-billion for FY2003-2007 to $290-

million through FY 2013, but goals and timelines have remained stable in recent years.[19] The meaning of these budget cuts is not clear. It is possible that SBI is receiving more funds from classified accounts, or funding is being diverted to other classified programs. In any case, the program remains on the books and can be ramped up at any time.

While the development of an integrated space-based strike vehicle may be possible within years rather than decades, building a militarily effective strike system with global coverage remains a significant challenge. A truly global system would require hundreds or even thousands of vehicles in orbit, and thus a launch capacity about five to 10 times greater than the current US launch capacity.[20] An examination of the technical feasibility of such a system for missile defense, 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.[21] The US Congressional Budget Office estimated the full cost of a system with a similar coverage of the globe, but with the capability to intercept only liquid-fueled ballistic missiles with longer launch timelines, at between $27-billion and $40-billion. Such a system presumed considerable advances in kill vehicle components. Without these advances, coverage would cost between $56-billion and $78-billion.[22]

In summary, there have been no space-based strike systems tested or deployed to date, although Cold War-era 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 space-based strike programs, particularly 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 its completion remain.

TREND 8.2: A growing number of countries are developing an increasing number of advanced space-based strike enabling technologies through other civil, commercial, and military programs

Due to the potentially significant effects of space-based strike systems on space security dynamics, it is important to assess research into advanced enabling technologies that could support the development of space-based strike capabilities. The enabling technologies described below are dual-use. None are related to dedicated space-based strike programs, but are part of 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 space-based strike purposes, the dual-use applications of these advances do bring actors technologically closer to such a strike capability.

The advanced enabling technologies listed in Figure 8.2 are those required for each of the major space-based strike concepts over and above basic space access and use capabilities, such as orbital launch capability, satellite manufacturing, satellite telemetry, tracking and control, mission management, and Earth imaging. This analysis is based on the characteristics of these weapons systems as widely described in open source literature.[23]

Figure 8.2: Advanced SBSW enabling 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 aperture deployable optics					■	
Precision attitude control					■	■
Precision re-entry technology		■	■	■		
Nuclear weapons				■		

Key: ■ = Enabling capability

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 that 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 in 2007.[24] The Chinese manned spacecraft, the Shenzhou series, is also equipped with a docking mechanism.[25]

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 or de-orbit to reach the target is fundamental for several space-based strike 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 and suborbital space access.

Accurate *global positioning* capabilities required for all space-based strike concepts are possessed primarily by the US (GPS) and Russia (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 Trend 3.4). 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 the 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. India and Japan are also developing this capability.[26]

Relatively extensive *global missile warning and missile tracking* capabilities, required for the SBI and SBL concepts, were developed by the US and the USSR during the Cold War (see Space Systems Protection Trend 6.1). Early warning of missile launches is currently provided by the US Defense Support Program satellites and the Russian Oko and Prognoz satellites; both states are working on upgrades and/or replacements for these systems. The US Space Based Infrared System (SBIRS) and Space Tracking and Surveillance System are being designed to be more advanced in this regard, although both systems are behind schedule.[27] No other states currently have space-based early-warning capabilities, but France is developing two early-warning satellites, Spirale-1 and -2, to launch in 2008.[28]

Launch on demand capabilities to maintain an effective global space-based strike system are provided by rockets with an operational readiness of less than one week. Russia currently leads with the shortest average period between launches, but no state yet possesses a launch on demand capability. The US is developing a responsive launch capability through its Falcon program.[29] Some commercial actors, in particular Space-X, are aiming to provide more responsive and less expensive space launches (see Space Systems Protection Trend 6.4).[30] Although US concepts for a military space plane envision launch on demand capabilities, physical constraints would limit its utility.[31]

Microsatellite construction, which allows for reduced weight and increased responsiveness of space-based interceptors, is also a key enabling capability for an effective SBI system.

High-power laser systems envisioned 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, MIRACL, and Joint High Powered Solid State Laser (JHPSSL) programs (see Space Systems Negation Trend 7.3). None of those efforts have reached fruition due to continuing technical challenges. China has also operated a high-power laser program since 1986 and it now has multiple hundred-megawatt lasers.[32] The technology does not exist to build a high-power space-based laser.[33]

High-power generation systems for space, necessary for powering the SBL concept and for high thrust propellants for kinetic strike capabilities, have been developed and deployed both by the US and former Soviet Union, particularly through the use of nuclear power. For example, the US System for Nuclear Auxiliary Power-10A mission launched in 1965 had a 45-kilowatt thermonuclear reactor. NASA is working on several nuclear projects under Project Prometheus.[34] Between 1967 and 1988 the USSR launched 31 low-powered reactors in Radar Ocean Reconnaissance Satellites.[35] 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 and the latter applicable for all space-based strike concepts, 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.[36] 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.[37]

Precision re-entry technology, needed to prevent burn-up and lateral lift caused by atmospheric for kinetic space-to-Earth strike concepts has been developed by states with a human spaceflight capability, namely China, Russia, and the US. ESA has this capability under development with its Applied Re-entry Technology program and through the joint NASA-ESA Crew Return Vehicle (X-38).[38] France's Centre National d'Etudes Spatiales (CNES) has announced the development of a new re-entry vehicle program for civil space purposes.[39] In addition, the Japan Aerospace Exploration Agency has some experimental re-entry vehicle programs.[40] States with nuclear weapons have also developed precision re-entry technologies for their nuclear warhead re-entry vehicles. The capabilities needed for a rapid strike from space are more advanced, however, due to the higher speed at which re-entry would occur.[41]

Figure 8.4 provides a schematic overview of the space-based strike enabling technologies 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 space-based strike systems.

Figure 8.4: Space-based strike enabling technologies of key space actors[42]

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[43]	□	□			□	□	□	■	□	■
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 power	■		■	■	■	■	■	■	■	■
SBSW										
Space-based laser								(□)		(□)
Space-based interceptors								(□)		□
Hypervelocity rod bundle										
SB munitions delivery (conventional)										
Neutral particle beam								(□)		(□)

Key: ■ = Some capability[44] □ = Capability under development (□) = Past development (■) = Past capability

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

2006: Advances in US space-based interceptor programs but funding for tests temporarily blocked

The US Missile Defense Agency (MDA) has a new Space Applications Center of Excellence that "leads a multi-agency, Department of Defense (DoD) and industry team in developing, testing, and deploying space systems for the Missile Defense Agency (MDA)."[45] Its major programs include the Space Tracking and Surveillance System, Near Field Infrared Experiment (NFIRE), the Missile Defense Space Experimentation Center, and MDA space technology development including an eventual space-based testbed.[46]

In the FY2007 budget request MDA signaled its intention to move forward with the development of a Space Based Interceptor Test Bed by indicating that it would request $45-million (since reduced to $10-million) for FY2008 to develop space-based ballistic missile interceptors that would attack ballistic missiles in boost phase.[47] In May 2006, however, the Subcommittee on Strategic Forces banned the Pentagon from using certain funds for the development of anti-satellite capabilities and space-based interceptors due to concerns that enemy assets could be targeted and that such targeting would arouse international response.[48] The Pentagon must submit to Congress a detailed report on the project before funding can proceed, providing, inter alia, the following information: "1) a description of the system's essential components, and of its interaction with other missile defense systems; 2) acquisition and life-cycle cost estimates; 3) an analysis of its vulnerability to counter-measures such as other interceptors and nuclear detonations in space; and 4) an analysis of implication on foreign policy and national security, as well as probable responses from other countries."[49]

Despite these political obstacles, the technical capabilities for space-based interceptors advanced in 2006 with the successful demonstration of a prototype rocket for MDA's Multiple Kill Vehicle (MKV) Payload system.[50] It was tested on the Ground-based Midcourse Defense (GMD) interceptor on 1 September 2006 when the GMD successfully intercepted a missile launched from Alaska.[51] However, the program budget for FY2007 was considerably reduced in 2006 from $165-million to $100-million.[52] According to the MDA Deputy for Advanced Systems, Gary Payton, the MKV cannot be based in space as designed. Some of its components, however, could eventually be integrated into a space-based interceptor.[53]

Other moves were made to test space-based technologies that could potentially be integrated into a strike capability in the future. In the FY2007 budget, MDA requested funding for a new series of experiments under a Micro Sat project, which are possibly precursor programs to the Space Test Bed. "The three experiments based on maneuverable microsatellites will involve: 1) distributed sensing by two or three microsatellites; 2) a propulsion experiment believed to be the classified Microsatellite Propulsion Experiment (MPX) designed to test space-based interception technologies; and 3) a Target Risk-Reduction Experiment using a microsatellite as a target for ballistic missile interceptors."[54] The propulsion experiment will test the ability of the axial and divert propulsion system to maneuver a microsatellite to a specific point in space, as well as the survivability of the propulsion system after a dormant period. The Target Risk Reduction Experiment would use a microsatellite as a cooperative target to demonstrate the ability of an interceptor to track it. The distributed sensing experiment with three microsatellites is scheduled to be placed in orbit in early 2007.[55] Funding for the microsatellite programs is under the Ballistic Missile Defense Technology, Sensing Systems heading, which includes several other research programs for a total request of $207-million.[56]

The missile defense interceptor originally planned for the 2007 NFIRE test has been replaced by a German laser communications terminal.[57] The main purpose of the NFIRE satellite, scheduled for launch in the spring of 2007, is to distinguish between a missile body and its exhaust plume. This means that the sensors relate to a final homing stage. Because they are not designed to track missiles from afar, they are presumably designed for testing space-based missile defense interceptors. A fly-by missile test will be conducted during the first mission to verify the capability of the sensors. Revival of the interceptor is listed as justification for a second NFIRE mission in the FY2007 budget request "in response to congressional encouragement in the FY 06 Defense Appropriations bill to complete development of the Kill Vehicle."[58] However, MDA has repeatedly stated that it has no plans to revive it. MDA requested $10.8-million for overall NFIRE spending in FY2007.[59]

Space security impact

The ongoing absence of space-based strike weapons testing or deployment continued to bode well for space security in 2006. Restraint exercised by US policymakers in testing such capabilities is positive and indicates concern for space security and the challenge of balancing terrestrial missile defense requirements with the need to maintain freedom from space-based threats.

TREND 8.2: A growing number of countries are developing an increasing number of space-based strike enabling technologies through other civil, commercial, and military programs

2006: Testing of hypersonic vehicles in the US and Australia developing advanced enabling technologies for space-based strike

Although not designed for space-based strike capabilities, in the long-term hypersonic air/space vehicles are intended to provide "small, low cost and responsive space vehicles"[60] – a capability that could support a global space-based strike system. In the near term, research into hypersonic vehicles is developing some of the advanced enabling technologies needed to support space-based strike, particularly technologies for high-power, precision re-entry. For example, the joint US Defense Advanced Research Projects (DARPA)/Air Force Hypersonic Test Vehicle (HTV – formerly the Common Aero Vehicle/CAV)[61] of the Falcon program is working on a "thermal protection system...to withstand 3,000-degree temperatures and incredible exterior pressures, 25 times more than those experienced by the space shuttle".[62] The first HTV vehicle was initially scheduled for test flight in 2007 but was abandoned following technical difficulties. The Falcon project is now developing a second test vehicle (HTV-2) that is easier to produce.[63] The first test flight for the HTV-2 is scheduled for 2008. The realization of a reusable, hypersonic cruise vehicle remains a long-term goal.

Hypersonic propulsion research is being conducted by the US DARPA/Air Force X-51 Scramjet Wave-Rider hypersonic cruise missile.[64] In 2006, Pratt & Whitney Rocketdyne completed ground testing of the scramjet propulsion system at Mach 5; the first flight test, to be launched by a B-52 bomber, is scheduled for 2008.[65] Australia is also developing hypersonic air-breathing engines at the University of Queensland, under the HyShot program. Two scramjet engines were flight tested in 2001 and 2002, and there were three tests in 2006, one of which reached Mach 8.[66] The program is sponsored by research and defense institutions in Australia, the US, the UK, Japan, Germany, and South Korea.[67] The US Air Force Research Lab and the Australian Defence Science and Technology Organization signed an agreement on 10 November 2006 to collaborate on further hypersonic technology development through the Hypersonic International Flight Research Experimentation (HiFIRE) project, worth $54-million over six years.[68] There is no evidence that hypersonic vehicles are intended to serve as strike weapons from space – indeed, the CAV was renamed the HTV when weaponization concepts were dropped by the Falcon program. Of interest here are the advanced technologies associated with this research that could enable a space-based strike capability.

2006: Upgrades in US and Russian global missile tracking and warning

Missile tracking and warning capabilities are key components for some space-based strike concepts, particularly space-based ballistic missile defense. A number of countries are working towards establishing or improving these capabilities. USAF's missile early warning Space Based Infrared System (SBIRS) advanced slightly in 2006 as did the Space Tracking and Surveillance System, but both programs remain far behind originally planned schedules and are over budget. Due to persistent cost and time overruns of the SBIRS, the USAF also began to develop the Alternative Infrared Satellite System, which is intended to be simpler and cheaper to build. Russia announced plans to restore the space-based component of its missile attack warning system (MAWS), and has recently increased MAWS funding[69] (see Space Systems Protection Trend 6.1).

2006: The US, Europe, China, Russia, and India continue research and development of global positioning systems

A number of countries continued to develop, upgrade, or acquire access to global positioning systems in 2006 (see Civil Space Programs and Global Utilities Trend 3.4). Global positioning capabilities are required for all space-based strike concepts. In 2006, the US continued its program of modernizing its GPS.[70] Russia made plans to cooperate with China and India on GLONASS, which currently has 19 satellites in orbit.[71] India is developing a separate GAGAN civilian satellite augmenting navigation system, which passed a preliminary ground test in 2006, and is planning an independent Indian Regional Navigation Satellite System.[72] China continued work on its regional navigation system, the Beidou satellite series, which is to be used specifically for military purposes.[73] The first signals from the prototype satellite for the EU's Galileo system were received in January 2006 but the second prototype was delayed to 2007.[74]

2006: Advances in high energy laser technologies for missile defense

The Airborne Laser (ABL) made a comeback late in 2006 following earlier reports of technical problems related to its weight, beam strength, and optics, as well as cost and time overruns.[76] Nonetheless, the challenges to ABL are daunting and it remains unclear whether the system will ever come to fruition due to continuing problems with beam stabilization and the weight of the chemicals required to power it. The ABL would be a high-powered chemical laser mounted on a modified Boeing 747 jet, to be used as a direct energy interceptor for short-range ballistic missiles. A flight test of the illuminator laser is planned for 2007 and a boost phase missile intercept demonstration is forecasted for 2008.[77] The entire program has cost $3.5-billion to date.[78] In 2006 Northrop Grumman and Textron System were chosen by the US Army Space and Missile Defense Command to develop the third phase of the Joint High Power Solid State Laser (JHPSSL) program.[79] A long-term goal of the program is the development of "precision strike for airborne platforms."[80] Despite these advances in laser technologies for missile defense, "the technology does not currently exist to build a high-power space-based laser"[81] – even the ABL's range is limited to a few hundred kilometers. An overview of additional laser programs and their potential ground-based ASAT capabilities is provided in Space Systems Negation Trend 7.3.

Space security impact

Space-based systems 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 technologies that also provide enabling capabilities for space-based strike systems continued in 2006, but there was no evidence that states were developing such capabilities for strike purposes.

Space Security Working Group Meeting

Institute of Air and Space Law, McGill University
Montreal, Quebec
15-16 March 2007

Participants

Douglas Aldworth
Senior Policy Advisor, Department of Foreign Affairs and International Trade Canada

Marcel Arsenault
Board Chair, Secure World Foundation and Arsenault Family Foundation

Jean-Christian Brillant
Missiles and Export Controls Policy Officer, Non-Proliferation, Arms Control and Disarmament Division, Department of Foreign Affairs and International Trade Canada

Richard DalBello
Vice President Government Relations, Intelsat General Corporation

Paul Dempsey
Director, Institute of Air and Space Law, McGill University

Nancy Gallagher
Associate Director for Research, Center for International and Security Studies, University of Maryland

Tom Gillon
Senior Policy Office, Directorate of Arms and Proliferation Control Policy, Department of National Defence, Canada

Marty Hauser
Vice-President, Washington Operations, Research and Analysis, Space Foundation

Hong Yuan
Associate Professor, Center for Arms Control and Non-proliferation Studies, Institute of American Studies, Chinese Academy of Social Sciences

Bhupendra Jasani
Professor, Department of War Studies, King's College London

Ajey Lele
Fellow, Institute for Defence Studies and Analyses, India

Jeffrey Lewis
Director, Nuclear Strategy and Nonproliferation Initiative, New America Foundation

Scott Lofquist-Morgan
Researcher and Centre Administrator, Canadian Centre for Treaty Compliance

Jonathan McDowell
Associate, Center for Astrophysics, Harvard College Observatory

Philip Meek
Associate General Counsel (International Affairs), United States Air Force

Goetz Neuneck
Professor, Centre for Science and International Security, University of Hamburg, Germany

Isabelle Sourbes-Verger
Researcher, Centre National de la Recherche Scientifique/Deputy Director, Laboratoire Communication et Politique, France

Lucy Stojak
Consultant/International Space University Faculty Member

Michael Taylor
Chief, Space and International Law, United States Air Force Space Command

Peter Van Fenema
Adjunct Professor, Institute of Air and Space Law, McGill University

Spacesecurity.org Members

Maria Buzdugan
Research Coordinator, Spacesecurity.org

Cynda Collins Arsenault
President, Secure World Foundation and Arsenault Family Foundation

Martine De Serres
Researcher, Spacesecurity.org

Amb. Thomas Graham Jr.
Chairman of the Board, Cypress Fund for Peace and Security

Joseph Hillier
Researcher, Spacesecurity.org

Wade Huntley
Program Director, Simons Centre for Disarmament and Non-Proliferation Research, University of British Columbia

Ram Jakhu
Associate Professor, Institute of Air and Space Law, McGill University

William Marshall
Post-Doctoral Fellow, Space Policy Institute, George Washington University/Mission Planner, NASA-Ames Research Center

Yaw Nyampong
Researcher, Spacesecurity.org

Andrew Shore
Deputy Director, Non-Proliferation, Arms Control and Disarmament Division, Department of Foreign Affairs and International Trade Canada

John Siebert
Executive Director, Project Ploughshares

Karan Singh
Researcher, Spacesecurity.org

Susan Trepczynski
Researcher, Spacesecurity.org

Jessica West
Program Associate, Project Ploughshares

Brian Wong
Researcher, Spacesecurity.org

Observers

Jian Chang
Attaché, Chinese Embassy in Ottawa

Simone Garneau
Lowik Media

Caleb Halstead
Institute of Air and Space Law, McGill University

Brandon Hart
Institute of Air and Space Law, McGill University

Anna Jaikaran
People Against Weapons in Space

Robert Lefebvre
Canadian Space Agency

Bruno Legendre
Canadian Space Agency

Peggy Mason
Rideau Institute

Anthony Salloum
Rideau Institute and Secure World Foundation

Steve Staples
Rideau Institute

Ivan Vlasic
Institute of Air and Space Law, McGill University

ANNEX TWO: 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-22A	Chang Zheng 3A	China	Communications	GEO	12/09/2006
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
Zi Yuan 2	Chang Zheng 4B	China	Imaging	LEO	27/10/2002
Beidou 3	Chang Zheng 3A	Chin	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
France					
Syracuse 3A	Ariane 5GS	France	Communications	GEO	13/10/2005
Syracuse 3B	Ariane 5ECA	France	Communications	GEO	08/11/2006
Helios 2A	Ariane 5G+	France	Imaging	LEO	18/12/2004
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
Germany					
SAR-Lupe 1	Kosmos-11K65M	Russia	Imaging	LEO	12/19/2006
Israel					
Ofeq-5	Shaviyt 1	Israel	Imaging	LEO	28/05/2002
Italy					
Sicral	Ariane 44L	France	Communications	GEO	07/02/2001
Japan					
IGS Opitcal-2	H-IIA 202	Japan	Imaging	LEO	11/09/2006
IGS-1b	H-IIA 2024	Japan	Imaging	LEO	28/03/2003
IGS-1a	H-IIA 2024	Japan	Imaging	LEO	28/03/2003

Based on Jonathan McDowell's Satellite Database (1 January 2007). Due to the nature of some military satellites, it is not always known when a satellite changes its status from operational to no longer operational. This list only discounts satellites which are publicly known to be inactive and as such is likely to overestimate the number of active military satellites.

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Russia					
Meridian No. 1	Soyuz-2-1A	Russia	Communications	HEO	24/12/2006
Gonets-D1	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
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
Molniya-1T	Molniya 8K78M	Russia	Communication	HEO	18/02/2004
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
Kosmos-2371	Proton-K/DM-2	Russia	Communications	GEO	04/07/2000
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
Raduga	Proton-K/DM-2	Russia	Communications	GEO*	30/09/1993
Raduga	Proton-K/DM-2	Russia	Communications	GEO*	25/03/1993
Kosmos-2422	Molniya 8K78M	Russia	Early Warning	HEO	21/07/2006
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

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Kosmos-2368	Molniya 8K78M	Russia	Early Warning	HEO	27/12/1999
Kosmos-2423	Soyuz-U	Russia	Imaging	LEO	14/09/2006
Kosmos-2420	Soyuz-U	Russia	Imaging	LEO	03/05/2006
Kosmos-2392	Proton-K/17S40	Russia	Imaging	MEO	25/07/2002
Kosmos-2425	Proton-K/DM-2	Russia	Navigation	UKN	25/12/2006
Kosmos-2426	Proton-K/DM-2	Russia	Navigation	UKN	25/12/2006
Kosmos-2424	Proton-K/DM-2	Russia	Navigation	UKN	25/12/2006
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-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-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-2375	Proton-K/DM-2	Russia	Navigation	MEO	13/10/2000
Kosmos-2374	Proton-K/DM-2	Russia	Navigation	MEO	13/10/2000
Kosmos-2361	Kosmos 11K65M	Russia	Navigation	LEO	24/12/1998
Kosmos-2421	Tsiklon-2	Russia	Signals Intelligence	LEO	25/06/2006
Kosmos-2406	Zenit-2	Russia	Signals Intelligence	LEO	10/06/2004
Kosmos-2369	Zenit-2	Russia	Signals Intelligence	LEO	03/02/2000
Kosmos-2360	Zenit-2	Russia	Signals Intelligence	LEO	28/07/1998
South Korea					
Koreasat 5	Zenit-3SL	France	Communications	GEO	22/08/2006

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
Spain					
XTAR-EUR	Ariane 5ECA	France	Communications	HEO	12/02/2005
Spainsat	Ariane 5ECA	France	Communications	GEO	11/03/2006
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
US					
NMARS	Space Shuttle	US	Communications	LEO	10/12/2006
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-6	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
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
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

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
USA 113	Atlas IIA	US	Communications	UKN*	31/07/1995
UFO 5	Atlas II	US	Communications	GEO*	31/05/1995
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
DSCS III B-5	Space Shuttle	US	Communications	UKN**	03/10/1985
DSCS III B-4	Space Shuttle	US	Communications	UKN**	03/10/1985
LES 9	Titan IIIC	US	Communications	GEO**	15/03/1976
DSP F21 (USA 159)	Titan 402B/IUS	US	Early Warning	GEO	06/08/2001
DSP F20 (USA 149)	Titan 402B/IUS	US	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
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
Tacsat 2	Minotaur	US	Imaging	LEO	16/12/2006
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 404A	US	Imaging	LEO*	20/12/1996

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
USA 69	Titan 403A	US	Imaging	LEO**	08/03/1991
Navstar GPS IIR-M3	Delta 7925-9.5	US	Navigation	MEO	17/11/2006
Navstar GPS IIR-M2	Delta 7925-9.5	US	Navigation	HEO	25/09/2006
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 7925	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 40	Delta 7925	US	Navigation	MEO	16/07/1996
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

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
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 28	Delta 7925	US	Navigation	MEO*	10/04/1992
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
NNS O-23	Scout G-1	US	Navigation	LEO**	
NNS O-25	Scout G-1	US	Navigation	LEO**	
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 184	Delta 4M+(4,2)	US	Signals Intelligence	HEO	28/06/2006
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 121	Titan 403A	US	Signals Intelligence	LEO*	12/05/1996
USA 120	Titan 403A	US	Signals Intelligence	LEO*	12/05/1996
USA 119	Titan 403A	US	Signals Intelligence	LEO*	12/05/1996
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/Centaur	US	Signals Intelligence	UKN**	14/05/1995
USA 105	Titan 401A/Centaur	US	Signals Intelligence	UKN**	27/08/1994

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

Satellite name	Launch vehicle	Launching state	Function	Orbit	Launch date
USA 103	Titan 401A/Centaur	US	Signals Intelligence	HEO*	03/05/1994
USA 81	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
ANDE-FCAL	Space Shuttle	US	Calibration	LEO	10/12/2006
RAFT1	Space Shuttle	US	Calibration	LEO	10/12/2006
RADCAL	Scout G-1	US	Calibration	LEO*	25/06/1993
DMSP 5D-3 F-17 (USA 191)	Delta 4M	US	Meteorology	LEO	04/11/2006
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
ANDE-MAA	Space Shuttle	US	Science	UKN	10/12/2006
MTI	Taurus 1110	US	Science	LEO	12/03/2000
USA 193	Delta 7920-10C	US	Technology	LEO	14/12/2006
MEPSI 2A/2B	Space Shuttle	US	Technology	LEO	10/12/2006
USA 189	Delta 7925-9.5	US	Technology	GEO	21/06/2006
USA 188	Delta 7925-9.5	US	Technology	GEO	21/06/2006
USA 187	Delta 7925-9.5	US	Technology	GEO	21/06/2006
XSS-11 (USA 165)	Minotaur	US	Technology	LEO	11/04/2005
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
STEP M0	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" (1994), online: Friends and Partners in Space <http://www.friends-partners.org/oldfriends/jgreen/bispaper.html> (date accessed: 24 April 2007).

2 Brad Thomas, "STS 121", Space Center Roundup, Lyndon B. Johnson Space Center (April 2006) at 8, online: NASA Johnson Space Center <http://www.jsc.nasa.gov/roundup/online/2006/0406_p8_11.pdf> (date accessed: 24 April 2007).

3 US Strategic Command Public Affairs, Offutt Air Force Base, Fact sheet, "Space Control: Reentry Assessment and Space Surveillance" (March 2004); D. Mehrholz, L. Leushacke, W. Flury, R. Jehn. H. Klinkrad. M. Landgraf, "Detecting, Tracking and Imaging Space Debris" (February 2002) 109 *ESA Bulletin* at 128; Jonathan McDowell's Satellite Database, online: Jonathan's Space Report <http://www.planet4589.org/jsr.html> (date accessed: 24 April 2007).

4 8 *Orbital Debris Quarterly News* (2004) at 5.

5 10(2) *Orbital Debris Quarterly News* (2006) at 1-2.

6 William J. Broad, "Orbiting Junk, Once a Nuisance, Is Now a Threat," *New York Times* (6 February 2007), online: nytimes.com <http://www.nytimes.com/2007/02/06/science/space/06orbi.html?ei=5070&en=52e4fd924f69b8b9&ex=1179374400&pagewanted=print> (date accessed: 15 May 2007).

7 D. Mehrholz, L. Leushacke, W. Flury, R. Jehn. H. Klinkrad. M. Landgraf, "Detecting, Tracking and Imaging Space Debris" (February 2002) 109 *ESA Bulletin* at 128.

8 Jeremy Singer, "Space-Based Missile Interceptors Could Pose Debris Threat" *Space News* (13 September 2004).

9 US National Research Council, *Orbital Debris: A Technical Assessment* (Washington, DC: National Academy Press, 1995) at 4-5, online: The National Academies Press <http://books.nap.edu/books/0309051258/html/index.html> (date accessed: 24 April 2007).

10 Center for Orbital and Reentry Debris Studies, Fact Sheet, "Space Debris Basics: What Are the Risks?", online: The Aerospace Corporation <http://www.aero.org/capabilities/cords/debris-risks.html> (date accessed: 24 April 2007).

11 "Monthly Number of Catalogued Objects in Earth Orbit by Object Type" (January 2007) 11 *Orbital Debris Quarterly News* at 8.

12 NASA Orbital Debris Program Office, Orbital Debris, Photo Gallery, online: <http://orbitaldebris.jsc.nasa.gov/photogallery/photogallery.html> (date accessed: 24 April 2007).

13 Orbital Debris at 4.

14 Orbital Debris at 4.

15 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).

16 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) at A14; (4) Michael Katz-Hyman, "The Death of the Solwind Satellite", Henry L. Stimson Center, Space Security Briefs (14 July 2005), online: The Henry L. Stimson Center <http://www.stimson.org/?SN=WS20050714867> (date accessed: 24 April 2007).; (5) Phillip S. Clark, "Space Debris Incidents Involving Soviet/Russian Launches" (1994), online: Friends and Partners in Space <http://www.friends-partners.org/oldfriends/jgreen/bispaper.html>

(date accessed: 24 April 2007); D S McKnight, “Determining the Cause of a Satellite Breakup: A Case Study of the Kosmos 1975 Breakup” *Aviation Week & Space Technology* (9 March 1992) at 19; David J Nauer, History of On-Orbit Satellite Fragmentations (Colorado Springs, CO.: Teledyne Brown Engineering, 1993) at 154; (5) Kenneth Silber, “Space Junk Piles High” *Insight on the News* (18 November 1996).

17 Space Debris Mitigation Guidelines at the UN” (July 2005) *Orbital Debris Quarterly News* 9 at 1.

18 Peter de Selding, “FCC Enter Orbital Debris Debate” *Space News* (28 June 2004). “Mitigation of Orbital Debris” 70 *Federal Register* (12 October 2005) at 59276.

19 *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: European Space Agency <http://www.esrin.esa.it/gsp/completed/execsum00_N06.pdf> (date accessed: 24 April 2007).

20 “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: European Space Agency <gate.etamax.de/NoCDebris/Publications/Alby%20et%20al-ANAE-2002.pdf> (date accessed: 24 April 2007).

21 United Nations Committee on the Peaceful Uses of Outer Space, 511th Meeting, Unedited transcripts (17 June 2003) at 5, online: United Nations Office for Outer Space Affairs <http://www.oosa.unvienna.org/Reports/transcripts/copuos/2003/COPUOS_T511E.doc> (date accessed: 24 April 2007).

22 Inter-Agency Space Debris Coordination Committee, “Support to the IADC Space Debris Mitigation Guidelines” (5 October 2004) at 3, 13, online: Inter-Agency Space Debris Coordination Committee <http://www.iadconline.org/docs_pub/IADC.SD.AI20.3.10.2004.pdf> (date accessed: 24 April 2007).

23 “Support to the IADC Space Debris Mitigation Guidelines” at 3, 13.

24 NASA Orbital Debris Program Office, “Orbital Debris Graphics”, online: NASA Orbital Debris Program Offic <http://www.orbitaldebris.jsc.nasa.gov/photogallery/beehives.html> (date accessed: 24 April 2007).

25 Inter-Agency Space Debris Coordination Committee, “Protection Manual Version 3.3” (April 2004), online: Inter-Agency Space Debris Coordination Committee <http://www.iadc-online.org/index.cgi?item=docs_pub> (date accessed: 24 April 2007).

26 American Institute of Aeronautics and Astronautics, “New FCC Orbital Debris Ruling: ISO TC20/SC14 to Develop Standard for Orbital Debris Mitigation” (6 June 2004), online: American Institute of Aeronautics and Astronautics <http://intranet.aiaa.org/industryresources/PDF/FCCSATRulingPR.pdf> (date accessed: 24 April 2007).

27 “Electrodynamic Tethers: Clean Up Debris - Power or Boost Spacecraft” Technovelgy.com (11 May 2004), online: Technovelgy < http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=252> (date accessed: 24 April 2007); “The Terminator Tether Aims to Clean up Low Earth Orbit” Technovelgy.com (5 November 2004), online: Technovelgy <http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=252> (date accessed: 24 April 2007); “Terminator Tether - EDT Solution To Space Debris Update” Technovelgy.com (17 November 2004), online: <http://technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=264> (date accessed: 24 April 2007); Orbital Recovery Ltd., Orbital Recovery Fact sheet, online: Orbital Recovery Ltd. <http://www.orbitalrecovery.com/images/fact_sheet_v1_5.pdf> (date accessed: 24 April 2007); Tariq Malik, “Orbital Assistance: ConeXpress Spacecraft Could Extend Satellite Missions” Space.com (2 June 2004), online: Space.com <http://www.space.com/businesstechnology/technology/conexpress_techwed_040602.html> (date accessed: 24 April 2007); Gunter Dirk Krebs, “ConeXpress-OLEV (CX-OLEV),” online: Gunter’s Space Page <http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/conexpress-ors.htm> (date accessed: 24 April 2007)..

28 Federation of American Scientists, Joint Data Exchange Center (JDEC), <http://www.fas.org/nuke/control/jdec/index.html> (date accessed: 24 April 2007).

29 "Improving Our Vision: Approaches for Shared Space Situational Awareness," Report of the Sept. 15-16, 2006 Conference, The Antlers Hotel, Colorado Springs, Colo., The World Security Institute's Center for Defense Information and The U.S. Air Force Academy's Center for Space and Defense Studies, (2007) at 10.

30 Peterson Air Force Base, 20th Space Control Squadron, Detachment 1, Fact Sheet, online: Peterson Air Force Base <www.peterson.af.mil/library/factsheets/factsheet.asp?id=4729> (date accessed: 24 April 2007).

31 "National Defense Authorization Act for Fiscal Year 2004," 117 Stat. 1565 Public Law 108–136-24 (November 2003), online: CelesTrack <http://www.celestrak.com/Norad/elements/Section913.pdf> (date accessed: 24 April 2007).

32 Bruce deBlois, Richard Garwin, Scott Kemp, and Jeremy Marwell, "Space Weapons Crossing the US Rubicon" (Fall 2004) 29 International Security 29 at 50-84; Jeremy Singer, "Surveillance Remains Most Pressing Space Control Need" *Space News* (11 October 2004).

33 DARPA, Tactical Technology Office, "Deep View" (5 October 2004), online: DARPA <http://www.darpa.mil/tto/> (date accessed: 24 April 2007). RDT&E Budget Item Justification Sheet, (February 2007), at 256, online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2008/DARPA/0603287E.pdf> (date accessed: 17 May 2007).

34 DARPA, Tactical Technology Office, "Space Surveillance Telescope" (5 October 2004), online: <http://www.darpa.mil/tto/> (date accessed: 24 April 2007). RDT&E Budget Item Justification Sheet (February 2007), at 253.

35 John A. Tirpak, "Securing the Space Arena" 87(7) *Air Force Magazine* (July 2004), online: Air Force Magazine online <http://www.afa.org/magazine/July2004/0704space.asp> (date accessed: 24 April 2007).

36 "The SSS Space Surveillance System," Jane's Space Directory (23 December 2003). Center for Defense Information, "Improving Our Vision," at 10.

37 Sourcebook on the Okno Space Surveillance Site, Version of 28 September 2006, online: Federation of American Scientists <http://www.fas.org/spp/military/program/track/okno.pdf> (date accessed: 24 April 2007).

38 "The SSS Space Surveillance System.".

39 "The SSS Space Surveillance System.."

40 Pavel Podvig, "Strategic Defense," (May 2006), online: Russian Strategic Forces <http://russianforces.org/eng/defense/> (date accessed: 24 April 2007).

41 ONERA, "GRAVES Space Surveillance System" (2003), online: ONERA <http://www.onera.fr/photos-en/instexp/graves.php> (date accessed: 24 April 2007).

42 GlobalSecurity.org, "German Space Agencies," online: GlobalSecurity.org <http://www.globalsecurity.org/space/world/germany/agency.htm#ref21> (date accessed: 24 April 2007); 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) at 7, online: UN Office for Outer Space Affairs <http://www.oosa.unvienna.org/COPUOS/stsc/2004/presentations/flury2.ppt> (date accessed: 24 April 2007).

43 Walter Flury et al. "Searching for Small Debris in the Geostationary Ring – Discoveries with the Zeiss 1-metre Telescope" 104 *ESA Bulletin* (November 2000), online: European Space Agency <http://www.esa.int/esapub/bulletin/bullet104/flury104.pdf> (date accessed: 24 April 2007).

44 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: Federation of American Scientists <http://www.fas.org/spp/military/program/track/klinkrad.pdf> (date accessed: 24 April 2007).

45 European Space Agency, “Spacecraft Operations, Space Debris Avoidance”, online: European Space Agency <http://www.esa.int/spacecraftops/ESOC-Article-fullArticle_idBanner-1092735449782_item_selected-19_5_00_par-47_1091629030048.html> (date accessed: 24 April 2007).

46 European Commission, Press Release, “Space Researchers Respond to EU Security Initiative” (22 April 2004), online: Europa, European Commission <http://europa.eu.int/comm/space/news/article_914_en.html> (date accessed: 24 April 2007); European Commission, Press Release, “Research Commissioner Convenes ‘Panel of Experts on Space and Security’” (15 June 2004), online: Europa, European Commission <http://europa.eu.int/comm/space/news/article_1224_en.html> (date accessed: 24 April 2007).

47 “China Reports Progress in Space Debris Research,” Xinhua (14 August 2003) online: Xinhuanet English <http://news.xinhuanet.com/english/2003-08/14/content_1113433.htm> (date accessed: 24 April 2007).

48 “Alarm System Warns of Space Debris” *China Daily* (11 August 2003).

49 “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).

50 Globalsecurity.org, “Chinese Space Facilities” (last modified 19 October 2005), online: Globalsecurity.org <http://www.globalsecurity.org/space/world/china/facility.htm> (date accessed: 24 April 2007).

51 “Space Debris Radar Station Operational” *Japan Times* (9 April 2004).

52 IADC Observation Campaigns, Inter-Agency Space Debris Coordination Committee presentation to 43rd Session of COPUOS Science and Technology Sub-Committee (February 2006), online: Inter-Agency Space Debris Coordination Committee <http://www.iadc-online.org/docs_pub/UN_Presentation_2006_final.pdf> (date accessed: 24 April 2007).

53 University of British Columbia, “MOST, Canada’s First Space Telescope” online: Astronomy at the University of British Columbia <http://www.astro.ubc.ca/MOST/milestones.html> (date accessed: 24 April 2007).

54 “Canada Considers Military Microsatellites” *Space News* (1 September 2003).

55 Harvey et al. (2006).

56 Tim Bonds et al., *Employing Commercial Satellite Communications: Wideband Investment Options for DoD* (Santa Monica, CA: RAND Corporation, 2000) at 17, online: RAND Corporation <http://www.rand.org/publications/MR/MR1192/> (date accessed: 24 April 2007).

57 Michael Calabrese and J.H. Snider, “Up in the Air” *Atlantic Monthly* (September 2003) at 46-47; Albert “Buzz” Merill and Marsha Weiskopf, “Critical Issues in Spectrum Management for Defense Space Systems” Crosslink (Winter 2002) at 14-19, online: Aerospace Corporation http://www.aero.org/publications/crosslink/winter2002/02.html (date accessed: 24 April 2007).

58 Merill and Weiskopf at 18.

59 Philip McAlister, “Follow the Money: Satellite Opportunities with the US Government” (17 November 2003), online: Futron Corporation <http://www.futron.com/pdf/sat%20oppor%20with%20us%20govt.pdf> (date accessed: 24 April 2007).

60 Glen Elfers and Stephen B. Miller, “Future US Military Satellite Communication Systems” Crosslink (Winter 2002), online: Aerospace Corporation <http://www.aero.org/publications/crosslink/winter2002/08.html> (date accessed: 24 April 2007).

61 "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." MILSATCOM, "Defense Satellite Communications System," online: Air Force Link <http://www.af.mil/factsheets/factsheet.asp?id=95> (date accessed: 24 April 2007).

62 Theresa Hitchens, *Future Security in Space: Charting a Cooperative Course* (Washington, DC: Center for Defense Information, September 2004) at 49.

63 Hitchens, at 49.

64 John C. Tanner, "SPACE JAM: Fighting Satellite Interference from the Ground up" Telecom Asia (1 November 2003) at 16-22, online: Look Smart, Find Articles <http://findarticles.com/p/articles/mi_m0FGI/is_11_14/ai_111694639> (date accessed: 24 April 2007).

65 Tanner.

66 Jefferson Morris, "Spectrum Plan Would Require Relocation of Defense Department Users by 2008" Aerospace Daily (24 July 2002).

67 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Plenipotentiary Conference* (Marrakesh, 2002).For an excellent description of the role of ITU see Francis Lyall, "Communications Regulations: The Role of the International Telecommunication Union" (1997) 3 Journal of Law and Technology, online: The University of Warwick <http://www2.warwick.ac.uk/fac/soc/law/elj/jilt/1997_3/lyall/> (date accessed: 24 April 2007).

68 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Plenipotentiary Conference* (Marrakesh, 2002), Art. 45 para. 197.

69 Merill and Weiskopf, at 15.

70 Merill and Weiskopf, at 16.

71 European Commission, Press Release, "EU and US a Step Further to Agreement over Galileo satellite Navigation" (25 February 2004), online: <http://www.eurunion.org/news/press/2004/20040030.htm> (date accessed: 24 April 2007).

72 Maricel E. Estavillo, "ASEAN to Harmonize Radio Frequency Spectrum" *BusinessWorld* (4 October 2005). European Commission Communication to the Council and European Parliament, *A Forward Looking Radio Spectrum Policy for the European Union: Second Annual Report*, document COM (2005) 411 final (June 2005), online: European Union <http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/com/2005/com2005_0411en01.pdf> (date accessed: 24 April 2007).

73 This figure is an estimate based on Jonathan's Satellite Catalogue. This is a catalogue of all satellites which includes a column on the satellite status which is updated when a satellite re-enters the Earth's atmosphere or when publicly available information shows that a satellite is no longer operational. The catalogue figure for the number of operational satellites in most cases is an over-estimate since it sometimes takes several years to become public knowledge that a satellite is no longer in operation. The following method is used to estimated the range given: of those satellites shown as operational in the catalogue (1) for the upper estimate, those that are over 15 years old as of the end of 2006 are assumed to be non-operational; and (2) for the lower estimate, those that are over 15 years old as of the end of 2006 and 1/3 of those that are over 10 years old are assumed to be non-operational. This age cut of is both realistic from the point of view of approximate statistics of satellite longevity and also because satellites of such age are often insignificant in capability compared to that of the current system. More importantly, the method of estimation seems to fit with the data points known on active GPS satellites. A clear limitation to this approximation is that such approximations should vary according to the longevity and capabilities of different types, rather than the blanket assumption made here.

74 Joel D. Scheraga, “Establishing Property Rights in Outer Space” (1987) 6 Cato Journal at 891.

75 International Telecommunication Union, *Constitution and Convention of the International Telecommunication Union: Final Acts of the Additional Plenipotentiary Conference*, 1993, Art. 33 (2).

76 Col. John E. Hyten, USAF, “A Sea of Peace or a Theater of War? Dealing with the Inevitable Conflict in Space” (Fall 2002) 16 Air and Space Power Journal at 90, note 11.

77 Scheraga, at 891.

78 US Federal Communications Commission, “DBS Spacing”, online: Federal Communications Commission <http://www.fcc.gov/ib/sd/dbs_spacing/> (date accessed: 24 April 2007).

79 Scheraga, at 892.

80 Tim Bonds et al., *Employing Commercial Satellite Communications: Wideband Investment Options for DoD* (Santa Monica, CA: RAND Corporation, 2000) at 17, online: RAND Corporation <http://www.rand.org/publications/MR/MR1192/> (date accessed: 24 April 2007).

81 Theresa Foley, “The World’s Hottest Real Estate: Orbital Slots Are Prime Property” Via Satellite (10 September 2001).

82 Liching Sung, “ITU’s Cost recovery: The Satellite Factor” Via Satellite (1 September 2004); see also International Telecommunications Union, “Ad Hoc Group on Cost Recovery for Satellite Network Filings,” online: International Telecommunications Union <http://www.itu.int/council/adhoc-snf/> (date accessed: 24 April 2007).

83 These dates are provided in Michael R. Gordon and David S. Cloud, “US Knew of China’s Missile Test, But Kept Silent,” *New York Times*, (23 April 2007), at 1.

84 CelesTrak (6 April 2007), online: CelesTrack <http://celestrak.com/events/asat.asp> (date accessed: 23 April 2007).

85 Frank Morring, Jr., “China ASAT Test Called Worst Single Debris Event Ever” *Aviation Week and Space Technology* (11 February 2007), online: Aviation Week <www.aviationweek.com/aw/generic/story.jsp?id=news/aw021207p2.xml> (date accessed: 24 April 2007). David Wright, “Debris from China’s Kinetic Energy ASAT Test,” (23 March 2007), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/debris-from-chinas-asat-test.html> (date accessed: 15 May 2007).

86 David Wright, Union of Concerned Scientists.

87 Large and medium sized objects refer to objects over 10 centimeters in diameter. NASA Orbital Debris Program Office, 10(1) *Orbital Debris Quarterly News* (January 2006) at 7, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007).

88 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 200,000 objects.

89 “Significant Increase of Satellite Breakups During 2006” 11 (1) *Orbital Debris Quarterly News* (January 2007) at 2, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i1.pdf> (date accessed: 11 April 2007).

90 “First Satellite Breakups of 2006” 10 (3) *Orbital Debris Quarterly News* (July 2006) at 1, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007); “Three More Satellites Involved in Fragmentations” 10(4) *Orbital Debris Quarterly News* (October 2006) at 1, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007); “Significant Increase of Satellite Breakups During 2006” 11 (1) *Orbital Debris Quarterly News*

(January 2007) at 2, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i1.pdf> (date accessed: 11 April 2007).

91 “First Satellite Breakups of 2006” 10 (3) *Orbital Debris Quarterly News* (July 2006) at 1, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007);

92 Comparison of “Orbital Box Score” data from NASA Orbital Debris Program Office, 10(1) *Orbital Debris Quarterly News* (January 2006) at 7 to 10(4) *Orbital Debris Quarterly News* (January 2007) at 9, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007).

93 Kelly Young, “Astronauts to Pitch Unwanted Gear off Space Station”, NewScientist.com (10 November 2006), online: New Scientist Space <http://space.newscientist.com/article/dn10512-astronauts-to-pitch-unwant> (date accessed: 8 February 2007); “The New Jettison Policy for the International Space Station” 10(3) *Orbital Debris Quarterly News* (July 2006) at 6, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007).

94 J.-C. Liou, N. L. Johnson, “Risks in Space from Orbiting Debris” 311 *Science* (20 January 2006) at 340.

95 NASA, “Space Transportation with a Twist”, online: NASA <http://www.nasa.gov/vision/universe/roboticexplorers/tethered_spacecraft.html> (date accessed: 8 February 2007).

96 “Progress in Space Tether Sever Modeling,” 9(4) *Orbital Debris Quarterly News* (October 2005) at 4, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007); Carmen Pardini, Toshiya Hanada, Paula H. Krisko, “Benefits and Risks of Using Electrodynamic Tethers to De-Orbit Spacecraft”, IAC-06-B6.2.10, online: Inter-Agency Space Debris Coordination Committee <http://www.iadc-online.org/index.cgi?item=docs_pub> (date accessed: 8 February 2007).

97 Carmen Pardini, Toshiya Hanada, Paula H. Krisko, “Benefits and Risks of Using Electrodynamic Tethers to De-Orbit Spacecraft”, IAC-06-B6.2.10, online: Inter-Agency Space Debris Coordination Committee <http://www.iadc-online.org/index.cgi?item=docs_pub> (date accessed: 8 February 2007).

98 “Large Area Debris Collector (LAD-C) Update” 10 (1) *Orbital Debris Quarterly News* (January 2006) at 2, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007); “ISS Large Are Debris Collector (LAD-C) Update” 10(3) *Orbital Debris Quarterly News* (July 2006) at 2, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007); “LAD-C – A Large Area Debris Collector on the ISS” 10(3) *Orbital Debris Quarterly News* (July 2006) at 6, online: *Orbital Debris Quarterly News* <http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007).

99 *United States National Space Policy, Unclassified* (31 August 2006), online: Executive Office of the President, Office of Science and Technology Policy <www.ostp.gov/html/US%20National%20Space%20Policy.pdf> (date accessed: 8 February 2007).

100 *China's Space Activities in 2006*, People's Daily Online (12 October 2006), online: People's Daily <http://english.people.com.cn/200610/12/eng20061012_311157.html> (date accessed: 8 February 2007).

101 Report of the Committee on the Peaceful Uses of Outer Space, United Nations General Assembly, Sixty-fist session, Supplement No. 20 (UN Doc. A/61/20), paras. 121 to 130; “Draft United Nations Space Debris Mitigation Guidelines” 10(2) Orbital Debris News Quarterly (April 2006) at 2, online: *Orbital Debris Quarterly News* < http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html> (date accessed: 8 February 2007).

102 Caitlin Harrington and Tony Skinner, “Next-Generation Satellites Move into Next Phase” *Jane's Defense Weekly* (16 August 2006) at 8.

103 John Liang, “Pentagon Cuts Space Fence Funding,” *InsideDefense.com NewsStand* (23 December 2006), online: Military.com < http://www.military.com/features/0,15240,121142,00.html> (date accessed: 16 May 2007).

104 Boeing, News Release, “Boeing Completes Key Risk Reduction Milestone for Space Surveillance System” (29 September 2006), online: Boeing <http://www.boeing.com/news/releases/2006/q3/060929b_nr.html> (date accessed: 8 February 2007).John A. Tirpak, “Space and Counterspace, *Air Force Magazine* Vol. 89, No. 6 (June 2006).

105 Jeremy Singer, “Briefs – Pentagon Cancels Funds For Deep Space Imager,” *Space News* (20 February 2006).

106 David Pugliese “Canada to Use Commercial Sats for Mission Imagery” Defense News (6 February 2006) at 19.

107 “Improving Our Vision: Approaches for Shared Space Situational Awareness,” Report of the Sept. 15-16, 2006 Conference, The Antlers Hotel, Colorado Springs, Colo., The World Security Institute’s Center for Defense Information and The U.S. Air Force Academy’s Center for Space and Defense Studies, (2007), at 13.

108 “Russia Plans to Improve Outer Space Monitoring Capabilities”, RIA, Novisti (9 November 2006), online: Space Daily <http://www.spacedaily.com/reports/Russia_Plans_To_Improve_Outer_Space_Monitoring_Capabilities_999.html> (date accessed: 8 February 2007).

109 “Improving our Vision” at 11.

110 Peter B. De Selding, “ESA Places Priority on Space Surveillance” DefenseNews.com (27 March 2006), online: DefenseNews.com <http://www.defensenews.com/story.php?F=1639067&C=airwar> (date accessed: 8 February 2007).

111 “Imminent Delivery of the French Surveillance System,” France ST Special Reports 75 (24 August 2005), online: France-Israel Teamwork in Science <http://www.fitscience.org/media/upload/FranceST_075.pdf> (date accessed: 8 February 2007); “Graves Le système français de surveillance de l’espace” Onera (4 May 2006), online: Onera <http://www.onera.fr/dprs/graves/index.php> (date accessed: 8 February 2007); Federation of American Scientists, “A GRAVES Sourcebook” (29 October 2006), online: FAS <http://www.fas.org/spp/military/program/track/graves.pdf> (date accessed: 8 February 2007).

112 Jacques Bouchard as quoted in “Imminent Delivery of the French Surveillance System,” France ST Special Reports 75 (24 August 2005), online: France-Israel Teamwork in Science <http://www.fitscience.org/media/upload/FranceST_075.pdf> (date accessed: 8 February 2007); “Graves Le système français de surveillance de l’espace” Onera (4 May 2006), online: Onera <http://www.onera.fr/dprs/graves/index.php> (date accessed: 8 February 2007)

113 “Successful Trial for BNSC-funded Space Surveillance Project”, Spacewar (9 November 2006), online: Spacewar <http://www.spacewar.com/reports/Successful_Trial_For_BNSC_funded_Space_Surveillance_Project_999.html> (date accessed: 8 February 2007).

114 Satellite Users Interference Reduction Group, “Interference Matrix Database”, online: SUIRG <http://www.suirg.org/interference/report_display.php> (date accessed: 8 February 2007).

115 Virgil Labador, “Top Stories of 2006” 4(8) Satmagazine.com (December 2006) at 20.

116 “Integral Satcom Initiative Holds Launch Meeting”, European Commission Space News and Features (16 February 2006), online: European Commission <http://ec.europa.eu/comm/space/news/article_3847_en.html> (date accessed: 8 February 2007).

117 Peter B. de Selding, “Europeans Raise Red Flags Over Chinese Satellite Navigation Plan” Space News (12 June 2006).

118 “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.” US Air Force, “Defense Satellite Communications

System, Fact Sheet”, online: < http://www.af.mil/factsheets/factsheet.asp?id=95> (date accessed: 24 April 2007).

119 Caitlin Harrington and Tony Skinner, “Next-Generation Satellites Move into Next Phase” *Jane's Defense Weekly* (16 August 2006) at 28.

120 Stephen Clark, “Kazakhstan Reaches Space in First Satellite Launch”, Spaceflight Now (19 June 2006), online: SPACE.com <http://www.space.com/missionlaunches/sfn_060619_proton _kazak1.html> (date accessed: 8 February 2007). This number includes Taiwan, Singapore, Greece and Cyprus as separate states.

121 “Vietnam's First Telecom Satellite to Blast Off” Space Daily (20 June 2006), online: Space News from SpaceDaily.com <http://www.spacedaily.com/2006/060620094018.oklz0kci.html> (date accessed: 8 February 2007).

122 Pham Le, “Satellite Project Picks up Speed” *Saigon Times Weekly* (12 November 2005).

123 “EchoStar Satellite L.L.C. Application to Conduct, Launch, and Operate a Direct Broadcast Satellite at the 86.5o W.L. Orbital Location”, FCC File No. SAT-LOA-20030609-00113 (29 November 2006).

124 “EchoStar Satellite L.L.C. Application,” at 6.

Chapter Two Endnotes

1 *Charter of the United Nations*, 26 June 1945, Can. T.S. 1945 No. 7, 59 Stat. 1031, 145 U.K.T.S. 805, 24 U.S.T. 2225, T.I.A.S. No. 7739.

2 *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).

3 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) at 59-71.

4 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).

5 Elizabeth Waldrop, “Weaponization of Outer Space: U.S. National Policy” (Winter 2005) 1 High Frontier 37, online: The University of Michigan Law School <www.law.umich.edu/curriculum/workshops/governance/WkshpPaper2006_Waldrop.pdf> (date accessed: 25 April 2007).

6 Lucy Stojak, “Key Concepts in Space Arms Control,” Report to Foreign Affairs Canada (February 2005) at 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*, 27 January 1967, 610 U.N.T.S. 205, 18 U.S.T. 2410, T.I.A.S. No. 6347, 6 I.L.M. 386 [hereinafter Outer Space Treaty] (entered into force on 10 October 1967).

8 “Convention on International Liability for Damage Caused by Space Objects,” Article II, Opeened for signature 29 March 1972; entered into force 1 September 1972.

9 Canada, China, France, Germany, Italy, Japan, and the UK have failed to register 3, 35, 15, 16, 6, 10, and 10 satellites respectively. Reuters, “Large Nations Fail to Register Satellites” (17 August 2001).

10 *Agreement Governing the Activities of States on the Moon and other Celestial Bodies*, 5 December 1979, 1363 U.N.T.S. 3, 18 I.L.M. 1434 [hereinafter *Moon Agreement*] (entered into force 11 July 1984), Article 3(4).

11 *Moon Agreement*.

12 Union of Concerned Scientists, "Backgrounder: International Legal Agreements Relevant to Space Weapons" (February 2004), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1157> (date accessed: 25 April 2007).

13 United Nations General Assembly Resolution Database, online: United Nations <http://www.un.org/documents/resga.htm> (date accessed: 26 April 2007).

14 UNGA First Committee Voting Record on Prevention of an Arms Race in Outer Space, A/C.1/60/L.27 (25 October 2005), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/1com/1com05/votes/L.27.pdf> (date accessed: 26 April 2007).

15 Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control* (Washington DC: US Government Printing Office, September 1985) at 93.

16 *Outer Space Treaty*, Article III.

17 *Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water*, 5 August 1963, 14 U.S.T. 1313, T.I.A.S. No. 5433, 480 U.N.T.S. 43 [hereinafter *Test Ban Treaty*].

18 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.

19 *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.

20 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.

21 *The Convention on the Prohibition of Military or any other Hostile Use of the Environmental Modification Techniques*, 18 May 1977, UST 31, no. 333.

22 *Anti-Satellite Weapons, Countermeasures, and Arms Control*, at 93.

23 *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.

24 *Treaty on Conventional Armed Forces in Europe*, 9 November 1992, 30 ILM 1, Article XV(2).

25 *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.

26 *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.

27 *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.

28 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.

29 See Missile Technology Control Regime Website, online: <http://www.mtcr.info/english/index.html> (date accessed: 26 April 2007).

30 Brought into effect on 25 November 2002.

31 Michel Bourbonnière, "LOAC and the Neutralization of Satellites or IUS in Bello Satellitis" in

International Security Research and Outreach Programme Report (Department of Foreign Affairs and International Trade, Canada, May 2003) at 17-23.

32 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: Eisenhower Institute <http://www.eisenhowerinstitute.org/programs/globalpartnerships/fos/newfrontier/grahambriefing.htm> (date accessed: 26 April 2007).

33 Dr. Peter Van Fenema, interview by author, McGill University, Montreal, 25 February 2005.

34 "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: United Nations <http://www.un.org/events/unispace3/> (date accessed: 26 April 2007).

35 Detlev Wolter, *Common Security in Outer Space and International Law*, Geneva: United Nations Institute for Disarmament Research, UNIDIR/2005/29 at 132.

36 Wolter at 131-136.

37 "Possible Elements of the Future International Legal Instrument on the Prevention of the Weaponization of Outer Space," CD/1645 (6 June 2001).

38 "Transparency and confident building measures in outer space activities," United Nations General Assembly Resolution A/Res/60/66 (6 January 2006), online: United Nations Office for Disarmament Affairs <http://disarmament.un.org/vote.nsf/5063335733dce716852570c200516189/479505242538e0d5852570a1004a6bd8/$FILE/60-66.pdf> (date accessed: 26 April 2007).

39 Union of Concerned Scientists, "A Treaty Limiting Anti-Satellite Weapons" (May 1983), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1153> (date accessed: 26 April 2007).

40 The Henry L. Stimson Center, "Model Code of Conduct for the Prevention of Incidents and Dangerous Military Practices in Outer Space" (2004), online: Stimson Center <http://www.stimson.org/wos/pdf/codeofconduct.pdf> (date accessed: 26 April 2007).

41 "Building the Architecture for Sustainable Space Security, Geneva, 30-31 March 2006," Conference Report, United Nations Institute for Disarmament Research (March 2004), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/cd/papers06/Space%20Security%202006%20conf.doc> (date accessed: 26 April 2007).

42 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 I*nternational co-operation in the peaceful uses of outer space*, UN General Assembly Resolution 1472 (12 December 1959).

43 Space Debris Mitigation Guidelines at the UN," *Orbital Debris Quarterly News* 9 (July 2005) at 1.

44 *United Nations Report of the Committee on the Peaceful Uses of Outer Space*, UN General Assembly document A/60/20 (2005).

45 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).

46 "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.

47 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.

48 Hereinafter referred to as the "Amorim proposal."

49 Office of Science and Technology Policy, *US National Space Policy* (6 October 2006), online: Office of Science and Technology Policy <http://www.ostp.gov/html/US%20National%20Space%20Policy.pdf> (date accessed: 26 April 2007).

50 *US National Space Policy*.

51 "Russia May Cooperate with US in Space Programs" *Itar-Tass* (21 January 2004).

52 "Status Report Requested of RAMOS Program" *CDI Missile Defence Update*, No. 16 (2003).

53 European Space Agency, Permanent Representation in Russia, online: European Space Agency <http://www.esa.int/SPECIALS/ESA_Permanent_Mission_in_Russia/index.html> (date accessed: 26 April 2007).

54 "Russia, China Discuss Joint Space Projects," Space.com (9 November 2006), online: <http://www.space.com/news/061109_russia_china_missions.html> (date accessed: 26 April 2007). Vinay Shukla, "Putin Clears Space Pact with India" Rediff India Abroad (6 November 2006), online: Rediff India News <http://www.rediff.com/news/2006/nov/06russia.htm> (date accessed: 26 April 2007).

55 Susan Eisenhower, Thomas Graham Jr., and Robert J. Lawson, *Space Security 2003* (Toronto: Northview Press, 2004) at 37.

56 "Russia to remain Leading Space Power – Head of Roscomosmos" RIA Novosti (19 August 2005).

57 Information Office of the State Council of the People's Republic of China, "China's Space Activities in 2006" (October 2006), online: People's Daily Online <http://english.peopledaily.com.cn/20061012_311157.html> (date accessed: 26 April 2007).

58 PRC Information Office of the State Council, "China's Space Activities" (2000), online: People's Daily Online <http://english.peopledaily.com.cn/features/spacepaper/spacepaper.html> (date accessed: 26 April 2007).

59 "China's Space Activities" (2000).

60 Signatories include China, Iran, Republic of Korea, Mongolia, Pakistan, and Thailand.

61 "China's Space Activities." (2000)

62 Indian Space Research Organization, "International Cooperation", online: Indian Space Research Organization <http://www.isro.org/international.htm> (date accessed: 26 April 2007).

63 David Long, "The Evolution and Shape of European Space Policy," Report to Foreign Affairs Canada (May 2004) at 18.

64 European Commission, Press Release, "Cooperation in Space Gets Major Boost" (18 February 2005), online: European Commission <http://europa.eu.int/comm/space/news/article_2151_en.html> (date accessed: 26 April 2007).

65 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) at x.

66 "Joint Doctrine for Space Operations" at x.

67 US Air Force, Future Concepts and Transformation Division, *Transformation Flight Plan* (November 2003), online: Air Force Link <http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf> (date accessed: 26 April 2007).

68 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1 (2 August 2004) at 2. The *Counterspace Operations* document represents the views of the USAF and not necessarily that of the US Government.

69 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) at 21-64, online: UNIDIR <http://www.unidir.org/bdd/fiche-article.php?ref_article=1989> (date accessed: 26 April 2007).

70 US Department of Defense, *Space Policy Directive 3100.10* (Updated 9 July 1999).

71 US Department of Defense, J*oint Doctrine; Tactics, Techniques, and Procedures for Space Operations, Joint Publication 3-14*; US Air Force, 2004 USAF Posture Statement (2003).

72 *National Missile Defense Act of 1999*, Public Law 106-38 (6 January 1999).

73 US National Space Policy.

74 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) at 1-2; Government of the Russian Federation, "Draft Russian Military Doctrine" *BBC Monitoring* (1999), Section 1.5. First Published: *Krasnaya Zvezda* (9 October 1999) at 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 at 13.

75 Government of the Russian Federation, "Draft Russian Military Doctrine" *BBC Monitoring* (9 October 1999), Section 1.10.a.

76 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 at 18-19.

77 "Russian Space Forces Commander Outlines Priorities" BBC Monitoring (30 April 2001).

78 "Putin Reiterates Priorities in Developing Space Forces" Interfax (7 April 2003).

79 "Svobodny Cosmodrome Has Special Role in Russia's Space Programs – Space Troops Chief" Interfax (14 April 2003).

80 Andrew Gowers, Robert Cottrell, and Andrew Jack, "Transcript: Interview with Vladimir Putin, 13 December" *Financial Times* (15 December 2001) at 2.

81 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" (20 October 2004), online: Acronym Institute for Disarmament Diplomacy <http://www.acronym.org.uk/un/2004paro.htm> (date accessed: 26 April 2007).

82 "China's Space Activities in 2006".

83 Government of China State Council Information Office, "China's National Defense in 2004" (27 December 2004), online: Federation of American Scientists <http://www.fas.org/nuke/guide/china/doctrine/natdef2004.html> (date accessed: 26 April 2007).

84 "Russia-China CD Working Paper on New Space Treaty," CD/1679 (28 June 2002).

85 "Space: A New European Frontier for an Expanding Union: An Action Plan for Implementing the European Space Policy," White Paper, European Commission (2003) at 6-7, online: The European Union On-Line <http://europa.eu.int/comm/space/whitepaper/pdf/spwhpap_en.pdf> (date accessed: 26 April 2007).

86 *Report of the Panel of Experts on Space and Security*, European Commission Project Number 200446 (1 March 2005) at 26, online: The European Union On-Line <http://europa.eu.int/comm/space/news/article_2262.pdf> (date accessed: 26 April 2007).

87 Report of the Panel of Experts on Space and Security, at 26.

88 "European Space Policy," Green Paper, European Commission (2003) at 4, online: The European Union On-Line <http://europa.eu.int/comm/space/doc_pdf/space-green-paper_en.pdf> (date accessed: 26 April 2007); "Space: A New European Frontier for an Expanding Union: An Action Plan for Implementing the European Space Policy," White Paper, European Commission (2003) at 6-7, online: The European Union On-Line <http://europa.eu.int/comm/space/whitepaper/pdf/spwhpap_en.pdf> (date accessed: 26 April 2007).

89 Michèle Alliot-Marie, "Discours de Madame le Ministre de la Défense: Lancement du satellite HELIOS II" (French Ministry of Defense, 18 December 2004).

90 *Convention for the Establishment of a European Space Agency*, Open for signature 30 May 1975, entered into force 30 October 1980, 14 ILM 864, Article II.

91 Vivek Raghuvanshi, "India Embraces New War Doctrine" Defense News (8 November 2004).

92 "India Begins Work on Space Weapons Command" Space War (12 April 2006), online: Space War <http://www.spacewar.com/reports/India_Begins_Work_On_Space_Weapons_Command.html> (date accessed: 26 April 2007).

93 Department of National Defence, Canada, *Strategic Vectors: Air Force Transformation Vision* (2004) at 14-16, online: Canada Air Force <http://www.airforce.forces.gc.ca/vision/strategic_e.asp> (date accessed: 26 April 2007).

94 These dates are provided in Michael R. Gordon and David S. Cloud, "US Knew of China's Missile Test, But Kept Silent," *New York Times*, (23 April 2007), at 1.

95 Randy Boswell, "Canada expresses 'strong concerns' over China's satellite destruction," CanWest News Service (20 January 2007), online: Canada.com < http://www.canada.com/topics/news/world/story.html?id=7535ab77-00b3-4c3d-a0a2-e52057e0e722&k=60363> (date accessed: 21 February 2007); Dennis Shanahan and Rowan Callick, "China test fuels fear of arms race," *The Australian*, (20 January 2007), online: couriermail.com.au <http://www.news.com.au/couriermail/story/0,23739,21089412-401,00.html> (date accessed: 21 February 2007); "India to assess China's antisatellite test," *The Hindu*, (20 January 2007), online: Hindu.com <http://www.hindu.com/thehindu/holnus/002200701202130.htm> (date accessed: 21 February 2007).

96 Gordon Johndroe quoted in Craig Covault, "China's ASAT test will intensify US-Chinese faceoff on space," *Aviation Week* (21 January 2007), online: Aviation Week <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw012207p2.xml > (date accessed: 21 Febuary 2007); Richard Spencer, "Chinese missile destroys satellite in space," *Telegraph* (21 January 2007), online: Telegraph.co.uk <http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2007/01/19/wchina19.xml> (date accessed: 21 February 2007).

97 "Japan's Abe charges China satellite test illegal," Agence-France Press (31 January 2007), online: SpaceWar <http://www.spacedaily.com/reports/Japan_Abe_Charges_China_Satellite_Test_Illegal_999.html> (date accessed: 21 February 2007).

98 Michael R. Gordon and David S. Cloud, "US Knew of China's Missile Test, But Kept Silent," *New York Times*, (23 April 2007), at 1.

99 United Nations, *Report of the First Committee, Prevention of an Arms Race in Outer Space*, UN Doc. A/61/393 (2006).

100 United Nations General Assembly, Press Release, "Arms Trade Treaty, 'Nuclear-Weapon-Free World', Outer Space Arms Race, Among Issues as General Assembly adopts 54 First Committee Texts," GA 10547 (6 December 2006), online: United Nations <http://www.un.org/News/Press/docs/2006/ga10547.doc.htm> (date accessed: 8 February 2007).

101 *United States National Space Policy, Unclassified* (31 August 2006), online: Executive Office of the President, Office of Science and Technology Policy <www.ostp.gov/html/US%20National%20Space%20Policy.pdf> (date accessed: 8 February 2007) at 2. See infra, section 2.3 for a detailed discussion of the policy.

102 Conference on Disarmament, *Final Record of the One Thousand and Twenty Fifth Plenary Meeting* (Geneva, 13 June 2006), CD Doc. CD/PV.1025, online: Conference on Disarmament <disarmament.un.org/.../a61ff5819c4381ee85256bc70068fa14/a911b376e1fda36b852571dc00579271/$FILE/cdpv1025.pdf> (date accessed: 8 February 2007).

103 United Nations, *Report of the Secretary General, Transparency and Confidence-Building Measures in Outer Space Activities*, UN Doc. A/61/532 (2006).

104 United Nations, *Report of the Secretary General, Transparency and Confidence-Building Measures in Outer Space Activities*, UN Doc. A/61/532 (2006).

105 United Nations General Assembly, Press Release, "Arms Trade Treaty, 'Nuclear-Weapon-Free World', Outer Space Arms Race, Among Issues as General Assembly adopts 54 First Committee Texts," GA 10547 (6 December 2006), online: United Nations <http://www.un.org/News/Press/docs/2006/ga10547.doc.htm> (date accessed: 8 February 2007).

106 Reaching Critical Will, *First Committee Monitor*, 2nd ed. (9-13 October 2006) at 6, online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/1com/FCM06/2006wk2.pdf> (date accessed: 8 February 2007).

107 United Nations General Assembly, *Report of the Legal Subcommittee on its 45th Session, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/871 (24 April 2006).

108 United Nations General Assembly, *Report of the Legal Subcommittee on its 45th Session, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/871 (24 April 2006).

109 United Nations, *Report of the Committee on the Peaceful Uses of Outer Space*, UN Doc. A/61/20 (2006).

110 United Nations, *Report of the Committee on the Peaceful Uses of Outer Space*, UN Doc. A/61/20 (2006).

111 United Nations General Assembly, *Progress Report of the Working Group on Space Debris, Scientific and Technical Sub-committee, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/C.1/L.284 (28 February 2006).

112 United Nations General Assembly, *Progress Report of the Working Group on Space Debris, Scientific and Technical Sub-committee, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/C.1/L.284 (28 February 2006).

113 United Nations General Assembly, *Report of the Scientific and Technical Subcommittee on its 43rd Session, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/869 (16 March 2006).

114 Conference on Disarmament, *Report of the Conference on Disarmament to the General Assembly of the United Nations*, CD Doc. CD/1805 (2006).

115 Reaching Critical Will, *The CD Report*, 2nd Session (1 June 2006), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/cd/speeches06/reports.html#june1> (date accessed: 8 February 2007).

116 Reaching Critical Will, *The CD Report*, 2nd Session, (8 June 2006), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/cd/speeches06/reports.html#june8> (date accessed: 8 February 2007).

117 Conference on Disarmament, *Definition Issues Regarding Legal Instruments on the Prevention of the Weaponization of Outer Space*, CD Doc. CD/1779 (22 May 2006).

118 Conference on Disarmament, *Existing International Legal Instruments and Prevention of the Weaponization of Outer Space*, CD Doc. CD/1780 (22 May 2006).

119 Conference on Disarmament, *Transparency and Confidence-Building Measures in Outer Space and the Prevention of Placement of Weapons in Outer Space*, CD Doc. CD/1778 (22 May 2006).

120 Conference on Disarmament, *A Gap Analysis of Existing International Constraints on Weapons and Activities applicable to the Prevention of an Arms Race in Outer Space Agenda Item of the Conference on Disarmament*, CD Doc. CD/1784 (14 June 2006).

121 Conference on Disarmament, *Final Record of the One Thousand and Twenty-Fourth Plenary Meeting*, CD Doc. CD/PV.1024 (8 June 2006).

122 Reaching Critical Will, *The CD Report*, 2nd Session, (8 June 2006), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/cd/speeches06/reports.html#june8> (date accessed: 8 February 2007).

123 Reaching Critical Will, *The CD Report*, 2nd Session, (8 June 2006), online: Reaching Critical Will <http://www.reachingcriticalwill.org/political/cd/speeches06/reports.html#june8> (date accessed: 8 February 2007).

124 Conference on Disarmament, *Final Record of the One Thousand and Twenty-Fifth Plenary Meeting*, CD Doc. CD/PV.1025 (13 June 2006).

125 United Nations General Assembly, *Report of the Scientific and Technical Subcommittee on its 43rd Session, Committee on the Peaceful Uses of Outer Space*, UN Doc. A/AC.105/869 (16 March 2006).

126 *United States National Space Policy, Unclassified* (31 August 2006), online: Executive Office of the President, Office of Science and Technology Policy <www.ostp.gov/html/US%20National%20Space%20Policy.pdf> (date accessed: 8 February 2007).

127 *United States National Space Policy, Unclassified* (31 August 2006).

128 *United States National Space Policy, Unclassified* (31 August 2006).

129 *United States National Space Policy, Unclassified* (31 August 2006).

130 Marc Kaufman, "Talk of Satellite Defense Raises Fears of Space War" *Washington Post* (17 December 2006), online: washingtonpost.com <http://www.washingtonpost.com/wp-dyn/content/article/2006/12/16/AR2006121600791_pf.html> (date accessed: 8 February 2007).

131 "US adopts tough new space policy" BBC News (18 October 2006), online: BBC News <http://news.bbc.co.uk/2/hi/americas/6063926.stm> (date accessed: 8 February 2007).

132 "US Defends its Opposition to Ban on Weapons in Space" Spacewar (13 December 2006), online: Space War <http://www.spacewar.com/reports/US_Defends_Its_Opposition_To_Ban_On_Weapons_In_Space_999.html> (date accessed: 8 February 2007).

133 *China's Space Activities in 2006*, People's Daily Online (12 October 2006), online: People's Daily <http://english.people.com.cn/200610/12/eng20061012_311157.html> (date accessed: 8 February 2007).

134 Information Office of the State Council of the People's Republic of China, "China's Space Activities in 2006" (October 2006), online: People's Daily <http://english.peopledaily.com.cn/20061012_311157.html> (date accessed: 26 April 2007).

135 European Commission, Press Release, “Parliamentarians Discuss European Space Policy in Brussels” (18 August 2006), online: European Commission <http://ec.europa.eu/enterprise/space/news/article_4269_en.html> (date accessed: 8 February 2007).

136 *China's National Defense in 2006* (29 December 2006), online: China.org.cn – China's Official Gateway to News & Information <http://www.china.org.cn/english/features/book/194421.htm> (date accessed: 8 February 2007).

137 *China's National Defense in 2006*.

138 K.K. Nair, *Space, the Frontiers of Modern Defence* (India: Center for Air Power Studies, 2006) at 75. The author notes that China's PLA “has outlined its mission regarding military space as consisting of two categories. The first is information supporting, and the second, battlefield combating, which loosely corresponds to missions of force enhancement and counter-space operations in western parlance.”

139 Richard Weitz, “China's New Defence Paper Continues Tradition of Military Secrecy”, World Politics Watch (18 January 2007), online: World Politics Watch < http://www.worldpoliticswatch.com/article.aspx?id=480> (date accessed: 8 February 2007).

140 US-China Economic And Security Review Commission, *2006 Report to Congress* (Washington, DC: US Government Printing Office, 2006) at 137, online: USCC.gov <http://www.uscc.gov/annual_report/2006/06_annual_report.php> (date accessed: 9 February 2007).

141 “Draft Bill Would Open Space to Military Use” *The Yomiuri Shimbun* (17 September 2006). See also: “Bill to Broaden Japan's Military Use of Space” IOL (17 September 2006), online: IOL: News from South Africa and the World <http://www.int.iol.co.za/index.php?set_id=1&click_id=31&art_id=qw1158479280523B212> (date accessed: 8 February 2007).

142 “Japan Moves to End Ban on Military Use of Space” Defense News (6 June 2006), online: DefenseNews.com <http://www.defensenews.com/story.php?F=1843677&C=airwar> (date accessed: 21 March 2007)

143 Barbara Opall-Rome, “Air Force to Lead Israel's Military Activities in Space” Defense News (27 February 2006), online: DefenseNews.com < http://www.defensenews.com/story.php?F=1556062&C=mideast> (date accessed: 8 February 2007).

144 B Barbara Opall-Rome, “Inability to Jam Hezbollah Satellite TV Signal Spurs Israeli Research” Space News (29 August 2006), online: Space.com <http://www.space.com/spacenews/archive06/jammit_0828.html> (date accessed: 9 February 2007).

145 *Air Force Doctrine Document 2-2.1*.

146 Vivek Raghuvanshi, “India to Examine Joint Space Command” DefenseNews.com (25 September 2006), online: DefenseNews.com < http://www.defensenews.com/story.php?F=2116320&C=airwar> (date accessed: 8 February 2007).

147 “India Begins Work on Space Weapons Command” Spacewar (12 April 2006), online: Spacewar <http://www.spacewar.com/reports/India_Begins_Work_On_Space_Weapons_Command.html> (date accessed: 8 February 2007).

148 K.K. Nair, *Space, the Frontiers of Modern Defence* (India: Center for Air Power Studies, 2006), forward by Jasjit Singh.

149 Assembly of the Western European Union, The Interparliamentary European Security and Defence Assembly, Press Release No. 31, “Colloquy on Space, Defence and European Security” (25 September 2006), online: Welcome to the Belgian Space Policy <http://www.belspo.be/belspo/eisc/pdf/docu_eisc_semi/CPKourou_en.pdf> (date accessed: 8 February 2007).

150 Assembly of the Western European Union, The Interparliamentary European Security and Defence Assembly, Press Release No. 31.

151 “Call to Consider EU’s Satellites for Military Use” *Financial Times* (13 October 2006), online: Financial Times <http://www.ft.com/cms/s/6226b684-5aeb-11db-8f80-0000779e2340.html> (date accessed: 8 February 2007).

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. Sea Launch website, online: <http://www.sea-launch.com> (date accessed: 25 April 2007).

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. International Launch Services, online: ILS < http://www.ilslaunch.com/partnerships/> (date accessed: 25 April 2007).

3 Data from Gunter Dirk Krebs, online: Gunter’s Space Page <http://www.skyrocket.de/space/> (date accessed: 25 April 2007). Dark grey indicates an independent orbital launch capability and dots indicate launch sites.

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: SSTL <http://www.sstl.co.uk/index.php?loc=5> (date accessed: 25 April 2007).

8 Jonathan’s Space Report, “Satellite Catalogue and Launch Catalogue”, online: Jonathan’s Space Report <http://planet4589.org/space/log/satcat.txt> (date accessed: 25 April 2007); Encyclopedia Astronautica, “Chronology 2004”, online: Encyclopedia Astronautica <http://www.astronautix.com/> (date accessed: 25 April 2007).

9 A list of all civil space agencies is available at Spacesecurity.org, “Directory of Space Actors,” (January 2007), online: Spacesecurity.org <http://www.spacesecurity.org/publications.htm> (date accessed: 25 April 2007).

10 Fernand Verger, Isabelle Sourbes-Verger, Raymond Ghirardi and Xavier Pasco, *The Cambridge Encyclopedia of Space* (Cambridge: Cambridge University Press, 2003) at 101.

11 Verger, et al. at 81.

12 Verger, et al. at 68-69.

13 National Aeronautics and Space Administration, “FY 2007 Budget and 2006 Strategic Plan” (2006), online: NASA <http://www.nasa.gov/about/budget/index.html> (date accessed: 25 April 2007). See annual increases under previous budget statements.

14 “ESA Gets 10 Percent Budget Hike for 2005” Space News (26 January 2005), online: Space.com <http://www.space.com/spacenews/archive05/hikearch_012405.html> (date accessed: 25 April 2007);

15 “Top Official Deplores Decline of Russian Space Program” *The Sunday Morning Herald* (12 December 2002), online: The Sunday Morning Herald <http://www.smh.com.au/articles/2002/12/11/1039379887168.html. Olga Zhdanovich, Discussion with author (Montreal, Quebec, 26 February 2005).

16 “The Government has Approved” *Aviation Week and Space Technology* (7 November 2005) at 28.

17 Eric Hagt, “Mutual Assured Vulnerabilities in Space,” *China Security*, 2 (2006), at 87.

18 “Disaster Monitoring Constellation Partners Hold 4th Meeting,” Spacedaily.com (14 December 2003), online: SpaceDaily.com <http://www.spacedaily.com/news/eo-03zzzzl.htm> (date accessed: 25 April 2007).

19 Eric Hagt, “Mutual Assured Vulnerabilities in Space,” at 88.

20 “Russia Approves Space Funding” *CNN News* (26 October 2005).

21 “Bush Unveils Vision for Moon and Beyond” CNN (15 January 2004), online: CNN <http://www.cnn.com/2004/TECH/space/01/14/bush.space/> (date accessed: 25 April 2007).

22 Data from Verger, et al.

23 Verger, et al. at 68-69.

24 “China to launch permanent manned space station within 15 years,” Agence France-Presse, 18 May 2004.

25 Eiichiro Sekigawa, “Return Vision: Japan’s Space Agency Counts ISS at Centre of 20-year Road Map” *Aviation Week and Space Technology* (April 2005) at 32.

26 Verger, et al. at 73-77.

27 Verger, et al. at 69.

28 Fred Weir, “As Space Work Goes on, Russia Key” *Christian Science Monitor* (4 February 2003).

29 Jane’s Space Directory (Surrey, UK: Jane’s Information Group, 2001) at. 14.

30 Verger, et al. at 68-69. “Chinese spends a 10th of NASA budget on space activities” Xinhua (12 Oct 2006), online: Xinhuanet <http://news.xinhuanet.com/english/2006-10/12/content_5194441.htm> (date accessed: 8 February 2007).

31 Verger, et al. at 96-97.

32 Data from Verger, et al.

33 Indian Space Research Organization, “Milestones of the Indian Space Research Organization (ISRO)”, online: ISRO <http://www.isro.org/mileston.htm> (date accessed: 25 April 2007).

34 Surrey Satellites Technologies Ltd, Press Announcement, “Surrey Launches Two More Satellites from Russia” (10 July 1998), online: <http://www.ee.surrey.ac.uk/SSC/CSER/UOSAT/press/tmsat-fasat-pr3.html> (date accessed: 25 April 2007).

35 Global Monitoring for Environment and Security, online: GMES <http://www.gmes.info/what_is/index.html> (date accessed: 25 April 2007).

36 Sean O’Keefe, “Remarks at the US Space Foundation Annual Symposium,” Colorado Springs, Colorado, 31 March 2004, online: NASA <http://www.nasa.gov/audience/formedia/speeches/ok_colorado_springs_033104.html> (date accessed: 25 April 2007).

37 NASA, *Spinoff 2004* (Washington DC: US Government Printing Office, 2004), online: NASA Scientifical and Technical Information <http://www.sti.nasa.gov/tto/> (date accessed: 25 April 2007).

38 Data from Verger, et al and Johnathan McDowell’s Satellite Database.

39 Videocosmos, “Mir Station”, online: Videocosmos <http://www.videocosmos.com/mir.shtm> (date accessed: 25 April 2007)

40 NASA, “History of Shuttle-Mir,” online: NASA Human Space Flight <http://spaceflight.nasa.gov/history/shuttle-mir/images/timeline.pdf> (date accessed: 25 April 2007).

41 Alexander Anekeev, “Statistics on International Orbital Station” (2006), online: Manned Astronautics: Figures and Facts <http://space.kursknet.ru/cosmos/english/other/siss.sht> (date accessed: 25 April 2007).

42 European Space Agency, “How Much Does it Cost?”, online: ESA <http://www.esa.int/export/esaHS/ESAQHA0VMOC_iss_0.html> (date accessed: 25 April 2007).

43 As of January 2006, China, Israel, Ukraine, India, Morocco, Saudi Arabia and South Korea had signed agreements to cooperate on Galileo.

44 US Environment Protection Agency, “Global Earth Observation System of Systems (GEOSS)”, online: EPA <http://www.epa.gov/geoss/basic.html> (date accessed: 25 April 2007).

45 Group on Earth Observations, “Declaration of the Earth Observation Summit” (31 July 2003); US Environment Protection Agency, “Global Earth Observation System of Systems (GEOSS)”, online: EPA <http://www.epa.gov/geoss/basic.html> (date accessed: 25 April 2007).

46 “China, Brazil to Co-Launch 2nd Satellite in Latter Half Year” *People’s Daily* (13 July 2002).

47 Futron Corporation, “Trends in Space Commerce” (US Department of Commerce, Office of Space Commercialization, June 2000).

48 The Space Report at 77. From ABI Research, Table of Contents for *Satellite Positioning Systems and Devices: Global Markets for GPS, GALILEO, GLONASS, and Other Satellite-Based Positioning Technologies* (2005), online: ABI Research <http://www.abiresearch.com/products/market_research/Satellite_Positioning_Systems_and_Devices> (date accessed: 25 April 2007).

49 “The Sky’s the Limit” *Economist* (8 March 2001).

50 US Department of Commerce, Office of Space Commercialization, “Trends in Space Commerce” (June 2001).

51 Russian Ministry of Defense, “Coordinational Scientific Information Center”, online: Russian Space Agency <http://www.glonass-center.ru/frame_e.html> (date accessed: 25 April 2007).

52 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: Russian Strategic Nuclear Forces <http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml> (date accessed: 25 April 2007).

53 European Union, “Satellite Navigation” (6 April 2006), online: Europa: The European Union On-Line <http://europa.eu.int/comm/space/russia/sector/satellite_navigation_en.html> (date accessed: 25 April 2007); “Russia to Lift GLONASS Restrictions for Accurate Civilian Use,” *GPS Daily* (14 November 2006), online: <http://www.gpsdaily.com/reports/Russia_To_Lift_Glonass_Restrictions_For_Accurate_Civilian_Use_999.html> (date accessed: 25 April 2007).

54 M. Somasekhar, “Indigenous Satellite Navigation System on the Anvil” *The Hindu* (11 May 2005).

55 Jonathan’s Space Report, “Satellite Catalogue and Launch Catalogue”, online: Jonathan’s Space Report <http://planet4589.org/space/log/satcat.txt> (date accessed: 25 April 2007); Mark Wade, “Chronology 2004”, online: Encyclopedia Astronautica <http://www.astronautix.com/> (date accessed: 25 April 2007).

56 “The Beidou System,” Presentation to the Union of Concerned Scientists, Summer Syposium, Beijing, August 2004.

57 Interagency GPS Executive Board, “Joint Announcement, Second Japan-US GPS Plenary Meeting, 2002” (16 October 2002).

58 European Commission, Press Release, “GALILEO: YES, at Last!” (26 March 2002), online: Europa: The European Union On-Line <http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/02/478> (date accessed: 25 April 2007).

59 ESA, Press Release, “Galileo: Contracts for the First Satellites” (11 July 2003), online: ESA <http://www.esa.int/export/esaCP/Pr_43_2003_p_EN.html> (date accessed: 25 April 2007).

60 “Where It’s at: A European Satellite-navigation Network Is on Its Way,” *Economist* (29 January 2004).

61 Delegation of the European Commission to the United States, Press Release, “EU and US a Step Further to Agreement over Galileo Satellite Navigation” (25 February 2004), online: European Union

Delegation of the European Commission to the USA <http://www.eurunion.org/news/press/2004/20040030.htm> (date accessed: 25 April 2007).

62 European Union, "Galileo Services" (1 March 2006), online: European Union On-Line <http://europa.eu.int/comm/dgs/energy_transport/galileo/programme/services_en.htm> (date accessed: 25 April 2007).

63 "Galileo navigation satellites hugely over budget," *New Scientist* (23 May 2006), online: NewScientist.com <http://www.newscientist.com/article.ns?id=dn9210> (date accessed: 22 May 2007).

64 Jonathan's Space Report, "Satellite Catalogue and Launch Catalogue", online: Jonathan's Space Report <http://planet4589.org/space/log/satcat.txt> (date accessed: 25 April 2007).

65 WMO Space Programme, "Current Polar-Orbiting Satellites Coordinated within CGMS" (25 November 2005).

66 Third Earth Observation Summit, Press Release, "Earth Observation: Global Cooperation Becomes a Reality" (16 February 2005), online: Europa: The European Union On-Line <http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/05/185&format=HTML&aged=0&language=EN> (date accessed: 25 April 2007); US Environmental Protection Agency, Global Earth Observation System of Systems, "Basic Information" (22 April 2005), online: <http://www.epa.gov/geoss/basic.html> (date accessed: 25 April 2007).

67 Surrey Satellite Technologies, Press Release, "SSTL Readies First DMC Satellite for November Launch" (19 November 2002).

68 COSPAS-SARSAT Secretariat, interview with author, 16 May 2005.

69 International Cospas-Sarsat Programme, "Information Bulletin," 19 (February 2007), online : Cospas-Sarsat <http://www.cospas-sarsat.org/DocumentsInformationBulletin/Bul19-Feb07_E_web.pdf> at 5 (date accessed: 1 May 2007).

70 COSPAS-SARSAT Secretariat, interview with author, 16 May 2005. International Cospas-Sarsat Programme, "Information Bulletin," at 6.

71 The total includes Singapore, Greece, Cyprus and Taiwan as separate states.

72 "Kazakhstan Launches Its First Satellite" Associated Press (17 June 2006), online: MSNBC <http://www.msnbc.msn.com/id/13390784/> (date accessed: 8 February 2007).

73 "Egypt to Launch First Scientific Satellite in Late 2007" Xinhua (7 November 2006), online: China View <http://news.xinhuanet.com/english/2006-11/08/content_5302314.htm> (date accessed: 8 February 2007); "1st Indonesian-Developed Satellite to be Launched in October" Xinhua (14 September 2006), online: China View <http://news3.xinhuanet.com/english/2006-09/14/content_5090674.htm> (date accessed: 8 February 2007).

74 "Belarus to Announce Tender for New National Satellite" RIA Novosti (17 August 2006), online: RIA Novosti World <http://en.rian.ru/world/20060817/52753000.html> (date accessed: 8 February 2007).

75 Peter B. de Selding, "SSTL to Build Second Nigerian Earth Observation Satellite" *Space News* (6 November 2006), online: *Space News* <http://www.space.com/spacenews/satellitecomm/nigeriasat2_110606.html> (date accessed: 8 February 2007).

76 Ed Stoddard, "SA to Launch Micro-satellite from Russia as Cabinet Approves Plans for Space Agency" Cape Times (1 August 2006), online: *Cape Times* <http://www.capetimes.co.za/index.php?fSetId=198&fSectionId=271&fArticleId=3370073> (date accessed: 8 February 2007).

77 European Space Agency, Press Release, "Successful Firing of Vega's First-Stage Motor in Kouru" (30 November 2006), online: ESA <http://www.esa.int/SPECIALS/Launchers_Home/SEMTHGD4VUE_0.html> (date accessed: 8 February 2007).

78 European Space Agency, Press Release, “ESA and ANU Make Space Propulsion Breakthrough” (13 January 2006), online: ESA <http://www.esa.int/techresources/ESTEC-Article-fullArticle_par-28_1134728785014.html> (date accessed: 8 February 2007).

79 Korea Aerospace Research Institute (KARI), “Research and Development: Space Launch Vehicle”, online: KARI <https://www.kari.re.kr/index1.asp> (date accessed: 8 February 2007); “First South Korean Space Rocket to Launch in 2008” Space Daily (2 January 2007), online: Space Daily <http://www.spacedaily.com/reports/First_South_Korean_Space_Rocket_To_Launch_In_2008_999.html> (date accessed: 8 February 2007).

80 K.S. Jayaraman, “Indian GSLV Fails in Fourth Flight” *Space News* (10 July 2006).

81 Currency numbers are not exact due to conversion to USD. For currency conversions, see online: Xe.com <www.xe.com>.

82 K.S. Jayaraman, “Record-Setting Indian Space Budget Includes Funds for Large Satellites” *Space News* (6 March 2006), online: *Space News* <http://www.space.com/spacenews/asia/IndiaWeb_111006.html> (date accessed: 8 February 2007).

83 RIA, “Russia To Spend More on Space Over Next Decade” Space Daily (10 April 2006), online: <http://www.spacedaily.com/reports/Russia_To_Spend_More_On_Space_Over_Next_Decade.html> (date accessed: 8 February 2007). “Russia remains leader in spacecraft launches – space agency,” RIA Novosti (26 December 2006), online: RIA Novosti Russia <http://en.rian.ru/russia/20061226/57833667.html> (date accessed: 12 April 2007).

84 European Space Agency, “How big is ESA’s budget?”, online: ESA <http://www.esa.int/esaCP/GGG4SXG3AEC_index_0.html> (date accessed: 8 February 2007); Peter B. de Selding, “2006 ESA Budget Emphasizes Independence, Satcom Technology” *Space News* (23 January 2006), online: *Space News* <www.space.com/spacenews/archive06/ESA_012306.html> (date accessed: 8 February 2007).

85 Peter B. de Selding, “Rocket Launches High-Resolution Korean Imaging Satellite” *Space News* (28 July 2006), online: *Space News* <http://www.space.com/spacenews/launchindustry/Kompsat_072806.html> (date accessed: 8 February 2007).

86 Courtesy of JAXA, Public Affairs Department.

87 Brian Berger, “No Raise for NASA for 2007,” *Space News* (12 December 2006), online: *Space News* <http://www.space.com/spacenews/spacepolicy/NoNASARaiseweb_121206.html> (date accessed: 8 February 2007).

88 Dean Cheng, “Dragons in Orbit: China’s Space Program Merits Greater Attention” *Space News* (21 August 2006). Figures quoted from members of China’s National Space Administration place its budget as high as $2-billion. “Chinese spends a 10th of NASA budget on space activities” Xinhua (12 Oct 2006), online: Xinhuanet <http://news.xinhuanet.com/english/2006-10/12/content_5194441.htm> (date accessed: 8 February 2007).

89 Ed Stoddard, “SA to Launch Micro-satellite from Russia as Cabinet Approves Plans for Space Agency” Cape Times (1 August 2006), online: *Cape Times* <http://www.capetimes.co.za/index.php?fSetId=198&fSectionId=271&fArticleId=3370073> (date accessed: 8 February 2007).

90 NASA, Release 06-224, “NASA Set to Launch Lunar Reconnaissance Orbiter in 2008” (18 May 2006), online: NASA <http://www.nasa.gov/home/hqnews/2006/may/HQ_06224_LRO_update.html> (date accessed: 8 February 2007).

91 NASA, Release 06-361, “NASA Unveils Global Exploration Strategy and Lunar Architecture” (4 December 2006), online: NASA <http://www.nasa.gov/home/hqnews/2006/dec/HQ_06361_ESMD_Lunar_Architecture.html> (date accessed: 8 February 2007).

92 Dennis Overbye, “NASA to Cut Back Scientific Missions because of Budget,” *New York Times* (1 March 2006).

93 AFP, “Russian Says Moon and Mars Space Targets by 2030” Space Daily (12 April 2006), online: Space Daily <http://www.spacedaily.com/reports/Russian_Says_Moon_And_Mars_Space_Targets_By_2030.html> (date accessed: 8 February 2007); RIA Novosti, “Russia Plans Lunar Mission In 2012, Eyes US Lunar Return Partnership” Moon Daily (8 December 2006), online: Moon Daily <http://www.moondaily.com/reports/Russia_Plans_Lunar_Mission_In_2012_Eyes_US_Lunar_Return_Partnership_999.html> (date accessed: 8 February 2007).

94 Vladimir Isachenkov, “Rocket Chief: Russia Could Fall Behind in Space Race if it Doesn’t Develop New Spacecraft” Associated Press (11 January 2007), online: Cron.com <http://www.chron.com/disp/story.mpl/space/4464067.html> (date accessed: 8 February 2007).

95 Sun Dangen, “Shenzhou and Dreams of Space” (2006) 2 China Security: China’s Space Ambitions at 59.

96 “Chandrayaan Lunar Mission Will Carry NASA Payload” SPX (1 May 2006), online: Moon Daily <http://www.moondaily.com/reports/Chandrayaan_Lunar_Mission_Will_Carry_NASA_Payload.html> (date accessed: 8 February 2007).

97 K.S. Jayaraman, “India’s Space Agency Seeks Government Approval of Manned Spaceflight Program” *Space News* (10 November 2006), online: *Space News* <http://www.space.com/spacenews/asia/IndiaWeb_111006.html> (date accessed: 8 February 2007).

98 European Space Agency, Press Release, “Impact Landing Ends SMART-1 Mission to the Moon” (3 September 2006), online: ESA <http://www.esa.int/esaCP/Pr_31_2006_p_EN.html> (date accessed: 8 February 2007).

99 European Space Agency, “The Aurora Programme: Europe’s Framework for Space Exploration” *ESA Bulletin* 126 (May 2006), online: ESA <http://www.esa.int/esapub/bulletin/bulletin126/bul126b_messina.pdf> (date accessed: 8 February 2007).

100 “Russia Signs Space Cooperation Deal with Europe” AFP (13 March 2006), online: Space Daily <http://www.spacedaily.com/reports/Russia_Signs_Space_Cooperation_Deal_With_Europe.html> (date accessed: 8 February 2007); Peter B. de Selding, “ESA and Russia Join in Effort to Explore New Spacecraft Designs” *Space News* (29 June 2006), online: *Space News* <http://www.space.com/spacenews/archive06/Esa_062606.html> (date accessed: 8 February 2007).

101 Simon Saradzhyan, “China Joins Russia in Mars Mission” *Space News* (29 August 2006), online: *Space News* <www.space.com/spacenews/archive06/chinarussiamars_0828.html> (date accessed: 8 February 2007); “China and Russia Discuss Lunar Project” XNA (12 November 2006), online: Moon Daily <http://www.moondaily.com/reports/China_And_Russia_Discuss_Lunar_Project_999.html>(date accessed: 8 February 2007).

102 “Russia to Take First South Korean To Space” AFP (11 December 2006), online: Space Travel <http://www.space-travel.com/reports/Russia_To_Take_First_South_Korean_To_Space_999.html> (date accessed: 8 February 2007); “Deal Signed on Launch of First Malaysian Astronaut” AFP (19 May 2006), online: Space Daily <http://www.spacedaily.com/reports/Deal_signed_on_launch_of_first_Malaysian_astronaut.html> (date accessed: 8 February 2007).

103 Peter B. de Selding, “France, Russia Commit to Develop Heavy Launcher” *Space News* (20 February 2006). "Russia and South Africa to Step up Cooperation in Space and Healthcare" RIAN (6 September 2006), online: Earth News from Terradaily.com <http://www.terradaily.com/reports/Russia_And_South_Africa_To_Step_Up_Cooperation_In_Space_And_Healthcare_999.html> (date accessed: 8 February 2007).

104 “NASA Teams Up with Japan and Europe to Study the Sun” SPX (19 September 2006), online: Space Daily <http://www.spacedaily.com/reports/NASA_Teams_Up_With_Japan_And_Europe_To_Study_The_Sun_999.html> (date accessed: 8 February 2007).

105 Leonard David, “Climate Change Constellation Successfully Placed in Orbit” *Space News* (24 April 2006).

106 Brian Berger, “Griffin Agrees to Explore Working with China in Several Areas of Space Science” *Space News* (26 September 2006).

107 K.S. Jayaraman, “India to Launch Russian Glonass Satellite” *Space News* (27 March 2006).

108 “Malaysia to Work with India on Space Technology” XNA (14 June 2006), online: Spacemart <http://www.spacemart.com/reports/Malaysia_To_Work_With_India_On_Space_Technology.html> (date accessed: 8 February 2007); “Israel will launch its Tauvex II scientific telescope on India’s GSAT-4 satellite in mid-2007” *India Daily* (20 June 2006), online: India Daily <http://www.indiadaily.com/editorial/10023.asp> (date accessed: 8 February 2007).

109 European Space Agency, News Release, “SURE on the Road Update – Romania” (8 March 2006), online: ESA <http://www.esa.int/esaHS/SEMTM9NVGJE_business_0.html> (date accessed: 8 February 2007).

110 “US, Europe Take Steps to Advance Polar Satellite Cooperation” EUMETSAT Media (22 February 2006), online: EUMETSAT <http://www.eumetsat.int/Home/Main/Media/Press_Releases/005264?l=en> (date accessed: 8 February 2007).

111 “Estonia Joins EUMETSAT Community of Nations” EUMETSAT Media (19 December 2006), online: EUMETSAT <http://www.eumetsat.int/Home/Main/Media/Press_Releases/029294?l=en> (date accessed: 8 February 2007); “Croatia Officially Joins EUMETSAT Community of Member States” EUMETSAT Media (15 December 2006), online: EUMETSAT <http://www.eumetsat.int/Home/Main/Media/Press_Releases/029194?l=en> (date accessed: 8 February 2007).

112 European Union, Press Release, “EU and the Republic of Korea Seal Their Agreement” (11 September 2006), online: Europa – The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1170&format=HTML&aged=0&language=EN&guiLanguage=fr> (date accessed: 8 February 2007); European Space Agency, News Release, “EU and Morocco seal their agreement on Galileo” (12 December 2006), online: Europa – The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1774&format=HTML&aged=0&language=EN&guiLanguage=fr> (date accessed: 8 February 2007).

113 Global Monitoring for Environment and Security, “What is GMES?”, online: GMES <http://www.gmes.info/158.0.html> (date accessed: 8 February 2007).

114 Chinese National Space Administration (CNSA), White Paper, “China’s Space Activities in 2006” (12 October 2006), online: CNSA <http://www.cnsa.gov.cn/n615709/n620682/n639462/79381_1.html> (date accessed: 8 February 2007).

115 “Chinese Bank Offers US$200 mln in Loan for Satellite Project” XNA (14 January 2006), online: People’s Daily Online <http://english.peopledaily.com.cn/200601/14/eng20060114_235361.html> (date accessed: 8 February 2007).

116 “Venezuela, China Sign 19 Cooperation Accords” People’s Daily Online (30 January 2005), online: People’s Daily Online <http://english.people.com.cn/200501/30/eng20050130_172360.html> (date accessed: 8 February 2007).

117 Jeremy Singer, “Delta 2 Launches USAF’s Third GPS 2RM Satellite” *Space News* (17 November 2006).

118 “GPS III Delay and the Great Integrity Debate,” *GPS World* (July 2006), online: GPS World <http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=338746> (date accessed: 24 May 2007).

119 Pavel Podvig, “Three Glonass-M navigation satellites join constellation,” Russian Nuclear Forces Project (25 December 2006), online: Russian strategic nuclear forces <http://russianforces.org/blog/2006/12/three_glonassm_navigation_sate.shtml> (date accessed: 22 May 2007).

120 “Russia Launches Three Glonass Satellites” RIA Novosti (26 December 2006), online: RIA Novosti - Russia <http://en.rian.ru/russia/20061226/57810801.html> (date accessed: 8 February 2007).

121 “GLONASS to be Made Available for Civilian Use in 2006 – Official” RIA Novosti, 31 April 2006, online: RIA Novosti - Russia <http://en.rian.ru/russia/20060331/45039973.html> (date accessed: 8 February 2007).

122 K.S. Jayaraman, “India to Develop Regional Navigation System” *Space News* (22 May 2006).

123 “ISRO, Raytheon Complete Tests for GAGAN Satellite Navigational System” India Defence (20 July 2006), online: India Defence <http://www.india-defence.com/reports/2239> (date accessed: 8 February 2007).

124 “GAGAN Ready for Demo Phase” The Hindu Business Line (19 July 2006), online: The Hindu Business Line <http://www.thehindubusinessline.com/2006/07/20/stories/2006072000450900.htm> (date accessed: 8 February 2007).

125 “China Starts to Build Own Satellite Navigation System” GPS Daily (3 November 2006), online: GPS News <http://www.gpsdaily.com/reports/China_Starts_To_Build_Own_Satellite_Navigation_System_999.html> (date accessed: 9 February 2007)

126 European Space Agency, News Release, “Commission is Looking for New Ways to Benefit from Galileo Navigation System” (8 December 2006), online: Europa – The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1709&format=HTML&aged=0&language=EN&guiLanguage=en> (date accessed: 8 February 2007); ESA, News Release, “Commission Takes Stock of the GALILEO Programme” (7 June 2006), online: Europa – The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/744&format=HTML&aged=0&language=EN&guiLanguage=fr> (date accessed: 8 February 2007).

127 European Space Agency, News Release, “Commission takes stock of the GALILEO Programme” (7 June 2006), online: Europa – The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/744&format=HTML&aged=0&language=EN&guiLanguage=fr> (date accessed: 8 February 2007). The ESA has now concluded cooperation agreements for the Galileo system with India, Israel, China, the United States, Canada, Ukraine, South Korea, Morocco, Ukraine and Saudi Arabia.

128 “China to Launch 22 more Meteorological Satellites by 2020” Xinhua (8 December 2006), online: Xinhuanet <http://news.xinhuanet.com/english/2006-12/08/content_5455953.htm> (date accessed: 8 February 2007).

129 “China to Launch 3 Satellites for Disaster-monitoring” Xinhua (21 August 2006), online: Xinhuanet <http://news.xinhuanet.com/english/2006-08/22/content_4990023.htm> (date accessed: 8 February 2007).

130 NASA, News Releases, “NASA Launches Satellites for Weather, Climate, Air-Quality Studies” 28 April 2006), online: NASA <http://www.nasa.gov/home/hqnews/2006/apr/HQ_06190_Cloudsat_CALIPSO_launch.html> (date accessed: 8 February 2007).

131 The Orbital Report News Agency, “Space Launches of 2006”, online: Space-Launcher.com <http://www.orbireport.com/Logs/Log06/index.html> (date accessed: 8 February 2007).

132 Peter de Selding, “Europe Moves Ahead With Weather Satellite Blacklist,” *Space News* (9 January 2006).

133 EUMETSAT Media, Press Releases, “First MetOp Successfully Launched” (19 October 2006), online: EUMETSAT <http://www.eumetsat.int/Home/Main/Media/Press_Releases/028729?l=en> (date accessed: 8 February 2007).

134 “India May Quit EU-led GPS Project” *The Times of India* (16 October 2006), online: The Times of India <http://timesofindia.indiatimes.com/articleshow/2172710.cms> (date accessed: 8 February 2007).

135 Launches whose primary payload was a civil satellite.

136 "JianBing-5/Remote Sensing Satellite-1 Synthetic Aperture Radar Satellite" Chinese Defence Today (17 May 2006), online: SinoDefence.com <http://www.sinodefence.com/strategic/spacecraft/jianbing5.asp> (date accessed: 9 February 2007). Union of Concerned Scientists, "Satellite Database" (updated January 2007),online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/satellite_database.html> (date accessed: 16 April 2007). "CZ 4B Chronology" (2007), online: Astronautix <http://www.astronautix.com/lvs/cz4b.htm> (date accessed: 24 April 2007).

Chapter Four Endnotes

1 Eurospace, "Facts & Figures: The European Space Industry in 2002" (2004) at 7, online: Eurospace<http://www.eurospace.org/> (date accessed: 25 April 2007).

2 Futron Corporation, *State of the Satellite Industry Report*, "2005 Satellite Industry Statistics" (June 2006) at 8, online: Futron Corporation <http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf> (date accessed: 25 April 2007).

3 US Federal Aviation Administration, "The Economic Impact of Commercial Space Transportation on the US Economy: 2002 Results and Outlook for 2010" (March 2004) at 3, online: FAA<http://ast.faa.gov/files/pdf/2004Economic_Impact.pdf> (date accessed: 25 April 2007).

4 Communications Satellite Corporation, or COMSAT, is a private communications satellite company organized and started by the US Congress. See Comsat International, "Comsat International History", online: Comsat International <http://www.comsatinternational.com/about/history.html> (date accessed: 25 April 2007); President's National Security Telecommunications Advisory Committee (NSTAC), "Satellite Task Force Report, Factsheet" (March 2004) at 6.

5 John Higginbotham, "Private Possibilities in Space," in Edward L. Hudgins, ed., *Space: The Free Market Frontier* (New York: Cato Institute, 2002) at 146.

6 Futron Corporation, "2005 Satellite Industry Statistics" (June 2006) at 6, online: Futron Corporation<http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf> (date accessed: 25 April 2007)

7 "Satellite Task Force Report, Factsheet" at 6.

8 Space Foundation, *The Space Report* (2006) at 52.

9 Data taken from annual commercial launch reports by the Futron Corporation, available online: Futron Corporation <http://www.futron.com/resource_center/friends_of_futron/report_archives/launch_report.htm> (date accessed: 25 April 2007)

10 "2005 Satellite Industry Statistics" at 15. The Federal Aviation Administration calculates launch revenues to be about half of these figures, reporting $1.2-billion in 2005 and $1.4-billion in 2006. Federal Aviation Administration, "Commercial Space Transportation 2006 Year in Review" (2006), online: FAA <http://ast.faa.gov/rep_study/yir.htm> (date accessed: 25 April 2007).

11 Peter B. de Selding, "Launch Price Increases Expected despite Overcapacity" *Space News* (19 September 2005).

12 Federal Aviation Administration, "Commercial Space Transportation 2006 Year in Review" at 14.

13 "2005 Satellite Industry Statistics" at 14.

14 "2005 Satellite Industry Statistics."

15 Futron Corporation, "Futron Launch Report" (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; Federal Aviation Administration,

"Commercial Space Transportation: 2005 Year in Review" (January 2006), online: <http://ast.faa.gov/files/pdf/2005_YIR_FAA_AST_0206.pdf> (date accessed: 25 April 2007).

16 Tamar H. Mehuron, "2004 Space Almanac" *Air Force Magazine* (August 2003), online: Air Force Association <http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf> (date accessed: 25 April 2007); Futron Corporation, "Futron Launch Report" (January 2007). 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.

17 "Commercial Space Transportation: 2005 Year in Review" at 7.

18 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> (date accessed: 25 April 2007).

19 Futron Corporation, "Space Transportation Costs: Trends in Price per pound to Orbit 1990-2000" (6 September 2002) at 4-5, online: Futron Corporation <http://www.futron.com/pdf/FutronLaunchCostWP.pdf> (date accessed: 25 April 2007).

20 "China Eyes Commercial Space Flights in 20 Years" Agence-France Presse (3 November 2004).

21 All data derived from Federal Aviation Administration, "Commercial Space Transportation Year in Review" (1997 through 2006), online: FAA <http://ast.faa.gov/rep_study/yir.htm> (date accessed: 25 April 2007).

22 Frank Sietzen, Jr., "The H-II Failure: Japan's Commercial Launch Industry Take a Hit" Space.com (18 November 1999), online: Space.com <http://www.space.com/missionlaunches/l aunches/hs_japan_991118.html> (date accessed: 25 April 2007).

23 Futron Corporation, "Futron Launch Report" (December 2006).

24 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) at 16, online: US Department of State <http://fpc.state.gov/documents/organization/17353.pd> (date accessed: 25 April 2007).

25 Sea Launch, "History", online: <http://www.sea-launch.com/history.htm> (date accessed: 25 April 2007).

26 Sea Launch, "Sea Launch Facilities", online: Sea Launch <http://www.sea-launch.com/slfacilities.htm> (date accessed: 25 April 2007).

27 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. Orbital Sciences Corporation, "Pegasus", online: Orbital Sciences Corporation <http://www.orbital.com/PrinterFriendly.php?NavMenuID=291> (date accessed: 25 April 2007); Transformational Space Corporation, Press Release, "t/Space Demonstrates New Air-Launch Technology" (14 June 2005), online: SpaceRef.com <http://www.spaceref.com/news/viewpr.html?pid=17117> (date accessed: 25 April 2007); Jeremy Singer, "DoD Small-Rocket Contract Produces Fierce Competition" *C4ISR Journal* (2 June 2005), online: C4ISR Journal <http://www.c4isrjournal.com/story.php?F=890851> (date accessed: 25 April 2007); 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?" (26 September 2005), online: Center for Defense Information <http://www.cdi.org/program/document.cfm?documentid=3152&programID=68&from_page=../friendlyversion/printversi on.cfm> (date accessed: 25 April 2007). India aims to cut future satellite launch costs to between $500 and $1000 per kilogram to LEO with a scramjet, but it is not anticipated before 2015. Federal Aviation Administration Commercial Space Transportation, "Quarterly Launch Report, 2nd Quarter 2006" (2006) at 2. V.Brinda et al "Mission Analysis of a Reusable Launch Vehicle Technology Demonstrator, » American Institute of Aeronautics and Astronautics, 13th International Space Planes and Hypersonics Systems and Technologies (2005).

28 Futron Corporation, "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000" (6 September 2002) at 3, online: Futron Corporation <http://www.futron.com/pdf/FutronLaunchCostWP.pdf> (date accessed: 25 April 2007).

29 Prices quoted per pound and converted to per kilogram. "Space Transportation Costs: Trends in Price Per Pound to Orbit 1990-2000" at 4.

30 Federal Aviation Administration Commercial Space Transportation, "Quarterly Launch Report, 2nd Quarter 2006" (2006) at 2. V.Brinda et al "Mission Analysis of a Reusable Launch Vehicle Technology Demonstrator, » American Institute of Aeronautics and Astronautics, 13th International Space Planes and Hypersonics Systems and Technologies (2005).

31 All data derived from Federal Aviation Administration, "Commercial Space Transportation Year in Review" (1997 through 2006), online: FAA <http://ast.faa.gov/rep_study/yir.htm> (date accessed: 25 April 2007). This data differs from the figures provided by the Futron Corporation in Figure 4.2.

32 Missy Frederick, "Internet Mapping Portal Competition Benefits Satellite Imagery Businesses" (24 April 2006).

33 "2005 Satellite Industry Statistics" at 13.

34 *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).

35 Space Foundation, *The Space Report* (2006) at 29.

36 Scaled Composites, Press Release, "SpaceShipOne Makes History: First Private Manned Mission to Space" (21 June 2004), online: Scaled Composites <http://www.scaled.com/projects/tierone/062104-2.htm> (date accessed: 25 April 2007).

37 Federal Aviation Administration, "Suborbital Reusable Launch Vehicles and Emerging Markets" (February 2005) at 6.

38 Leonard David, "Bigelow Aerospace to Take Inflatable Space Habitats" Space.com (24 May 2004), online: *Space.com* <http://www.space.com/news/businessmonday_040524.html> (date accessed: 25 April 2007).

39 Futron Corporation, "Survey of Satellite Industry Professionals" (June 2004) at 4, online: Futron Corporation<www.futron.com/pdf/2004%20ISCe%20Survey%20results.pdf> (date accessed: 25 April 2007).

40 D. Dowd Muska, "Houston, We Have no Purpose" Nevada Journal (November 1998), online: *Nevada Journal* <http://nj.npri.org/nj98/11/cover_story.htm> (date accessed: 25 April 2007).

41 Mark Wade, "USAF to subsidize EELVs", online: Encyclopedia Astronautica. <http://www.astronautix.com/lvs/atlasv.htm> (date accessed: 25 April 2007).

42 US Space Transportation Policy Fact Sheet (6 January 2005).

43 Brian Berger, "SpaceX Fighting for USAF Launches" *Space News* (31 October 2005).

44 Jeff Foust, "A Year-end Reality Check" *Space Review* (29 December 2003), online: *The Space Review* <http://www.thespacereview.com/article/78/1> (date accessed: 25 April 2007).

45 "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.

46 Russian Space Web, "Rockets: Angara Family", online: Russian Space Web <http://www.russianspaceweb.com/angara.html> (date accessed: 25 April 2007); "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> (date accessed: 25 April 2007).

47 "Cash-Strapped Russia Says ISS May Have to Be Mothballed," Center for Defense Information Russia Weekly, No. 224 (27 September 2002), online: CDI <http://www.cdi.org/russia/224-7.cfm> (date accessed: 25 April 2007).

48 Scott Pace et al., "Appendix B: GPS History, Chronology, and Budgets," in The Global Positioning System: Assessing National Policies (RAND 1995) at 248.

49 "Russia to Lift GLONASS Restrictions for Accurate Civilian Use," GPS Daily (14 November 2006), online: <http://www.gpsdaily.com/reports/Russia_To_Lift_Glonass_Restrictions_For_Accurate_Civilian_Use_999.html> (date accessed: 25 April 2007)

50 "China to Launch 2 Satellites for Compass Navigation System" Xinhua (13 November 2006), online: Xinhua English <http://news.xinhuanet.com/english/2006-11/13/content_5322002.htm> (date accessed: 25 April 2007).

51 Pace et al., p. 248-249; Missy Frederick, "Commercial Use of GPS Expanding into More Markets" *Space News* (28 November 2005).

52 Daniel J. Marcus, "Commerce Predicts Big '92 Growth for US Space Business" *Space News* (6 January 1992).

53 Kim Thomas, "Mobile Telephones Offer A New Sense of Direction" *Financial Times* (London) (17 November 2006) at 7.

54 K. Kaisti, *GPS Receivers and LBS Applications* (7 November 2005), slide 11, online: MobileMonday Global <http://media.mobilemonday.net/presentations/2005-11-07_kaisti.pdf.pdf> (date accessed: 25 April 2007).

55 Futron Corporation, "Satellite Insurance Rates on the Rise: Market Correction or Overreaction?" (10 July 2002), online: Futron Corporation <http://www.futron.com/pdf/Futron-SatInsurance.pdf> (date accessed: 25 April 2007).

56 Michael A. Taverna, "Worsening Insurance Crunch Worries Space Industry" A*viation Week & Space Technology* (20 May 2002) at 47.

57 J. Bates, "Satellite Insurance: Market Stabilizes After Tough Stretch" *Via Satellite* (1 June 2006), online: Satellite Today <http://www.satellitetoday.com/cgi/pub/via/via06010606.html> (date accessed: 25 April 2007)

58 "Quarterly Launch Report: 2nd Quarter 2006," FAA Commercial Space Transportation, 2006, p. SR-7.

59 Taverna, at 47; US Federal Aviation Administration, "Commercial Space Transportation Quarterly Launch Report, 4th Quarter" (2002) at 10, online: FAA <http://ast.faa.gov/files/pdf/FourthQuarterFinal.pdf> (date accessed: 25 April 2007).

60 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006 (2006) at SR-8.

61 *A Bill to Facilitate Commercial Access to Space, and for Other Purposes*, Public Law No: 100-657, H.R. 04399 (14 November 1988).

62 *Commercial Space Act of 2003*, HR 3245, 108th Congress (2 October 2003).

63 Satellite Industry Association, "US Space Transportation Policy Review" (11 October 2002), online: SIA <http://www.sia.org/agenda/launch/Space%20Transportation%20Review.pdf> (date accessed: 25 April 2007).

64 Missile Technology Control Regime, online: <http://www.mtcr.info/english/> (date accessed: 25 April 2007).

65 Nuclear Threat Initiative, "China's Export Controls", online: Nuclear Threat Initiative <http://www.nti.org/db/china/excon.htm> (date accessed: 25 April 2007).

66 Steven Pifer, "The US and Russia: Space Cooperation and Export Controls," Testimony before the House Science Committee, Subcommittee on Space and Aeronautics (11 June 2003), online: US Department of State <http://www.state.gov/p/eur/rls/rm/2003/21487.htm> (date accessed: 25 April 2007).

67 *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); Department of Foreign Affairs and International Trade Canada, "Definitions for Terms in Groups 1 and 2", online: DFAIT <http://www.dfait-maeci.gc.ca/trade/eicb/military/gr1-2-en.asp?#spac> (date accessed: 25 April 2007); *Regulations of the People's Republic of China on Export Control of Missiles and Missile-related Items and Technologies* (August 2002), online: Center for Nonproliferation Studies <http://cns.miis.edu/research/china/chiexp/misreg.htm> (date accessed: 25 April 2007); Seema Galut and Anupam Srivastava, "Nonproliferation Export Controls in India" (June 2005), online: Center for International Trade and Security <www.uga.edu/cits/documents/pdf/EXEC%20SUMMARY%2020050616.pdf> (date accessed: 25 April 2007).

68 Satellite Industry Association, "Background: Satellite Export Controls", online: SIA <http://www.sia.org/agenda/trade/History%20of%20Export%20Controls.pdf> (date accessed: 25 April 2007).

69 "Satellite Task Force Report, Factsheet" at 5.

70 Satellite Industry Association, "Effects of Export Controls on the U.S. Satellite Industry: Anecdotal Evidence" at 2, online: SIA <http://www.sia.org/agenda/trade/Effects%20of%20Export%20Control.pdf> (date accessed: 25 April 2007).

71 Peter B. de Selding, "European Satellite Component Maker Says It is Dropping U.S. Components Because of ITAR," *Space News* (9 June 2005).

72 The White House, Fact Sheet, "US Commercial Remote Sensing Space Policy" (13 May 2003), online: White House <http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html> (date accessed: 25 April 2007); "Business Report" *Space News* (27 May 2003).

73 Peter B. de Selding, "France Reviews Spot Imagery Policy" *Space News* (19 October 2001).

74 K.S. Jayaraman, "Russia Wants Access to Indian Satellite Imagery Market" *Space News* (27 January 2003).

75 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) at 431, online: RAND Corporation <http://www.rand.org/pubs/monograph_reports/MR1229/> (date accessed: 25 April 2007); "Proceedings of the Standing Senate Committee on Foreign Affairs, Issue 21 – Evidence – November 22 meeting" (22 November 2005), online: Parliament of Canada <http://www.parl.gc.ca/38/1/parlbus/commbus/senate/Com-e/fore-e/21eva-e.htm?Languag> (date accessed: 25 April 2007). 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.

76 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.

77 McAlister.

78 Patrick Chisholm, "Buying Time: Disconnects in Satcom Procurement" (29 November 2003), online: Military Information Technology <http://www.military-information-technology.com/article.cfm?DocID=285> (date accessed: 25 April 2007).

79 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: AFCEA International <http://www.afcea.org/signal/articles/anmviewer.asp?a=90&print=yes> (date accessed: 25 April 2007).

80 "Satellite Task Force Report, Factsheet," p. 10.

81 The White House, Fact Sheet, "US Commercial Remote Sensing Space Policy" (13 May 2003), online: <http://www.whitehouse.gov/news/releases/2003/05/20030513-8.html> (date accessed: 25 April 2007).

82 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007).

83 Futron Corporation, "Launch Report" (January 2007), online: Futron Corporation <http://www.futron.com/pdf/friends_of_futron_reports/launch_reports/FutronLR2007-01.pdf> (date accessed: 8 February 2007).

84 Futron Corporation, "Launch Report" (January 2006), online: Futron Corporation <http://www.futron.com/pdf/friends_of_futron_reports/launch_reports/FutronLR2006-01.pdf> (date accessed: 8 February 2007).

85 Futron Corporation, "Launch Report" (January 2007), online: Futron Corporation <http://www.futron.com/pdf/friends_of_futron_reports/launch_reports/FutronLR2007-01.pdf> (date accessed: 8 February 2007).

86 Futron Corporation, "State of the Satellite Industry Report" (June 2006), online: Futron Corporation <http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf> (date accessed: 8 February 2007).

87 FAA "2006 Year in Review" at 13.

88 Futron Corporation, "Launch Report" (January 2007), online: Futron Corporation <http://www.futron.com/pdf/friends_of_futron_reports/launch_reports/FutronLR2007-01.pdf> (date accessed: 8 February 2007).

89 Futron Corporation, "State of the Satellite Industry Report" (June 2006), online: Futron Corporation <http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf> (date accessed: 8 February 2007).

90 *Futron Corporation Manufacturing Report* (January 2007).

91 Futron Corporation, "State of the Satellite Industry Report" (June 2006), online: Futron Corporation <http://www.futron.com/pdf/resource_center/reports/SIA_2005_Indicators.pdf> (date accessed: 8 February 2007).

92 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007). Forecast International, T*he Market for Civil and Commercial Remote Sensing Satellites*, cited in European Association of Remote Sensing Companies (EARSC), "Commercial Remote Sensing Satellite Market Stabilizing" (May 2006), online: EARSC <http://www.earsc.org/web/template.php?page=individual&ID=234>.

93 Missy Frederick, "Internet Portal Mapping Competition Benefits Satellite Imagery Business" *Space News* (24 April 2006).

94 Kim Thomas, "Mobile Telephones Offer A New Sense of Direction" *Financial Times* (London) (17 November 2006) at 7.

95 Canalys, "Smart Mobile Device and Navigation Trends Report 2006/2007" (2006), online: Canalys <http://www.canalys.com/reports/index.htm> (date accessed 27 March 2007).

96 Dan Llett, "Heading Toward A Host of Services" *Financial Times* (London) (18 October 2006) at 7; Canalys, "Smart Mobile Device and Navigation Trends Report 2006/2007" (2006), online: Canalys <http://www.canalys.com/reports/index.htm> (date accessed 27 March 2007).

97 Canalys, "Smart Mobile Device and Navigation Trends Report 2006/2007" (2006), online: <http://www.canalys.com/reports/index.htm> (date accessed 27 March 2007).

98 John S. Edwards, "Waiting for the Rebound; Commercial Communications Satellite Makers and Their Suppliers Eye Moderate Market Growth" 164(3) *Aviation Week & Space Technology* (16 January 2006) at 161.

99 Alcatel Alenia Space, Press Release, "Alcatel Alenia Space, Record Orders in 2006" (25 January 2007), online: Alcatel Alenia Space <http://www1.alcatel-lucent.com/space/pdf/pressereleases/AAS_Bilan_2006_EN.pdf> (date accessed: 8 February 2007).

100 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007).

101 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquartersoffices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007); GeoEye Corporation, "Corporate," online: GeoEye Corporation <http://www.geoeye.com/corporate/default.htm> (date accessed: 8 February 2007). SES Global, Press Release, "SES Global Completes Acquisition of New Skies Satellites" (30 March 2006), online: SES Global <http://www.ses-global.com/ses-global/siteSections/mediaroom/Latest_News/06_03_30/index.php> (date accessed: 8 February 2007). Intelsat, News Release, "Intelsat Completes Acquisition of PanAmSat" (3 July 2006), online: Intelsat <http://www.intelsat.com/_files/press_releases/2006/20060703.pdf> (date accessed: 8 February 2007). Telesat, Press Release, "Telesat to be acquired by Canadian Pension Fund PSP Investments and Loral" (18 December 2006), online: Telesat <http://www.telesat.ca/news/2006/06-13.htm> (date accessed: 8 February 2007). Rocketplane-Kistler, "Two Commercial Space Companies Join Forces" (7 March 2006), online: Rocketplane-Kistler <http://www.rocketplanekistler.com>; Frank Morring, Jr., "In Orbit" 164(13) *Aviation Week & Space Technology* (27 March 2006) at 19. Boeing, News Release, "Boeing and Lockheed Martin Complete United Launch Alliance Transaction" (1 December 2006), online: Boeing <http://www.boeing.com/news/releases/2006/q4/061201a_nr.html> (date accessed: 8 February 2007). Lockheed Martin, Press Release, "Lockheed Martin and Boeing Complete United Launch Alliance Transaction" (1 December 2006), online: Lockheed Martin <http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=18050&rsbci=0&fti=112&ti=0&sc=400> (date accessed: 8 February 2007). "News Breaks" 165(14) *Aviation Week & Space Technology* (9 October 2006) at 21; Michael A. Dornheim, "Back to Basics: Government Abandons Commercial Practices on EELV" 164(11) *Aviation Week & Space Technology* (13 March 2006) at 28. Frank Morring, Jr., "Launch Alliance Launch" 165(23) *Aviation Week & Space Technology* (11 December 2006) at 17. Marguerite Reardon "Shareholders approve Alcatel, Lucent merger," CNET News.com, (7 September 2006), online: <http://news.com.com/Shareholders+approve+Alcatel,+Lucent+merger/2100-1037_3-6113357.html> (date accessed: 23 February 2007).

102 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007); GeoEye Corporation, "Corporate," online: GeoEye Corporation <http://www.geoeye.com/corporate/default.htm> (date accessed: 8 February 2007).

103 Telesat, Press Release, "Telesat to be Acquired by Canadian Pension Fund PSP Investments and Loral" (18 December 2006), online: Telesat <http://www.telesat.ca/news/2006/06-13.htm> (date accessed: 8 February 2007).

104 "News Breaks" 165(14) *Aviation Week & Space Technology* (9 October 2006) at 21; Michael A. Dornheim, "Back to Basics: Government Abandons Commercial Practices on EELV" 164(11) Aviation Week & Space Technology (13 March 2006) at 28.

105 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007).

106 Lockheed Martin, Press Releases, "Lockheed Martin Completes Sale of International Launch Services" (11 October 2006), online: Lockheed Martin <http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=17969&rsbci=0&fti=112&ti=0&sc=400>; "Lockheed Martin Plans to Take over Marketing" 165(10) Aviation Week & Space Technology (11 September 2006) at 16.

107 FAA "2006 Year in Review," at 7.

108 K.S. Jayaraman, "Indian GSLV Fails in Fourth Flight" *Space News* (10 July 2006).

109 FAA "2006 Year in Review," at 13.

110 The Aerospace Corporation, "Study of the Liability Risk-Sharing Regime in the United States for Commercial Space Transportation<' (1 August 2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarter_offices/ast/report_studies/media/Risk_Study(final).pdf> (date accessed: 8 February 2007).

111 Renae Merle, "Rocket Monopoly Approved," *Washington Post* (4 October 2006), at D01.

112 "The Declining US Role in The Commercial Launch Industry," (June 2005) online: Futron Corporation <http://www.futron.com/pdf/US%20Commercial%20Launch%20Industry%20White%20Paper.pdf> (date accessed: May 2005).

113 Merle at D01.

114 NASA "NASA Invests in Private Sector Spaceflight with SpaceX, Rocketplane-Kistler" NASA: Exploration News (18 August 2006), online: NASA <http://www.nasa.gov/mission_pages/exploration/news/COTS_selection_prt.htm> (date accessed: 8 February 2007).

115 NASA "NASA Invests in Private Sector Spaceflight with SpaceX, Rocketplane-Kistler" NASA: Exploration News (18 August 2006), online: NASA <http://www.nasa.gov/mission_pages/exploration/news/COTS_selection_prt.htm> (date accessed: 8 February 2007); Brian Berger, "SpaceX, Rocketplane Kistler Win NASA COTS Competition" Space.com (18 August 2006), online: *Space.com* <http://www.space.com/news/060818_nasa_cots_wrap.html> (date accessed: 8 February 2007).

116 Brian Berger, "Falcon 1 Failure Traced to Busted Nut," *Space News* (19 July 2006).

117 Ryan Chilcote, "Female Space Tourist Blasts Off" CNN.com (18 September 2006), online: CNN.com <http://www.cnn.com/2006/TECH/space/09/18/space.female.tourist/index.html> (date accessed: 8 February 2007).

118 California Space Authority, "California Space Enterprise Strategic Plan 2007-2010" (November 2006) at 24, online: California Space Authority <http://www.californiaspaceauthority.org/images/pdfs/strat-plan-2007.pdf> (date accessed: 8 February 2007).

119 ESA, "ESA to Help Europe Prepare for Space Tourism" (20 July 2006), online: ESA <http://www.esa.int/SPECIALS/GSP/SEM2YABUQPE_0.html> (date accessed: 8 February 2007). As part of the initiative European private companies with plans for space tourism activities may

submit proposals to ESA, which will select a maximum of three that will receive further study. Each company that submits a proposal selected by ESA will receive € 150,000 to assist in developing its ideas.

120 Warren Ferster, "Private Space Habitat Could Launch by 2010" Space.com (21 September 2006), online: Space.com <http://www.space.com/news/060921_bigelow_plans.html> (date accessed: 8 February 2007).

121 Leonard David, "Bigelow's Big Gamble: Building a Space Station" Space.com (21 July 2006), online: Space.com <http://www.space.com/news/060721_genesis-1_impact.html> (date accessed: 8 February 2007).

122 Space Adventures, Press Release, "Space Adventures Announces $265 Million Spaceport Development Project" (17 February 2006), online: Space Adventures <http://www.spaceadventures.com/media/releases/2006-02/347>; FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007).

123 FAA Commercial Space Transportation, "Quarterly Launch Report: 2nd Quarter 2006" (2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2Q2006_QLR.pdf> (date accessed: 8 February 2007); Heath Haussamen, "Richardson Signs Spaceport Bills into Law" Las Cruces [New Mexico] Sun-News (2 March 2006) at 1A.

124 Leonard David, "Oklahoma Spaceport Gets AST Nod to Operate a Launch Site" Space.com (29 June 2006), online: Space.com <http://www.space.com/spacenews/archive06/Ports_062606.html> (date accessed: 8 February 2007).

125 US Government Accountability Office, "Commercial Space Launches: FAA Needs Continued Planning and Monitoring to Oversee the Safety of the Emerging Space Tourism Industry" (20 October 2006), online: GAO <http://www.gao.gov/new.items/d0716.pdf (date accessed: 8 February 2007).

126 FAA Commercial Space Transportation, "New Regulations Govern Private Human Spaceflight Requirements for Crew and Spaceflight Participants" (15 December 2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/human_space_flight_reqs/> (date accessed: 8 February 2007); See also *Human Spaceflight Requirements for Crew and Spaceflight Participants; Final Rule*, 71 Fed. Reg. 75616 (2006).

127 Safety Approvals; Final Rule, 71 Fed. Reg. 46847 (2006).

128 Michael Fabey, "Firms See Opportunity in US Sat Delays," Defense News (27 March 2006) at 1, 8; Dawn S. Onley, "Military Leaders Recognize Limitations on Launching their Own Birds," Government Computer News (20 March 2006), online: Government Computer News <http://www.gcn.com/cgi-bin/udt/im.display.prntable?client.id=gcn&story.id=4068> (date accessed: 8 February 2007).

129 Bob Brewin, "Satellite Development Delays Cost DOD $1B," FCW.com (26 January 2007), online: FCW.com <http://www.fcw.com/article97492-01-26-07-Web> (date accessed: 8 February 2007).

130 David Cavossa, Satellite Industries Association Executive cited in Jerome Bernard, "US Using Space Supremacy to Wage Combat in Iraq, Afghanistan," Defense News (23 June 2006), online: Defensenews.com <http://www.defensenews.com/story.php?F=1890797&C=airwar> (date accessed: 8 February 2007).

131 US Government Accountability Office, "Congressional Requesters, Subject: Department of Defense Actions to Modify its Commercial Communications Satellite Services Procurement Process" (17 April 2006), online: US Government Accountability Office <http://www.gao.gov/new.items/d06480r.pdf> (date accessed: 8 February 2007).

132 US Department of Defense, "Contracts," Defenselink (6 Janaury 2006) online: US Department of Defense <http://www.defenselink.mil/Contracts/Contract.aspx?ContractID=3168> (date accessed: 8 February 2007).

133 "India says no to Google Earth's peering," PhysOrg.com (10 March 2006), online: PhysOrg.com <http://www.physorg.com/news11634.html> (date accessed: 8 February 2007).

134 Satellite Industry Association, "Director's Report" (31 January 2006), online: SIA <http://www.sia.org/news_events/drarchive/2006.html>.

135 John M. Doyle & Michael L. Bruno, "Don't Hold Your Breath; Even if Leadership in Congress Changes Next Year, There's Little Appetite For Big Reforms in Export Control Laws" 165(3) *Aviation Week & Space Technology* (17 July 2006) at 100; California Space Authority, "California Space Enterprise Strategic Plan 2007-2010" (November 2006) at 21, online: California Space Authority <http://www.californiaspaceauthority.org/images/pdfs/strat-plan-2007.pdf> (date accessed: 8 February 2007).

136 FAA Commercial Space Transportation, "2006 Commercial Space Transportation Forecasts" (May 2006), online: FAA/AST <http://www.faa.gov/about/office_org/headquarters_offices/ast/media/2006_Forecast_GSO_NGSO_May_24.pdf> (date accessed: 8 February 2007).

137 Frank Morring, Jr., "Target Practice; Inexperience, Ignorance and ITAR Cited in Failure of DART Exploration Testbed" 164(21) *Aviation Week and Space Technology* (22 May 2006) at 37.

138 Neelam Mathews, Michael A. Taverna & Frank Morring, Jr., "Easing Exports; New Pacts Will Simplify Launches of US Spacecraft from India" 164(11) *Aviation Week & Space Technology* (13 March 2006) at 26.

139 Eurospace, "The European Space Industry in 2005. Industry Facts and Figures" (June 2006), online: Eurospace <http://www.eurospace.org/> (date accessed: 8 February 2007).

140 *United States National Space Policy, Unclassified* (31 August 2006), online: Executive Office of the President, Office of Science and Technology Policy <www.ostp.gov/html/US%20National%20Space%20Policy.pdf> (date accessed: 8 February 2007).

141 *China's Space Activities in 2006*, People's Daily Online (12 October 2006), online: People's Daily <http://english.people.com.cn/200610/12/eng20061012_311157.html> (date accessed: 8 February 2007).

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: Space Daily <http://www.spacedaily.com/news/satellite-biz-03zzzl.html> (date accessed: 9 February 2007).

2 Jonathan McDowell, "Satellite Database," updated January 2007, unpublished.

3 Jonathan McDowell, "Satellite Database." It is difficult to assess the lifetime of Russian military spacecraft, and thus to have a reliable count of the number of active Russian satellites.

4 Tamar A. Mehuron, "2004 Space Almanac" Air Force Magazine (August 2004) at 43, online: The Air Force Association <http://www.afa.org/magazine/Aug2004/0804space_alm.pdf> (date accessed: 9 February 2007).

5 Mehuron at 44.

6 Glen Elfers and Stephen B. Miller, "Future US Military Satellite Communications Systems" Crosslink (Winter 2002).

7 Mehuron at 43-46.

8 Verger, et al. at 344.

9 Mehuron at 44.

10 Verger, et al. at 336.

11 Verger, et al. at 337.

12 Verger, et al. at 337, 339.

13 Verger, et al. at 338.

14 Union of Concerned Scientists, "Satellite Database," (January 2007). There are at least two NROL classified satellites operated by the National Reconnaissance Office, which are believed to be either radar reconnaissance or SIGINT.

15 Mehuron at 44.

16 Union of Concerned Scientists, "Satellite Database," (January 2007).

17 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) at 3, online: Department of Defense, Office of Force Transformation <http://www.oft.osd.mil/initiatives/ors/Cebrowski%20Testimony.doc> (date accessed: 9 February 2007).

18 James Canan, "Renaissance for Military Space" Aerospace America (June 2003), online: American Institute of Aeronautics and Astronautics <http://www.aiaa.org/aerospace/Article.cfm?issuetocid=364&ArchiveIssueID=39> (date accessed: 9 February 2007).

19 Robert K. Ackerman, "Small Satellite Offers Glimpse of the Future" Signal Magazine (January 2004); Gunter Dirk Krebs, "TacSat 1" (1 January 2005), online: Gunter's Space Page <http://space.skyrocket.de/index_frame.htm?http://space.skyrocket.de/doc_sdat/tacsat-1.htm> (date accessed: 9 February 2007).

20 M. Hurley, "Tactical Microsatellite Experiment (TacSat 1)" Navy Research Laboratory Review (2004), online: US Naval Research Laboratory <http://www.nrl.navy.mil/content.php?P=04REVIEW207> (date accessed: 9 February 2007).

21 US Air Force, Fact Sheet, "Evolved Expendable Launch Vehicle" (April 2003), online: <http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=3643> (date accessed: 9 February 2007); Anthony Young, "Heavy Lifting for the New Millennium" The Space Review (26 April 2004).

22 Young (26 April 2004); Tariq Malik, "Delta 4 Heavy Rocket Lifts off for First Time" MSNBC (21 December 2004), online: MSNBC.com <http://www.msnbc.msn.com/id/6743383/> (date accessed: 9 February 2007).

23 "Evolved Expendable Launch Vehicle" (January 2005).

24 "Report of the Commission to Assess United States National Security Space Management and Organization" (11 January 2001) at 8-9, online: Federation of American Scientists <www.fas.org/spp/military/commission/report.htm> (date accessed: 9 February 2007). 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) at 4.

25 Fernand Verger, Isabelle Sourbes-Verger, and Raymond Ghirardi, *The Cambridge Encyclopedia of Space* (Cambridge: Cambridge University Press, 2003) at 70-72; Gunter Dirk Krebs, "Chronology", online: Gunter's Space Page <http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/home.htm> (date accessed: 9 February 2007); NASA, "Worldwide Space Launches 2004", online: NASA <http://www.hq.nasa.gov/osf/2004/launch04.html> (date accessed: 9 February 2007). Johnathan McDowell, "Satellite Database," (January 2007), unpublished.

26 "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) at 5. There is still only one satellite in orbit as of the January 2007, Union of Concerned Scientists, "Satellite Database."

27 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: Russian Strategic Nuclear Forces <http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml> (date accessed: 9 February 2007).

28 Podvig.

29 Podvig.

30 Podvig; see also Verger, et al. at 349.

31 "Russian Space Conference Looks at Problems and Challenges" (25 November 2005), online: RedOrbit.com <http://www.redorbit.com/news/space/302983/russian_space_conference_looks_at_problems_challenges/index.html> (date accessed: 26 April 2007).

32 Pavel Podvig, "History and the Current Status of the Russian Early Warning System" 10 *Science and Global Security* (2002) at 21-60.

33 Podvig, "History and the Current Status of the Russian Early Warning System" at 21-60.

34 Podvig, "History and the Current Status of the Russian Early Warning System."

35 Verger, et al. at 341.

36 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).

37 Podvig, "Russia and Military Uses of Space."

38 Verger, et al. at 319-323.

39 Podvig, "Russia and Military Uses of Space".

40 Mission Control Centre, "GLONASS Constellation Status for 06.12.06 under the Analysis of the Almanac Accepted in IANC", online: Mission Control Centre <http://www.mcc.rsa.ru/IACKVO/ENG/StatSys/OrbCon/m_sostOG_en.htm> (date accessed: 9 February 2007). "Three Glonass-M navigation satellites join constellation," *Russian Strategic Nuclear Forces – Blog*, 25 December 2006. Online: http://russianforces.org/blog/2006/12/three_glonassm_navigation_sate.shtml.

41 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: CDI <http://www.cdi.org/program/issue/document.cfm?DocumentID=2322&IssueID=140&StartRow=1&ListRows=10&appendURL=&Orderby=DateLastUpdated&ProgramID=68&issueID=140#3> (date accessed: 9 February 2007); "Russia Does Not Plan Launching Nuclear Weapons in Space," ITAR-TASS (14 July 2004).

42 "No More Reductions of Russian Satellite Fleet Planned" Interfax (14 July 2004).

43 Verger, et al. at 70-72; Gunter Dirk Krebs, "Chronology", online: Gunter's Space Page <http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/home.htm> (date accessed: 9 February 2007); NASA, "Worldwide Space Launches 2004", online: NASA <http://www.hq.nasa.gov/osf/2004/launch04.html> (date accessed: 9 February 2007).

44 Verger, et al. at 70-72; Molczan and Pike.

45 Verger, et al. at 70-72.

46 Verger, et al. at 72.

47 Theresa Hitchens & Tomas Valasek, "National Programs" in Theresa Hitchens & Tomas Valasek, *European Military Space Capabilities, A Primer* (Center for Defense Information, 2006) at 24.

48 "Europe begins debate on next-generation spy satellites," *Defense News* (6 February 2006).

49 French Imagery Intelligence, "The First European Military Observation Satellite", online: Federation of American Scientists <http://www.fas.org/spp/guide/france/military/imint/helios1a.htm> (date accessed: 9 February 2007).

50 CNES, "Pléiades: A Multi-Missions Concept and a Partnership Program", online: CNES <http://smsc.cnes.fr/PLEIADES/> (date accessed: 9 February 2007).

51 "European Rocket Sends French Military Satellite Aloft" *Space News* (28 November 2005).

52 EADS Astrium, Press Release, "EADS Astrium Selects Arianespace to Launch Spirale" (17 October 2005), online: EADS Astrium <http://www.astrium.eads.net/press-center/archives/2005/eads-astrium-selects-arianespace-to-launch-spirale> (date accessed: 9 February 2007).

53 For a discussion see online: Federation of American Scientists <http://www.fas.org/spp/guide/france/military/imint/> (date accessed: 9 February 2007).

54 *Military Balance 2003-2004* at 230.

55 *Military Balance 2003-2004* at 257.

56 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" (10 February 2005), online: Gunters Space Page <http://space.skyrocket.de/doc_sdat/sar-lupe.htm> (date accessed: 9 February 2007).

57 Alenia Spazio, "COSMO-Skymed", online: Alenia Spazio <http://www.aleniaspazio.it/earth_observation_page.aspx?IdProg=23> (date accessed: 9 February 2007).

58 *Military Balance 2003-2004* at 230.

59 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) at 25.

60 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) at 14.

61 GlobalSecurity.org, "China Military Space Projects", online: GlobalSecurity.org <http://www.globalsecurity.org/space/world/china/military.htm> (date accessed: 9 February 2007).

62 Mark Stokes, "Appendix III: Space Support for Strategic Modernization" at 173; and "Chapter 2: Foundations of Strategic Modernization" at 6, both in *China's Strategic Modernization: Implications for the United States* (Strategic Studies Institute, September 199).

63 GlobalSecurity.org, "China and Imagery Intelligence", online: GlobalSecurity.org <http://www.globalsecurity.org/space/world/china/imint.htm> (date accessed: 9 February 2007).

64 "Government and Non Government Space Programs: China" Jane's Space Directory (14 October 2004).

65 *Military Balance 2003-2004* at 230, 304.

66 "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) at 6.

67 Surrey Satellite Technologies Ltd., SSTL Space Missions, "Disaster Monitoring and High-Resolution Imaging" (2005), online: SSTL <http://www.sstl.co.uk/index.php?loc=121> (date accessed: 9 February 2007). It has been reported that "Government departments will also use the satellite during

emergencies to aid decision-making of the central government." From "Beijing-1 Satellite Starts Remote Sensing Service," *People's Daily Online*, 8 June 2006. Online: http://english.people.com.cn/200606/08/eng20060608_272262.html.

68 John Pike, "The Military Uses of Outer Space" in *SIPRI Yearbook 2002* (Oxford: Oxford University Press: 2002) at 24; Center for Nonproliferation Studies, "China: Military Programs", online: Center for Nonproliferation Studies <http://cns.miis.edu/research/space/china/mil.htm> (date accessed: 9 February 2007).

69 Pike at 24.

70 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" 12 Science and Global Security (2004) at 232.

71 James Lewis, "China as a Military Space Competitor" at 12, online: Space Policy Institute <http://www.gwu.edu/~spi/spaceforum/China.pdf> (date accessed: 9 February 2007).

72 Indian Space Research Organization, "Indian Space Research Organization Annual Report 2004-2005" (2005), online: ISRO <http://www.isro.org/rep2005/EOS.htm> (date accessed: 9 February 2007).

73 *Military Balance 2003-2004* at 291. AerospaceGuide.net, "Pakistan's Space Program" (27 March 2007), online: AerospaceGuide.net <http://www.aerospaceguide.net/worldspace/pakistan.html> (date accessed: 26 April 2007).

74 "India to Set Up Military SBS System by 2007" *Space News* (9 August 2005).

75 *Military Balance 2003-2004* at 292.

76 "Pakistan to Launch Remote Sensing Satellite System" Dawn (22 August 2005).

77 Gunter Dirk Krebs, "IGS-Optical 1, 2" (4 January 2005), online: Gunter's Space Page <http://www.skyrocket.de/space/doc_sdat/igs-optical-1.htm> (date accessed: 9 February 2007); Gunter Dirk Krebs, "IGS-Radarl 1, 2" (4 January 2005), online: Gunter's Space Page <http://www.skyrocket.de/space/doc_sdat/igs-radar-1.htm> (date accessed: 9 February 2007).

78 Globalsecurity.org, "Information Gathering Satellites: Imagery Intelligence", online: Globalsecurity.org <http://www.globalsecurity.org/space/world/japan/imint.htm> (date accessed: 9 February 2007).

79 Paul Kallender-Umezu, "Japan Plans to Launch 3 Satellites" Defense News (13 September 2004) at 23; "Japan Plans to Develop Advanced Spy Satellite" SPX (27 September 2004), online: Space Daily <http://www.spacedaily.com/news/spysat-04c.html> (date accessed: 9 February 2007).

80 "Japan to Deploy Intelligence System" *Space News* (11 January 2005).

81 Kim Yong-ho, "Air Force Begins Establishment of the Space Command Center in Full-Scale" *Seoul Kukpang Journal* (1 December 2003).

82 Pike at 641.

83 The order was placed in 1996. *Military Balance 2003-2004* at 306.

84 "Thailand Signs Deal with French Company for Spy Satellite" Agence-France Presse (19 July 2004).

85 "Taiwan Planning Spy Satellite: Report" Agence France-Presse (10 October 2005); "Taiwant Plans Launch of Spy Satellite" *Mail and Guardian* (10 October 2005).

86 "Israel Launch New Satellite" Defense Update (Updated 9 July 2002), online: Defense Update <http://www.defense-update.com/news/ofeq5.htm> (date accessed: 9 February 2007); Military Balance 2003-2004 at 230. The launch of Ofek-4 in 1999 failed. *Military Balance 2003-2004* at 281.

87 Wendy Elliman, "Israel in Space" (January 2003), online: Israel Ministry of Foreign Affairs <http://www.mfa.gov.il/mfa/mfaarchive/2000_2009/2003/1/focus%20on%20israel-%20israel%20in%20space> (date accessed: 9 February 2007). Ori Lewis, "Israel Launches Satellite

Over Iran" Defense News (25 April 2006), online: DefenseNews.com <http://defensenews.com/story.php?F=1729480> (date accessed: 26 April 2007).

88 "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 at 6.

89 Arieh O'Sullivan, "Successful Test of New Rocket Launcher" *Jerusalem Post* (14 July 2005).

90 Yitaf S. Shapir, "The Spirit is Willing: Iran's Effort to conquer Space" 152 Tel Aviv Notes (6 November 2005); Ali Akbar, "Iran Now Syas Satellite Can Spy on Israel" Associated Press (16 November 2005).

91 Robin Hughes, "Long Range Ambitions" *Jane's Defence Weekly* (13 September 2006) at 26.

92 GlobalSecurity.org, "Australia and Satellite Communication Systems", online: Globalsecurity.org <http://www.globalsecurity.org/space/world/australia/comm.htm> (date accessed: 9 February 2007).

93 Stephen Butler, "DSTO Plans Unique Test Phase to Model New Era Defence C1 Communications Satellite" (23 June 2003), online: Australian Defence Science and Technology Organization, <http://www.dsto.defence.gov.au/news/3775/> (date accessed: 9 February 2007).

94 David Pugliese, "Canada Nears Access To Dedicated Milsats" 21 (37) Defense News (25 September 2006) at 16.

95 DND/CF News Release, "Project Polar Epsilon Will Enhance Canada's Surveillance and Security Capability" (2 June 2005), online: Canada National Defence <http://www.forces.gc.ca/site/newsroom/view_news_e.asp?id=1674> (date accessed: 9 February 2007).

96 Stephen Thorne, "Feds Look to Satellite to Assert Arctic Sovereignty" Canadian Press (28 August 2005).

97 Verger, et al. at 72; Gunter Dirk Krebs, "Spacecraft: Military", online: Gunter's Space Page <http://www.skyrocket.de/space/space.html> (date accessed: 9 February 2007); Small Satellites Home Page, "Modern Military Small Satellites", online: Surrey Satellite Company <http://centaur.sstl.co.uk/SSHP/list/list_mil.html> (date accessed: 9 February 2007). Union of Concerned Scientists, "Satellite Database."

98 Greece and Belgium also use the Helios satellites through their participation in the Besoin Operationnel Commune framework agreement, but they do not have independent dedicated military satellites.

99 "US Military Space Programs Seen Facing Budget Cuts" Reuters (20 November 2006), online: Reuters <http://yahoo.reuters.com/news/articlehybrid.aspx?storyID=urn:newsml:reuters.com:20061121:MTFH49730_2006-11-21_00-25-53_N20320919&type=comktNews&rpc=44> (date accessed: 9 February 2007).

100 Jeremy Singer, "Delta 2 Launches USAF's Third GPS 2RM Satellite" *Space News* (17 November 2006).

101 "America's Wideband Gapfiller Satellite Program," *Defense Industry Daily* (26 April 2007), online: Defense Industry Daily < http://www.defenseindustrydaily.com/2007/04/americas-wideband-gapfiller-satellite-program/index.php> (date accessed: 26 May 2007).

102 Boeing, News Release, "Boeing to Build Fourth USAF WGS" (9 November 2006), online: Boeing <http://www.boeing.com/news/releases/2006/q4/061109a_nr.html> (date accessed: 9 February 2007).

103 "Northrop Grumman Team Achieves Critical Test Milestone for High-Data-Rate Laser Communication System" (31 March 2006), online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=96555> (date accessed: 9 February 2007).

104 "T-SAT Budget Designed to Win Back Congress" *Space News* (20 February 2006), online: The Eisenhower Institute <http://www.eisenhowerinstitute.org/programs/globalpartnerships/fos/newfrontier/S-Watch2006-2-20.htm> (date accessed: 9 February 2007).

105 "Special Report: The USA's Transformational Communications Satellite system (TSAT-Updated)," Defense Industry Daily (18 May 2007), online: Defense Industry Daily <http://www.defenseindustrydaily.com/2007/05/special-report-the-usas-transformational-communications-satellite-system-tsat-updated/index.php> (date accessed: 29 May 2007).

106 Michael Fabey (18 December 2006).

107 Andrea Shalal-Esa, "US Air Force Focusing on New Satellite Plan" Reuters (25 September 2006), online: SignOnSanDiego.com <http://www.signonsandiego.com/news/business/20060925-1343-arms-satellites.html> (date accessed: 9 February 2007).

108 "Special Report: The USA's Transformational Communications Satellite system (TSAT-Updated)," Defense Industry Daily (18 May 2007), online: Defense Industry Daily <http://www.defenseindustrydaily.com/2007/05/special-report-the-usas-transformational-communications-satellite-system-tsat-updated/index.php> (date accessed: 29 May 2007).

109 Missy Frederick, "Growing Use of UAVs Strains Bandwidth," *Space News* (17 July 2006).

110 "Lockheed Martin Delivers Key Payload Hardware for the Second Missile Warning Satellite" Space War (27 October 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Lockheed_Martin_Delivers_Key_Payload_Hardware_For_Second_Missile_Warning_Satellite_999.html> (date accessed: 9 February 2007).

111 United States Government Accountability Office, "Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems," Report to Sub-Committee on Strategic Forces, Committee on Armed Services, House of Representatives (17 November 2006), online: GAO <http://www.gao.gov/new.items/d0796.pdf> (date accessed: 26 April 2007).

112 Paul Dykewicz, "Next Generation Weather Satellite Faces Critical Review" Defense News (13 March 2006) at 44.

113 "Defense Policy Changes Could be Advantageous to Lockheed Martin" Space Security Update (8 June 2006), online: Center for Defense Information <http://www.cdi.org/program/document.cfm?DocumentID=3499&from_page=../index.cfm#contents> (date accessed: 9 February 2007).

114 Andrea Shalal-Esa, "NRO spy Satellite Maybe Total Loss" Reuters (6 March 2007), online: Reuters <http://www.reuters.com/article/newsOne/idUSN0638934120070307> (date accessed: 9 February 2007)

115 "New Era of Rocket Launches begins from California Base" Spaceflight Now (27 June 2006), online: Spaceflight Now <http://www.spaceflightnow.com/delta/d317/> (date accessed: 9 February 2007). Open sources disagree as to what the purpose of the NROL-22 may be. The Union of Concerned Scientists "Satellite Database" lists it as a reconnaissance satellite, as does Aviation week, however others suspect that it may be a next-generation SIGINT satellite. See Jonathan's Space Report, "NROL-22," No. 567 (6 July 2006), online: Jonathan's Space Report <http://www.planet4589.org/space/jsr/back/news.567> (date accessed: 29 May 2007).

116 Air Force Research Laboratory, Factsheets, "TacSat 2 Microsatellite (Current as of September 2006)", online: Air Force Research Laboratory <www.vs.afrl.af.mil/factsheets/tacsat-2.pdf> (date accessed: 26 April 2007).

117 Andreas Parsch, "X-37/X-40" (2006), online: Directory of U.S. Military Rockets and Missiles <http://www.designation-systems.net/dusrm/app4/x-37.html> (date accessed: 1 June 2007).

118 Space Exploration Technologies Corporation, "Official Falcon 1 Launch Manifest", online: SpaceX <www.spacex.com> (date accessed: 9 February 2007).

119 "Russia's Space Defenses Stage a Revival" NOVOSTI (4 October 2006), online: RIA Novosti <http://en.rian.ru/analysis/20061004/54509604-print.html> (date accessed: 9 February 2007).

120 Russian Strategic Nuclear Forces, “Military Launches in 2006” (5 May 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/05/military_launches_in_2006_eigh.shtml> (date accessed: 9 February 2007).

121 Russian Strategic Nuclear Forces, “Launch of Naval Reconnaissance Satellite” (25 June 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/06/launch_of_cosmos2421_naval_rec.shtml> (date accessed: 9 February 2007).

122 Russian Strategic Nuclear Forces, “End of Cosmos 2423 Mission” (21 November 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/11/end_of_cosmos2423_mission.shtml> (date accessed: 9 February 2007).

123 “Officials Deny that Russia’s Cosmos De-orbited over Breakdown” NOVOSTI (20 November 2006), online: RIA Novosti - Russia <http://en.rian.ru/russia/20061120/55824706.html> (date accessed: 9 February 2007).

124 Russian Strategic Nuclear Forces, “Cosmos 2422 Launch Seems to Upgrade the Early Warning System” (21 July 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/07/cosmos2422_launch_seems_to_aim.shtml> (date accessed: 9 February 2007).

125 Russian Strategic Nuclear Forces, “Launch of Meridian Communications Satellite” (24 December 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/12/launch_of_meridian_communicati.shtml> (date accessed: 9 February 2007).

126 “Russian Space Conference Looks at Problems and Challenges” (25 November 2005), online: News RedOrbit <http://www.redorbit.com/news/space/302983/russian_space_conference_looks_at_problems_challenges/index.html http://www.planet4589.org/space/jsr/back/news.575>

127 “Russia to Restore Space Missile Warning System” Johnson’s Russia List (6 April 2006), online: Center for Defense Information <http://www.cdi.org/russia/johnson/9112-27.cfm> (date accessed: 8 February 2007).

128 Russian Strategic Nuclear Forces, “Three GLONASS M Communications Satellites Join Constellation” (25 December 2006), online: Russian Strategic Nuclear Forces <http://russianforces.org/blog/2006/12/three_GLONASSm_navigation_sate.shtml> (date accessed: 9 February 2007).

129 KROSS Aerospace, “Four more GLONASS-M Satellites to be Orbited in 2006” (20 March 2006), online: Aerospace - Knowledge Research Open Source Solutions <http://www.kross.ro/defense/defense_industry/aerospace> (date accessed: 9 February 2007).

130 “Japanese Spy Satellite Rockets into Orbit” Space Flight (11 September 2006), online: Spaceflight Now <http://www.spaceflightnow.com/news/n0609/11h2aigs/> (date accessed: 9 February 2007).

131 “Japanese Military Going into Space” Space Daily (5 June 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Japanese_Military_Going_Into_Space.html> (date accessed: 9 February 2007).

132 “Sea Launch Delivers Koreasat 5 Satellite to Orbit” Space Travel (23 August 2006), online: Space Exploration and Technology News at Space-Travel.com <http://www.space-travel.com/reports/Sea_Launch_Delivers_Koreasat_5_Satellite_To_Orbit_999.html> (date accessed: 9 February 2007).

133 “Koreasat 5 Launched” Asia Satellite News (29 August 2006), online: TelecomsEurope <http://www.telecomseurope.net/article.php?id_article=2979> (date accessed: 26 April 2007).

134 “Russian Rocket Launches South Korea’s Kompsat 2” NOVOSTI (28 July 2006), online: GIS Development: The Geospatial Resource Portal <http://www.gisdevelopment.net/news/print.asp?id=GIS:N_sawjfmqrvz&cat=New+Products&subc=Satellite+Imagery> (date accessed: 9 February 2007).

135 Spot Image, "Kompsat 2: The Alternative Metric Solution" online: Spot Image <http://www.spotimage.fr/html/_167_171_1155_.php> (date accessed: 9 February 2007).

136 "Taiwanese Military Shows Satellite Images of China's Military Build-up" Yahoo! Asia News (20 January 2006), online: Yahoo! Asia News < http://asia.news.yahoo.com/060119/kyodo/d8f7mj280.html> (date accessed: 9 February 2007).

137 "Fenghuo-1 Military Communications Satellite" Chinese Defence Today (14 September 2006), online: SinoDefence.com <http://www.sinodefence.com/strategic/spacecraft/fenghuo1.asp> (date accessed: 9 February 2007).

138 John Pike, "The Military Uses of Outer Space" in *SIPRI Yearbook 2002* (Oxford: Oxford University Press: 2002) at 24; Center for Nonproliferation Studies, "China: Military Programs", online: Center for Nonproliferation Studies <http://cns.miis.edu/research/space/china/mil.htm> (date accessed: 26 April 2007).

139 "Remote Sensing Satellite Successfully Launched" Xinhua (27 April 2006), online: Xinhuanet <http://news.xinhuanet.com/english/2006-04/27/content_4480989.htm> (date accessed: 9 February 2007).

140 "JianBing-5/Remote Sensing Satellite-1 Synthetic Aperture Radar Satellite" Chinese Defence Today (17 May 2006), online: SinoDefence.com <http://www.sinodefence.com/strategic/spacecraft/jianbing5.asp> (date accessed: 9 February 2007). Union of Concerned Scientists, "Satellite Database" (updated January 2007),online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/satellite_database.html> (date accessed: 16 April 2007).

141 "CZ 4B Chronology" (2007), online: Astronautix <http://www.astronautix.com/lvs/cz4b.htm> (date accessed: 24 April 2007).

142 "China to Launch 'Sinosat-3' after Previous Satellite Failure" China Daily (28 November 2006), online: China Daily Website <http://www.chinadaily.com.cn/china/2006-11/28/content_745252.htm> (date accessed: 9 February 2007).

143 Globasecurity.org, "DFH-4" (27 April 2005), online: Globasecurity.org <http://www.globalsecurity.org/space/world/china/dfh-4.htm> (date accessed: 9 February 2007).

144 "China Starts to Build Own Satellite Navigation System" GPS Daily (3 November 2006), online: GPS News <http://www.gpsdaily.com/reports/China_Starts_To_Build_Own_Satellite_Navigation_System_999.html> (date accessed: 9 February 2007)

145 Peter B. de Selding, "Europeans Raise Red Flags Over Chinese Satellite Navigation Plan" *Space News* (12 June 2006).

146 "German Radar Spy Satellite Launches into Space" Spaceflight Now (19 December 2006), online: Spaceflight Now <http://www.spaceflightnow.com/news/n0612/19sarlupe/> (date accessed: 9 February 2007).

147 Tom Kington "Crunch Time for Europe" Defense News (6 February 2006) at 11.

148 Peter B. De Selding, "OHB to Build French-German Recon Satellite Interface" *Space News* (1 December 2006).

149 "German Forces Will Receive Secure Network with Two Satellites" Space War (9 July 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/German_Armed_Forces_Will_Receive_Secure_Network_With_Two_Satellites_999.html> (date accessed: 9 February 2007).

150 "Successful Launch of French Military Communications Satellite" Space War (15 August 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Successful_Launch_Of_French_Military_Communications_Satellite_Syracuse_3B_999.html> (date accessed: 9 February 2007).

151 "Spainsat Communications Satellite Successfully Launched" (11 March 2006), online: Space Systems/Loral <http://www.ssloral.com/html/pressreleases/pr20060313.html>

152 Peter B. De Selding, "Biove B launch slips to 2007" *Space News* (1 September 2006).

153 "Galileo navigation satellites hugely over budget," *New Scientist* (23 May 2006), online: NewScientist.com <http://www.newscientist.com/article.ns?id=dn9210> (date accessed: 22 May 2007).

154 George Parker, "Call to consider EU Galileo for Military Use" Financial Times (14 October 2006), online: AccessMyLibrary <http://www.accessmylibrary.com/comsite5/bin/pdinventory.pl?pdlanding=1&referid=2930&purchase_type=ITM&item_id=0286-20590768> (date accessed: 9 February 2007).

155 Peter B. De Selding, "ESA Positioning itself on Europe's Security and Defense Issues" *Space News* (27 March 2006).

156 Peter B. De Selding.

157 Luca Del Monte cited in Peter B. De Selding, "ESA Positioning itself on Europe's Security and Defense Issues."

158 "Israel's Eros B imaging satellite reaches orbit" *Space News* (1 May 2006), online: *Space News* <http://www.space.com/spacenews/archive06/Eros_050106.html>

159 "Bidders vie for Turkey's Military Satellite" Turkish Daily News (19 August 2006), online: Turkish Daily News <http://gbulten.ssm.gov.tr/arsiv/2006/08/19/01.htm> (date accessed: 9 February 2007).

160 "India Begins Work on Space Weapons Command" Space Daily (12 April 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/India_Begins_Work_On_Space_Weapons_Command.html> (date accessed: 9 February 2007). While some reports claim that it will be a space weapons command, others maintain that it would be used to protect India's space assets, and to use them for military purposes during conflict.

161 National Remote Sensing Agency, Department of Space, Government of India, "Risat", online: NRSA <http://www.nrsa.gov.in/satellites/risat.html> (date accessed: 9 February 2007).

162 David Pugliese, "Canada Nears Access to Dedicated Milsats" Defense News (25 September 2006) at 16.

163 David Pugliese "Canada to Use Commercial Sats for Mission Imagery" Defense News (6 February 2006) at 19.

164 DND/CF News Release, "Project Polar Epsilon Will Enhance Canada's Surveillance and Security Capability" (2 June 2005), online: Canada National Defence <http://www.forces.gc.ca/site/newsroom/view_news_e.asp?id=1674> (date accessed: 9 February 2007).

165 Launches whose primary payload was a military satellite.

Chapter Six Notes

1 Bruce deBlois, Richard Garwin, Scott Kemp, Jeremy Marwell, 2004, "Space Weapons Crossing the US Rubicon" 29 International Security (Fall 2004) at 50-84.

2 deBlois, et al. at 50-84.

3 Gunter Dirk Krebs, "SPIRALE 1, 2", online: Gunter's Space Page <http://www.skyrocket.de/space/doc_sdat/spirale-1.htm> (date accessed: 26 April 2007).

4 Pavel Podvig, "History and the Current Status of the Russian Early Warning System" 10 *Science and Global Security* (2002) at 21-60.

5 Pavel Podvig, "Reducing the risk of an accidental launch," 14 *Science and Global Security* (2006) at 35.

6 V. G. Morozov, “Vsevidashcheye oko Rossii (The all-seeing eyes of Russia)” Nezavisimoye voyennoye obozreniye (14 April 2000).

7 Air Force Space Command, Strategic Master Plan FY06 and Beyond (1 October 2003), online: Center for Defense Information <http://www.cdi.org/news/space-security/afspc-strategic-master-plan-06-beyond.pdf> (date accessed: 26 April 2007).

8 Pavel Podvig, “Reducing the risk of an accidental launch,” 14 *Science and Global Security* (2006) at 30.

9 Theresa Hitchens, “Ante Up On Space Situational Awareness,” *Space News* (12 March 2007), online: Center for Defense Information <http://www.cdi.org/program/document.cfm?DocumentID=3867&StartRow=1&ListRows=10&appendURL=&Orderby=D.DateLastUpdated&ProgramID=68&from_page=index.cfm> (date accessed: 22 May 2007); “$126.2M Paid Out as STSS SBIRS-Low is Rebaselined and Stretched Out,” Defense Industry Daily (9 November 2006), online: Defense Industry Daily online <http://www.defenseindustrydaily.com/mt/mt-search.cgi?IncludeBlogs=2&search=SBIRS> (date accessed: 22 May 2007).

10 Marcia Smith, “Military Space Programs: Issues Concerning DoD’s SBIRS and STSS Programs” CRS Report for Congress, RS21148 (3 November 2003) at 10-11, online: Federation of American Scientists <http://www.fas.org/spp/starwars/crs/RS21148.pdf> (date accessed: 26 April 2007).

11 Marcia Smith at 3.

12 Jefferson Morris, “First SBSS Satellite Launch to Slip Several Months” Aerospace Daily & Defense Report (4 October 2004). Gary Payton, “SBIRS Alternative Will Keep Missile Warning on Track” *Space News* (15 May 2006).

13 Globalsecurity.org, “Yuan Wang Tracking Ships” (last updated: 23 July 2005), online: Globalsecurity.org <http://www.globalsecurity.org/military/world/china/yuan-wang.htm> (date accessed: 26 April 2007); Globalsecurity.org, “Large Phased-Array Radar (LPAR)”(last updated: 28 April 2005), online: Globalsecurity.org <http://www.globalsecurity.org/wmd/world/china/lpar.htm> (date accessed: 26 April 2007).

14 Heiner Klinkrad, “Monitoring Space – Efforts Made by European Countries”, paper 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: Federation of American Scientists <http://www.fas.org/spp/military/program/track/klinkrad.pdf> (date accessed: 26 April 2007).

15 Globalsecurity.org, “RAF Fylingdales” (last updated: 27 April 2005), online: Globalsecurity.org <http://www.globalsecurity.org/space/facility/fylingdales.htm> (date accessed: 26 April 2007).

16 “National Defense Authorization Act for Fiscal Year 2004” 117 Stat. 1565 Public Law 108–136– (24 November 2003), online: CelesTrack <http://www.celestrak.com/Norad/elements/Section913.pdf> (date accessed: 26 April 2007).

17 Air Force Research Laboratory, Fact Sheet, “Radio Frequency Threat Warning and Attack Reporting Factsheet.” This program is still underdevelopment as of 2006.

18 “A -- Rapid Attack Identification, Detection, and Reporting System Spiral 2 Studies” FBO Daily, Issue #1033 (24 September 2004), online: FBO Daily <http://www.fbodaily.com/archive/2004/09-September/24-Sep-2004/FBO-00679518.htm> (date accessed: 26 April 2007).

19 Corey Dahl, “New squadron activates at Peterson,” Air Force Print News (21 May 2007).

20 Jeremy Singer, “Air Force ANGELS: Satellite Escorts to take Flight,” *Space News* (30 November 2005).

21 Gunter Dirk Krebs, “Vela”, online: Gunter’s Space Page < http://space.skyrocket.de/> (date accessed: 26 April 2007).

22 President’s National Security Telecommunications Advisory Committee (NSTAC), Fact Sheet, “Satellite Taskforce Report, Factsheet” (March 2004), online: National Communications Systems

<http://www.ncs.gov/nstac/reports/2004/Satellite%20Task%20Force%20Fact%20Sheet%20(March%202004).pdf> (date accessed: 26 April 2007); Theresa Hitchens, e-mail communication with author, 17 March 2005.

23 EADS-Astrium UK, e-mail communication with author (December 2004).

24 Scott A. Henderson, Lt. Col, USAF, former commander, 2nd Space Operations Squadron – GPS, telephone conversation with author (2 May 2005).

25 "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: GAO <http://www.gao.gov/new.items/d02781.pdf> (date accessed: 26 April 2007).

26 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, US Army Corps of Engineers (December 1990); W.E. Burrows, *Deep Black Space Espionage and National Security* (Random House: New York, 1986) at 182. Roohi Banu, Tanya Vladimirova, and Martin Sweeting, "On-Board Encryption in Satellites," Paper presented at 2005 MAPLD International Conference, Washington, DC, 7-9 September 2005. Abstract online: NASA Office of Logic Design <http://klabs.org/mapld05/abstracts/184_banu_a.html> (date accessed: 26 April 2007); Eric Swankoski and Vijaykrishnan Narayanan, "Dynamic High-Performance Multi-Mode Architectures for AES Encryption", paper presented at 2005 MAPLD International Conference, Washington, DC, 7-9 September 2005. Abstract online: NASA Office of Logic Design <http://klabs.org/mapld05/abstracts/103_swankoski_a.html> (date accessed: 26 April 2007).

27 Frater and Ryan.

28 Don J. Hinshilwood and Robert B. Dybdal, "Adaptive Nulling Antennas for Military Communications" 3 Crosslink, The Aerospace Corporation (Winter 2001/2002) at 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.

29 Hinshilwood and Dybdal; Mark Wade, "Milstar", online: Encyclopedia Astronautica <http://www.astronautix.com/craft/milstar.htm> (date accessed: 26 April 2007).

30 US Department of Defense, "Fiscal Year 2006/2007 Budget Estimates. Research, Development, Test and Evaluation (RDT&E) Descriptive Summaries, Volume I: Defense Advanced Research Projects Agency" (February 2005) at 423, online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2006/DARPA/0603768E.pdf> (date accessed: 26 April 2007); 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) at 8.

31 "China to Launch its First Anti-Jamming Satellite Next Year" *China Daily* (4 March 2004).

32 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual.* (Cambridge MA: American Academy of Arts & Sciences, 2005).

33 Lt. Col. Richard E. Fitts, ed., *The Strategy of Electromagnetic Conflict* (Peninsula Publishing: Los Altos, 1980).

34 Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Stimson Center, 2003).

35 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).

36 European Commission, Press Release, "Loyola de Palacio Welcomes the Outcome of EU/US Discussions on GALILEO" (26 February 2004), online: Europa – The European Union On-Line <http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/264&format=HTML&aged=0&language=EN&guiLanguage=en> (date accessed: 26 April 2007); European Commission, Press Release, "GALILEO and GPS will Navigate Side by Side: EU and US Sign Final Agreement" (26 June 2004), online: Europa – The European Union On-Line <http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/04/805&format=HTML&aged=0&language=en&guiLanguage=en> (date accessed: 26 April 2007).

37 Dennis Papadapolous, "Satellite Threat Due to High Altitude Nuclear Detonations", online: Lightwatcher <http://www.lightwatcher.com/chemtrails/Papadopoulos-chemtrails.pdf> (date accessed: 26 April 2007).

38 Dennis Papadapolous.

39 Michael Krepon and Christopher Clary, *Space Assurance or Space Dominance? The Case Against Weaponizing Space* (Washington DC: The Stimson Center, 2003).

40 Michael Krepon and Christopher Clary.

41 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: Globalsecurity.org <http://www.globalsecurity.org/wmd/library/congress/2004_r/04-07-22emp.pdf> (date accessed: 26 April 2007).

42 Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible" 10 International Security (Spring 1986) at 46-98; Federation of American Scientists, "Laser ASAT Test Verification"; Wright, et al.

43 Carter at 79.

44 Tamar H. Mehuron, "2004 Space Almanac," *Air Force Magazine* (August 2003), online: The Air Force Association <http://www.afa.org/magazine/Aug2003/0803spacealmanac.pdf> (date accessed: 26 April 2007).

45 "Military Planning Nuclear Exercises" *Moscow Times* (2 February 2004).

46 Pavel Podvig, "Russia and Military Uses of Space" (June 2004), online: Russian Strategic Nuclear Forces <http://russianforces.org/podvig/eng/publications/space/20040700aaas.shtml> (date accessed: 26 April 2007).

47 *Strategic Master Plan FY06 and Beyond* at 5.

48 Formerly called US Force Application from the Continental US (FALCON) but the acronym was dropped when the program ended its strike component.

49 DARPA, "FALCON Broad Agency Announcement, Phase I Proposer Information Pamphlet" (29 July 2003). Frank Colucci, "FALCON Aims at Global Striking Power," *Military Aerospace Technology*, 6, 1 (February 2007).

50 Air Force Research Laboratories, Fact Sheet, "Space Maneuver Vehicle" (September 2002).

51 Andreas Parsch, "X-37/X-40" (2006), online: Directory of U.S. Military Rockets and Missiles <http://www.designation-systems.net/dusrm/app4/x-37.html> (date accessed: 1 June 2007).

52 V.Brinda et al "Mission Analysis of a Reusable Launch Vehicle Technology Demonstrator, » American Institute of Aeronautics and Astronautics, 13th International Space Planes and Hypersonics Systems and Technologies (2005).

53 "Clearing Skies" Jane's Defense Weekly (29 April 1998).

54 Alexander Zhelezniakov, "New Space Carrier Rocket 'Mikron'" Russian Pereplet (15 February 2002), online: Russian Pereplet <http://www.pereplet.ru/cgi/science.cgi?id=61> (date accessed: 26 April 2007).

55 David Wright et al, *Physics of Space Security* (Cambridge: American Academy of Arts and Sciences, 2005), at 83.

56 MissileThreat, "Space Based Infrared System –High (SBIRS-High)", online: MissileThreat <http://www.missilethreat.com/missiledefensesystems/id.56/system_detail.asp> (date accessed: 9 February 2007).

57 Amy Butler, "Pentagon Turns on First SBIRS Sensor" Aviation Week and Space Technology (20 November 2006), online: Aviation Week <http://www.aviationnow.com/avnow/news/channel_awst_story.jsp?id=news/aw112006p2b.xml> (date accessed: 9 February 2007).

58 Amy Butler.

59 Amy Butler.

60 Jeremy Singer, "New Technology Offers Low-Risk Approach to SBIRS Replacement" *Space News* (17 April 2006), online: *Space News* <http://www.space.com/spacenews/archive06/Sbir_041706.html> (date accessed: 9 February 2007).

61 Marcia S. Smith, "Military Space Programs: Issues Concerning DOD's SBIRS and STSS Program," Congressional Research Service (30 January 2006) at 3-4; MissileThreat, "Space Based Infrared System –High (SBIRS-High)".

62 Jefferson Morris, "First SBSS Satellite Launch to Slip Several Months" Aerospace Daily & Defense Report (4 October 2004). Gary Payton, "SBIRS Alternative Will Keep Missile Warning on Track" *Space News* (15 May 2006).

63 "USAF Awards GD Contract for Alternative Infrared Satellite System" Spacewar (12 December 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/USAF_Awards_GD_Contract_For_Alternative_Infrared_Satellite_System_999.html> (date accessed: 9 February 2007).

64 "$126.2M Paid as STSS SBIRS-Low is Rebaselined and Stretched Out" Defense Industry Daily (9 November 2006), online: Defense Industry Daily <http://www.defenseindustrydaily.com/2006/11/1262m-paid-as-stss-sbirslow-is-rebaselined-and-stretched-out/index.php> (date accessed: 9 February 2007). MissileThreat, "Space Tracking and Surveillance System (STSS)", online: Missilethreat.com <http://www.missilethreat.com/missiledefensesystems/id.60/system_detail.asp> (date accessed: 9 February 2007).

65 Marcia S. Smith, "Military Space Programs: Issues Concerning DOD's SBIRS and STSS Program," at 5. "Cost estimates are problematic because there is no final system architecture and the schedule is in flux." In 2001 it was reported that the program life cycle had grown from $10-billion to $23-billion.

66 Missile Defense Agency, Press Release, "Space Tracking and Surveillance System Delivers Sensor Payload" (10 March 2006), online: MDA Link <www.mda.mil/mdalink/pdf/06fyi0073.pdf> (date accessed: 9 February 2007); Missile Defense Agency, Press Release, "Space Tracking and Surveillance System - Delivers Second Sensor Payload" (19 December 2006), online: MDA Link <www.mda.mil/mdalink/pdf/06fyi0092.pdf> (date accessed: 9 February 2007).

67 "Russia Puts New Early Warning Radar Station on Combat Duty" RIA Novosti (22 December 2006), online: RIA Novosti -Russia <http://en.rian.ru/russia/20061222/57586624.html> (date accessed: 26 April 2007).

68 Russian Strategic Nuclear Forces, "Current Status – Early Warning" (3 April 2007), online: Russian Strategic Nuclear Forces Project <http://russianforces.org/sprn/> (date accessed: 26 April 2007).

69 Pavel Podvig, "Reducing the risk of an accidental launch," at 34-35.

70 Jeremy Singer, "Air Force ANGELS: Satellite Escorts to Take Flight" *Space News* (30 November 2005), online: SPACE.com

<http://www.space.com/businesstechnology/051130_airforce_angels.html> (date accessed: 9 February 2007). Aeroastro put out a fact sheet for their Escort microsatellite that does pretty much what Angels does. There is no reference to Escort on their website so one may assume that their work was for the Angels contract but lost out to Lockheed Martin. Same situation with Spacedev with Space Daily reporting them receiving a $1.24 million dollars contract to develop Angels but that was the end of the story.

71 "LM Awarded USAF Contract for Nanosatellites" Space Daily (3 August 2006), online: <http://www.spacedaily.com/reports/LM_Awarded_USAF_Contract_For_Nanosatellites_999.html> (date accessed: 9 February 2007).

72 Jeremy Singer, "Air Force ANGELS: Satellite Escorts to Take Flight" *Space News* (30 November 2005), online: SPACE.com <http://www.space.com/businesstechnology/051130 _airforce_angels.html> (date accessed: 9 February 2007).

73 "STRATCOM Treating all Satellite Disturbances as Attacks for Practice" 12(22) Inside Missile Defense (25 October 2006).

74 "China Enhances Spacecraft Monitoring Network" Xinhua News Agency (12 December 2006), online: Xinhuanet <http://news3.xinhuanet.com/english/2006-12/12/content_5473204.htm> (date accessed: 9 February 2007). Zhour Honghsun and Liu Wubing, "Status Quo and Assumption of China's Space Satellite Monitoring," *China Communications*, June 2006, p. 123.

75 QinetiQ Press Release, "Japan's Space Communications Corporation to Benefit from Anti-satellite Jamming System" (28 February 2006), online: QinetiQ <http://www.qinetiq.com/home/newsroom/ news_releases_homepage/2006/1st_quarter/qinetiq_secures_further.html> (date accessed: 9 February 2007).

76 "QinetiQ's Satellite Interference Location Service," (2 November 2006), online: GeoConnextion < http://www.geoconnexion.com/geo_news_article/QinetiQ_s-satellite-interference-location-service/506> (date accessed: 22 May 2006).

77 European Space Agency, Press Release, "Another world first for Artemis: a laser link with an aircraft" (18 December 2006), online: ESA <http://www.esa.int/esaTE/SEMN6HQJNVE_index_0.html> (date accessed: 9 February 2007).

78 "JAXA and DLR Conduct Orbit to Ground Optical Communication Experiment" Spacemart.com (12 June 2006), online: SpaceMart <http://www.spacemart.com/reports/JAXA_And_DLR_ Conduct_Orbit_To_Ground_Optical_Communication_Experiment.html> (date accessed: 9 February 2007).

79 Michael Fabey, "Air Force Approach Raises Questions about TSAT Capability and Cost", Aerospace Daily and Defense Report (18 December 2006), online: Aviation Week <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=aerospacedaily&id=news/TSAT 12186.xml> (date accessed: 9 February 2007).

80 Northrop Grumman, Press Release, "Lockheed Martin/ Northrop Grumman Team Achieves Critical Test Milestone for High-Data-Rate Laser Communication System" (31 March 2006), online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=96555> (date accessed: 9 February 2007).

81 Boeing, Press Release, "Boeing Demonstrates TSAT Next-Generation Processor Router Capability" (20 June 2006), online: Boeing <http://www.boeing.com/news/releases/2006/q2/060620a_nr.html> (date accessed: 9 February 2007).

82 Michael Fabey (18 December 2006).

83 Bruce Rolfsen, "US Air Force Plans for Cyberspace Command Take Shape" The Journal of Net-centric Warfare (2 November 2006), online: C4ISRJournal.com <http://www.isrjournal.com/story.php?F=2329048> (date accessed: 9 February 2007).

84 John T. Bennett, "Air Force to Establish New Cyberspace Operations Command" Inside the Air Force (4 October 2006), online: World Politics Watch <http://www.worldpoliticswatch.com/article.aspx?id=233> (date accessed: 9 February 2007).

85 Defense Advanced Research Projects Agency, "Orbital Express Space Operations Architecture" (8 August 2006), online: DARPA <http://www.darpa.mil/tto/programs/oe.htm> (date accessed: 9 February 2007).

86 United Launch Alliance, News Release, "United Launch Alliance Successfully Launches First USAF Atlas V", online: United Launch Alliance <http://www.ulalaunch.com> (date accessed: 26 April 2007)

87 Michael A. Dornheim, "Express Service," Aviation Week and Space Technology (5 June 2006) at 46-50.

88 Michael A. Dornheim at 46-50.

89 "UF, Honeywell Engineers Building First Space Supercomputer" University of Florida News (26 October 2006), online: University of Florida News <http://news.ufl.edu/2006/10/26/space-supercomputer/> (date accessed: 9 February 2007).

90 John Samson Jr, "NMP ST* High Performance Dependable Multiprocessor", Presentation at the 10th High Performance Embedded Computing Workshop, MIT Lincoln Laboratory, 20 September 2006.

91 NASA Jet Propulsion Laboratory, "Space Technology 8" (28 April 2006), online: NASA <http://nmp.jpl.nasa.gov/st8/tech/eaftc_tech1.html> (date accessed: 9 February 2007).

92 Brian Berger, Jeremy Singer, "Field Narrows for DARPA's Falcon Program; Decision Expected Soon" *Space News* (29 August 2005), online: *Space News* <http://www.space.com/spacenews/archive05/Falcon_082905.html> (date accessed: 9 February 2007).

93 AirLaunch LLC, Press Release, "AirLaunch LLC Completes Additional Tests as it Approaches Design Review" (3 November 2006), online: Airlaunchllc News <http://www.airlaunchllc.com/News.htm> (date accessed: 9 February 2007); Debra Facktor, "AirLaunch's QuickReach Small Launch Vehicle: Development Status of Phase 2B", Paper delivered to the 2006 International Astronautical Congress, Valencia, Spain, 2-6 October 2006 (IAC paper IAC-06-D2.1.09).

94 Debra Facktor, "AirLaunch's QuickReach Small Launch Vehicle: Development Status of Phase 2B", Paper delivered to the 2006 International Astronautical Congress, Valencia, Spain, 2-6 October 2006 (IAC paper IAC-06-D2.1.09).

95 Jefferson Morris, "Falcon SLV Program Nearing Next Phase" Aerospace Daily and Defense Report (8 December 2006), online: Aviation Week <http://www.aviationnow.com/avnow/news/channel_space_story.jsp?id=news/FALC12086.xml> (date accessed: 9 February 2007).

96 "NASA to Partner with AirLaunch on Small Satellite Development" Space Daily (27 July 2006), online: SpaceDaily.com <http://www.spacedaily.com/reports/NASA_To_Partner_With_AirLaunch_On_Small_Satellite_Development_999.html> (date accessed: 9 February 2007).

97 *Aviation Week and Space Technology* (3 March 2006).

98 Yuri Zaitsev, "Russia and Kazakhstan to Develop Unique Space System" Spacewar (21 May 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Russia_And_Kazakhstan_To_Develop_Unique_Space_System.html> (date accessed: 9 February 2007).

99 Yuri Zaitsev, "Russia and Kazakhstan to Develop Unique Space System" Spacewar (21 May 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Russia_And_Kazakhstan_To_Develop_Unique_Space_System.html> (date accessed: 9 February 2007). Note: The article mention 160 kg payload into 300 km circular orbit and 60 kg into 120 km circular orbits, but it is likely that the author meant 1,200 km circular orbits.

100 Yuri Zaitsev, "Russia and Kazakhstan to Develop Unique Space System" Spacewar (21 May 2006), online: SPACEWAR.com <http://www.spacewar.com/reports/Russia_And_Kazakhstan_To_Develop_Unique_Space_System.html> (date accessed: 9 February 2007).

101 Robert Hewson, "China Plans New Space Launchers", Jane's Defense Weekly (22 November 2006).

Chapter Seven Endnotes

1 Negation of space systems is called 'offensive counterspace' in current Air Force terminology, and includes the 'Five Ds' mission. US Air Force, *Air Force Doctrine Document 2-2.1* (2 August 2004) at 3, online: Federation of American Scientists <http://www.fas.org/irp/doddir/usaf/afdd2_2-1.pdf> (date accessed: 26 April 2007).

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" (25 November 2001), online: NASA <http://www-istp.gsfc.nasa.gov/Education/Iradbelt.html> (date accessed: 26 April 2007). See also "Van Allen Belts" in Alan Isaacs, ed., *A Dictionary of Physics* (Oxford: Oxford University Press, 2000).

3 Bruce DeBlois et al., "Space Weapons: Crossing the US Rubicon" (Fall 2004) 20 International Security at 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: BBC News <http://news.bbc.co.uk/1/hi/world/americas/3077303.stm> (date accessed: 26 April 2007).

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: BBC News <http://news.bbc.co.uk/1/hi/world/middle_east/193529.stm> (date accessed: 26 April 2007).

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) at 1, online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2004/AirForce/0604421F.pdf> (date accessed: 26 April 2007).

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) at 3, online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2005/AirForce/0603438F.pdf> (date accessed: 26 April 2007).

11 "Space Control Technology" at 1.

12 Office of Science and Technology Policy, Fact Sheet, "US Space-Based Positioning, Navigation, and Timing Policy" (15 December 2004), online: Office of Science and Technology Policy <http://www.ostp.gov/html/FactSheetSPACE-BASEDPOSITIONINGNAVIGATIONTIMING.pdf> (date accessed: 26 April 2007).

13 US Department of Defense, "Quadrennial Defense Review Report" (30 September 2001) at 45, online: US Department of Defense <http://www.defenselink.mil/pubs/qdr2001.pdf> (date accessed: 26 April 2007).

14 *Air Force Doctrine Document 2-2.1* at vii.

15 "National Defense Authorization Act for Fiscal Year 2004" 117 Stat. 1565 Public Law 108-136-24 (November 2003).

16 United States Air Force, Fact Sheet, "Space Situational Awareness Integration Office" (April 2004), online: Peterson Air Force Base <http://www.peterson.af.mil/hqafspc/Library/FactSheets/FactsSheets.asp?FactChoice=23> (date accessed: 26 April 2007).

17 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" (1998) 11 Lincoln Laboratory Journal, online: Lincoln Laboratory MIT <http://www.ll.mit.edu/ST/sbv/sbv.pdf> (date accessed: 26 April 2007).

18 US Air Force, *US Air Force Transformation Flight Plan*, "Appendix D: Brief Descriptions of Programs, ACTDs and Future System Concepts" (November 2003) at D-10, online: US Air Force <http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf> (date accessed: 26 April 2007).

19 "Boeing Snags 189 million Pentagon Space Contract" Space Wire (31 March 2004), online: Space Daily <http://www.spacedaily.com/2004/040330232730.r3ab2j2p.html> (date accessed: 26 April 2007).

20 US Air Force, *US Air Force Transformation Flight Plan*, "Appendix D: Brief Descriptions of Programs, ACTDs and Future System Concepts" (November 2003) at D-9, online: US Air Force <http://www.af.mil/library/posture/AF_TRANS_FLIGHT_PLAN-2003.pdf> (date accessed: 26 April 2007).

21 "Improving Our Vision: Approaches for Shared Space Situational Awareness," Report of the Sept. 15-16, 2006 Conference, The Antlers Hotel, Colorado Springs, Colo., The World Security Institute's Center for Defense Information and The U.S. Air Force Academy's Center for Space and Defense Studies, 2007.

22 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) at 4, online: Federation of American Scientists <http://www.fas.org/spp/military/program/asat/ADA377346.pdf> (date accessed: 26 April 2007); Laura Grego, "A History of US and Soviet ASAT Programs" (9 April 2003), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1151>(date accessed: 26 April 2007); 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).

23 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. at 61.

24 *Air Force Doctrine Document 2-2.1* at 3.

25 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, "US Space Programs: Civilian, Military, and Commercial," *CRS Issue Brief for Congress* (21 October 2004), online: Federation of American Scientists <http://www.fas.org/spp/civil/crs/IB92011.pdf> (date accessed: 26 April 2007). Funding in FY 2005 was $14.0-million. Theresa Hitchens, Michael Katz-Hymen, and Jeffrey Lewis, "US Space Weapons: Big Intentions, Little Focus" (March 2006) 13(1) Nonproliferation Review at 43, Table 4.

26 "US Space Weapons: Big Intentions, Little Focus" at 43, Table 4.

27 David C. Isby, "US Army continues with KE-ASAT" Jane's Missiles and Rockets (March 2005); Costa; Sandra I. Erwin, "US Space Command Chief Warns About Technological Complacency" National Defense (May 2001), online: National Defense Magazine

<http://www.nationaldefensemagazine.org/issues/2001/May/US_Space.htm> (date accessed: 26 April 2007); United States Department of Defense, Press Release No. 503-04, "Contracts: Army" (25 May 2004), online: US Department of Defense <http://www.defenselink.mil/contracts/2004/ct20040525.html> (date accessed: 26 April 2007).

28 "Raytheon Delivers Exoatmospheric Kill Vehicle Payloads for Fort Greely" Space Daily (18 August 2004), online: <http://www.spacedaily.com/news/bmdo-04y.html> (date accessed: 26 April 2007).

29 Raytheon, Fact Sheet, "Ground-Based Midcourse Defense (GBM) Exoatmospheric Kill Vehicle (EKV)", online: Raytheon <http://raytheonmissiledefense.com/matrix/pdfs/fs/fs_ekv.pdf> (date accessed: 26 April 2007).

30 David Wright and Laura Grego, "ASAT Capabilities of Planned US Missile Defense System" 68 Disarmament Diplomacy (December 2002-January 2003) at 7-10.

31 Wright and Grego at 7.

32 "Gorgon (SH-11/ABM-4)" Missilethreat.com, online: Missilethreat.com <http://www.missilethreat.com/systems/gorgon.html> (date accessed: 26 April 2007).

33 Wang Qing, Yang Bao-Qing, Ma Ke-mao, "PWPF Optimizing Design and Its Application Research to Terminal Guidance of Kinetic Killing Vehicle" (2005) 5 Journal of Astronautics 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" (2005) 4 Journal of Astronautics at 420-424, 435; Liu Shi-yong, Wu Rui-lin, Zhou Buo-zhao, "Bearings-only Passive Ranging for Exo-atmospheric Interceptor" (2005) 3 Journal of Astronautics at 307-313; Wang Qing-chao, Li Da, "A Study of Kinetic Interceptor Attitude Control System Based on Feedback Linearization" (2005) 3 Journal of Astronautics; Liu Shi-yong, Wu Rui-lin, Zhou Bo-zhao, "Research on Midcourse Guidance for Fuel-Exhaustion-Shutoff exo-Atmospheric Interceptor" (2005) 2 Journal of Astronautics at 156-163; Lu Yadong, Yang Ming, and Wang Zicai, "Midcourse Guidance of Interceptor Based on Zero Effort Miss Forecasting" (2005) 6 Aerospace Control at 17-21; Yu Jiang and Yu Yao, "Analysis of Attitude Control Effect for Extra-atmospheric Mass Moment Spinning Interceptor" (2005) 5 Aerospace Control at 4-8; Liu Shiyong, Wu Ruilin, and Zhou Bozhao, "Midcourse Guidance Based on the Interception Point for Exo-atmospheric Interceptor" (2005) 2 Aerospace Control at 54-58; Cheng Long and Chen Yong, "A Method of Determining Intercepting Orbit" (2005) 1 Aerospace Control at 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" (1997) 5 Modern Defense Technology at 10- 17; Zhou Di, Mu Chun-Di, and Xu Wen-li, "Integrated Attitude Control of the Space Interceptorm" (1999) 1 Tsinghua Science and Technology at 106-109; Liu Shi-yong, Wu Rui-lin, Zhou Bo-zhao, "Research on Burnout Reference Guidance Law for an Exo-Atmospheric Interceptor" (2004) 2 Aerospace Control 24-28; Zhou Hongjian, Zhao Yongjun, Wu Ruilin, "Application of PWPF Modulator in Space Interceptor Side Force Control" (1997) 2 System Engineering and Electronics 9-12; Tang Guojian, Ren Xuan, Wu Ruilin, "A Method for Attitude Control of Space Interceptor Rapidly Tracking LOS" (2000) 2 Aerospace Control at 52–58; Ma Kemao, Shi Xiaoping, and Wang Zicai, "Terminal Guidance Law Design in Space Interception" (1998) 1 Aerospace Control at 39-42; Chen Fen-zhou, Wan Ziming, and Cheng Shi-lu, "Terminal Guidance Analysis of Extra Atmospheric Kinetic Kill Vehicle" (2002) 1 Flight Dynamics 38-41; Jia Peiran and Tang Guojian, "Realization of Target Satellite Interception with Velocity-Gain Guidance" (1992) 2 National University of Defense Technology Journal 72-77; M. Benett, "Optimal Guidance & Control of Exo-Atmospheric Kill Vehicles," Presented at the 2nd AAAF International Conference on Missile Defence. Abstract online: AAAF <http://www.aaaf.asso.fr/contenu2id-77.html> (date accessed: 26 April 2007).

34 These dates are provided in Michael R. Gordon and David S. Cloud, "US Knew of China's Missile Test, But Kept Silent," *New York Times*, (23 April 2007), at 1.

35 Pavel Podvig, "Russian Military Space Capabilities" in Phillip E. Coyle, ed., *Ensuring America's Space Security* (Washington, D.C.: Federation of American Scientists, September 2004) at 127.

36 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) at 215-228.

37 Union of Concerned Scientists, “History of Russia’s ABM System” (27 October 2002), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/missile_defense/page.cfm?pageID=609> (date accessed: 26 April 2007).

38 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: International Atomic Energy Agency <http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48-17.pdf> (date accessed: 26 April 2007).

39 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).

40 S. Karamow, “Army Scores a Hit on Satellite in Test of Laser” USA Today (21 October 1997) at A6.

41 Laura Grego, “A History of US and Soviet ASAT Programs” (9 April 2003), online: Union of Concerned Scientists <http://www.ucsusa.org/global_security/space_weapons/page.cfm?pageID=1151> (date accessed: 26 April 2007).

42 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.

43 See: Theresa Hitchens, Michael Katz-Hyman and Jeffrey Lewis, “Space Weapons Spending in the Fiscal Year 2006 Presidential Request: A Preliminary Assessment” (10 February 2005), online: Center for Defence Information: <http://www.cdi.org/PDFs/FY06-1.pdf> (date accessed: 22 May 2007).

44 “Counterspace Systems,” Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Program Element 0604421F (February 2004) at 875, online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2005/AirForce/0604421F.pdf> (date accessed: 26 April 2007).

45 Missile Defense Agency, Fact Sheet, “The Airborne Laser” (last updated May 2006), online: MDA Link <http://www.mda.mil/mdalink/pdf/laser.pdf> (date accessed: 26 April 2007).

46 Tariq Malik, “The Power of Light: An Airborne Laser for Missile Defense” Space.com (17 November 2004), online: Space.com <http://www.space.com/businesstechnology/airborne_laser_techwed_041117.html> (date accessed: 26 April 2007).

47 "Airborne Laser fact sheet", online: Missile Threat.com <http://www.missilethreat.com/missiledefensesystems/id.8/system_detail.asp> (date accessed: 22 May 2007); Jeremy Singer, "MDA Officials Lay Out Milestones for Airborne Laser," *Space News* (13 March 2006), online: Space.com <http://www.space.com/spacenews/archive06/ABL_031306.html> (date accessed: 22 May 2007).

48 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.

49 Yang Wen-shi, Wang Wei-li, Sun Wei-na, Bi Guo-jiang, Zhu Chen, Wang Xiao-han, "Beam Quality of the High Power DPL" (2005) 5 Infrared and Laser Engineering at 511-516. Shi Xiang-chun, Chen Wei-biao, Hou Xia, "Application of All Solid State Laser in Space" (2005) 2 Infrared and Laser Engineering, at 127-131.

50 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." Surrey Satellite Technology, "News" (23 March 2005), online: SSTL <http://www.sstl.co.uk/index.php?loc=6> (date accessed: 26 April 2007). 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" (22 July 2003), online: Center for Nonproliferation Studies <http://cns.miis.edu/pubs/week/020722.htm> (date accessed: 26 April 2007); a full description of the Tsinghua-1/SNAP mission is online: Surrey Space Center <http://www.ee.surrey.ac.uk/SSC/> (date accessed: 26 April 2007).

51 Orbital Recover Group, Press Release, "Orbital Recovery Group Signs a Reservation for the First Satellite Servicing Mission Using its CX-OLEVTM 'Space Tug'" (11 October 2005), online: Orbital Recover Group <http://www.orbitalrecovery.com/news15.html> (date accessed: 26 April 2007).

52 "Microsatellite Constellation to Watch Over Disasters Forges Ahead" Space Daily (15 May 2002).

53 Jeffrey Lewis, "NFIRE Kill Vehicle Finally Dead. Really," (23 August 2005), online: Armscontrolwonk.com: <http://www.armscontrolwonk.com/741/nfire-kill-vehicle-finally-dead-really> (date accessed: 22 May 2007).

54 "Ballistic Missile Defense System Interceptors," Unclassified RDT&E Budget Item Justification Sheet, Exhibit R-2, Program Element 0603886C (February 2004), online: Defense Technical Information Center <http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf> (date accessed: 26 April 2007).

55 Mark Wade, "Rockets" (May 2005), online: Encyclopedia Astronautica <http://www.astronautix.com> (date accessed: 26 April 2007).

56 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).

57 "Overview of the Taurus Rocket" SpaceFlight Now (19 September 2001), online: SpaceFlight Now <http://www.spaceflightnow.com/taurus/t6/010919taurus.html> (date accessed: 26 April 2007).

58 See note 44.

59 Sea Launch Web Site, online: <http://www.sea-launch.com/> (date accessed: 26 April 2007).

60 See for example the SHTIL SLBM launch identified in Brian Harvey, *Russia in Space the Failed Frontier?* (Chichester, UK: Springer-Praxis Books, 2001) at 236.

61 Sea Launch Web Site.

62 Sea Launch Web Site.

63 Muhammad Shamsui Kamal Adnan and Md. Azlin Md. Said, "Aircraft-Based Satellite Launching (ABSL) System - Future Space Transportation System", online: German Aerospace Center <http://www.dlr.de/iaa.symp/archive_5/pdf/0810P_Kama_Adnan.pdf> (date accessed: 26 April 2007).

64 Orbital Sciences Corporation, "Space Launch Systems" (May 2005), online: Orbital Sciences Corporation <http://www.orbital.com/> (date accessed: 26 April 2007).

65 "China Tracks Space Debris" Space.Com, online: Space.com <http://www.space.com/astronotes/astronotes.html> (date accessed: 26 April 2007).

66 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" (2002) 34(5) Advances in Space Research at 1143-1149.

67 "Status of CNES Optical Observations" at 1143-1149.

68 National Space Development Agency of Japan, "Space Debris Optical Observation and Orbit Determination Experiment Initiated" (September 2000), online: NASDA <http://www.nasda.go.jp/lib/nasda-news/2000/09/head_e.html> (date accessed: 26 April 2007).

69 Harvey at 209.

70 US Air Force, "Space Surveillance" (May 2005), online: Air University <http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm> (date accessed: 26 April 2007).

71 Wei Long, "Chinese Space Workers Celebrate Their Labour to Launch Shenzhou" Space Daily (9 January 2002).

72 Heiner Klinkrad, "Monitoring Space – Efforts Made by European Countries", paper presented at the International Colloquium on Europe and Space Debris, sponsored by the Académie National de l'Air et de l'Espace, Toulouse, France, 27-28 November 2002, online: Federation of American Scientists <http://www.fas.org/spp/military/program/track/klinkrad.pdf> (date accessed: 26 April 2007).

73 Klinkrad.

74 Radio Atmospheric Science Center, Kyoto University, "Introduction to MU Radar", online: Sato Laboratory, Graduate School of Informatics, Kyoto University <http://www-lab26.kuee.kyoto-u.ac.jp/study/mu/mu_e.html> (date accessed: 26 April 2007).

75 Harvey at 209.

76 "Space Surveillance."

77 Department of Earth Observation and Space Systems, Delft University, "Satellite Laser Ranging for ERS-1" (8 August 1998), online: Delft University of Technology <http://www.deos.tudelft.nl/ers/tracking1/global.html> (date accessed: 26 April 2007).

78 European Space Agency, "ConeXpress Orbital Life Extension Vehicle (CX-OLEV)" (May 2005), online: ESA Telecommunications <http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=17870> (date accessed: 26 April 2007).

79 "Soyuz Launches Progress Cargo Flight to ISS/Automated Rendezvous Tests" Space and Tech (26 June 2002), online: Space and Tech <http://www.spaceandtech.com/digest/flash2002/flash2002-060.shtml> (date accessed: 26 April 2007).

80 NASA, "DART Mission" (May 2005), online: NASA <http://www.nasa.gov/mission_pages/dart/main/> (date accessed: 26 April 2007).

81 "ConeXpress Orbital Life Extension Vehicle."

82 Mark Wade, "Polyot 11A59" (May 2005), online: Encyclopedia Astronautica <http://www.astronautix.com/lvs/pol11a59.htm> (date accessed: 26 April 2007).

83 "ConeXpress Orbital Life Extension Vehicle."

84 "Autonomous Proximity Microsatellites" Technology Horizons (December 2003), online: Air Force Research Laboratory Technology Horizons <http://www.afrlhorizons.com/Briefs/Dec03/VS0304.html> (date accessed: 26 April 2007).

85 "ConeXpress Orbital Life Extension Vehicle."

86 "Autonomous Proximity Microsatellites."

87 The Advanced Video Guidance Sensor was first demonstrated in the 1990s with the space shuttle in NASA's Automated Rendezvous and Capture project. NASA, Fact Sheet, "DART Demonstrator to Test Future Autonomous Rendezvous Technologies in Orbit" (September 2004).

88 Michael Braukus and Kim Newton, "On Orbit Anomaly Ends DART Mission Early" (16 April 2005), online: NASA <http://www.nasa.gov/mission_pages/dart/media/05-051.html> (date accessed: 26 April 2007).

89 Lt. Col. James Shoemaker, "Orbital Express Space Operations Architecture" DARPA (19 October 2004).

90 Gerd Hirzinger et al., "DLR's Robotics Technologies for On-Orbit Servicing" (2003) 2 Advanced Robotics at 139-174, online: DLR Institute of Robotics and Mechatronics <http://www.robotic.dlr.de/Klaus.Landzettel/ars.pdf> (date accessed: 26 April 2007).

91 Wang Chaoqun, "Semi Physical Simulation Technique about the RF/IR Dual-mode Integrated Homing Guidance System" (2005) 1 Aerospace Control at 76-78.

92 Peter de Selding, "Libya Pinpointed as Source of Months-Long Satellite Jamming in 2006" *Space News* (9 April 2007).

93 Jeremy Wagstaf, "Satellite Interference: Indonesian Hackers Show How Easy It Is to Get Information from the Sky" *The Wall Street Journal* (15 September 2006).

94 B Barbara Opall-Rome, "Inability to Jam Hezbollah Satellite TV Signal Spurs Israeli Research" *Space News* (29 August 2006), online: *Space.com* <http://www.space.com/spacenews/archive06/jammit_0828.html> (date accessed: 9 February 2007).

95 *Air Force Doctrine Document 2-2.1*.

96 Sharon Weinberger, "Just Over the Horizon" Defense Technology International (January/February 2006) at 12, online: Defense Technology International <http://www.nxtbook.com/nxtbooks/mh/dti0206/index.php> (date accessed: 9 February 2007).

97 Weinberger at 12.

98 Weinberger at 12.

99 Y. Juan, S. Weiyi, M. Genwang, H. Hongqing, "On Calculating Effectiveness of Plasma Defense on Low-Orbit Spy Satellite" (2005) 23(1) Journal – Northwestern Polytechnical University at 93-97.

100 Boeing, News Release, "Boeing Completes Key Risk Reduction Milestone for Space Surveillance System" (29 September 2006), online: Boeing <http://www.boeing.com/news/releases/2006/q3/060929b_nr.html> (date accessed: 8 February 2007).John A. Tirpak, "Space and Counterspace, *Air Force Magazine* Vol. 89, No. 6 (June 2006).

101 Jeremy Singer, "Briefs – Pentagon Cancels Funds For Deep Space Imager," *Space News* (20 February 2006).

102 "China Enhances Spacecraft Monitoring Network" Xinhua News Agency (12 December 2006), online: Xinhuanet <http://news3.xinhuanet.com/english/2006-12/12/content_5473204.htm>

(date accessed: 9 February 2007). Zhour Honghsun and Liu Wubing, “Status Quo and Assumption of China's Space Satellite Monitoring” *China Communications* (June 2006) at 123.

103 Duan Xiaojun et al., “Detection of Systematic Error Based on Integral Matched Filter” 26(1) Chinese Space Science and Technology (February 2006); Liu Yuan et al., “Relatively Locating a Space Target Using Angle Only Measurements” 26(1) Chinese Space Science and Technology (February 2006).

104 Craig Covult, “China's ASAT Test will Intesify Chinese-US Faceoff in Space”AviationWeek.com (21 January 2007), online: <http://www.aviationnow.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw012207p2.xml> (date accessed: 26 April 2007)

105 US General Cartwright claims that China attempted two previous attempts prior to the successful test on 11 January 2007. Amy Butler, “Chinese Anti-sat hit was Third Attempt” AviationWeek.com (16 April 2007), online: AviationWeek.com <http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=space&id=news/saty041607.xml&headline=Chinese%20Anti-sat%20Hit%20Was%20Third%20Attempt> (date accessed: 26 April 2007). Dates are provided in Michael R. Gordon and David S. Cloud, “US Knew of China's Missile Test, But Kept Silent,” *New York Times*, (23 April 2007), at 1.

106 Craig Covault, “China's ASAT Test Will Intessify US-Chinese Faceoff in Space” *Aviation Week and Space Technology* (21 January 2007), online: Aviation Week <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw012207p2.xml> (date accessed: 26 April 2007).

107 GlobalSecurity.org, “Chinese Anti-Satellite [ASAT] Capabilities” (last updated 18 January 2007), online: GlobalSecurity.org <http://www.globalsecurity.org/space/world/china/asat.htm> (date accessed: 26 April 2007).

108 Martin Staff, “China Officially Announces Anti-Satellite Test Successful” *Spacewar* (24 January 2007), online: Space War <http://www.spacewar.com/reports/China_Officialy_Announces_Anti_Satellite_Test_Successful_999.html> (date accessed: 26 April 2007).

109 “China Jamming Test Sparks US Satellite Concerns” USA Today Online Edition (5 October 2006), online: USATODAY.com <http://www.usatoday.com/tech/news/2006-10-05-satellite-laser_x.htm?POE=TECISVA> (date accessed: 9 February 2007).

110 During a test in 1997, a 30-W ground-based tracking laser reportedly dazzled an imaging satellite at 500 km altitude, although few details are available. John Donnelly, “Laser of 30 Watts Blinded Satellite 300 Miles High” Defense Week (8 December 1997) at 1, cited in David Write et al, *The Physics of Space Security: A Reference Manual* (Cambridge: American Academy of Arts and Sciences, 2005) at 128.

111 Union of Concerned Scientists, “Satellite Laser Ranging in China” (8 January 2007), online: UCSUSA <http:// http://www.ucsusa.org/global_security/space_weapons/chinese-lasers-and-us-satellites.html> (date accessed: 25 March 2007)

112 “US Claims that China Has Used Lasers to Attack Satellites” *Jane's Defense Weekly* (16 October 2006).

113 Elaine M. Grossman, “Is China Disrupting US Satellites?” InsideDefense.com (13 October 2006), online: Military.com <http://www.military.com/features/0,15240,116694,00.html> (date accessed: 9 February 2007).

114 Northrop Grumman, Press Release, “Northrop Grumman Chosen to Proceed with Developing Solid-State Laser Technology for Military Applications” (5 Janaury 2006) online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=91947> (date accessed: 24 April 2007); Textron Systems, Press Release, “Textron Systems Receives Award to Develop Joint High Powered Solid State Laser (JHPSSL) for the US Army” (16 February 2006), online: Textron Defense Systems <http://www.textrondefense.com/news/2006/02_16_06.htm> (date accessed: 9 February 2007).

115 Northrop Grumman, Press Release, “Northrop Grumman Chosen to Proceed with Developing Solid-State Laser Technology for Military Applications”.

116 Jeremy Singer, “Program Officials Prepare for Critical ABL Intercept” Defense News (13 March 2006) at 42; “Boeing Airborne Laser Rolls Out Modified Aircraft and Prepares for Tests” Spacewar (30 October 2006), online: Space War <http://www.spacewar.com/reports/Boeing_Airborne_Laser_Team_Rolls_Out_Modified_Aircraft_And_Prepares_For_Flight_Tests_999.html> (date accessed: 8 February 2007); Lockheed Martin, Press Release “Lockheed Martin Verifies Integrated Beam Control Performance for Missile Defense Agency’s Airborne Laser” (27 October 2006), online: Lockheed Martin <http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=17995&rsbci=0&fti=112&ti=0&sc=400> (date accessed: 8 February 2007).

117 Northrop Grumman, Press Release, “Northrop Grumman Successfully Fires Most Powerful, Continuously Pulsed Illuminator Laser to Date” (12 October 2006), online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=106752> (date accessed: 9 February 2007).

118 “Boeing Demonstrates Aerospace Relay Mirror System” Spacewar.com (8 August 2006), online: Space War <http://www.spacewar.com/reports/Boeing_Demonstrates_Aerospace_Relay_Mirror_System_999.html> (date accessed: 26 April 2007).

119 “Boeing Demonstrates Aerospace Relay Mirror System”.

120 Theresa Hitchens, “US Air Force Plans a Laser Test Against a Satellite in FY 07” (3 May 2006), online: Center for Defense Information <http://www.cdi.org/program/document.cfm?DocumentID=3411&StartRow=11&ListRows=10&&Orderby=D.DateLastUpdated&ProgramID=68&typeID=(8)&from_page=relateditems.cfm> (date accessed: 26 April 2007).

121 Hitchens, “US Air Force Plans a Laser Test Against a Satellite in FY 07.”

122 Jeff Hetch, “US stymies anti-satellite laser weapons development,” *Optoelectronics Report*, 15 May 2006.

123 Qiang Xi-wen, “Nonliear Effects on Propagation of Ultrashort Intense Laser Pulses in the Atmosphere” (2006) 35(1) Infrared and Laser Engineering at 49-54, online: WANFANG DATA <http://www.wanfangdata.com.cn/qikan/periodical.articles/hwyjggc/hwyj2006/0601/060111.htm> (date accessed: 9 February 2007); Rao Rui-zhong, “Combined Effect of Turbulence and Thermal Blooming of Laser Propagation in Atmosphere” (2006) 35(2) Infrared and Laser Engineering at 130-134, online: WANFANG DATA <http://www.wanfangdata.com.cn/qikan/periodical.articles/hwyjggc/hwyj2006/0602/060202.htm> (date accessed: 9 February 2007).

124 Tong Shu-feng, Liu Yub-qing, Jiang Hui-lin, “Power Analysis of APT Coarse Tracking Link of Free Space Laser Communication System” (2006) 35(3) Infrared and Laser Engineering at 322-325, 350, online: WANFANG DATA <http://www.wanfangdata.com.cn/qikan/periodical.articles/hwyjggc/hwyj2006/0603/060317.htm> (date accessed: 9 February 2007); Yao Jin-bin, Wang Ming-jun, Wu Zhen-sen, Huang Chao-jun, Wang Yun-qiang, “Design Principle of Laser Range Doppler Imaging Radar System Based on Detecting Space Target” (2006) 35(4) Infrared and Laser Engineering at 445-448, online: WANFANG DATA <http://www.wanfangdata.com.cn/qikan/periodical.articles/hwyjggc/hwyj2006/0604/060416.htm> (date accessed: 9 February 2007).

125 “US Condemns North Korea Missile Tests” CBC News (4 July 2006), online: CBC.ca News <http://www.cbc.ca/world/story/2006/07/04/korea-missile.html> (date accessed: 9 February 2007).

126 “North Korea Fires Seventh Missile” CNN.com (5 July 2006), online: CNN.com <http://www.cnn.com/2006/WORLD/asiapcf/07/05/korea.missile/> (date accessed: 9 February 2007).

127 “Outcry at N Korea ‘Nuclear Test’” BBC News (9 October 2006), online: BBC NEWS <http://news.bbc.co.uk/2/hi/asia-pacific/6033457.stm> (date accessed: 9 February 2007).

128 “France Says North Korean Blast ‘About Half a Kiloton’” *International Herald Tribune* (9 October 2006), online: International Herald Tribune <http://www.iht.com/articles/ap/2006/10/09/europe/EU_GEN_France_Koreas_Nuclear.php> (date accessed: 9 February 2007).

129 Office of the Director of National Intelligence Public Affairs Office, Press Release, "Statement by the Office of the Director of National Intelligence on the North Korea Nuclear Test" (16 October 2006), online: Council on Foreign Relations <http://www.cfr.org/publication/11735/statement_by_the_office_of_the_director_of_national_intelligence_on_the_north_korea_nuclear_test.html?breadcrumb=%2Fregion%2Fpublication_list%3Fid%3D276> (date accessed: 9 February 2007); "Success, Failure or Bluff? Scientists Pore Over Data" Khaleej Times (9 October 2006), online: *Khaleej Times* <http://www.khaleejtimes.com/DisplayArticleNew.asp?xfile=data/theworld/2006/October/theworld_October303.xml&section=theworld> (date accessed: 9 February 2007).

130 Justin Ray, "Delta 2 Rocket Puts Military Experiment into Space" Spaceflight Now (21 June 2006), online: Spaceflight Now <http://spaceflightnow.com/delta/d316/> (date accessed: 9 February 2007).

131 Justin Ray.

132 Justin Ray.

133 Defense Technical Information Center, "DARPA FY 2007 Exhibit R-2 RDT&E Project Justification"(February 2006), online: DTIC <www.dtic.mil/descriptivesum/Y2007/AirForce/0604855F.pdf> (date accessed: 9 February 2007) at 261.

134 Ryan Caron, "CDI Factsheet: MiTEx (Micro-satellite Technology Experiment)" (14 July 2006), online: Center for Defense Information <http://www.cdi.org/friendlyversion/printversion.cfm?documentID=3591> (date accessed: 9 February 2007).

135 Jeremy Singer, "Critics Worry There May Be More to MiTEx than Meets the Eye" *Space News* (5 July 2006), online: Space News <http://www.space.com/spacenews/archive06/Mitex_070306.html> (date accessed: 9 February 2007).

136 Ryan Caron.

137 Ryan Caron.

138 Theresa Hitchens, Michael Katz-Hyman, Victoria Samson, "Space Weapons Spending in the FY 2007 Defense Budget" (Center of Defense Information and the Henry L. Stimson Center, 6 March 2006), online: The Henry L. Stimson Center <http://www.stimson.org/wos/?SN=WS20050210773> (date accessed: 9 February 2007).

139 "US Air Force FY 2007 Exhibit R-2A RDT&E Project Justification" (February 2006), online: Defense Technical Information Center <www.dtic.mil/descriptivesum/Y2007/AirForce/0605306F.pdf> (date accessed: 9 February 2007) at 418.

140 "US Air Force FY 2007 Exhibit R-2A RDT&E Project Justification" at 418.

141 "Military Micro-Sat Explores Space Inspection, Servicing Technologies" Space.com (last updated 22 July 2005), online: Space.com <http://www.space.com/businesstechnology/050722_XSS-11_test.html> (date accessed: 9 February 2007).

Chapter Eight Endnotes

1 Jeffrey Lewis, "Space-Based Laser in the Black Budget?" (1 June 2004), online: Armscontrolwonk.com <http://www.armscontrolwonk.com/161/space-based-laser-in-the-black-budget> (date accessed: 22 May 2007).

2 Elizabeth Waldrop, "Weaponization of Outer Space: US Policy," *Annals of Air and Space Law* 29 (2004) at 1-28.

3 David Wright, Lauara Grego, and Lisbeth Gronlund, *The Physics of Space Security* (Cambridge: American Academy of Arts and Science, 2005), at 97.

4 US Air Force, *Counterspace Operations*, Air Force Doctrine Document 2-2.1 (2 August 2004) at 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 US 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: Federation of American Scientists <http://www.fas.org/spp/eprint/article05.html#33> (date accessed: 25 April 2007).

5 Bob Preston et al., *Space Weapons, Earth Wars* (Santa Monica: RAND Corporation, 2002), online: RAND Corporation <http://www.rand.org/publications/MR/MR1209/> (date accessed: 25 April 2007).

6 J.C. McDowell, Personal communication with author (3 April 2005).

7 J.C. McDowell, "The Soviet Fractional Orbital Bombardment System, A Short History," publication in preparation; personal communication with author (3 April 2005).

8 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" (November 1994), online: Lawrence Livermore National Laboratory <http://www.llnl.gov/etr/pdfs/11_94.2.pdf> (date accessed: 25 April 2007); Ball Aerospace, "Relay Mirror Experiment", online: Ball Aerospace <http://www.ball.com/aerospace/rme.html> (date accessed: 25 April 2007); 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); Ball Aerospace, "Brilliant Pebbles: Fact Sheet," online: Ball Aerospace <http://www.ball.com/aerospace/bpebbles.html> (date accessed: 25 April 2007).

9 Mark Wade, "Chronology 2004," Encyclopedia Astronautica. Online: http://www.astronautix.com/; Jonathan's Space Report, "Satellite Catalogue and Launch Catalogue", online: Jonathan's Space Report <http://planet4589.org/space/log/satcat.txt> (date accessed: 25 April 2007).

10 "Space Based Laser Put on Hold" *Arms Control Today* (December 2002).

11 David Wright, Lauara Grego, and Lisbeth Gronlund, *The Physics of Space Security* (Cambridge: American Academy of Arts and Science, 2005), at 89.

12 Air Force Research Laboratory, "Space-Based Laser Research" (August 2004), online: Air Force Research Laboratory Technology Horizons <http://www.afrlhorizons.com/Briefs/Aug04/DE0302.html> (date accessed: 25 April 2007); Jeffrey Lewis, "Liftoff for Space Weapons," Center for International and Security Studies at Maryland (CISSM), 21 July 2003.

13 David Pugliese, "US 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).

14 US Naval Research Laboratory, "Clementine – DSPSC" (2002), online: US Naval Research Laboratory <http://www.cmf.nrl.navy.mil/clementine/> (date accessed: 25 April 2007); NASA-GSFC, "Clementine Project Information", online: NASA <http://nssdc.gsfc.nasa.gov/planetary/clementine.html> (date accessed: 25 April 2007).

15 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification" (February 2004), online: Defense Technical Informational Center <http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf>(date accessed: 25 April 2007).

16 David Ruppe, "House Committee Cuts Space Interceptor Test Program" Global Security Newswire (15 June 2004), online: Nuclear Threat Initiative <http://www.nti.org/d_newswire/issues/2004/6/15/ed3ecef6-efb6-4740-a39c-b49388ec20a9.html> (date accessed: 25 April 2007); Jeremy Singer, "MDA to remove "kill vehicle" sensor from NFIRE," *Space News*, 23 August 2004.

17 Air Force Material Command, "Microsatellite Propulsion Experiment Industry Day" (30 August 2004), online: SpaceRef.com <http://www.spaceref.com/news/viewsr.html?pid=13807> (date accessed: 25 April 2007).

18 Missile Defense Agency, "MDA Exhibit R-2 RDT&E Budget Item Justification" (February 2004), online: Defense Technical Informational Center <http://www.dtic.mil/descriptivesum/Y2005/MDA/0603886C.pdf> (date accessed: 25 April 2007).

19 Sam Black, "Evolution of the Space Test Bed" (21 March 2007), online: Center for Defense Information <http://www.cdi.org/friendlyversion/printversion.cfm?documentID=3884> (date accessed: 25 April 2007).

20 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: APS <http://www.aps.org/public_affairs/popa/reports/nmd03.cfm> (date accessed: 25 April 2007).

21 Barton et al.

22 Congressional Budget Office, "Alternatives for Boost-Phase Missile Defense" (July 2004), online: CBO <http://www.cbo.gov/ftpdoc.cfm?index=5679&type=1> (date accessed: 25 April 2007).

23 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) at 50-84.

24 European Space Agency, "Automated Transfer Vehicle", online: ESA <http://www.esa.int/esaMI/ATV/index.html> (date accessed: 25 April 2007).

25 Marcia S. Smith, "Chinese Space Program: An Overview," CRS Report for Congress RS21641 (18 October 2005), online: Federation of American Scientists <http://www.fas.org/sgp/crs/space/RS21641.pdf> (date accessed: 22 May 2007).

26 John Pike and Peter Voth, "Current Plans for Missile Defence" *Disarmament Forum*, No. 1 (2001) at 7.

27 Victoria Samson, "A Contender for SBIRS High," *Space News Business Report* (13 March 2006), online: Space.com <http://www.space.com/spacenews/archive06/SamsonOpEd_031306.html> (date accessed: 22 May 2007).

28 Gunter Dirk Krebs, "Spirale 1, 2", online: Gunter's Space Page <http://www.skyrocket.de/space/index_frame.htm?http://www.skyrocket.de/space/doc_sdat/spirale-1.htm> (date accessed: 25 April 2007).

29 Formerly called Force Application and Launch from Continental US program (FALCON) but the acronym was dropped when the program ended its strike component.

30 Space Exploration Technologies, "Company Description" , online: Spacex<http://www.spacex.com/> (date accessed: 25 April 2007).

31 David Wright et al, *Physics of Space Security*, at 104.

32 Sun, et al; Huang at 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.

33 David Wright et al, Physics of Space Security, at 134.

34 Ibid., at 74.

35 Uranium Information Centre, Briefing Paper 8, "Nuclear Reactors in Space" (January 2004), online: UIC <http://www.uic.com.au/nip82.htm> (date accessed: 25 April 2007).

36 Gunter Dirk Krebs, "Military Satellites," online: Gunter's Space Page <http://www.skyrocket.de/space/sat.htm> (date accessed: 25 April 2007).

37 "China to launch first space solar telescope in 2008," *Press Trust of India*, 24 October 2004.

38 European Space Agency, "Crew Return Vehicle for the International Space Station," online: ESA <http://www.esa.int/esaHS/ESARZS0VMOC_iss_0.html> (date accessed: 25 April 2007).

39 CNES, “CNES and Aquitaine Regional Council join forces for atmospheric re-entry programmes” (8 November 2004), online: CNES <http://www.cnes.fr/html/_455_463_1545_2863_.php> (date accessed: 25 April 2007).

40 Japanese Aerospace Exploration Agency (JAXA), “Research on Flight Demonstrations”, online: JAXA <http://www.ista.jaxa.jp/res/b01/0b02.html> (date accessed: 25 April 2007).

41 David Wright et al, *Physics of Space Security*, at 59.

42 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.

43 The Galileo navigation system is an initiative of the European Commission of the EU in partnership with the European Space Agency, which is responsible for the technical aspects of the project. All EU members will have access to it, as well as Norway and Switzerland, who are ESA member states. Additional international partners include Israel, Ukraine, India, Morocco, Saudi Arabia and South Korea, the US and Russia. China will not have access to the encrypted service. See Civil Space and Global Utilities Trend 3.4.

44 The capabilities in each prerequisite technology can vary a great deal. The filled square only indicates that there is some capability.

45 Jane Quirk, Missile Defense Agency, “Missile Defense Agency Space Application Center of Excellence Presentation for the MDA Small Business Day Conference,” (12 September 2006), online: <
http://www.mdasmallbusiness.com/conference/download/2006presentations/06-MDA-1887%20Quirk.pdf> (date accessed: 10 February 2007).

46 Jane Quirk.

47 Theresa Hitchens, Michael Katz-Hyman, and Victoria Samson, “Space Weapons Spending in the FY 2007 Defense Budget” (6 March 2006), online: Center for Defense Information <http://www.cdi.org/pdfs/FY07SpaceWeapons.pdf> (date accessed: 8 February 2007). The actual request for FY2008 was only $10-million.

48 Caitlin Harrington, “US Stays Firm on Right to Defend Space Assets” *Jane’s Defence Weekly* (12 July 2006) at 6.

49 “House, Senate Authorizers Block Space-Based Interceptor Funding” *Inside Missile Defense* (25 October 2006).

50 “Multiple Kill Vehicle Test Successful” MDA News (19 July 2006), online: MDA <http://www.mda.mil/mdalink/pdf/06fyi0080.pdf> (date accessed: 10 February 2007).

51 Nathan Hodge, “Successful Intercept Boosts US Missile Defence Programme” *Jane’s Defence Weekly* (September 2006).

52 House Armed Services Committee, “Strategic Forces Subcommittee Portion of the NDAA FY07 Mark-Up Summary” (2 May 2006), online: House Armed Services Committee <http://armedservices.house.gov/Issues%20109th/NDAAFY07/full%20cmte%20marks/Strategic%20FC%205.3.06.htm> (date accessed: 25 April 2007)

53 Theresa Hitchens, Michael Katz-Hyman, and Victoria Samson, “Space Weapons Spending in the FY 2007 Defense Budget” (6 March 2006), online: Center for Defense Information <http://www.cdi.org/pdfs/FY07SpaceWeapons.pdf> (date accessed: 8 February 2007); Jeffery Lewis, Multiple Kill Vehicle (MKV) (12 September 2005), online: ArmsControlWonk <http://www.armscontrolwonk.com/781/multiple-kill-vehicles-mkv> (date accessed: 25 April 2007).

54 Theresa Hitchens, Michael Katz-Hyman, and Victoria Samson.

55 Missile Defense Agency, BMD Basics, "Microsatellites", online: MDA <http://www.mda.mil/mdalink/html/asptmicrosat.html> (date accessed: 9 February 2007).

56 Missile Defense Agency, "FY 2007 Exhibit R-2A RDT&E Project Justification", online: Defense Technical Information Center <www.dtic.mil/descriptivesum/Y2007/MDA/0603895C.pdf> (date accessed: 9 February 2007) at 12.

57 Jeremy Singer, "Tesat Delivers Lasercom Hardware for NFIRE" *Space News* (19 December 2006).

58 Theresa Hitchens, Michael Katz-Hyman, and Victoria Samson, "Space Weapons Spending in the FY 2007 Defense Budget" (6 March 2006), online: Center for Defense Information <http://www.cdi.org/pdfs/FY07SpaceWeapons.pdf> (date accessed: 8 February 2007).

59 "Missile Defense Agency Plans NFIRE Follow On" *Space News Briefs* (6 March 2006), online: *Space News* <http://www.space.com/spacenews/archive06/Briefs_030606.html> (date accessed: 8 February 2007); Jeremy Singer, "Tesat Delivers Lasercom Hardware for NFIRE" *Space News* (19 December 2006).

60 Michael P. Kleiman, "High-speed air vehicles designed for rapid global reach," (27 January 2006), online: Air Force Link <http://www.af.mil/news/story.asp?id+123015809> (date accessed: 1 June 2007).

61 The Common Aero Vehicle was re-named the Hypersonic Technology Vehicle and weaponization of the vehicle is no longer part of the Falcon program.

62 Graham Warwick, "US Hypersonic Aircraft Project Faces Change as Congress Urges Joint Technology Office" Flight (30 May 2006), online: Flight Global <http://www.flightglobal.com/Articles/Article.aspx?liArticleID=206909&PrinterFriendly=true> (date accessed: 10 February 2006).

63 Ibid.

64 Jeff Hecht, "Hypersonic weapons projects to begin test flights," *New Scientist*, V. 23 no. 35, 4 January 2007. The X-51 is based on NASA's X-43 test vehicle.

65 Pratt & Whitney, Press Release, "Pratt & Whitney Rocketdyne Completes Mach 5 Testing of World's First Closed-Loop Hydrocarbon-Fueled Hypersonic Propulsion System" (27 July 2006), online: Pratt & Whitney, http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=47f350b7d32de010VgnVCM100000c45a529f.

66 University of Queensland, News Release, "Hyshot Scramjet Experiment Blasts off in South Australian Desert" (25 March 2006), online: The University of Queensland <http://www.uq.edu.au/news/index.html?article=9258> (date accessed: 9 February 2007).

67 University of Queensland, News Release, "Hyshot Scramjet Experiment Blasts off in South Australian Desert" (25 March 2006), online: The University of Queensland <http://www.uq.edu.au/news/index.html?article=9258> (date accessed: 9 February 2007). The sponsoring institutions are: The University of Queensland, Astrotech Space Operations, Defence Evaluation and Research Agency (DERA, UK), National Aeronautics and Space Agency (NASA, USA), Defence, Science and Technology Organisation (DSTO, Australia), Dept. of Defence (Australia), Dept. of Industry Science and Resources (Australia), The German Aerospace Centre (DLR, Germany), Seoul, National University (Korea), The Australian Research Council, Australian Space Research Institute (ASRI), Alesi Technologies (Australia), National Aerospace Laboratories (NAL, Japan), NQEA (Australia), Australian Research and Development Unit (ARDU, Australia), the Air Force Office of Scientific Research (AFOSR, USA) and Luxfer, Australia.

68 Air Force Research Laboratory, News Release, "Multi-national Agreement to Advance High-speed Flight" (14 November 2006), online: Spaceflight Now <http://spaceflightnow.com/news/n0611/14hifire/> (date accessed: 9 February 2007).

69 “Russia to Restore Space Missile Warning System” Johnson’s Russia List (6 April 2006), online: Center for Defense Information <http://www.cdi.org/russia/johnson/9112-27.cfm> (date accessed: 8 February 2007).

70 ”Improved GPS Satellite in Orbit” Defense News (27 November 2006) at 18.

71 “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: RIA Novosti Russia <http://en.rian.ru/russia/20051116/42110098.html> (date accessed: 8 February 2007).

72 Torkel Patterson, “Taping into India’s Military and Civil Markets” 4 *Technology Today* (2006), online: Technology Today <http://wwwxt.raytheon.com/technology_today/current/feature_5.html> (date accessed: 8 February 2007). K.S. Jayaraman, “India to Develop Regional Navigation System” *Space News* (22 May 2006).

73 Robert Hewson, “New Chinese Guided Bomb Kit Produced” *Jane’s Defence Weekly* (16 November 2006) at 7.

74 ESA News Release, “Commission is Looking for New Ways to Benefit from Galileo Navigation System” (8 December 200) online: Europa The European Union On-Line <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1709&format=HTML&aged=0&language=EN&guiLanuage=en> (date accessed: 9 February 2007).

75 “High-Energy Laser Systems Have One of the Most Successful Years Ever in 2006” Spacewar (4 January 2007), online: Spacewar <http://www.spacewar.com/reports/High_Energy_Laser_Systems_Have_One_Of_The_Most_Successful_Years_Ever_In_2006_999.html> (date accessed: 8 February 2007).

76 Michael Fabey, “SBIRS, ABL, Poses Challenges for US Defense” Defense News (6 February 2006) at 18.

77 Jeremy Singer, “Program Officials Prepare for Critical ABL Intercept” Defense News (13 March 2006) at 42; “Boeing Airborne Laser Rolls Out Modified Aircraft and Prepares for Tests” Spacewar (30 October 2006), online: Spacewar <http://www.spacewar.com/reports/Boeing_Airborne_Laser_Team_Rolls_Out_Modified_Aircraft_And_Prepares_For_Flight_Tests_999.html> (date accessed: 8 February 2007); Lockheed Martin, Press Release “Lockheed Martin Verifies Integrated Beam Control Performance for Missile Defense Agency’s Airborne Laser” (27 October 2006), online: Lockheed Martin <http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=17995&rsbci=0&fti=112&ti=0&sc=400> (date accessed: 8 February 2007).

78 Jim Wolf, “US Hails Airborne Laser as Weapons Milestone” Reuters (27 October 2006), online: REUTERS <http://today.reuters.com/news/articleinvesting.aspx?type=companyNews&storyid=307945+27-Oct-2006+RTRS> (date accessed: 9 February 2007).

79 Northrop Grumman, Press Release, “Northrop Grumman Chosen to Proceed with Developing Solid-State Laser Technology for Military Applications” (5 January 2006), online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.html?d=91947> (date accessed: 9 February 2007); Textron Systems, Press Release, “Textron Systems Receives Award to Develop Joint High Powered Solid State Laser (JHPSSL) for the US Army” (16 February 2006), online: Textron Defense Systems <http://www.textrondefense.com/news/2006/02_16_06.htm> (date accessed: 9 February 2007).

80 “Northrop Grumman Chosen to Proceed with Developing Solid-State Laser Technology for Military Applications” News Releases (5 Janaury 2006) online: Northrop Grumman <http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=91947> (date accessed: 24 April 2007).

81 David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security*, (Cambridge: American Academy of Ars and Science, 2005) at 134.

“The benefits and advantages that space can provide for all mankind are becoming as ubiquitous as the air we breathe. For policy makers, for journalists, for technical professionals, and for those just interested in space, the Space Security Index is a unique resource. There is no more comprehensive and up-to-date source of information on developments in space, and the threats to space security, than the Space Security Index.”

Hon. Philip E. Coyle
Senior Advisor, Center for Defense Information
Former Assistant Secretary of Defense and Director, Operational Test and Evaluation,
US Department of Defense

“Over the past year we have seen a number of important developments in space which force us to think even more critically about how to achieve stability in this arena. *Space Security 2007* is an excellent review of the developments in military and civil space and how they affect space security. It is essential for space professionals and political leaders to understand these developments.”

Brigadier General Simon P. Worden
United States Air Force (Ret.).

“Keeping space a secure environment in which all users can be confident that they can operate free from threats of disruption is an issue gaining increasing attention on the international agenda. I recently chaired a workshop on space security in Tokyo; speakers from Japan, China, India, and Korea all referred to the Space Security Index. It has clearly become the accepted starting point for international discussions of space security.”

Prof. John Logsdon
Director, Space Policy Institute, George Washington University

“The space environment is evolving rapidly in terms of actors, space applications, and space traffic. Many benefits from spaceflight are emerging, but also the pending weaponization of space seems to be possible. In this complex situation, *Space Security 2007* needs the widest possible readership. This carefully researched book is an indispensable resource that includes economic, technical, legal, and political facts for those interested in space and global security.”

Dr. Götz Neuneck
Institute for Peace Research and Security Policy, University of Hamburg

“The Space Security Index is a one-stop-shopping site for all those with an interest in the security issues that affect civil, commercial, and military operations in space. It serves as both a repository of objective data and as an overview of trends, making it a particularly useful resource for those who are new to field as well as a must-have document for researchers, industry, legislators and policy-makers with space-related responsibilities.”

Theresa Hitchens
Director, Center for Defense Information

SPACE SECURITY 2007

SPACESECURITY.ORG