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Peace through Mutually Assured Survival -

Global Transparency through Ubiquitous Satellite Imagery

by

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Abstract

The US can achieve increased situational awareness and sensor density, even in an anti-area/access denial (A2/AD) environment, by pursuing international or commercial collaborative efforts for space-based surveillance. The United States no longer enjoys dominance in space and adversaries are seeking ways to mitigate American force multiplication provided by space capabilities. Collaboration with commercial efforts or international programs could approach ubiquitous or nearly ubiquitous satellite imagery and would provide greater peace through global transparency.

Expansion of the spaced-based imagery market is increasing both the number and capabilities of commercial satellites. The US government can no longer afford to build the number of satellites needed to achieve ubiquitous imagery and should pursue both commercial and international efforts. Two commercial programs offer the foundations of ubiquitous satellite imagery, Skybox Imaging and the hosted payload opportunity on the Iridium NEXT constellation. The advantages and gains from global transparency would offset potential disadvantages/losses for open societies, like the United States.

Such steps would also move towards survivability and deter aggression in space by potential adversaries. Similar to the collective defense of NATO during the Cold War, an adversary would be less willing to attack satellites belonging to an international consortium than they would be to attack a satellite owned by the US government.

Introduction

Anti-access and area denial environments present challenges to US space dependencies that can be greatly mitigated by expanding international and commercial cooperation but that approach requires changes to US laws and policies. Such arrangements may make adversaries less willing to attack space assets belonging to multiple countries or international commercial entities. Therefore, creating a coalition to build, fly, and operate satellites would reduce collective vulnerability through shared deterrence.

Surveillance from space can deter hostile actions (state and non-state actors) by providing: indications and warnings, ability to influence public perception, coalition building/preservation, and undeniable "proof" of actions for retribution and/or punishment. However, it takes focused effort to provide situational awareness from space. Orbital mechanics limits the time satellite based sensors can "see" a spot on the earth. Thus, adversaries can forecast when US surveillance satellites are overhead and can take steps to hide or disrupt space-based observations. In fact, a $2 application on the iTunes store provides exact time of satellite visibility as well as predicted ground separation distance for any location.[1] Launching more satellites can provide longer cumulative observations, but at increased costs.

Unfortunately, due to economic conditions, the United States cannot afford to go it alone in satellite imagery.[2] Concerns over losing control of satellite imagery from commercial sources prompted the current US remote sensing policy, restricting both resolution and availability (aka "shutter control"). However, as recent history has shown, the commercial satellite imagery market is growing, but is expanding faster outside US control. No longer should the US fear commercial satellite imagery. Near-ubiquitous satellite imagery[3] from commercially derived

programs should be ardently pursued. The US military has long been nervous about greater availability of commercial satellite imagery;[4] however, increased satellite imagery would approach global transparency, albeit with benefits and drawbacks. There are a few barriers to achieving global transparency (threats and policy) and two near-term commercial efforts may provide global satellite imagery coverage, but policy and legal changes must occur. US leadership in space is no longer assured[5] and the threat is only growing more acute.

Threats

The United States no longer enjoys uncontested use of space and the threats to US space imaging are only going to grow. The current environment sees increasing threats and declining budgets.[6] Global proliferation of ASAT technology and diminishing opportunities for US industry leadership are accelerating the threat to US satellite imagery.[7]

Anti-Satellite Threats

ASAT technology is proliferating. Originally, ASATs were kinetic (hit-to-kill) or nuclear. The US and Soviet Union pursued such ASAT programs as early as 1968, but halted overt development[8] due to global backlash.[9] The Chinese admitted to an ASAT test in January 2007 and obliquely described two similar events as "missile defense tests" in January 2010 and May 2013.[10] The Chinese ASAT efforts reignited the global ASAT debate.[11] Hoping adversaries do not use ASATs to target US imaging satellites is not a strategy.[12]

ASATs are power projection capabilities[13] and other countries, like India, are investigating various ASAT technologies.[14] ASATs are not just kinetic. Lasers can blind (temporarily or permanently) imaging satellites. President Gerald Ford accused the Soviets of laser illumining two US satellites in 1975.[15] In 2006, the director of the National Reconnaissance Office (NRO) acknowledged[16] the Chinese illuminated a US spy satellite with a ground based laser. The US Army conducted an ASAT laser test in 1997.[17] Other weapons may

have already been developed that increase the threat to US imaging satellites. In September 2013, the Chinese demonstrated close proximity space flight between two satellites – one satellite equipped with a manipulator arm. Even though such capability has clear military implications, the Chinese couched these tests using terms like "space debris observation" and "space maintenance technologies."[18] To be effective, an ASAT does not need to be destructive.

Satellites have several points of vulnerability. In this case, an imaging satellite is a collection of sub-systems, working together to take and deliver imagery to a customer. Besides lasers that affect the imaging sub-system, different parts of the satellite can be attacked to disrupt the imagery collection. For instance, the satellite is commanded via its uplink and sends telemetry and mission data over its downlink. All satellites are vulnerable to link jamming and countermeasures are hard to design[19] and can add up to 40% to a satellite's cost.[20] Intentional jamming has occurred on at least three occasions. Since 2003, the Iranian government has jammed non-state owned TV channels.[21] In September 2013, Al Jazeera publically accused the military-based Egyptian government of jamming its television broadcast since July 7th, 2013.[22] As far back as 1986, technology widely existed to not just jam, but hijack satellite downlinks.[23] This example quickly slides into the newest and most concerning threat -- cyber-attacks.

As nations become more adept at cyber operations, satellites are inherently more vulnerable to cyber-attacks. In their 2011 annual report to Congress, the US-China Security and Economic Commission claimed the Chinese military hacked into, but stopped just short of sending rogue commands, to Landsat-7 and the Terra spacecraft.[24] In 1999, hackers tried to blackmail the British government with threats to alter the orbit of a British military communication satellite.[25]

As a result of these very real and expanding threats, there are now efforts to ban anti-satellite weapons or establish "international agreements to limit competition or ban specific weapons."[26] Yet, experts, see these efforts as "pious nonsense"[27] with very low likelihood of successfully stemming cyber ASAT proliferation. Diplomatic efforts to deter cyber-attacks may buy some time but will not provide assured access to satellite imagery in a time of crisis. In a May 2012 interview, then Secretary of Defense Panetta commented that a cyber-attack that "took down our government systems…would constitute an act of war" While Secretary Panetta was not specifically addressing threats to satellites, the Secretary did conclude the US should "take steps to prevent a mistake that could be very damaging to our security."[28] Deterring or withstanding attacks is not the only threat to ubiquitous imagery from space. Shrinking budgets may limit future options for the US, too.

Diminishing Opportunity

The number of US optical imaging satellites has been falling quite drastically over the last three years, see Figure 1. Commercial imaging companies are under tremendous financial pressure and the US share of global satellite imaging continues to decline. One gloomy forecast predicts there may be fewer collaborative opportunities to pursue.[29] A contrarian view sees over 100 commercial remote sensing satellites by 2021, but not all of these will produce visible images and few will be US owned and operated.[30] This was ominously foreshadowed in January 2013 when the two largest commercial remote sensing companies in the United States merged due to reduced government demand for satellite imagery.[31] These companies had used a $7 Billion contract from the DOD to "buy time to establish a commercial market for their imagery" but government restrictions led the companies to "set aside other business prospects."[32] Figure 1 shows the US commercial remote sensing industry is further suffering from government-imposed restrictions.[33]

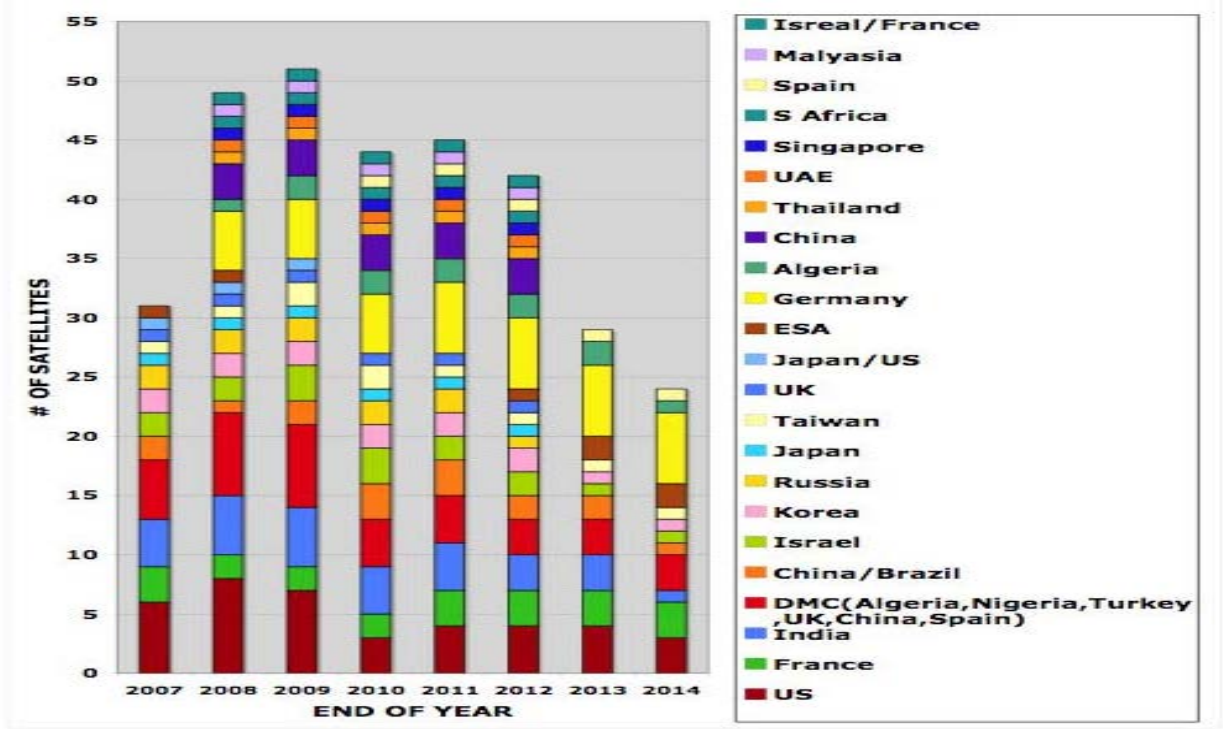

Figure 1 Predicted On-orbit Optical Satellites (better than 50m resolution) [34]

In 2012, the Aerospace Industries Association, a trade group of US satellite manufacturers, issued a report saying the US lost 35% market share, totaling $21 Billion, and approximately 9,000 jobs from 1999 to 2009.[35] One analyst puts business losses at 50% of global satellite commerce.[36] One of the causes of this decline is that US laws and policy restrict the ability of US companies to compete internationally, while competitors like France and China show no compunction to hamstring their businesses.[37] Often China uses satellite sales "to cement ties with key foreign countries" and to garner good will[38] to be exchanged for cooperation in other realms. Thus, some countries are changing laws enabling their domestic industries to compete for global satellite market share.[39] Japan recently amended its laws to allow Mitsubishi Electric Company to offer commercial customers access to satellite technology previously reserved for the government. This move enabled Mitsubishi to win a two-satellite deal with Turkey.[40] It is important to note that the Turkish Transportation Ministry

acknowledged that the Japanese government contributed to Mitsubishi beating US-based Lockheed Martin for the $751 million deal.[41] Additionally, in a blow to American prestige and influence on the world market, in 2013, United Arab Emirates chose a French company over Lockheed Martin to supply that country's military surveillance satellites, worth an estimated $955 million.[42] One analyst attributed this loss of business directly to the "US State Department's restrictions."[43] Some countries equate advanced satellites with national pride,[44] yet US trade policies restrict what US companies can offer potential customers.[45]

Intended to reduce international arms trade[46] and prevent countries from gaining access to missile technology,[47] US export regulations have undergone many changes since the first export controls were enacted as part of the Foreign Assistance Act of 1974 (Nelson-Bingham Amendment). This required the President to notify Congress of upcoming "government sponsored arms sales in excess of $25 million. However, after some notable shenanigans by Presidents Nixon and Ford,[48] Congress passed tighter restrictions. The subsequent Arms Export Control Act was the culmination of a battle between Congress and the President over foreign policy, especially in the sales of military items to other nations.[49] The Congress included "commercial sales" of technology and in the 1990s added spacecraft and associated equipment in these export controls.[50] Additionally, Congress has repeatedly tightened export controls in response to other countries' actions or policies, further hampering US businesses.[51] These changes have not prevented the proliferation of technology, only reduced US industrial lead.[52] Only recently has Congress taken steps to allow US companies to regain competitiveness, but more changes are still needed.[53]

The US State Department made additional minor changes to the International Traffic in Arms Regulations (ITAR) in May 2013[54] to remove some of the "stigma and headaches"

associated with US companies selling space technology internationally. Unfortunately, these changes are not widespread and are creating more confusion. One industry group cautioned the new ITAR rules would further "impede the use and benefits of…commercial systems for non-DOD specific requirements."[55] Other countries are offering commercial satellite imagery, free of ITAR restrictions that compete more favorably than restrained US companies do around the world.

In 2009, a German company, called RapidEye, started offering "high-resolution, large-area image data" refreshed in as little as 19 minutes[56] using five cubesats.[57] Images at that resolution and refresh rate would be militarily significant.[58] Providing situational awareness in anti-access/area denial environments does not require super fine resolution or hundreds of satellites. Using commercially available systems can aid military planning as well as contribute to peace negotiations or other diplomatic efforts.[59]

Viable Commercial Options

In 2002, George Tenent, Director of Central Intelligence directed the US Intelligence Community to shift to using commercial imagery "to the greatest extent possible." Tenet's intent was to "stimulate…and maintain…a robust US commercial space imagery industry."[60] Since the French launched the first commercial imagery satellite in 1986, governments have struggled with controlling access to high resolution images from space and the need to protect national interests. The US government has seemingly been at crossroads with US space industry – trying to advance satellite imaging technology, prevent technology proliferation, yet encourage US industrial leadership. As early as 1994, Congress directed the DOD to specifically evaluate using commercially available imagery[61] for national security and military needs. In fact, President Carter set the stage for reliance on commercial satellite imagery in Presidential

Directive/NSC-54 in November 1979: "our goal is the eventual operation by the private sector of our civil land remote sensing activities."[62] There is a natural friction between government interests (e.g. protecting US secrets) and commercial ones (e.g. profit, increasing market share, etc.). However, there are areas for cooperation. In 2008, the Director of National Intelligence and the Secretary of Defense agreed to have the NRO purchase two commercially-derived imaging satellites instead of producing their own designs.[63] This agreement stops short of full commercialization because the ground infrastructure will be developed and operated by the National Geospatial Intelligence Agency. The 2010 National Space Policy notes, "a robust and competitive commercial space sector is vital to continued progress in space."[64] The "fundamental truth for government space programs is that budgets are policy"[65] encourages increased cooperation, both commercially and internationally. There may be a middle-ground…where both the government and the company have a little skin in the game.

The US government has experience using joint ventures with industry, often done to "expand the nation's industrial base."[66] One long-standing example is government owned, contractor operated (GOCO) facilities. Governed by Part 45.3 of the Federal Acquisition Regulations, GOCOs are where the government provides property "peculiar to the mission (e.g. military or space property)."[67] Today the National Laboratories are GOCO, although they are operated by commercial companies.[68] There is another form of cooperation the US government that closer connects government and industry…hosted payloads.

In September 2011, commercial satellite operator SES launched SES-2 (a for-profit commercial communications satellite) with an infrared sensor for missile detection. This effort, known as Commercially Hosted Infrared Payload (CHIRP), is important because this was several firsts for the US government: first tri-party commercially hosted payload,[69] first DOD payload

on a foreign-owned satellite,[70] and first waiver allowing the DOD to use foreign launches.[71] CHIRP led to another important change in US export controls. The Secretary of Defense can request permission to launch on boosters from friendly countries (e.g. not "China, North Korea, and any country that is a state sponsor of terrorism").[72] This change opens the aperture wider to allow DOD greater flexibility to host payloads on non-US owned satellites. Couple this flexibility to use space available on foreign launchers with smaller satellites mean increased chances to put satellites or payloads into orbit.

To expand opportunities, the Air Force established a Hosted Payload Office. This office is developing open contracts for hosting government payloads on commercial satellites.[73] Funding and politics now become the problem; the FY2014 Omnibus Appropriations Bill cut funding for future hosted payload efforts, citing rationale that the efforts were "ahead of need."[74] It is time for the pendulum to swing the other way. Instead of hosting a payload, the DOD should secure access to advanced satellite imaging technology by outright "buying into" commercial programs. This was previewed in December 2000, when the DOD secured "unlimited use" of Iridium's global telephone network.[75] Buying into an emerging imaging satellite constellation offers huge potential value for the DOD, both operationally and strategically.

Return on Investment

The US space industry has tremendous impact on national security and the US economy. According to the Aerospace Industry Association's 2012 Annual report, a strong domestic industrial base produces advances in materials, sensors, and data processing. These businesses have employees in every state, offer some of the highest-skilled and best pay for any US workforce demographic, and contribute more to a positive trade balance than any other US manufacturing sector.[76] It is difficult to quantify the specific return on investment in space

systems. Although, experts previously estimated a 14-to-1 return on investment from the 1960s to 1980s.[77] Today, for example, the commercialization of GPS creates an estimated $122 Billion and over 5 million jobs.[78]

Other countries see the economic and societal benefits of space based surveillance. France was the first country to challenge the United States' lead in space-based commercial surveillance. In 1986, the European Space Agency built and launched SPOT-1, a joint effort between France, Argentina, and Belgium,[79] which offered better resolution than Landsat[80] and was the first imaging satellite planned to serve mostly commercial, not government customers. China has repeatedly cooperated with other countries in imaging satellites (Brazil,[81] Pakistan,[82]and Venezuela[83]). Smaller countries, like Chile, are purchasing commercially-derived surveillance satellites to simultaneously serve both government and commercial customers.[84] Countries gain goodwill from cooperation by cooperating with each other regarding satellite imagery and a more deliberate US policy in this direction would be helpful.[85]

For example, after making Landsat data publicly available in the 1970s, the US gained tremendous soft-power as over 130 countries signed up for data access[86] and today 14 countries have ground stations supporting the Landsat program, including China.[87] The US government continued to solely fund the Landsat, but even with this international cooperation, future funding is uncertain.[88] Thus, the National Research Council strongly encouraged the DOD to "establish partnerships with commercial firms and international land imaging programs."[89] It is safe to assume government agencies want higher resolutions, yet most military missions can be satisfied using commercial capabilities. Historically, governments and commercial entities have traded cost for resolution.[90] Today, commercial technology has caught up to and is likely to surpass most government needs.

Resolution Tradeoffs

Imaging satellites are valued by the quality of their images. The universal metric is called ground sampling distance (GSD). GSD is the minimum distance between two objects that both can be seen distinctly. Objects closer than a satellite's GSD may appear as one object. While specific performance is classified, numerous reports claim US government reconnaissance satellites' GSD is 0.13 meters.[91] Although few commercial satellites approach this GSD, commercially available technology provides sufficient resolution for most situational awareness requirements. Following a French proposal in 1981, the United Nations evaluated what GSD would be needed for satellite surveillance functions (See Appendix D). Commercial imaging satellites available today provide detection, recognition, and identification of most military targets. Commercial satellites have offered resolution better than 1 meter since IKONOS-1. From Appendix D, a satellite with 1-meter GSD would meet 40% of surveillance functions; a 0.5-meter GSD (as in WorldView-1, GeoEye-1, etc.) would meet 60%. Therefore, pursuing a strategy of more numerous cheaper albeit less capable (0.5-1 meter GSD) satellites would offload the majority of imaging requirements from more capable, but less numerous national systems (see Appendix E for more comparisons).[92]

Potential Drawbacks

Increasing the number of satellites decreases obscurity,[93] increasing the situational awareness, and providing sensor density over time and distance. Said simply, more satellites equal more pictures, more pictures equals increased awareness of events on the ground. There are concerns that more pictures allow abuse by the government or stalkers.[94] In fact, the proliferation of surveillance technology has caused some backlash among the American public about potential abuse.[95] A 2008 plan by the Department of Homeland Security to provide domestic law enforcement entities access to detailed satellite imagery raised privacy concerns[96]

and promoted a Congressional inquiry.[97] Technology is not good or evil. It is how people use the technology. Terrorists have been known to use Google Earth but no known attack is directly attributed to satellite imagery available on the internet.[98] However, research has shown Americans "are willing to make tradeoffs between liberty and security."[99]

Another drawback is that other states may object based on sovereignty or internal security concerns.[100] Pro-Israel groups successfully lobbied to have US policy limit imagery of publicly available imagery of Israel to no better than is commercially available from non-US commercial resources.[101] National governments lose control over who has information about their domestic situation. Sovereignty is threatened by increased satellite imagery.[102] The United States Commercial Remote Sensing Policy was such an attempt to protect the vital interests of the United States and allies for these very reasons.[103] However, the rest of the world is catching up and the US government must take actions or risk being out-innovated.[104] Restricting US companies only encourages non-US entities to pursue high resolution imaging satellites while embracing emerging commercial ventures can bring other advantages.

Potential Advantages

Ubiquitous satellite imagery will advance transparency, enable trust building, and reduce the likelihood of conflicts escalating out of control due to mistaken beliefs or perceptions. Besides the obvious advantage of simply having more imagery of known threats, decreasing the revisit time reduces the likelihood of missing an important event. For instance, in December 2012, two commercial imagers provided "much more reliable" information about China's new Y-20 transport aircraft.[105] Similarly, the internet is full of examples of private citizens using commercial satellite imagery to identify concerns to US national security.[106] In short, more satellites provide more information, which provides greater sensor density and situational awareness that approaches global transparency.

Support to civil authorities will be tremendously aided by this "growing transparency" increased satellite imagery will provide. Relief agencies could respond faster and more effectively to refugee movements or international disputes.[107]Human rights groups are using satellite imagery to document and report on abusive regimes.[108] No other nation is as invested in space as is the United States, yet "space is an Achilles' heel."[109] Much as information technology progressed from government sponsorship to market driven innovation of today, the next space age will be "driven by competition and 'adventure capitalists,'"[110] not governments. US policy must change to allow industry to remain competitive against the rest of the world (see Appendix B for a summary of US and DOD policy).

Near-term Commercial Opportunities

Commercial ventures are out-pacing the US government's satellite efforts, especially surveillance (see Appendix C) and industry makes technical advances faster than military-sponsored research.[111]

The last telling bit of data from Appendix C is the age of commercial satellites versus their government cousins. Commercial satellites are newer while 131 state-owned satellites are beyond their design life. This is indicative of where future investments will come. Experts warned, "space commerce is becoming more and more international, making it difficult for [governments] to tell what [country a satellite] belongs to."[112] As with Iridium, if future imaging satellites are owned by an international consortium, an adversary may be less likely to attack them. Therefore, the US should do more to enable commercial imaging satellites and encourage companies to pursue investment from friendly nations. One such example is a small startup company from Silicon Valley.

Skybox Imaging

A California company plans to launch 24 satellites to provide near-real time imaging by 2018. Skybox Imaging's catch phrase is "Your world, on demand" and provides high resolution imagery to support growing commercial demand.[113] The company launched its first satellite, Skybox-1, a 100-kg, $50M satellite, using a Russian rocket on 21 November 2013 and released the first image on 11 December.[114] Skybox-1 also records HD video,[115] which is good enough for global situational awareness (see Figure 2) and the HD video opens the potential for near ubiquitous global transparency while providing sensor density to mitigate anti-access or area denial techniques.

Figure 2 Comparison of Skybox Imaging (left), Google Maps (center), and DigiGlobe commercially available imagery (right) of Zayed University in Abu Dhabi, UAE[116]

A constellation of 24 Skybox-1 satellites (8 planes) would provide average revisits of less than 4 minutes for almost all areas between 65°N and 55°S latitude.[117] Assuming no economies of scale or cost reduction due to technology advances, at $50M per satellite, the Skybox constellation will cost $1.2 billion. As comparison, the GeoEye-1 satellite cost $502 Million[118] and the US government routinely spends $1-2 Billion for one reconnaissance satellite.[119] The DOD should invest in Skybox Imaging in the same way it purchased unlimited use of Iridium. Skybox Imaging is not the only commercial option; the US government already well-familiar with another immediate option, Iridium.

Iridium NEXT

In February 2007, Iridium announced the next generation of their communication satellites,[120] with an added ability to carry a hosted payload.[121] All 66 satellites in the upcoming second generation of Iridium will have size, weight, and power and downlink suitable for an imaging mission.[122,123] Commercially available optics packages could produce a new image of every spot on Earth every 4-7 minutes.[124]

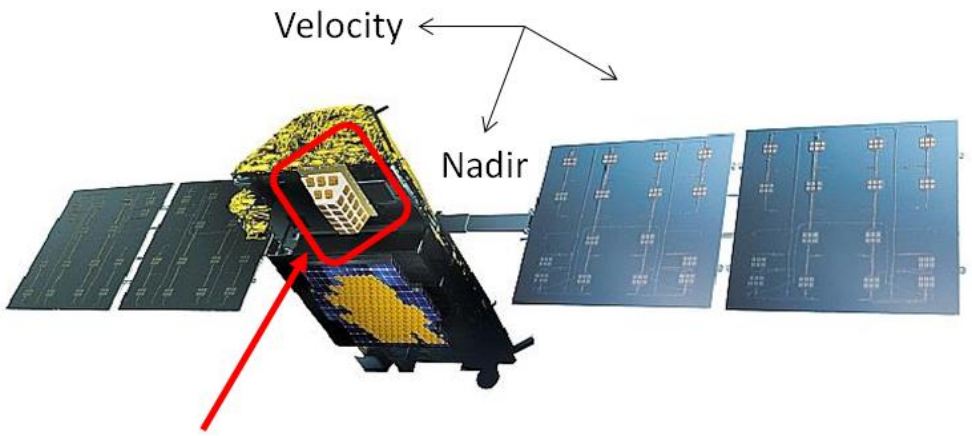

Figure 3 Iridium NEXT Hosted Payload location

Skybox and Iridium NEXT are both poised to offer huge decreases in the cost of satellite imagery; see Appendix D for details.

International Efforts

Partnering with other countries creates "a geostrategic dilemma" for adversaries and counters A2/AD threats.[125] This was demonstrated in 2007 when Australia joined the US by funding the sixth satellite of the Wideband Global SATCOM (WGS) program.[126] Five additional countries joined in 2012 by funding WGS-9, in exchange for access to the entire WGS constellation.[127] The DOD plans to "shift much of its communications traffic" to WGS, making WGS a likely target in an anti-access or area denial environment. However, with WGS being used by seven countries a potential adversary may be less likely to disrupt or degrade WGS.[128]

International cooperation spreads out costs, thus reducing financial burden, too. [129] Even though not every international effort runs smoothly, there are several other benefits from working with other countries.

Reduced Rivalry

Since the beginning of the space era with Sputnik, countries have competed against each other. As one example, the Europeans started the European Space Agency to "spread the financial burden"[130] while promoting European cooperation in science and technology.[131] A shared satellite imagery system was predicted to greatly strengthen NATO, as well as encourage member nations to live up to their treaty obligations,[132] contribute to international stability, and "create new forms of social engagement."[133] Cooperation in space would create a collective identity and link countries together.[134] Extending the offer of cooperation could bring the US "precious political capital" with allies and adversaries, alike.[135]

Attitudes, beliefs, and perceptions hamper information sharing,[136] but sharing satellite mission data has occurred for 30+ years. The international search and rescue satellite system, COSPAS/SARSAT, started in 1980 with sharing agreements among Canada, USA, USSR, and France. Since inception, five other countries joined.[137] These partners see themselves as members of a broader group.[138] Thus, further sharing is "a stabilizing factor in global terms."[139] Sharing reduces mistrust[140] and makes friends of potential rivals.[141] Cooperating nations see themselves as friends and typically offer a unified front to outside threats. This is the basis of NATO…collective assurance.

Collective Assurance

The NSSS introduces collective assurance as a way to keep adversaries from pursuing or performing counter-space activities.[142] At times, since 1978, the US has used this collective security to dissuade or deter aggression in space. For example, President Carter declared that

destruction of an American satellite would be considered "an aggressive act and a violation of the provisions" of the United Nations Charter.[143] Then in 1999, then Secretary of Defense William Cohen declared "an attack on US satellites is an attack on the United States." This was more recently echoed by General Moseley, the US Air Force Chief of Staff in 2007 when China conducted its anti-satellite test.[144] Yet, rhetoric alone will not guarantee the availability of satellite imagery. Cooperative efforts with other countries may provide "the same unity in numbers that has proven…in other domains."[145]

Deterring an adversary is to affect their calculus of acceptable costs versus derived benefit. Maximizing the use of all space systems (government and commercial) can minimize the risk of war or limit conflicts that do occur.[146] Additionally, allies developing their own national security space capabilities "can spread the risk of adversary attacks against satellite systems."[147] As far back as 1985, some suggested the best way to prevent an arms race in space is to "promote its commercial development."[148]

Global Transparency

Leveraging commercial satellites and seeking international collaboration would approach a state of global transparency. No state would be able to hide massive troop movements or construction of destabilizing facilities.[149] In fact, Canada recognized the stabilizing influence of satellite imagery and called for international 'paxsats' or peace satellites.[150] No government wants to expose the capabilities of its advanced spy satellites and thus even open governments like the United States are reluctant to share imagery from national systems,[151] but history has lessons to learn from. Eisenhower previewed global transparency with his 1955 Open Skies proposal. Yet, Soviet fear and distrust stalled cooperation until 1992.[152] Today, Open Skies enhances "mutual understanding and confidence" between participating nations.[153,154] and

imagery is made available to all 34 participating countries.[155] Imagine if availability of this data was increased 100 fold for 1/20th the cost.

Commercial US companies may pave the way for international satellite imagery partnerships. One shining example is the Iridium constellation which is partially owned by financial interests in over 60 countries.[156] Attacking one country's satellite is relatively easy. Attacking satellites belonging to 60 is an entirely different ballgame. Plus, a large constellation is inherently more resilient.[157] Reducing the threat to imaging satellites would ensure greater situational awareness, even in A2/AD environments.

The DOD pursuing commercial access via companies like Skybox or hosted payloads on Iridium could lead to ubiquitous satellite imagery. Multiple second or third order benefits could follow, such as crowd-sourced intelligence.[158] Using crowd sourcing, a team from MIT took less than nine hours to locate ten "targets" located around the country.[159] Likewise, there is recent examples of military benefits from civilians having ready access to satellite imagery, even from weather satellites.[160] The Air Force is pursuing crowd-sourcing, offering more than $100,000 in prizes.[161] Other benefits of ubiquitous satellite imagery include real-time satellite imagery guiding precision munitions, new MASINT sources (e.g. measuring wakes on oceans or ripples on rivers), and greatest of all, the potential for global coherent change detection.[162]

Conclusion

Space is vital to national security of many countries, not just the United States. Space is a force-multiplier[163] and imagery does not lie.[164] Yet, dependence on satellite imagery is America's "soft ribs and strategic weaknesses."[165] Threats to assured space-based imagery are growing. Two opportunities in the remote sensing market (Skybox Imaging and hosted payloads on Iridium NEXT) would help. International cooperation shares costs and offers collective

security in space. The DOD must further change its policy and pursue increased collaboration, domestically and abroad.

Appendix A – Ground Sample Distance (GSD) Requirements

In 1981, France submitted a proposal to the United Nations to create an international agency expressly for arms control agreements and crisis management.[166] In the original report, UN experts devised a table of resolutions (i.e. ground separation distance, GSD) needed for satellite surveillance functions (see Table 2 below).[167]

Object	Detection	Recognition	Identification	Description	Analysis[168]
Troop Units of bivouacs	6	2.1	1.2	0.30	0.08
Aircraft	4.5	1.5	0.9	0.15	0.03
Vehicles	1.5	0.6	0.3	0.05	0.03
Roads	9	6	1.8	0.6	0.15
Military Airfields	-	90	4.5	1.5	0.15
Submarines (on surface)	30	6	1.5	0.9	0.03
Radar installations	3	0.9	0.3	0.15	0.04
Radio communications	3	1.5	0.3	0.15	0.15
Land mine fields	9	6	0.9	0.025	-
Marshalling yards/railway depots	30	15	6	1.5	0.6
Medium-sized surface vessels	7.5	4.5	0.6	0.30	0.08

Table 1 GSD Requirements for Satellite Surveillance Functions (in meters)

Notes[169]
Detection: location
Recognition: general target type
Identification: discrimination of specific type, composition
Description: equipment count, layout, configuration
Analysis: model or variant, readiness levels

Appendix B –US Policy

US policy on satellite imagery stems from two documents: the National Space Policy of the United States of America and the 2003 Commercial Remote Sensing Policy. Since 1978, US policy has restricted the resolution of US commercial remote sensing systems.[170] Today, the Commercial Remote Sensing Act continues limiting quality or timeliness of images that US companies can sell to non-governmental users for national security interests.[171] No other space-faring country is as restrictive.[172] Luckily, it appears US policy is easing.

In 2006, the Bush Administration published an update to the then 10 year old National Space Policy. This document expressed US intentions to "cooperate with other nations" with a desire to "dissuade or deter others from impeding…or developing capabilities" to threaten US space capabilities.[173] This document also stressed the need to "strengthen and maintain the US Space-Related Science, Technology, and Industrial Base."[174] President Obama released a new National Space Policy in 2010. The most obvious difference was "openness and transparency," as compared to earlier policies.[175] Further, this policy seeks to leverage foreign and commercial space and non-space capabilities.[176] To this end, in November 2013, the Senate gave the Executive Branch authority to partially relax restrictions on US companies.[177] DOD policy must be modified as well to take advantage of increased commercial opportunity.

DOD Policy

DOD policy encourages building coalitions and partnerships with other US government agencies and commercial partners.[178] DOD Space Policy, updated in October 2012, notes that enhancing cooperation among government, civil, and commercial space sectors will result in increased interoperability.[179] The same document directs the DOD to use proven commercial systems and technologies to meet mission requirements, when cost-effective.[180] This is not enough; size matters.

Before 2013, the DOD pursued large satellites that cost billions of dollars. In August 2013, Air Force Space Command publicly advocated a new strategy called "disaggregation."[181] Industry has pushed the DOD to move away from "unaffordable…large and complex Class A systems" to smaller satellites that create "innovative space systems architectures." This approach would break the "Space Acquisition Vicious Circle"[182] by offering reduced life cycle costs, stimulating the industrial base, and allowing rapid technology refresh and innovation.[183] Only politics restricts international cooperation for satellite imagery,[184] but a thaw in US policy points to the potential for increased cooperation.

National Security Space Strategy

National space interests and commercial space enterprises are converging. In 1997, the commander of US Space Command predicted, "It is not the future of military space that is critical to the United States – it is the continued commercial development of space that will provide continued strength for our great country in the decades ahead."[185] An international or commercially-shared satellite program may lessen the threats to US situational awareness from space.

In 2011, the Director of National Intelligence issued the first National Security Space Strategy (NSSS). This document noted the fierce competition in space: US satellite market share down 30%, US industry consolidation, and losses in maintaining a qualified workforce.[186] The DNI identified five approaches to protect US space capabilities (see below).[187]

Focus Area	Approach
Promote responsible, peaceful and safe use of space	Lead by example, supporting development of transparency and confidence-building measures (TCBMs)
Provide improved U.S. space capabilities	• Continue improving space acquisition, technology development, and space cadre • Foster robust, competitive, flexible, and healthy space industrial base
Partner with responsible nations, international	• Operate in coalitions of like-minded spacefaring nations; pursue opportunities for cost-and risk-sharing

organizations, and commercial firms	• Explore sharing space-derived information as “global utilities” like GPS
Prevent and deter aggression against space infrastructure that supports U.S. national security	Multilayered approach: shape the international environment, encourage potential adversary restraint, improve our intelligence posture, and develop a range of response options
Prepare to defeat attacks and to operate in a degraded environment	Improve resilience of systems and constellations

Table 2 Approaches to Implement National Security Space Strategy

Appendix C –Satellites on Orbit

According to the UCS Satellite Database, as of August 2013, 1,084 satellites were on orbit, with 205 of these belonging to US commercial entities. Of these, the Union of Concerned Scientists lists 200 imaging satellites (see below).[188]

Country/Organization	Government	Military	Commercial
China	29	12	0
European Space Agency	4	0	0
France (independently)	2	0	0
France (coalition)	2*	2	2
Germany	6#	5	1^
Germany/USA	2	0	0
India	9	3$	0
Israel	0	4	2%
Japan	10@	0	0
United States	17	22	4+

Table 3 Remote Observation Satellites on orbit (as of September 2013)

Notes

* Includes Calipso (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) between France/USA

Includes Bird 2 (Bispectral InfraRed Detector 2) which is funded by the German government and German space interests

^Includes TerraSAR-X 1 (Terra Synthetic Aperture Radar X-Band) which is co-funded by the German government and commercial interests

$ Includes TES (Technology Experiment Satellite) which is funded by the India military and civil space interests

% Includes EROS A1 and B1 (Earth Resources Observation Satellite) which is co-funded by the Israeli military and a commercial entity

@ Includes TRMM (Tropical Rainfall Measuring Mission) which is a joint effort between Japan and the USA

+ Includes Worldview 1 & 2, Quickbird 2, and Ikonos 2 which are used by the US government, military, and commercial interests

Appendix D – Costs of Satellite Imagery

No cost estimates details for Iridium NEXT hosted payloads are available. Skybox Imaging promises "orders of magnitude decrease in cost,"[189] but the company has not released pricing figures yet. However, it is helpful to compare current costs for commercially available satellite images.[190]

Satellite	Resolution (for 10x10 km image)	Price (new standard tasking, not archive image, specified within 2 weeks period)
COSMO-SkyMed	1 meter	$9,450
GeoEye-1	0.5 meter (panchromatic)[1] 2.0 meter (multispectral)	$4,200 $4,500
IKONOS	0.8 meter (panchromatic) 3.2 meter (multispectral)	$4,000
WorldView-1[3] WorldView-2	0.5 meter (panchromatic)[2] 1.8 meter (multispectral)	Not Available $17,850
QuickBird[4]	0.61 meter (panchromatic) 2.44 meter (multispectral)	$20,090 $20,825
SPOT[5]	2.5 meter (color)	$3,060

Table 4 Commercial Satellite Images through e-geos VAR

Notes
1: GeoEye-1 products are limited to 0.5 meter resolution, panchromatic and 2.0 meter, multispectral
2: WorldView-1 and 2 products are limited to 0.5 meter resolution (panchromatic)
3: WorldView-1/2 minimum image is 15km x 14km
4: Quickbird minimum image is 17.5km x 14 km
5: SPOT image size is 20 km x 20 km

Skybox Imaging has not released cost details of its imagery. However, the company founder claims to be able to offer satellite imagery at 1/100th the cost of imagery currently available.[191]

Appendix E – Revisit Rates

In 2004, two students at the Naval Post Graduate School calculated the best orbits to achieve global satellite visibility, based on altitude and the number of satellites. After some detailed analysis, these students identified a 24-ball satellite, 8-plane constellation would achieve the maximum coverage (as defined by shortest revisit time) for the majority of the Earth's landmass.[192]

Limitations of physics and adversary concealment, camouflage, and deception (CCD) efforts can be overcome. The laws of physics govern satellite motions and the orbital altitude (height above the earth's surface) determines a satellite's orbital period and thus length of time over one spot on Earth. Table 1 gives sample values of satellite orbital performance.

Altitude (km)	Orbital Period[193] (minutes)	Visibility[194], time above horizon (minutes)	Sensor Maximum Field of View,[1] (km x km) [195]	Ground Separation Distance[2,3]
200	88.3	6.9	209 x 209	0.61 meters
500	94	11.5	524 x 524	1.5 meters
700	98	14	732 x 732	2.1 meters
1000	105	17.6	1047 x 1047	3.0 meters

Table 5 Comparison of Sample Orbits for Imagery

Notes
1: Assuming 60° sensor operating at 0.5μm, the center of the visible spectrum
2: Assuming an 8-inch (200 mm) telescope, allowing for 4 cm for processing/control hardware to fit in the Iridium NEXT allowed volume.
3: The ECAM-C50 Color CMOS Camera, 5 Megapixel was used to calculate GSD. This space-qualified camera offers a 58mm x 58mm CMOS sensor, and 2592x1944 pixels.

This table shows the trade-offs between satellite coverage and visibility as a function of altitude (higher altitude means a wider swath, but less resolution for the same optical power camera). Lower altitude means more satellites to provide global coverage, but provide higher resolution (greater detail per image). Higher altitudes mean fewer satellites, but require

advanced technology to provide similar resolution. Two-dimensional CCDs, like the ones in Skybox Imaging satellites offer this commercial, off the shelf technological advancement. Now is where the commercial imaging industry becomes attractive.

Endnotes

[1] See Anthony Goodwin's review of the SpyMeSat iOS application, http://dailyappshow.com/spymesat
[2] For example, see McLean, p133.
[3] While not officially codified in US doctrine or law, Merriam-Webster defines ubiquitous as a simultaneous presence everywhere.
[4] In 1973, the CIA analyzed China's use of commercially available LANDSAT imagery for ballistic missile targeting. See United States. Central Intelligence Agency. Directorate of Intelligence. Probable Chinese Collection of US Satellite Imagery. N.p.: CIA?BGI, 1973. The National Security Archive. George Washington University, 27 Nov. 2012. <http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/01.pdf>.
[5] See the Space Foundation's report on ITAR and the U.S. Space Industry, available: http://www.spacefoundation.org/sites/default/files/downloads/SpaceFoundation_ITAR_0.pdf
[6] See Slide 5 of "Working Session I Assessing Commercial Space Alternatives in Early Stages of the Government Acquisition Process." *Government Payloads on Commercial Host Spacecraft*. Proc. of National Space Symposium, Boradmoor Hall, Colorado Springs, CO. Hosted Payload Alliance, 8 Apr. 2013. <http://www.hostedpayloadalliance.org/AM/Template.cfm?Section=Documents&Template=/CM/ContentDisplay.cfm&ContentID=3384>.
[7] See McLean, p58.
[8] See Moltz, James Clay. *The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests*. Stanford, CA: Stanford Security Studies, 2008.
[9] For example, Joan Johnson-Freese claimed, "China suffered global condemnation after [their] 2007 test." See "CHINA US Focus - Exclusive Analysis of the Politics, Economics, Military and Culture of China-US Relations." *CHINA US Focus Chinas AntiSatellite Program Theyre Learning Comments*. China-United States Exchange Foundation, 12 July 2013. <http://www.chinausfocus.com/peace-security/chinas-anti-satellite-program-theyre-learning/>.
[10] See Brian Weeden's "Time for Obama To Go Public on China's ASAT Program." *Defense News*. Gannett Company, 2 June 2013. <http://www.defensenews.com/article/20130602/DEFREG/306020009/>.
[11] For example, see Dr. Rajagopalan's article "China's Missile Defence Test: Yet Another Milestone?" *China's Missile Defence Test: Yet Another Milestone?* Institute for Defence Studies and Analyses (IDSA), 1 Feb. 2010. <http://www.idsa.in/idsacomments/ChinasMissileDefenceTest_rprajagopalan_010210>.
[12] Paraphrasing Rudy Giuliani's Keynote Speech to Day 2 of the 2008 Republican National Convention.
[13] See p27 of the *Annual Report To Congress Military Power of the People's Republic of China 2008*. <http://www.defense.gov/pubs/pdfs/china_military_report_08.pdf>.
[14] See Defense Minister V. K. Saraswat's comments, as quoted in "India Developing Anti-satellite Weapons." *India Developing Anti-satellite Weapons*. United Press International, 23 Apr. 2012. <http://www.spacewar.com/reports/India_developing_anti-satellite_weapons_999.html>.
[15] See Moltz, p179.
[16] See Reuters. "China Jamming Test Sparks U.S. Satellite Concerns - USATODAY.com." *China Jamming Test Sparks U.S. Satellite Concerns - USATODAY.com*. USA Today, 5 Oct. 2006. <http://usatoday30.usatoday.com/tech/news/2006-10-05-satellite-laser_x.htm>.
[17] The US Army fired their Mid Infrared Advanced Chemical Laser at the US Air Force's Multi-Sensor Technology Integration -3 satellite. See the SpaceNews article by Ferster and Clark, "NRO Confirms Chinese Laser Test Illuminated U.S. Spacecraft." *SpaceNews.com*. SpaceNews, Inc., 3 Oct. 2006. <http://www.spacenews.com/article/nro-confirms-chinese-laser-test-illuminated-us-spacecraft>.
[18] See David's "Mysterious Actions of Satellites Have Experts Guessing China's Intentions." NBC News - Science. NBC News Digital, 10 Sept. 2013. <http://www.nbcnews.com/science/mysterious-actions-satellites-have-experts-guessing-chinas-intentions-8C11122565>.
[19] The US Air Force National Air and Space Intelligence Center released a report on threats to US Space Superiority. The report was nicely summarized in SIGNAL Magazine, see, Robert K. Ackerman's "Space Vulnerabilities Threaten U.S. Edge in Battle." *Signal Magazine Online*. AFCEA International, June 2005. <http://www.afcea.org/content/?q=node/973>.
[20] See Table 8-11 on page 237 of Wertz, James Richard., and Wiley J. Larson. "Hardness and Survivability Requirements."*Space Mission Analysis and Design*. 3rd ed. Torrance, CA: Microcosm, 1999. 237.

[21] See a Los Angeles Times article by Morin and Rubin. "Cuba Jams Broadcasts to Iran, U.S. Says." *Los Angeles Times*. Los Angeles Times, 17 July 2003. <http://articles.latimes.com/2003/jul/17/local/me-irantv17>.
[22] See "Egypt Jamming Al Jazeera's Satellite Signals." *Egypt Jamming Al Jazeera's Satellite Signals*. Al Jazeera, 4 Sept. 2013. 2013. <http://www.aljazeera.com/video/middleeast/2013/09/201393183256834226.html>.
[23] In April 1986, a disgruntled satellite TV dish businessman, named John MacDougall, hijacked HBO's satellite transmission for over four minutes. See. "Captain Midnight: 'No Regrets' about Jamming HBO Back in '86."*Buzzblog*. Network World, 26 Apr. 2011. <http://www.networkworld.com/community/blog/captain-midnight-has-no-regrets-about-jamming>.
[24] Terra is a cooperative effort for Earth Observing between US, Canada, and Japan. See p216 of the *2011 Report to Congress of the US China Economic and Security Review Commission*. Rep. *USCC Annual Reports*. US Government Printing Office, Nov. 2011. <http://origin.www.uscc.gov/sites/default/files/annual_reports/annual_report_full_11.pdf>.
[25] See reports such as Tribune News Service's "Hackers Reportedly Seize Control Of Military Satellite." *Around the World*. Chicago Tribune, 01 Mar. 1999.
[26] See Moltz, p 25.
[27] See Moltz, p25.
[28] See "Leon Panetta: A Crippling Cyber Attack Would Be 'Act of War'." Interview by Jake Tapper. *Political Punch*. ABC News, 27 May 2012. <http://abcnews.go.com/blogs/politics/2012/05/leon-panetta-a-crippling-cyber-attack-would-be-act-of-war/>.
[29] See W. E. Stoney, ASPRS Guide To Land Imaging Satellites, NOBLIS INC., 12 February 2008. Available: http://info.asprs.org/news/satellites/ASPRS_DATABASE_021208.pdf
[30] "Imaging to Drive Remote Sensing Satellite Market." *Market News*. Optics.org, 31 May 2012.. <http://optics.org/news/3/5/43>.
[31] See "DigitalGlobe and GeoEye Complete Merger." *DigitalGlobe and GeoEye Complete Merger*. SpacePolicyOnline.com, 31 Jan. 2013. <http://www.spacepolicyonline.com/news/digitalglobe-and-geoeye-complete-merger>.
[32] This merger reduced the number of planned satellites (between the two companies) from five to three, with two of these already built. See Overly's "Satellite Imagery Companies Brace for Cut in Federal Funding for Contracts." Washington Post - Capital Business. The Washington Post, 01 Apr. 2012. <http://www.washingtonpost.com/business/capitalbusiness/satellite-imagery-companies-brace-for-cut-in-federal-funding-for-contracts/2012/04/01/gIQAN5rcpS_story.html>.
[33] See Ferster's "New Export Law Seen as Boon to U.S. Satellite, Component Makers."*SpaceNews.com*. SpaceNews, Inc., 4 Jan. 2013. <http://www.spacenews.com/article/civil-space/33047new-export-law-seen-as-boon-to-us-satellite-component-makers>.
[34] See Stoney's *ASPRS GUIDE TO LAND IMAGING SATELLITES*. 2008. MS. Bethesda. MD. *Http://info.asprs.org/news/satellites/ASPRS_DATABASE_021208.pdf*. American Society for Photogrammetry and Remote Sensing (ASPRS), 12 Feb. 2008. <http://info.asprs.org/news/satellites/ASPRS_DATABASE_021208.pdf>.
[35] Aerospace Industries Association. Rep. Aerospace Industries Association, Dec. 2012. <http://www.aia-aerospace.org/assets/aia_yearender_web_2012.pdf>.
[36] See Clark's "Obama Signs Law Easing Satellite Export Controls." Spaceflight Now - Breaking News. Spaceflight Now, INC, 3 Jan. 2013. <http://spaceflightnow.com/news/n1301/03exportcontrol/>.
[37] China has been described as "eager to establish itself as the country that will train space professionals." See Morring, et al, "New Space Power." *Aviation Week and Space Technology* 175.40 (2013): 54-55. Print.
[38] Since selling is first commercial satellite in 2007, China has sold satellites to multiple countries. See Hancock's "Chinese Satellites Selling Well in the Developing World." SmartPlanet Global Observer. CBS Interactive, 25 Jan. 2012. <http://www.smartplanet.com/blog/global-observer/chinese-satellites-selling-well-in-the-developing-world/>.
[39] Hauser, Marty, and Micah Walter-Range. *ITAR and the U.S. Space Industry*. Issue brief. Space Foundation, 2008. <http://www.spacefoundation.org/sites/default/files/downloads/SpaceFoundation_ITAR_0.pdf>, p2.
[40] Although this deal was for two communication satellites, the precedent is that other countries are encouraging their companies to be more competitive in the global space market. See Svitak and Perrett, "ESA Eyes Commercial Market Goal." *ESA Eyes Commercial Market Goal*. Aviation Week & Space Technology, 18 Mar. 2013. <http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_03_18_2013_p45-557782.xml>.

[41] The two governments signed a bilateral agreement to work closer together on future space programs. See de Selding's "Melco Lands Two-satellite Contract with Turkey." SpaceNews. SpaceNews, Inc., 8 Mar. 2011. <http://www.spacenews.com/article/melco-lands-two-satellite-contract-turkey>.
[42] See Seibt's "France Beats US to Abu Dhabi Spy Satellite Deal." *France 24 - International News 24/7*. France 24, 23 July 2013. <http://www.france24.com/en/20130723-france-beats-us-abu-dhabi-spy-satellite-deal/>.
[43] See Mutafa and Tran: "French-UAE Intel Satellite Deal in Doubt." *Defense News - C4ISR & Networks*. Gannett Government Media Corporation, 7 Jan. 2014. <http://www.defensenews.com/apps/pbcs.dll/article?AID=2014301070023>.
[44] See Broad's "A U.S. Spy Satellite May Be Sold Abroad." *The New York Times*. The New York Times, 17 Nov. 1992. <http://www.nytimes.com/1992/11/17/science/a-us-spy-satellite-may-be-sold-abroad.html>.
[45] See Seibt.
[46] See 22 USC. Sec. 2571. 2010. Print. Available: http://www.gpo.gov/fdsys/pkg/USCODE-2010-title22/html/USCODE-2010-title22-chap39.htm.
[47] See Ferster's "New Export Law Seen as Boon to U.S. Satellite, Component Makers."*SpaceNews.com*. SpaceNews, Inc., 4 Jan. 2013. <http://www.spacenews.com/article/civil-space/33047new-export-law-seen-as-boon-to-us-satellite-component-makers>.
[48] Congress feared getting entangled in other commitments, like Vietnam, after Nixon secretly sold "sophisticated weaponry" to Iran, Saudi Arabia, and Kuwait. See Tompa, pp294-6.
[49] After the Vietnam War, Congress frequently questioned Executive Branch decisions regarding international relations and sought to expand its influence on foreign policy. The resulting Arms Export Control Act of 1976 gave Congress the ability proactively shape arms sales and technology transfer. See Tompa's "The Arms Export Control Act and Congressional Codetermination over Arms Sales." American University International Law Review 1, no. 1 (1986): 291-330.
[50] Export controls require US companies to secure a license to sale satellites to foreign countries. This adds time and cost to every commercial contract US companies attempt to win. See 22 Code of Federal Regulations Ch. I, Subchapter M, Section 121.1 (4–1–13 Edition)
[51] In 1989, Congress added China to the list of forbidden exports in response to the Tiananmen Square massacre. See Gertz's "Feds: France Hinders Probe of Satellite Technology Sale to China." Washington Times. The Washington Times, 20 Dec. 2011. <http://www.washingtontimes.com/news/2011/dec/20/us-probes-french-tech-sales-to-china/?page=all>.
[52] A 2013 study estimated ITAR directly cost the US industry 19% market share since 1999. See St. John's "A Brief Overview of US Export Control Policy for Space Technology." *The View From Above*. Denver Journal Of International Law and Policy, 16 Apr. 2013. <http://djilp.org/3812/a-brief-overview-of-us-export-control-policy-for-space-technology/>.
[53] The process to secure export license can take 60-170 days. See page 11 of United States Department of Commerce "Introduction to U.S. Export Controls for the Commercial Space Industry." Office of Space Commercialization, Oct. 2008. <http://www.space.commerce.gov/library/reports/2008-10-intro2exportcontrols.pdf>.
[54] See de Selding, Peter B. "Proposed ITAR Changes a Mixed Bag for U.S. Satellite Industry."*SpaceNews.com*. SpaceNews, Inc., 14 June 2013. <http://www.spacenews.com/article/satellite-telecom/35794proposed-itar-changes-a-mixed-bag-for-us-satellite-industry>.
[55] In a blog about the new ITAR controls, IntelSat General, a commercial SATCOM company in the market to host payloads for the DOD, discussed ramifications of the new rules. The blog quotes the Hosted Payload Alliance commenting on proposed changes that declare hosted payloads as subject to export controls, "even if they are commercial in nature." See "ITAR Changes Could Increase Satellite Industry Export Challenges - See More At: Http://www.intelsatgeneral.com/blog/itar-changes-could-increase-satellite-industry-export-challenges#sthash.nOCpyi2K.dpuf." Web log comment. *ITAR Changes Could Increase Satellite Industry Export Challenges*. Intelsat General Corporation, 24 Sept. 2013. <http://www.intelsatgeneral.com/blog/itar-changes-could-increase-satellite-industry-export-challenges>.
[56] See Krebs' "RapidEye 1, 2, 3, 4, 5." *RapidEye 1, 2, 3, 4, 5*. N.p., 11 Sept. 2013. <http://space.skyrocket.de/doc_sdat/rapideye-1.htm>.
[57] Now called Blackbridge, after emerging from bankruptcy. The five cubesats were spaced 19 minutes apart in the same orbit and are expected to remain operational until 2019, providing 5m panchromatic imagery. See "RapidEye

Satellite Sensor." *RapidEye Satellite Imagery and Satellite System Specifications*. Satellite Imaging Corporation, n.d. <http://www.satimagingcorp.com/satellite-sensors/rapideye.html>.

[58] See page 20 of Weber and O'Connell's Alternative Futures: United States Commercial Satellite Imagery in 2020. Department of Commercial, Commercial Remote Sensing Regulatory Affairs, Nov. 2011. <www2.gwu.edu/~nsarchiv/.../docs/37.pdf>.

[59] During Dayton peace talks to end the Serbian conflict, unclassified satellite images were used to help reach agreement, see Windrem's "Spy Satellites Enter New Dimension." *Space on NBCNews.com*. NBC News, 9 Oct. 2001. <http://www.nbcnews.com/id/3077885/ns/technology_and_science-space/t/spy-satellites-enter-new-dimension/>.

[60] See the Directive Type Memorandum from DCI Tenet to NIMA, "Expanded Use of US Commercial Space Imagery." Letter to Director, National Imagery and Mapping Agency. 7 June 2002. *Declassified Documents Trace U.S. Policy Shifts on Use of Commercial Satellite Imagery from 1970s to Today*. National Security Archive, 9 Mar. 2011. <http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/20.pdf>.

[61] The Defense Appropriations Act for 1994 (Public Law 103-139, HR 3116) directed the Defense Mapping Agency to evaluate using commercially available images from satellites belonging to the Former Soviet Union. See Defense Mapping Agency Report on the Evaluation and Procurement OF Former Soviet Union Imagery And Materials, <http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/11.pdf>.

[62] See paragraph 2.b of Presidential Directive/NSC-45, <http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/04.pdf>.

[63] The program, called the Broad Area Space-based Imagery Collector (BASIC), specifies that the NRO will procure two "commercial-class" imaging satellites with 1.1 meter GSD resolution. See United States. Director of National Intelligence. Office of the Director. The National Security Archive. By J. M. McConnell and Robert M. Gates. George Washington University, 27 Nov. 2012. <http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB404/docs/26.PDF>.

[64] See page 3 of the 2010 National Space Policy, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[65] See Recommendation 4.1, page 11 of Dr. Scott Pace's "Integrating National Interests in Space." *Symposium On Space Policy, Regulations, and Economics*. Proc. of E3.2 – International Cooperation: Goals, Constraints, and Means, Italy, Naples. 63rd International Astronautical Congress, Oct. 2012. <https://www.gwu.edu/~spi/assets/docs/IAC-12.E3.2.7%20Pace%20Final.pdf>.

[66] For a very good review of the economics of government owned, contractor operated facilities, see Bennett and Hodges, Jr., An Exploratory Study of Costs to Operate Government-Owned, Contractor-Operated (GOCO) Facilities. Diss. Air Force Institute of Technology, 1981. Dayton: AFIT, 1981. Defense Technical Information Center. School of Systems and Logistics, n.d. <www.dtic.mil/dtic/tr/fulltext/u2/a104854.pdf>.

[67] Subpart 45.3 of the FAR governs providing government property to contractors. See Federal Acquisition Regulation (FAR), 48 C.F.R. Part 45.3 (2006).

[68] See Ullrich's "Government Owned/Contractor Operated Heritage." Government Owned/Contractor Operated Heritage. Sandia Corporation, 2013. <http://www.sandia.gov/about/history/goco.html>.

[69] The first DOD payload hosted on a commercial satellite was the Internet Protocol Routing in Space (IRIS) Joint Capability Technology Development. The IRIS JCTD effort was managed by Intelset and incorporated onto Intelsat-14, which launched on 23 November 2009. See "Service Offerings - Hosted Payloads." *Internet Routing in Space (IRIS)*. Intelsat General Corporation, 2013. <http://www.intelsatgeneral.com/service-offerings/hosted-payloads/heritage/internet-routing-space-iris>.

[70] Although the contract was managed by a US based subsidiary (SES Government Solutions of McLean, VA), SES is publicly traded company and is listed on the Luxembourg and Euronext Paris Stock exchanges. See "Shareholders." Press Release Rss. SES S.A., 2014. <http://www.ses.com/shareholders>.

[71] For specifics, see page 191 of GAO's *2013 Annual Report: Actions Needed to Reduce Fragmentation, Overlap, and Duplication and Achieve Other Financial Benefits*. N.p., 9 Apr. 2013. <http://www.gao.gov/modules/ereport/handler.php?1=1&path=/ereport/GAO-13-279SP/data_center_savings/General_government/24._Opportunities_to_Help_Reduce_Government_Satellite_Program_Costs#_ftn2_ref2>.

[72] As specified in the FY2014 National Defense Authorization Act (NDAA), see pp20-21 the Space Foundation's FY2014 budget analysis, *U.S. Defense Space-Based and Related Systems Fiscal Year 2014 Budget Comparison*.

Rep. no. Update #6. Space Foundation, 2014.
<http://www.spacefoundation.org/sites/default/files/downloads/01.15.14%20FY%2014%20Military%20Space.pdf>.
[73] For the Sources Sought Synopsis, see "Government Payloads on Commercial Host Spacecraft." *Government Payloads on Commercial Host Spacecraft*. FedBizOpps.gov, 28 Jan. 2013.
<https://www.fbo.gov/index?s=opportunity&mode=form&id=3a4414f3a159efab053a103903f0e6d0&tab=core&_cview=1>.
[74] The Advanced Extremely High Frequency (AEHF) Satellite Program Office had requested funds to conduct risk reduction and concept definition activities for a hosted communication payload in the FY2014 Presidential Budget. This $7M amount was specifically cut. See page 4 of the Space Foundation's FY2014 budget analysis, *U.S. Defense Space-Based and Related Systems Fiscal Year 2014 Budget Comparison*. Rep. no. Update #6. Space Foundation, 2014.
[75] For a paltry $72 Million, the DOD secured unlimited use of the Iridium global network for 20,000 users. See American Forces Press Release Service. "DoD Gets Global with Iridium Satellite-phone System." *Breaking News*. Spaceflight Now, INC, 13 Dec. 2000. <http://spaceflightnow.com/news/n0012/13iridium/>.
[76] See page 9 of Aerospace Industries Association 2012 Annual Report, Dec. 2012.<http://www.aia-aerospace.org/assets/aia_yearender_web_2012.pdf>.
[77] The National Journal estimated the return on NASA funding as 14-to-1. See "Measuring The NASA Stimulus." *NationalJournal.com*. National Journal Group Inc, 27 Aug. 2010.
<http://www.nationaljournal.com/njonline/no_20100827_1798.php>.
[78] The NDP Consulting Group is a Washington, DC based think tank. In 2011, they conducted an economic study to defend the GPS constellation against likely interference from LightSquared. The $122Billion and 5 million jobs were quoted by Jeffrey Hill's "NDP Study Outlines GPS Industry's Economic Impact." *News Feed*. Satellite TODAY, 23 June 2011. <http://www.satellitetoday.com/publications/st/2011/06/23/ndp-study-outlines-gps-industrys-economic-impact/>.
[79] See Belgian Air and Space Policy homepage, http://www.belspo.be/belspo/space/biCoop_en.stm.
[80] See page 10 Vedda's U.S. National Security and Economic Interests in Remote Sensing: The Evolution of Civil and Commercial Policy.
[81] See slides 4-7 of Huadong's "China's Earth Observing Satellites." *The Express Tribune Pakistan Inches towards Its First Imaging Satellite Comments*. Proc. of XXII ISPRS Congress, Australia, Melbourne. International Society for Photogrammetry and Remote Sensing, 28 Aug. 2012. <http://tribune.com.pk/story/374121/pakistan-inches-towards-its-first-imaging-satellite/>.
[82] Pakistan chose China for their first imaging satellite after China worked launched Pakistan's first communication satellite. See Ghauri's "Pakistan Inches towards Its First Imaging Satellite." *The Express Tribune*. The Express Tribune News Network, 4 May 2012.. <http://tribune.com.pk/story/374121/pakistan-inches-towards-its-first-imaging-satellite/>.
[83] In 2012, China launched the $140 Million Venezuelan Remote-Sensing Satellite 1 (VRSS-1). Although not state of the art, this satellite will provides two panchromatic/multispectral images at better than 2.5meter resolution from 640km. See Svitak, Amy. "VRSS-1 Is Model For Chinese Remote-Sensing Exports." *VRSS-1 Is Model For Chinese Remote-Sensing Exports*. Penton, 25 Nov. 2013.. <http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_11_25_2013_p55-637309.xml>.
[84] In December 2011, Chile's $70Million, 130-kg Sistema Satelital de Observación Terrestre reached orbit to provide 1.45m resolution images to support "national defense, particularly anti-drug trafficking operations, it will also contribute to civil applications such as agriculture, reforestation, weather monitoring, urban planning, and disaster monitoring." See p125 of Space Security's 2012 Space Security Index, available: http://swfound.org/media/93632/SSI_FullReport_2012.pdf.
[85] For example, the US Embassy is quoted as saying sharing Landsat imagery helped "the US government [gain] a million dollars worth of Malian political mileage." See pp 188=190 of Mack's "*Viewing the Earth: The Social Construction of the Landsat Satellite System*. Cambridge, MA: MIT, 1990. 188-90.
[86] See page 9 of James A. Vedda's U.S. National Security and Economic Interests in Remote Sensing: The Evolution of Civil and Commercial Policy.
[87] For locations, see *International Ground Station (IGS) Network*. US Geological Survey, 12 Nov. 2013.
<http://landsat.usgs.gov/about_ground_stations.php>.

[88] See "Uncertain Funding Jeopardizes U.S. Land Imaging Satellites." *Environment News Service RSS*. International Daily Newswire, 8 Aug. 2013. <http://ens-newswire.com/2013/08/08/uncertain-funding-jeopardizes-u-s-land-imaging-satellites/>.
[89] See the US Department of the Interior, US Geological Survey (USGS). *Initial Synopsis of NRC Report "Landsat and Beyond"*. By The Federal Geographic Data Committee. NGAC Landsat Advisory Group, 30 Aug. 2013., <http://www.fgdc.gov/ngac/meetings/september-2013/draft-LAG-synopsis-of-NRC-report-landsat-ngac-sep-2013.pdf>.
[90] See the presentation by Skybox Imaging at the 2013 Ground System Architecture Workshop, Guinan, Oliver. "Commercial Imaging Constellation Meets Cloud Computing." *GSAW 2013 Agenda, Presentations, & Tutorials*. Aerospace Corporation, 10 July 2013.. http://gsaw.org/wp-content/uploads/2013/06/2013s11b_guinan.pdf
[91] See Windrem's "Spy Satellites Enter New Dimension." *Space on NBCNews.com*. NBC News, 9 Oct. 2001. <http://www.nbcnews.com/id/3077885/ns/technology_and_science-space/t/spy-satellites-enter-new-dimension/>.
[92] Using one collection system to tip or queue collection by another system is not new. Even commercial companies are advocating this approach. See Second Line of Defense. "Monitoring the Gulf Of Hormuz: A New Option | SLDInfo." *What's New*. SLDinfo.com, 12 June 2012. <http://www.sldinfo.com/monitoring-the-gulf-of-hormuz-a-new-option/>.
[93] In 2007, a classified submarine propeller was clearly visible on Microsoft's Virtual Earth servers. See Weinberger's "January/February 2014." *Discover Magazine*. Kalmbach Publishing Co, 21 July 2008. <http://discovermagazine.com/2008/aug/21-can-you-spot-the-chinese-nuclear-sub>.
[94] Alex Salkever describes a scenario where a disgruntled spouse uses near-real time satellite imagery to check up on a dishonest spouse, see "So Long, Privacy: New Satellites Blow Google Earth Away."*DailyFinance.com*. AOL Inc, 4 Dec. 2009. <http://www.dailyfinance.com/2009/09/14/so-long-privacy-new-satellites-blow-googleearth-away/>.
[95] The Albuquerque Police Department is storing six-months worth of license plate images. The American Civil Liberties Union is concerned about increased collection being used in violation of privacy rights. See Patrick Lohmann's "Who's Watching You Now?" *Albuquerque Journal* 25 Aug. 2013, 237th ed., sec. A: 1-6. *ABQJournal Online*. Albuquerque Journal, 25 Aug. 2013. <http://www.abqjournal.com/253009/news/new-apd-policy-on-keeping-license-plate-data.html>.
[96] See Broache's "Homeland Security: We're Ready to Launch Spy Satellite Office." *CNET News*. CBS Interactive, 02 Apr. 2008. <http://news.cnet.com/8301-10784_3-9909638-7.html?tag=nefd.blgs>.
[97] The US House of Representatives' Homeland Security Committee held a hearing on and requested the Bush Administration delay operations by the DHS planned National Applications Office. See Anne Broache's "Democrats: Delay Spy Satellite Expansion." *CNET News*. CBS Interactive, 07 Sept. 2007. <http://news.cnet.com/8301-10784_3-9773741-7.html>.
[98] See Hearn's "Terrorist Use of Google Earth Raises Security Fears." *National Geographic*. National Geographic Society, 12 Mar. 2007. <http://news.nationalgeographic.com/news/2007/03/070312-google-censor.html>.
[99] A study on airport security procedures showed a willingness to sacrifice security for protection against terrorism. See Jason DeBruyn's "Looks like You Want to Give up Your Privacy for Security." *Triangle BizBlog*. American City Business Journals, 16 Aug. 2013. <http://www.bizjournals.com/triangle/blog/2013/08/looks-like-you-want-to-give-up-your.html>.
[100] See page 10 of Vedda's U.S. National Security and Economic Interests in Remote Sensing: The Evolution of Civil and Commercial Policy.
[101] Called the Kyl-Bingham Amendment to the 1997 Defense Authorization Act. See Twing's "U.S. Bans High-Resolution Imagery of Israel." *Washington Report on Middle East Affairs*. American Educational Trust, Sept. 1998. <http://www.wrmea.org/component/content/article/196-1998-september/8224-us-bans-high-resolution-imagery-of-israel.html>.
[102] See Florini, para 7.
[103] Section 1064 of the 1997 National Defense Authorization Act limits resolution of US commercial imaging satellites to no better than what is "available from commercial sources." In 1998, NOAA set this limit to 1-meter resolution. See Fenton's "Why Google Earth Pixelates Israel." *PC Magazine*. Ziff Davis, 14 June 2011. <http://www.pcmag.com/article2/0,2817,2386907,00.asp>.
[104] Turkey is preparing Gokturk-1, a better than 1-meter resolution imaging satellite, for launch in 2015. Israel tried, and field, to negotiate restrictions on images of Israel. For specifics, see Reuters's "Turkish Satellite to Roll Back

Israel's Turf Veil." *Al Arabiya News.* AL ARABIYA NETWORK, 10 Mar. 2011. <http://english.alarabiya.net/articles/2011/03/10/140977.html?PHPSESSID=c13hf5kijshfhcdffu6mr3mfl2>.

[105] Wired magazine reported that GeoEye-1 and IKONOS satellites imaged the Y-20 at the Yanliang Airfield in central China. While US Government satellites may have caught the same event, having two additional satellites equates to multiple imaging opportunities. See David's Axe's article, "Satellites Spot China's Mysterious New Warplane." *Wired.com*. Conde Nast Digital, 02 Jan. 0013. <http://www.wired.com/dangerroom/2013/01/chinas-new-transport/>.

[106] For several years, internet advocates have used Google Earth to find unique or mysterious structures in the Chinese desert. See Shachtman's "More Mammoth (and Mysterious) Structures Found in China's Desert."*Wired.com Danger Room*. Conde Nast Digital, 13 Nov. 2011. <http://www.wired.com/dangerroom/2011/11/mammoth-mysterious-china/>.

[107]Florini may be been the first to label increased access to satellite imagery "a growing transparency." See Florini, "Policy Implications of Commercial Remote Sensing Satellites." *Policy Implications of Commercial Remote Sensing Satellites*. Proc. of No More Secrets?: Policy Implications of Commercial Remote Sensing Satellites - Carnegie Endowment for International Peace, United States, Washington, DC. Washington, DC: Carnegie Endowment for International Peace, 1999. *Carnegie Endowment for International Peace*. Carnegie Endowment for International Peace, 2013. <http://carnegieendowment.org/1999/07/01/no-more-secrets-policy-implications-of-commercial-remote-sensing-satellites/b0e>.

[108] See Josh Calder's "Who Will Be Free? The Battles for Human Rights to 2050." *The Futurist* Nov. 2012: 15-16. *The Futurist*. World Future Society. <http://www.wfs.org/futurist/november-december-2012-vol-46-no-6/who-will-be-free-battles-for-human-rights-2050>.

[109] See the introduction to The Politics of Space Security by James Moltz.

[110] See, Joseph N Pelton's "The New Age of Space Business." *The Futurist* Sept. 2012: 15-16.*World Future Society*. World Future Society. <http://www.wfs.org/futurist/september-october-2012-vol-46-no-5/new-age-space-business>.

[111] McLean notes items "designed for civilian space programs" can be used for military purposes. See page 4-7 of McLean's *Western European Military Space Policy.*

[112] See page 19 of Moltz's *The Politics of Space Security.*

[113] Skybox Imaging. Advertisement. Welcome. Skybox Imaging, 2013. <http://www.skyboximaging.com/>.

[114] "Skybox Unveils First Images from Newly Launched Earth-observation Satellite." Civil Space. SpaceNews.com, 11 Dec. 2013. <http://www.spacenews.com/article/civil-space/38605skybox-unveils-first-images-from-newly-launched-earth-observation-satellite>.

[115] For the video, see http://www.firstimagery.skybox.com/hd-video/. For details, see the Image Chain section of Skybox's Technology web page, "Technology." *Technology - Imaging Chain*. Skybox Imaging, INC, n.d. <http://www.skyboximaging.com/technology>.

[116] These images were taken from the following sources: Skybox Imaging (http://www.skyboximaging.com/news/SkySat1FirstLight), Google Maps (https://maps.google.com/maps?q=zayed-university-abu-dhabi-uae&ie=UTF-8&ei=7XOwUq6fEfKwsQTfjIBo&ved=0CAoQ_AUoAg), and MyDigitalGlobe (https://rdog.digitalglobe.com/myDigitalGlobe/Main.html). The Skybox image was taken on 4 December 2013 by Skysat-1. The DigiGlobe image was taken by WorldView-01 on 8 October 2013. Google Maps (and Google Earth) credits DigiGlobe with 10 August 2013 image copyright.

[117] See Figure 21, page 87, of Pegher and Parish.

[118] See page 30 of Shannon, et al. *Finding the Shape of Space*. Maxwell Air Force Base, Ala.: Air UP, 2011.

[119] See Anne Flaherty's "U.S. Plans Next-gen Spy Satellite Program." *Space on NBCNews.com*. NBCNews.com, 30 Nov. 2007. 2013. <http://www.nbcnews.com/id/22046019/ns/technology_and_science-space/t/us-plans-next-gen-spy-satellite-program/>

[120] See "Future of Iridium." *Global Satellite Communications*. N.p., n.d. <http://www.globalsatellitecommunications.com/iridium/future.html>.

[121] Orbital Sciences Corporation has been selected as the integrator for any hosted payloads on Iridium NEXT. For brief details, see Orbital's information webpage, "Iridium NEXT Hosted Payloads." *Hosted Payloads*. Orbital Sciences Corporation, 2013. <http://www.orbital.com/hostedpayloads/>.

[122] The current Iridium NEXT design shows a 40cm x 70cm x 30cm space to accommodate up to 50kg, while providing 50 Watts and an average of 100 Kbits/sec with bursts up to 1 Mbit/s data rates. See Kramer's "Iridium

NEXT - Satellite Missions - EoPortal Directory." *Iridium NEXT - Satellite Missions - EoPortal Directory*. European Space Agency, n.d. <https://directory.eoportal.org/web/eoportal/satellite-missions/i/iridium-next>.
[123] Iridium satellites remain nadir pointed so any imaging would only be done straight down, which coincides with the best image resolution. The tilt of the camera lens with respect to the ground plane affects resolution. High oblique angles "widen" the field of view and causes distortion. The least distortion and thus the highest resolving power for a camera is perpendicular to the image plane. For satellites, this is called nadir-pointing. For example, see "Optical Sensors." Lecture. GEOG 883. College of Earth and Mineral Sciences, University Park, PA. *Optical Sensors*. Penn State University. <https://www.e-education.psu.edu/geog883kls/node/434>.
[124] The spacing between satellites orbital planes is greatest at the equator. At the equator, the maximum period of time for handoff to occur between satellites is 7 minutes. At higher latitudes, the separation is less and the time lag would be shorter. See the introduction to UU Plus Iridium 9500 and 9505 *Modem Configuration Instructions*. UU Plus, n.d. <http://www.uuplus.com/documentation/Iridium%20Modem%20Configuration.pdf>.
[125] See the concluding three paragraphs of Sayers' "China's Asymmetrical Strategy." *Frontpagemag.com*. The Weekly Standard, 28 Dec. 2007. <http://archive.frontpagemag.com/Printable.aspx?ArtId=29343>.
[126] A good summary is provided by Australian News.com, available: http://www.news.com.au/national/military-satellite-deal-with-us/story-e6frfkvr-1111114282732.
[127] See Debra Werner's. "U.S. Air Force Expects To Order Another Wideband Global Satellite with Allies' Help." *Military Space*. SpaceNews.com, 11 Jan. 2012. <http://www.spacenews.com/article/us-air-force-expects-order-another-wideband-global-satellite-allies help>.
[128] See p12 of NATO's Deterrence and Defense Posture After the Chicago Summit, available https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&ved=0CGcQFjAG&url=http%3A%2F%2Fwww.dtic.mil%2Fcgi-bin%2FGetTRDoc%3FLocation%3DU2%26doc%3DGetTRDoc.pdf%26AD%3DADA569924&ei=ViWmUviQKfPfsASKtYCwDg&usg=AFQjCNEPKTLZ-pgI3l3WurW4AXBfRpV5Hw&sig2=WOo4dzsBqTw4Jq12YlKz-g
[129] See McLean, p65.
[130] ibid, p69.
[131] ibid, p80.
[132] Ibid, p112.
[133] See Moltz, p32.
[134] ibid, p39.
[135] ibid, p56.
[136] See p iix of Keller, et al. *Facilitating Information Sharing across the International Space Community: Lessons from Behavioral Sciences*. Santa Monica, CA: RAND Corporation, 2013.
[137] Britain, Norway, Bulgaria, Finland, and Denmark, see McLean, pp 32 and 36.
[138] See Keller et al., p12.
[139] See McLean, p34.
[140] The world was more accepting of the US shooting down a satellite in 2008 because of the "transparency factor." See Lele's "Is China Challenging Space Security." *Space Daily - Dragon Space*. Space Media Network, 24 Oct. 2013. <http://www.spacedaily.com/reports/Is_China_Challenging_the_Space_Security_999.html>.
[141] See p ix of Keller, et al.
[142] See Re-thinking the National Security Space Strategy: Chinese vs. American perceptions of space deterrence, by Christopher Stone. Available: http://www.thespacereview.com/article/2395/1.
[143] See page 131 of Jurimetrics Journal, Reynolds and Merges' *The Role of Commercial Development in Preventing War in Outer Space*. Berkeley Law Scholarship Repository. Faculty Scholarship. University of California Berkeley Law, 1 Jan. 1984. <http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1572&context=facpubs>.
[144] Moseley was quoted as saying, "I would say killing another nation's satellite is an act of war…no different than sinking a ship or killing an airplane." See "Interview with General Michael Moseley, USAF." Interview by Defense Writers Group. *Defense Writers Group Archive*. Air Force Magazine (Air Force Association), 24 Apr. 2007. <http://www.airforcemag.com/DWG/Documents/2007/042407moseley.pdf>.
[145] See United States. Department of Defense. Armed Forces Press Service. *Defense.gov News Article: Stratcom Strives to Build Coalitions for Space Operations*. By Donna Miles. N.p., 14 May 2013. http://www.defense.gov/News/NewsArticle.aspx?ID=120029>.
[146] See page 9 of McLean.

[147] As suggested by Sheldon in "Space Power and Deterrence: Are We Serious?" *George C. Marshall Policy Outlook* (2008): n. pag. George C Marshall Institute, Nov. 2008. <http://marshall.org/space-policy/space-power-and-deterrence-are-we-serious/>.
[148] See page 131 of Jurimetrics Journal, Reynolds and Merges' *The Role of Commercial Development in Preventing War in Outer Space*. Berkeley Law Scholarship Repository. Faculty Scholarship. University of California Berkeley Law, 1 Jan. 1984. <http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1572&context=facpubs>.
[149] See p24 of McLean.
[150] The Canadians went so far as to design two satellites (PAXSAT A and B) and offered to underwrite a portion of the construction. See Walter Dorn, "Paxsat: A Canadian Initiative in Arms Control." Editorial. *Peace Magazine.* Oct. 1987: 17. *PeaceMagazine.org*. Canadian Disarmament Information Service (CANDIS). <http://peacemagazine.org/archive/v03n5p17.htm>.
[151] Sharing imagery from spy satellites would reveal capabilities, which could then be exploited by adversaries. Additionally, reverse engineering the optical train could be used for denial or disruption attacks. See John Swan's "International Surveillance Satellites. Open Skies for All?" *Journal of Peace Research* 25.3 (1988): 229-44. *JSTOR*. Sage Publications, Ltd. http://www.jstor.org.aufric.idm.oclc.org/stable/423430>.
[152] For a brief summary of Open Skies, see the Defense Threat Reduction Agency's *Open Skies*. Defense Threat Reduction Agency, n.d. <http://www.dtra.mil/missions/ArmsControlVerification/OpenSkies.aspx>.
[153] United States. Department of State. Bureau of Arms Control, Verification and Compliance. *U.S. Department of State*. By Office of Euro-Atlantic Security Affairs. U.S. Department of State, n.d. <http://www.state.gov/t/avc/cca/os/index.htm>.
[154] The current Open Skies program is limited by quotas, as well as availability and costs associated with the aircraft. State parties to the Open Skies Treaty may only conduct as many observation flights (over other states) as they are willing to receive. The United States and Russia/Belarus quota is 42 monitoring flights per year.. See United States. Department of State. Bureau of Arms Control, Verification and Compliance. *U.S. Department of State*. By Under Secretary for Arms Control and International Security. U.S. Department of State, n.d. <http://www.state.gov/t/avc/trty/102337.htm>.
[155] The United States typically receives 6-8 observation flights and conducts 14-16 flights over other countries. See the Open Skies Treat Fact Sheet by the Office of the Spokesperson, US Department of State, United States. Department of State. Office of the Spokesperson. *Open Skies Treaty Fact Sheet*. N.p.: n.p., n.d. 23 Mar. 2012. <http://www.state.gov/r/pa/prs/ps/2012/03/186738.htm>.
[156] A Forbes article lists Brazil, Australia, the Netherlands, the US, and Saudi Arabia all have investors. See Hesseldahl's "The Return Of Iridium." *Forbes*. Forbes Magazine, 11 Nov. 2001. <http://www.forbes.com/2001/11/30/1130tentech.html>.
[157] When Irdium 33 was destroyed by Cosmos 2251, the constellation was quickly adjusted to eliminate the outage. See O'Neill's "Orbital Spares: Iridium Already Replaced Destroyed Satellite." *RSS*. Universe Today, 14 Feb. 2009. <http://www.universetoday.com/25447/orbital-spares-iridium-already-replaced-destroyed-satellite/>.
[158] See the third paragraph of Drummond's "Darpa's New Plans: Crowdsource Intel, Edit DNA." *Wired.com Danger Room*. Conde Nast Digital, 31 Jan. 2010. <http://www.wired.com/dangerroom/2010/02/darpas-new-plans-crowdsource-intel-immunize-nets-edit-dna/>.
[159] See Masnick's "Lessons Learned From DARPA Balloon Challenge." *(Mis)Uses of Technology*. Techdirt., 9 Dec. 2009. <http://www.techdirt.com/articles/20091207/1126427232.shtml>.
[160] In 1991, a professor at Plymouth college in England notified the UK Ministry of Defence that he could detect troop concentrations. See McLean, p101.
[161] See Sturm's "Air Force Launches Open Innovation Pavilion." *Open Government Initiative*. White House Office of Science and Technology Policy, 4 Mar. 2011. <http://www.crowdsourcing.org/document/air-force-launches-open-innovation-pavilion/2855>.
[162] Google Earth users could be paid for finding new structures in China, evidence of illegal mining, or count troop formations. See Shachtman's article.
[163] In 1989, the Soviet Union estimated that space systems increased the combat efficiency of Soviet military forces "by 50-100%." See p142 of McLean
[164] See page 8 of McLean.
[165] See Stone, paragraph 4.

[166] For details and an evaluation for national defense, see Canada. Department of National Defense. Operational Research and Analysis Establishment. *The Arms Control And Crisis Management Potential Of The Proposed International Satellite Monitoring Agency (ISMA)*. By Robin Ranger. DND Canada, 10 June 1985. <http://www.dtic.mil/dtic/tr/fulltext/u2/a154979.pdf>.
[167] For original, see p42 of Bortzmeyer, Hubert G. *The Implications of Establishing an International Satellite Monitoring Agency*. Rep. no. A/AC.206/14. Vol. SS-9. New York: Secretary-General of the United Nations, 1981. *Disarmament Study Series*. United Nations Office for Disarmament Affairs, 2013. <http://www.un.org/disarmament/HomePage/ODAPublications/DisarmamentStudySeries/PDF/SS-9.pdf>.
[168] The "Analysis" column comes from Jasani and Sakata, p15.
[169] Loosely taken from Jasani and Sakata, p15.
[170] In 1978, President Carter issued Presidential Directive 37 limiting resolution of us civilian remote sensing satellites to no better than 10 meters.
[171] See the good summary from the Office of Science Technology and Policy, United States. White House. Office of Science and Technology Policy. *US Commercial Remote Sensing Policy Fact Sheet*. N.p., 25 Apr. 2003. <http://www.whitehouse.gov/files/documents/ostp/press_release_files/fact_sheet_commercial_remote_sensing_policy_april_25_2003.pdf>.
[172] In October 2013, the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.; DLR) approved a commercial license for the Germany TerraSAR-X company to sell 0.25 meter radar imagery. See De Selding's "Commercial Earth Observation | German Imagery Policy Sets No Hard Limits on Resolution." *Civil Space*. SpaceNews, Inc., 14 Oct. 2013. <http://www.spacenews.com/article/civil-space/37666commercial-earth-observation-german-imagery-policy-sets-no-hard-limits-on>.
[173] Though replaced by President Obama's version in 2010, see pages 1-2 of the 2006 US National Space policy, available: http://www.au.af.mil/au/awc/awcgate/whitehouse/ostp_space_policy06.pdf.
[174] See page 4 of Section-by-Section Comparison of 1996 and 2006 National Space Policy Documents by The Space Review. Available: http://www.thespacereview.com/archive/745a.pdf
[175] See the Space Foundation's U.S. National Space Policy Comparison by Mariel John. *U.S. National Space Policy Comparison Comparing the 2010 National Space Policy to the 2006 National Space Policy*. Publication. Space Foundation, 1 June 2010. <http://www.spacefoundation.org/docs/USNationalSpacePolicy-2010vs2006.pdf>.
[176] See page 7 of the 2010 National Space Policy.
[177] Senate Report 113-120 accompanied the SSCI mark-up to Senate Bill 1681, FY2014 Intelligence Authorization Bill. See Smith's "Senate Intelligence Committee Recommends Relaxing Commercial Satellite Imagery Limits - UPDATE." *Senate Intelligence Committee Recommends Relaxing Commercial Satellite Imagery Limits - UPDATE*. SpacePolicyOnline.com, 7 Nov. 2013. <http://www.spacepolicyonline.com/news/senate-intelligence-committee-recommends-relaxing-commercial-satellite-imagery-limits>.
[178] See page 2 of DOD Directive 3100.10, paragraphs c, e, and f.
[179] See page 4 of DOD Directive 3100.10, paragraph o.
[180] See page 4 of DOD Directive 3100.10, paragraph k.3.
[181] Mehta, Aaron. "USAF: Pentagon Must Update Space Policy." *Defense News*. Gannett Government Media, 26 Aug. 2013. <http://www.defensenews.com/article/20130826/DEFREG02/308260010/>.
[182] Referred to as the Vicious Circle of Space Acquisition, the combination of delays, requirements creep, funding instability, and demand for low risk combine to produce expensive, be-all, end-all space systems. For more details see Thomas D Taverney's. "Resilient, Disaggregated, and Mixed Constellations." *The Space Review: (page 1)*. N.p., 29 Aug. 2011. <http://www.thespacereview.com/article/1918/1>.
[183] See Laura M. Delgado "Benefits Weighed of "Disaggregation" for Military Space Systems."*Benefits Weighed of "Disaggregation" for Military Space Systems*. SpacePolicyOnline.com, 30 Jan. 2013. <http://www.spacepolicyonline.com/news/benefits-weighed-of-disaggregation-for-military-space-systems>.
[184] See McLean, p127 and Swan, pp231-233.
[185] See page 7 of Moltz's *The Politics of Space Security*
[186] See slide 2 of the *National Security Space Policy,* from Defense.gov. Available: <http://www.defense.gov/home/features/2011/0111_nsss/docs/National_Security_Space_Strategy_Overview_Briefing.pdf>.

[187] See slide 7 of the *National Security Space Policy*, from Defense.gov. Available: <http://www.defense.gov/home/features/2011/0111_nsss/docs/National_Security_Space_Strategy_Overview_Briefing.pdf>.
[188] *UCS Satellite Database*. *Nuclear Weapons & Global Security » Space Weapons » Technical Issues*. Union of Concerned Scientists, 13 Sept. 2013. <http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html>.
[189] Skybox Imaging has not released pricing information as of December 2013, however they are frequently quoted as predicting images at 10-100 times cheaper than currently available competitors. See Arrington's "Why The Heck Did We Invest In Skybox Imaging, A Satellite Startup?" Weblog post. *Uncrunched*. N.p., 18 Apr. 2012. <http://uncrunched.com/2012/04/18/why-the-heck-did-we-invest-in-skybox-imaging-a-satellite-startup/>.
[190] Most commercial satellite companies only sell images through Value Added Resellers (VAR). e-geos is an Italian company that has tremendous market share of VAR for satellite images. See the E-geos *Price List*. Asi/Telespazio, 1 July 2013. <http://www.e-geos.it/products/pdf/prices.pdf>.
[191] See "Dan Berkenstock: The World Is One Big Dataset." *TED@BCG*. San Francisco, CA, Oct. 2013. *TED - Ideas worth Spreading*. TED.com, Feb. 2014. Web. <http://www.ted.com/talks/dan_berkenstock_the_world_is_one_big_dataset_now_how_to_photograph_it.html>.
[192] Two NPS students developed an algorithm to calculate the best orbital arrangement for the DISCOVERER II program. This program was synthetic aperture radar that was ultimately cancelled by Congress. However, the analysis Pegher and Parish completed is valid. They used a 770km orbit, whereas Iridium NEXT is planned for 700 km.
[193] The period, or time to complete one orbit, is given by related to the altitude above the earth's surface. The equation is $2\pi\sqrt{(\frac{r^3}{GMe})}$, where r = Radius of the Earth plus orbital altitude, G is the gravitational constant, and M_e is the mass of the Earth.
[194] Visibility values assume maximum visibility regardless of terrain or obscuration. It is important to note that an observation camera works best when it is pointed straight down, called nadir pointing. This is because the distance to the target is at the minimum. As the satellite races across the sky, the slant range increases dramatically. Additionally, adding the ability to slew the camera, compared to a rigid, fixed position adds complexity and cost.
[37]A satellite field of view (FOV) is the area on the ground that can be viewed by the camera and is dependent on orbital altitude. The equation for FOV is $D = \propto H$, where D is the ground footprint, α is the maximum optical viewing angle, and H is the orbital altitude. This is the maximum possible image size and will be limited by Rayleigh Criterion or other effects.

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