Appendix C: Military Uses of Civilian Remote Sensing Data

This appendix addresses the *military utility of data from civilian remote-sensing satellites.* This utility draws the interest Of those who might ignore the satellites and their more prosaic utility for Earth-sciences applications. Technically, it presses the satellites to their limits of resolution, both spatial and spectral, and timeliness. Politically, it raises questions of who should be allowed to buy what data. Militarily, it brings a whole new group of intelligence platforms, for what they are worth, into play for only their marginal cost. The Department of Defense has been purchasing remotely sensed data from EOSAT (Landsat) and SPOT Image (SPOT) for some time. [1] However, tile extensive use of Landsat and SPOT data in the Persian Gulf Conflict has awakened public and congressional interest in the subject and focused attention on the issues involved.

This appendix does *not* address such questions as the civilian (scientific) utility of military satellites, or the "overlap" of civilian and military satellite capabilities. Thus, the sensitive question of the capabilities of military satellites does not concern us here-we need only investigate the capabilities of civilian satellites, and the question of how well those capabilities might serve military needs.

| Military Remote Sensing Missions

Military remote sensing missions include reconnaissance (including broad area search, combat intelligence, indications and warning of war, and arms control verification); mapping, charting, and geodesy; and meteorology. While rule-of-thumb precepts quantifying the capabilities needed to perform certain tasks abound, we find them wanting and

[1] U.S. Congress, Office of Technology Assessment, *Remote Sensing* and *the Private Sector; Issues for Discussion,* OTA-TM-ISC-20 *(Washing[on,* DC: U.S. Government Printing Office, March 1984).

[2] Or capability—most such precepts reduce satellite capabilities to a single parameter, ''resolution.

prefer instead to be guided by instances in which specific satellites imaged specific targets of military interest, or targets like those of military interest. Seen in this light, even some of the least promising civilian satellites show surprising potential military utility.

RECONNAISSANCE MISSIONS

Reconnaissance is ''a mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy. ''3 This mission dates back at least as far as the spies Moses and Joshua sent into the Promised Land,[4] and has traditionally been the province of unarmed or Lightly armed scouts (like Joshua and his men), as well as cavalry, balloons,[5] and aircraft. Particular reconnaissance missions include (roughly in ascending order of difficulty) broad area search; indications and warning; combat intelligence; and arms control agreement verification.

Broad Area Search—This mission is the most unfocused reconnaissance possible: sweeping attention to an area of land or sea looking for previously undetected items of potential military significance, rather than for some particular military installation or formation. The enormous scope of the typical broad area search mission is, typically, somewhat offset by the large size of the targets of interest: when searching the hinterlands, one probably seeks clandestine or new military installations, indications of new military programs, and the like. Detailed examination of what one finds can be done later, with more focused coverage.

Broad area search is almost the norm for reconnaissance at sea: even in peacetime, ships and airplanes patrol the oceans to see whatever is there. While their efforts are largely focused on submarines, these difficult and yet important targets do not get all of the attention; tracking of surface ships remains a vital mission in the United States Navy.

Indications and Warning—Indications and Warning comprises:

> .,. those intelligence activities intended to detect and report time-sensitive intelligence information on foreign developments that could pose a threat to the United States or allied military, political, or economic interests or to U.S. citizens abroad. It includes forewarning of enemy actions or intentions; the imminence of hostilities; insurgent or other attack on the United States, its overseas forces, or allied nations; hostile reactions to United States reconnaissance activities, terrorists' attacks; and other similar events.[6]

During crisis, rearrangement of aircraft, tanks, railcars, or ships within their basing areas, or their departure from their basing areas, could lead one to expect that an attack, or at the very least an alert, was underway. Vigilance regarding warning signs is a major intelligence mission for the United States. By its very nature, this mission must be performed continuously. Its intensity increases during periods of tension and crisis.

Combat Intelligence-Combat intelligence is 'that knowledge of the enemy, weather, and geographical features required by a commander in the planning and conduct of military operations, It provides military forces with enormous leverage, and is a prerequisite for the American style of War,[8] and, indeed, for victory itself, ''Knowledge of the enemy" includes the size and character of his forces, where they are and where they are not, the routes by which they are supplied, the extent of their logistic preparation for movement or combat, the nature of any fortifications they may occupy, and so on. It also includes the character of terrain and weather where operations might occur.

3 *Department of Defense Dictionary of Military and Associated Terms* (Joint Pub 1-02, formerly JCS Pub 1). This is the first definition of "reconnaissance.' The second is more general and includes mapping, hydrography, etc..

4 *Numbers* 13: 1-25 and *Joshua* 2:1-24. (See also *Numbers* 13:27 and 13:28 for an early example of an ''On the one hand ... , but on the other hand . . . " intelligence assessment.)

5 Both crewed and otherwise. See Curtis Peebles, *The Moby Dick Project* (Washington, *DC:* Smithsonian Institution, 1991).

6 *Department of Defense Dictionary of Military and Associated Terms,* op. cit., footnote *3,* p. *177.*

7 Ibid., p. 74.

8 ''No commander can succeed unless he demands and receives the intelligence and combat information he needs.' United States Army FM **100-5,** *Operations,* August 1982, Washington, DC, p. 6-6.

Surprisingly, military weather *is* not quite the same as civilian weather. Civilian satellites presently make significant contributions to the military's weather forecasting: the military person's "theater' and the meteorologist ''mesoscale' correspond to about the same spatial dimensions-on the order of a million square kilometers. But the knowledge of weather required for the combat intelligence mission can include scales of time and space not normally associated with weather forecasts, right down to the limiting case of informing a commander as to the current weather at his present location. Military meteorology also includes measurement of parameters seldom wanted or needed in the civilian world, such as direct measurement of rain rate.[9] Civilian weather satellites' deficiencies in satisfying military needs include: atmospheric sensing and observation capabilities, meteorological data acquisition and assimilation systems, and models needed to make reliable forecasts and ''nowcasts' (descriptions of the weather within the coming day) of mesoscale weather with resolution of kilometers, extent of thousands of kilometers, and timescales of 6 to 72 hours. The military's goal of worldwide rapid response exceeds any current capability, military or civilian, for collecting data and turning them into a forecast. '"

Some argue that the military's asserted need for its own weather satellite system, the Defense Meteorological Satellite Program (DMSP), stems from bureaucratic, not meteorological, concerns:

> . . . there is considerable evidence to justify initiating action to converge the DMSP and TIROS systems. What has been lacking is sufficient impetus for the federal agencies involved to take such action.11

However, DMSP proponents can point to the woes of GOES-Next as evidence to support their position that the military need for weather forecasting is too great to be left in the hands of any other organization.

Monitoring Arms Control Agreements-Arms control agreement verification is:

> . . . a concept that entails the collection, processing, and reporting of data indicating testing or employment of proscribed weapon systems, including country of origin and location, weapon and payload identification, and event type. '2

It also entails the evaluation of those data, and the consideration of them in light of a larger political context. Congress, particularly the Senate-in the exercise of its Constitutional mandate to advise and consent in the making of treaties-has made verifiability a prerequisite for most arms control treaties. While verification entails many ingredients other than those listed above (including political judgment-calls), the Joint Chiefs' list includes most or all of what arms-control theorists refer to as the ''monitoring' part of verification; arms control agreement monitoring has become an important task for the U.S. intelligence community. Indeed, some have argued that this one task has preoccupied U.S. high-technology intelligence collection as a whole.[13]

MISSIONS OTHER THAN RECONNAISSANCE

Mapping, Charting, and Geodesy-Tradition dictates the use of the word "map" by ground forces and the use of the word ''chart' by naval forces, including each force's respective air arms.[14] Geodesy is the measurement of the shape of the Earth. The Defense Mapping Agency uses the phrase 'Mapping, Charting, and Geodesy" (MC&G) as the description of its principal mission,[15] defining the term *as* fOllows:

---

9 Civilian meteorologists can let rainwater accumulate and then issue a report of the amount of rainfall recorded overa certain time. Military meteorologists can need to know instantaneous rain rate, because of its effect on radar systems.

10 This paragraph draws on "Comments on Military Uses of Civilian Remote Sensing Satellites, " Major General Robert A. Rosenberg USAF, (retired), Aug. 4, 1992.

11 General Accounting Office, GAO NSIAD-87-107, *Weather Satellites, p. 4.*

12 *Department of Defense Dictionary of Military and Associated Terms,* op. cit., footnote 3, p. 36.

13 Angelo Codevilla, *Informing Statecraft* (New York, NY: Free Press, 1992), p. 112.

14 The joint services' *Department of Defense Dictionary of Military and Associated Terms* (Joint Pub 1-02, formerly JCS Pub 1) defines a ' 'map' as ''a graphic representation, usually on a plane surface, and at an established scale, of natural or artificial features on the surface of a part or the whole of the earth . . . ,' p. 219.

15 Defense Mapping Agency briefing to OTA staff, May 13, 1992.

MC&G is the combination of those sciences, processes and data which form the basis for preparing maps, charts and related products and for determining the size and shape of the Earth and its gravity and magnetic fields.

MC&G includes the collection, evaluation, transformation, generation, storage and dissemination of topographic, hydrographic, cultural, navigational, geographic names, geodetic, gravimetric and geomagnetic data. The data are manipulated to support air, land and sea navigation, weapon orientation, target positioning, military operations, planning and training.

Meteorology—Meteorological data are "meteorological facts pertaining to the atmosphere, such as wind, temperature, air density, and other phenomena which affect military operations. [16] The military voraciously consumes weather data. These data are routinely needed for mission planning and assessment of possible enemy operations, and occasionally needed for such other tasks as predicting the coverage of chemical weapons and smoke from frees.

Civilian Satellites and the Requirements of Military Remote Sensing Missions

To begin an evaluation of civilian satellites' military utility, we need to compare their characteristics to the requirements of the military's remote sensing missions, The previous section has treated the latter; we now turn to the former.

CIVILIAN SATELLITE CHARACTERISTICS

The most-discussed characteristic of remote sensing satellites is their imagers' ''ground resolution, ' or ability to distinguish objects on the surface of the Earth. (See box 4-B.) Sensor characteristics other than resolution are often overlooked. These include scene size, the spectral range within which the sensor operates, the availability of stereo imagery, whether the pictures are digitized or not, the "metric" or accuracy with which the sensor knows and reports its own location, the timeliness with which the images are returned, the frequency with which a given target can be revisited, the fraction of the time that the system can devote to taking pictures,[17] the entire system's throughput capacity, and the cost of the imagery. This section addresses a variety of civilian satellite capabilities, albeit with resolution as the first among equals (table C-l).

The basic image parameters-spatial resolution, scene size, spectral resolution, and spectral coverage-compete for satellite resources. Fixed or expensive-to-change constraints such as the data capacity of the downlink, the ' 'speed' of the sensor optics, and ultimately the weight of the satellite itself, place upper

Table C-l—" Resolution" (ground sample distance) of Selected Civilian Satellites

Satellite	Sensor	Resolution (in meters)
Resurs-F	KFA-1000, panchromatic or color	5[a]
Resurs-F	MK-4 (multispec.)	6[a]
SPOT	Panchromatic	10[b]
SPOT	Multispectral	20[b]
Almaz	Main SAR	15 - 30[c]
JERS-1	8-band optical	18 × 24[d]
JERS-1	SAR	18[d]
Seasat-A	SAR	25[e]
Landsat 4, 5	Multispectral	30[f]
Landsat 4, 5	Multispectral	80[f]
Landsat 6	Panchromatic	15[g]
Landsat 6	Multispectral	30[h]
Landsat 7	Panchromatic	5[h]
Landsat 7	Multispectral	30[h]
IRS-1a	Multispectral	36[d]

[a] Allen V. Banner, *Overhead Imaging for Verification and Peacekeeping Studies: Three Studies,* prepared for the Arms Control and Disarmament Division (Ottawa, Ontario, Canada: External Affairs and International Trade Canada, 1991), pp. 7-8.
[b] Ibid., p. 3.
[c] Hughes STX Corp., "Almaz-1 Synthetic Aperture Radar Data: An Overview" (Ref. No. 5132-92-HP), slide 10.
[d] Peter D. Zimmerman, *The Use of "Open Market" Observation Satellites for the Monitoring of Multilateral Arms Control Accords,* prepared for the United Nations Department of Disarmament Affairs, p. 21.
[e] Eli Brookner in *Arms Control Verification,* Kosta Tsipis, David W. Hafemeister, and Penny Janeway (eds.), p. 138.
[f] Banner, op. cit., footnote a, p. 6.
[g] D. Brian Gordon, Chairman, Tactical and Military Multispectral Requirements Working Group, Defense Intelligence Agency, testimony of hearings before the House Committee on Science, Space and Technology and the Permanent Select Committee on Intelligence, 102d Cong. 1st Sess., June 26, 1991. Scientific, Military, and Civilian Applications of the Landsat Program, p. 46.
[h] EOSAT/GE.

16 *Department of Defense Dictionary of Military and Associated Terms,* op. cit., footnote 3, p. 227.

17 As opposed to performing other activities, such as sending down to an Earth station the pieties that have already been taken.

limits on the amount of information the image can contain. Within those limits, tradeoffs must be made so as to maximize the image's utility for its intended purpose. A multipurpose satellite entails another level of tradeoff, compromise among purposes. A civilian satellite, especially a commercial one, is intended to be all things to all customers, and thus will not necessarily fill any one customer's bill perfectly.

Resolution----One often sees the optical acuity of remote sensing systems expressed in terms of the *ground resolution* (or ' 'resolution," or "ground sample distance") of their imagery-the closest that two objects can be and still be perceived as two separate objects.[18] In practice, it is usually about **twice the size** of the smallest item that can be perceived as a separate object.

Many sources in the open intelligence literature tabulate the utility of different ground resolutions (table C-2).[19] These sources generally list various objects and the ground resolutions needed to perform various tasks with respect to these objects, such as ''detection, ''recognition, ' ''identification, and ''technical analysis. ' For example, 9-meter resolution allows the detection of a ship, but 3- to 4-meter resolution may be needed to determine the type of the ship (e.g., ''submarine' and even finer resolution is needed to determine its class (e.g., *Oscar). The* many sources, some quoting from others, show rough agreement as to the resolutions needed for the different tasks.

A more sophisticated expression of sensor definition, the Image Interpretability Rating Scale (IIRS),

Table C-2—Resolution Requirements (in meters) Sorted by Task and Target

Target	Task		
	Detect	Identify	Analyze
Surface ships	15	0.15	0.04
Land minefield.	3	0.30	0.08
Missile sites	3	0.15	0.04

SOURCE: McDonnell Douglas, *Reconnaissance Handy Book,* 1982, p. 125.

takes into account aspects of image quality other than ground resolution. These include contrast, intensity, shadowing, and so on. The IIRS is, at base, a subjective rating system: it works *from the* image's utility in detecting, identifying, or analyzing given types of target to the image's rating on the scale.[20]

Both IIRS and the more objective (but simplistic) ground resolution paradigm address the utility of images. However, the tasks to which they refer are of the most rudimentary nature. Military consumers of remotely sensed data are really not interested in detecting, identifying, or analyzing particular objects. They care about such tasks as mapping, forecasting, targeting, and verifying. The ground resolution needed to perform these tasks is not so clear-cut, and deficiencies in image quality can in some cases be made good by virtuoso performance of the image interpreter's art. For example, ships too small to be seen at a given resolution could, if under way, be detected via their wakes. Fences, themselves an

18 The *Department of Defense Dictionary of Military and Associated Terms* (Joint Pub 1-02, formerly JCS Pub 1) defines ''resolution' as ''a measurement of the smallest detail which can be distinguished by a sensor system under specific conditions. " The role of the word ' 'distinguished" in this definition is sometimes given insufficient emphasis.

19 These include:

McDonnell Douglas Aircraft Corp., *The Reconnaissance Handy Book*, p. 125.

Ronald J. Ondrejka, ''Imaging Technologies, in *Arms Control Verification*, Kosta Tsipis, David W. Hafemeister, and Penny Janeway (eds.), p. 67.

Jeffery T. Richelson, ' 'Implications for Nations Without Space-Based Intelligence-Collection Capabilities, ' (in *Civilian Observation Satellites and International Security,* Peter Zimmerman et al. (eds.)), p. 60.

Ronald A. Scribner et al., *The Verification Challenge: Problems and Promise of Strategic Nuclear Arms Control Verification,* p. 32.

U. S, Congress, Office of Technology Assessment, *Verification Technologies: Cooperative Aerial Surveillance in International Agreements,* OTA-ISC-480, (Washington, DC: U.S. Government Printing Office, July 1991), p. 38.

United States Department of Defense, Headquarters, Department of the Army, STP 34-% D1-SM *Soldier's Manual Skill Level I MOS 96D Imagery Analyst,* pp. 2-146 to 2-150.

20 Itek C^3I Systems Bulletin IL-2, ''IIRS Image Interpretability Rating Scale" (Lexington, MA: Litton Itek Optical Systems, 1984).

indicator of the nature of the facility they surround,[21-22] can be detected by the way they channel foot traffic (and the paths it creates),[23] and by its effect on vegetation,[24] while dummy installations are given away by the absence of foot traffic in their vicinities[25] or the lack of snowmelt on their roofs.[26] In a most remarkable instance of detecting the non-resolvable, J. Skorve found a set of seven Soviet submarine-communications antennas in an 80-meter Landsat picture.[27] Although the antennas themselves cannot be seen, the snowflake pattern[28] created by their bases, their stays, and their stays' bases is some 1,700 meters across. Skorve apparently deduced the function of the antennas from their large size, which bespeaks a long wavelength most suitable for communication with submarines. He indicates that weather conditions prevented a cued follow-up shot with the higher-resolution SPOT. Working with even less raw material, Peter Zimmerman analyzed a SPOT picture of the Soviet Northern Fleet headquarters at Severomorsk, concluding that:

> . . . there are no buildings or rocky terrain around the base, which suggests that caverns have been blasted out of the cliffside.[29]

Photo interpreters are, however, only human, and their logic can at times be faulty. For example, analysts noted that a certain building in Iraq lacked the multiple surrounding fences associated with high-technology military work. However, it was later discovered that the building lay inside a huge military facility, whose security fences apparently lay entirely outside the boundaries of the overhead picture.[30]

Moreover, targets of sufficient contrast can be detected even if they are too small to be resolved. (We are familiar with this effect because of the operation of our own eyes, which can detect distant stars without resolving them.) Again citing the example of a ship, heat from machinery or absorbed sunlight could make the ship such a bright thermal infrared source, or reflected sunlight could make it such a bright visible, near infrared, or medium infrared source—in contrast to the surrounding sea—that it would light up a whole pixel[31] despite occupying far less space than is imaged by that pixel. Alternatively, concave corners in the ship's superstructure could strongly reflect energy straight back to a radar satellite (such as the now-defunct AlmaZ-l, or ERS-1), again lighting up a point on the image and showing that something other than the ocean was there, even though it could not be resolved.

The whole resolution concept is also confounded by targets that exceed the system's resolution in one dimension while falling short in another. A railroad, for example, is narrower than 30 meters but far longer—railroads can and do occasionally appear in

21 *Soldier's Manual Skill Level I, Imagery Analyst,* p. 2-439.

22 "The Space Media *Network* analysts who published a story about the Soviet electro-optical facility atop Mt. Sanglok in Tadjikistan felt confident that they had seen double fencing on that site. Such indications of security call attention to an industrial site that might otherwise have been overlooked. (Peter Zimmerman, "The Use of 'Open Market Observation Satellites for the Monitoring of Multilateral Arms Control Accords," p. 51.)

23 *Soldier's Manual Skill Level i,* op. cit., footnote 21, p. 2-367.

24 Ibid., p. 2-457.

25 Ibid., p. 2-360.

26 Dino A. Brugioni, "The Serendipity Effect of Aerial Reconnaissance, Interdisciplinary Science Reviews, vol. 14, No. 1, 1989, p. 16. Brugioni also points out that snowplowing habits can indicate facilities' functions: headquarters buildings typically receive the most prompt service.

27 Johnny Skorve, *The Kola Image Atlas,* Oslo, The Norwegian Atlantic Committee, 1991.

28 The sixfold symmetry arises because six antennas surround the seventh in a hexagon.

29 peter Zimmerman, "A New Resource fOr Arms Control," New *Scientist*, Sept. 23, 1989, p. 39.

30 Jay C. Davis and David A. Kay, "Iraq's Secret Nuclear Weapons Program," *Physics Today,* July 1992, p. 24.

31 A "p~el," short for "picture element," is a single one of the many dots, of differing color and/or brightness, that combine to form a picture. Computer graphics use true pixels, while newspaper and magazine pictures use an offset image printing process whose dots can be seen with a magnifying glass, Broadcast TV forms images that are discrete, like computer images, in the scan-to-scan dimension and diffuse, like emulsion film images, in the along-the-scan one.

Landsat images, because a pattern made up of non-resolvable elements can be discerned.[32]

Thus, resolution requirements are hard to specify. The following sections assess the military utility of particular satellites not just in terms of the resolutions needed for particular tasks, but in terms of the satellites' proven overall abilities to see targets of interest in MC&G, meteorology, broad area search, Indications and Warning, battlefield intelligence, and arms control monitoring. Considerable overlap exists in these target categories. For example, a large clandestine missile factory or radar would be a broad area search target and also an arms-control monitoring target.

Scene Size-Just as users will always hanker after finer resolution, they will always want larger scene sizes, everything else being equal. However, larger scenes come at a price-in dollars, resolution, or both-and therefore are subject to some limits.

Spectrum—"Panchromatic" sensors make images that a lay person would term a black-and-white photograph, using visible light.

"Spectral coverage' refers to the satellite's ability to detect light, and thus form images, in different parts of the spectrum, such as the visible band or infrared. These can all be combined into a "panchromatic" (black-and-white) picture, or separated. "Multispectral" sensors take, or construct, what the lay person would call color pictures. Normally the colors seen in the color pictures are not the colors of the orginal scene, but are instead a ''fauvist' color set chosen so as to make the information contained in the picture as apparent as possible to the human eye. One obvious reason for making such a color substitution is that the wavelengths orginally collected by the sensor may not be visible to the human eye. For example, the infrared portion of the spectrum (with wavelengths too long to be seen by the human eye) contains data useful in a variety of circumstances such as nighttime. Therefore a ''color composite' image is used, in which the various parts of the spectrum sampled by the sensor are represented by colors visible to the human eye. In the common case of a combination using the near infrared band, such as a Landsat 4,3,2 TM band combination, the term "false color" is often used to describe this form of enhanced presentation.

''Spectral resolution' refers to the satellite's ability to subdivide the covered portion of the spectrum into smaller segments, in effect discerning different colors in the scene. while multispectral sensors of the Landsat class collect images using a handful of wavelength bands, recent advances in detector technology and computational power have made it possible to build sensors that have hundreds of very narrow spectral bands. These "hyperspectral" imaging systems, still experimental in nature, have the potential to discern much additional information in the scene, contributing to the detection of camouflaged or concealed targets, ocean bottom features, small-plot crop plantings of interest to drug interdiction efforts, detailed structures in clouds, and other highly detailed image features of military interest. Whereas panchromatic sensors combine all the light they receive into a single image and multispectral sensors sample light in several non-adjacent color bands, hyperspectal sensors sort incoming light into a hundred or more mutually exclusive and collectively exhaustive ''bins. The detailed spectral information thus captured allows for detailed examination of the scene, especially with regard to identifying particular materials in the scene by their unique spectral "fingerprints."[33]

Synthetic Aperture Radars, such as those aboard the now-defunct Almaz-1, JERS - 1, and ERS - 1, operate at even longer wavelengths, the microwave portion of the electromagnetic spectrum. Their final products have the appearance of black-and-white photographs, but they can be colorized, for example to display soil characteristics of particular interest.

Stereoscope—Three-dimensional or "stereo" images are useful in a wide variety of tasks, and essential in map-making and the creation of scenery in flight simulators. A stereo satellite image combines images taken at slightly different locations in the fashion familiar from childhood's various ''3-D Viewer' toys

32 An even more complicated case is that of minefield. The minefield's extent can exceed the sensor's resolution in both directions, with each mine being nonresolvably small. In some cases, the trained eye can perceive the presence of the field, based on the *pattern* of nonresolved specks.

33 Rosenberg, op. cit., footnote 10, and an Aug. 27, 1992, briefing at the Naval Research Laboratory, Washington, DC, on their HYDICE (Hyperspectral Digital Imaging and Correlation Experiment) project.

and, indeed, from human depth perception itself. In some applications, a photo interpreter sees and benefits from this illusion personally;[34] in others, computers manipulate the data to produce a contour map, with no actual 3-D viewing having taken place. The value of stereoscopic coverage is so great as to elicit a rare instance of sardonic wit from the U.S. Army in its *Soldier's Manual, Skill Level I Irnagery Analyst:* "You will appreciate the advantages of stereoscope more each time you interpret photography that doesn't have sufficient overlap to permit stereo viewing. '[35] For best results with human viewing, the separation between the points where the picture was snapped should be about a tenth of the distance to the target.[36]

Photo reconnaissance aircraft produce the stereo pairs by taking photographs in rapid succession during their pass over the target. Civilian satellites currently lack this ability, and can make stereo pairs only by carefully planned shots on separate orbits. JERS-1 planning included the ability to make along-track stereo pairs .37

Metric—Accurate photogrammetric measurement of the objects seen in the image requires an accurate account of the distance and viewing angle from the sensor to the target. If, in addition, accurate absolute location of the objects with respect to a larger coordinate system (such as global latitude, longititude, and altitude) is desired, an accurate account of the absolute location of the sensor is needed. Such location is now best obtained from the Global Positioning System (GPS), whose unencrypted signals normally allow three-dimensional location to within 80 meters or better and time-domain location within a hundred-millionth of a second and whose encrypted signals provide even freer location and time accuracy. The analogous Russian GLONASS system provides comparable accuracy but poor coverage. Through repeated measurements, the accuracy of either system can be increased. Access to the ''precise-code' GPS output, which is normally encrypted, could allow a satellite to locate itself to within lo-meter accuracy or better. Special processing software can also improve metric accuracy. For example, routine decisionmaking data processing can locate SPOT data to within half a pixel.[38]

Considerable accuracy is possible even without such systems. France's SPOT, for example, can locate its pictures to within one kilometer purely through the use of its own orbit data.[39]

Timeliness-There are actually two aspects of timeliness, both desirable. First, the rapidity with which an order is filled, measured in terms of the length of time between the request and the collection of the imagery. Second, the freshness of the imagery, measured in terms of the length of time between the moment that the image is collected and the moment it is delivered to the customer. These two types of timeliness are not strongly related, except insofar as most customers will want them both.

The former depends in part on the ''revisit time' of the satellite (how long it takes between successive passes over the same spot) and the degree to which it can aim its camera obliquely, obviating the need for an exact pass over the target. These combine to create an average delay between successive opportunities to image the target. The actual delay—which one might term the "visit time' '-experienced by the customer will vary according to how lucky he or she is: a lucky customer will request a picture right before an opportunity to schedule it arises, while an unlucky one will request a picture just after a good time to take it has passed, resulting in a delay. Such a customer might want to shop around for a different satellite's services. Customers seeking visible-light views of regions frequently covered by clouds will also find themselves subject to collection delays caused by weather. Revisit times can be considered two ways: the revisit time of a particular satellite, or that afforded by a satellite system, in which a pair of satellites can halve the revisit time. The second column of the table below reflects

---

34 With, perhaps, an artificially exaggerated depth dimension so as to aid in the interpretation task.

35 *Soldier's Manual, Skill Level I,* op. cit., footnote 21, p. 2-281.

36 Donald Light, U.S.G.S National Aerial Photography Program

37 Zimmerman, op. cit., footnote 22, p.21.

38 William Kennedy, Hughes STX Corp., personal communication, July 8, 1992.

39 William Leith and David W. Simpson, ' 'Monitoring Underground Nuclear Tests, '' in Peter Zimmerman, *Civilian Observation Satellites and International Security (New* York, *NY:* St. Martin's, 1990), p. 116.

Table C-3—Timeliness of Selected Civilian Sensing Systems

Satellite	Revisit time (days)	"Freshness" (days)
JERS-1	44[a]	
SPOT	1-4[b]	variable[c]
Landsat[d]	8-16	1
Almaz	4-6[e]	

[a] Peter D. Zimmerman, *The Use of "Open Market" Observation Satellites for the Monitoring of Multilateral Arms Control Accords,* prepared for the United Nations Department of Disarmament Affairs, p. 21.

[b] Ronald J. Ondrejka, "Imaging Technologies," *Arms Control Verification,* Kosta Tsipis, David W. Hafemeister, and Penny Janeway (eds.), p. 79. Allen V. Banner, *Overhead Imaging for Verification and Peacekeeping Studies: Three Studies,* prepared for the Arms Control and Disarmament Division (Ottawa, Ontario, Canada: External Affairs and International Trade Canada, 1991), p. 18. Banner specifies that at 45 degrees from the equator, "up to 12 images can be acquired [at the same site] during one 26-day orbital cycle with time intervals from 1 to 4 days between successive images," p. 4.

[c] Banner says "Space Media Network [. . .] has made special arrangements to get SPOT imagery [to the media] within a few days for fast-breaking stories. However, this kind of delivery cannot be routinely provided and is very expensive. The delivery time for civilian imagery is usually several weeks or more, even for imagery that has already been acquired and archived." (Ibid., Banner, p. 21.) It is said that the U.S. military obtained pictures in about 48 hours during the Persian Gulf War.

[d] D. Brian Gordon, Chairman, Tactical and Military Multispectral Requirements Working Group, Defense Intelligence Agency, testimony of hearings before the House Committee on Science, Space and Technology and the Permanent Select Committee on Intelligence, 102d Cong., 1st Sess., June 26, 1991. Scientific, Military, and Civilian Applications of the Landsat Program, p. 29. Overlap of coverage in northerly regions can allow more than one photo opportunity in the 16-day cycle. For example, targets in the Kola peninsula can be seen by three different passes each 16 days (Johnny Skorve, *The Kola Image Atlas,* Oslo, the Norwegian Atlantic Committee, 1991.)

[e] William Kennedy, Hughes STX Corp., personal communication, July 8, 1992.

SOURCE: Office of Technology Assessment, 1993.

this distinction. Also counted as part of the "visit time' is the delay entailed in processing the customer's order on the ground. This delay-often best measured in weeks in business-as-usual commercial operation—is far beyond acceptable limits for many military uses.

The second type of timeliness, which one might term ' 'freshness, " depends upon the way pictures get from the satellite to the customer. Normally, processing on the ground-needed to turn a signal from the spacecraft into a usable image—accounts for much of this delay. In the case of Resurs-F, however, additional delay results from the use of a film-return-as opposed to TV-like-transmission of the picture from the satellite, Film-return systems return a capsule of photographic film to the ground for processing. A lucky customer will request a picture just before the roll of film is used up. This aspect of timeliness is a major difference between the two high-resolution competitors, SPOT (table C-3) and Resurs-F: SPOT uses a digital video downlink while Resurs-F uses a physical film-return system (see app, D).

Throughput—Image vendors can only sell pictures as fast as they can take them. At some level of demand, perhaps reachable by even a single customer during period of peak use such as a war, further pictures cannot be purchased at all for a while, and additional requests will have to go unfilled.

Cost—However important the mission, cost is an important consideration. Civilian satellites are no exception. Whether a cost is deemed 'high' or 'low' depends upon how it compares to the costs of alternative means of accomplishing the mission and to the cost of allowing the mission to remain unperformed (table C-4).

Control--space-race handicappers will already have noted that the civilian satellites with the freest resolutions (SPOT, Resurs-F, and the now-defunct Alrnaz) do not belong to the United States. Therefore, political considerations might vitiate the potential military utility of these satellites in a crisis, In the case of the Gulf War, this effect worked in favor of the United States: the French were on our side, and sold SPOT images only to ''well known clients in support of the allied effort. '[40] On the other hand, it has been stated that France denied the United States use of SPOT during planning for the 1986 raid on Libya. Even during normal peacetime operation Russia has had a policy of not selling Resurs-F imagery of its own territory, though Almaz images are available. This practice, too, could change in light of Russian needs for foreign exchange.

[40] Stèphane Chenard, ' 'Lessons of the First Space War, " *Space Markets,* April 1991, p. 5.

Table C-4-Costs and Capacities of Selected Civilian Satellites

Satellite	Scene size (sq. miles)	Cost per scene	Capacity (scenes/day)
Resurs-F (hi)	2,500	NA	NA
Resurs-F (lo)	10,000	NA	NA
SPOT (pan)	1,600+	$2,450[a]	NA
SPOT (msi)	1,600+	$2,450[a]	NA
Almaz	625	$1,400[a]	100[b]
Landsat 4,5 TM	10,000	$4,400	NA
Landsat 4,5 MSS	10,000	$1,000	NA
Old Landsat scenes	NA	$1,000	NA

NA—not available.

[a] William Kennedy, Hughes STX Corp., personal communication, July 8, 1992.

[b] Craig Covault, "Soviet Radar Satellite Shows Potential to Detect Submarines," *Aviation Week and Space Technology*, Oct. 8, 1990, pp. 22-23. Almaz's image processing facility in Moscow is projected to be able to handle about 100 images per day.

CIVILIAN SATELLITES' USE IN MILITARY MISSIONS

Mapping, Charting, and Geodesy (MC&G)— Multispectral imagery from civilian satellites provides considerable value-added for military MC&G, and saw considerable use in the Persian Gulf War.

One particular application of mapping is the study of deployment-constraining terrain characteristics in the deployment regions of the Russian land-mobile SS-25 missile. Budget Director Richard Darman cited the Defense Department ''absolute need' for multi-spectral images as a reason to turn the Landsat program over to DoD,[41] perhaps to perform this area limitation analysis.

Mapping does not necessarily mean undetailed coverage; some important targets for mapping, such as railroads, are not always visible at the resolutions often associated with maps. Because of its chancy success in picking up these targets, Landsat is the subject of varying performance assessments, ranging from 'Land-sat does not show the railroads, sometimes not even the rivers' '[42] to:

> . . . since MSI maps are images of the Earth, they show existing roads, trails, airfields, etc. Clear, open areas, which may be suitable for military purposes, also stand out and are easily factored into planning. For example, after the 82nd Airborne Division obtained a Landsat map of Kuwait City, it asked for national imagery to determine if there were traps or obstructions that would prevent an airborne landing. MSI images may be able to show surface or subsurface features down to 30 meters, depending on water clarity. The Navy used MSI data in planning amphibious operations during Operations Desert Shield and Desert Storm.[43]

Certainly some railroads, roads, and rivers are visible in the Landsat pictures (images 1-17) of the Kola peninsula used in J. Skorve's *The Kola Satellite Image Atlas* (footnote 27).

Both SPOT and Landsat data are used in military flight simulators. An important and emerging part of MC&G relates to combat intelligence: the creation of databases for guidance systems. While the creation of scenes used by DSMAC,[44] for example, could well be categorized as combat intelligence, the maps used by the pilot or TERCOM[45] during the approach properly belong to the realm of MC&G. Though Landsat data were not used in preparing TERCOM maps for the

[41] This account drawn from ''SAC needs Landsat to hunt mobile missiles, ' ' *Military Space,* Dec. 18, 1989 (Arlington, VA: Pasha Publications), p. 3.

[42] Brigadier General Dale E, Stovall, USAF, quoted in ''Lessons of the First Space War, ' *Space Markets*, April 1991, p. 6.

[43] Secretary of Defense Dick Cheney, U. S. Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress*, p. T-23 1. *This* reference, while in a section entitled 'Multi-Spectral Imagery: Landsat,'' might refer to SPOT MSI as well or instead. SPOT is mentioned in an earlier subsection but without acknowledgment that SPOT images were used in the Persian Gulf War, which they were.

[44] Digital Scene Matching and Correlation. This system accomplishes terminal guidance by relating a TV image of the sighted target area to a stored image, and guiding the missile to that part of the image that has been designated as the target.

45 Terrain Correlation and Matching. This system uses stored maps of certain patches to be overflown en route to the target. when the missile's inertial guidance system decides that it is over a patch, it activates an altimeter. The alimeter readings are then correlated with the elevations present in the patch to fiid the missile's ground track. A course correction can then be made, if necessary. Unlike DSMAC, TERCOM looks only at elevations on a one-dimensional ground track, not a two-dimensional landscape.

Tomahawk cruise missile strikes executed in Operation Desert Storm, the ability to make such use of Landsat data is expected in the near future.[46]

Uniquely, the MC&G mission demands extreme consistency in its data. *Change analysis* is useful in almost all military uses of remotely sensed data, but the changes exploited in MC&G imagery maybe so subtle that almost any alterations in the sensor are detrimental, perhaps even fatal, to completion of the mission .47 Thus, consumers of MC&G data often oppose "upgrades" in the sensors they use, preferring old ones—flaws and all-to new ones whose output will not be strictly comparable to the archived outputs of the old sensors. At the level of precision demanded by MC&G, software cannot compensate for the effects of concern. For example, some MC&G consumers oppose even integer-denominated improvements in resolution, even though one would think that, say, 30-meter resolution could be recovered from 15-meter data simply by averaging blocks of four 15-meter pixels into single 30-meter pixels. Because of possible nonlinearity in the response of the sensors to brightness, however, this approach can fail.

Meteorology—DoD operates meteorological satellite systems, completely devoted to serving the weather-forecasting needs of the military.

Two Defense Meteorological Support Program (DMSP) Block 5D-2 satellites, aided by the National Oceanic and Atmospheric Administration (NOAA) Polar-Orbiting Operational Environmental Satellites (POES) as well as the European Meteosat and Soviet Meteor civilian weather satellites, served the military's weather forecasting needs in the Gulf War.[48]

Weather and other forces change underwater currents in ways that the Navy must monitor in order to predict sonar propagation paths, This requirement is currently filled by civilian NOAA satellites.[49]

Broad Area Search-Broad area search for major installations could be accomplished by civilian satellites. Many sources, such as certain editions of the Department of Defense publication *Soviet Military Power* and even a novel by the author Tom Clancy, show photographs of such installations, taken by civilian satellites. (Which is not to say that that is how the Department of Defense or other civilian customers orginally became aware of them.) In the cases of the airfields, shipyards, and naval bases, even the untrained eye can readily identify the nature and function of the facilities.

Interestingly, the coarse resolution of civilian sensors (especially those best suited to broad area search) is less of an impediment, in the case of some high-contrast targets, than one might imagine: detection of *any* target in a supposedly desolate area, even one of sub-pixel size, is a success for the broad area searcher (table C-5). For example, Landsat-4, using its Band 7, detected the "Wrangel Island Anomaly," a circle 2 miles in diameter on the arctic ice near Wrangel Island. This circle called attention to dots near its center that might otherwise have been overlooked. These turned out to result from tests of a new Soviet submarine's ability to punch its way through the ice, preparatory to launching a ballistic missile. The circle was made by an observation aircraft circling the test site.[50] In other examples, buildings of the North Korean nuclear plant at Yongbyon show up (albeit as dots) in a Landsat Thematic Mapper[51] picture, and ships off California are visible in the Seasat-A radar image. The use of the Thematic Mapper in this role is intriguing, because it suggests the possibility of deliberately sacrificing resolution so as to obtain improved contrast against a target that is much hotter than the surrounding landscape. In the same vein, one could operate visible-light satellites at night, when

46 D. Brian Gordon, Chairman, Tactical and Military Multispectral Requirements Working Group, Defense Intelligence Agency, testimony of hearings before the House Committee on Science, Space and Technology and the Permanent Select Committee on Intelligence, 102d Congress, 1st Ses., June 26, 1991. Scientific, Military, and Civilian Applications of the Landsat Program, p. 31. Note that the essence of a TERCOM map is its elevation data, available only from stereo imagery.

47 Change detection for military purposes may not be as subtle as that used by MC&G.

48 Chenard, op. cit., footnote 40, p. 11.

49 Ibid.

50 Some sources refer to this circle as a contrail whereas others describe it as an actual trace on the ice, created by the slight rainmaking effect of the contrail. The latter explanation is more plausible in that a contrail would drift away and become diffuse, whereas a melted circle in the ice would become more pronounced the longer the airplane loitered.

51 DOD sources often call this device the "Thematic Imager," perhaps because its output is an image, not a map.

Table C-5-Civilian Satellite Images of Area-Search Targets

Installation	Location	Satellite	Source
Cities, towns	Kola, former USSR	DMSP	Skorve, p. 48
Ships	off California, U.S.	Seasat-A	*MX Basing*
Large Radar	Pechora, former USSR	SPOT	*SMP 1987,* p. 49
Large Radar	Krasnoyarsk, former USSR	SPOT	Zimmerman, p. 41
Airfield	Etorufu, former USSR	SPOT	*SMP 1987,* p. 68
Airfield	Schagui, former USSR	Landsat-TM, SPOT	Skorve, pp. 90-93
Naval Base	Gremikha, former USSR	Landsat-TM, SPOT	Skorve, pp. 86-90
Submarine C^3 antenna	Lovozero, former USSR	Landsat	Skorve, p. 112
Shipyard	Severodvinsk, former USSR	SPOT	*SMP 1988,* p. 35
Shipyard	Nicholayev, former USSR	SPOT	*SMP 1988,* p. 40
Airfield	Dolon, former USSR	SPOT	*SMP 1988,* p. 52
Command Center	Sharapovo, former USSR	SPOT	*SMP 1988,* p. 60
Naval Base	Vladivostok, former USSR	SPOT	*SMP 1988,* p. 84
Airfield	Ramenskoye, former USSR	SPOT	*SMP 1988,* p. 143
Laser Site	Dushanbaye, former USSR	Landsat	*CK*
Uranium Mine	Iraq	Resurs-F	*JD** p. 879
Nuclear Plant,	Yongbyon, North Korea	Landsat-TM	*NK*, p. 61
SSBN ice-breaking test	Wrangel Island, USSR	Landsat-TM	Image 4062123183

*This article describes the picture and its use, but does not reproduce the picture.

SOURCE KEY:

CK = *The Cardinal of the Kremlin* (novel). Tom Clancy

JD = Jane's Defense Weekly, 4/3/1990

Zimmerman = Peter Zimmerman, "A New Resource for Arms Control," *New Scientist*, Sept. 23, 1989

NK = North Korea: The Foundations of Military Strength, Defense Intelligence Agency, Washington, DC, October 1991

Skorve = Johnny Skorve, *The Kola Image Atlas*, Oslo, The Norweigian Atlantic Committee, 1991

SMN = Space Media Network

SMP 1987 = Soviet Military Power, U.S. Department of Defense, Washington, DC, 1987

SMP 1988 = Soviet Military Power, U.S. Department of Defense, Washington, DC, 1988

MX = MX Missile Basing, United States Congress, Office of Technology Assessment, OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 1981)

even the poorest resolution could allow sightings of large, illuminated cities and installations.[52] (Under the Soviet system, there were entire cities whose existence was not publicly revealed or acknowledged.[53] Similar conditions may apply today in other countries.)

Use of coarse-resolution, broad-area (and perhaps economical) sensors for wide-area search with selective follow-up by better and more narrowly focused sensors illustrates the important idea of *cueing:* objects seen with the first system receive special attention from the latter.[54] In many cases, what one might term ''retrocueing can also occur: once the target is discovered, earlier imagery can be re-examined and the target found in it as well.[55] J. Skorve recounts his successful implementation of both of these strategies using only civilian systems:

> It was by scrutinizing a Landsat-TM image from 1985 that the large Schagui airbase in southwestern Kola [in the Russian Federation, formerly the U. S. S. R.] was discovered. The revelation of the existence of Schagui was a real surprise since there were no indications of it in available open sources. First it

52 Skorve, op. cit., footnote 27, shows an example of this kind of image, made by a Defense Meteorological Progam satellite (p. 48).

53 ''In Russia, Secret Labs Struggle to Survive, ' New *York Times,* Jan. 14, 1992, p. Cl.

54 For more on cueing, see OTA's *Verification Technologies,* op.cit., footnote 19.

55 Professor R.V. Jones, retrocued by some signals intelligence, found a German V-2 rocket that had previously gone unnoticed in pictures of a V-1 test site in occupied Poland. His highly instructive account appears in his book *Most Secret War* (London, Hamish Hamilton, 1978), pp. 549-551, and is excerpted in OTA's *Verification Technologies,* op. cit., footnote 19, pp. 97-98.

> looked as though the airbase was still under construction at the time of imaging in 1985. However, later it was possible to reveal the time-sequence of the development of the Schagui airbase. A complete listing of the Landsat images of the area shows that there was coverage in 1972, 1974 and 1978. Even though the [Landsat] MSS pictures . . . are rather rough, it was possible to show that in the summer of 1972, the airfield was only 25-30 per cent of its present size. The rate of progress could be determined when the 1974 picture became available. It showed that Schagui by then had grown to its present size. . . . Even the Landsat TM image of 1985 was insufficiently detailed to show the most interesting features of the base. It was therefore a major advance when [my group] could requisition a SPOT-P image taken during the 1988 summer season.[56]

Skorve similarly describes his 1985 discovery of the Gremikha naval base in a 1985 SPOT picture, which retrocued him to earlier Landsat pictures.[57] The base also appears in the 1978 nighttime DMSP picture presented by Skorve.[58] Retrocueing was also used by U.S. Air Force mission planners in their Scud-hunting efforts during the Persian Gulf Conflict. When a launch was detected, planners would examine pre-existing SPOT pictures of the launch area, looking for likely launcher sites.[59]

Submerged submarines, an important target of broad area search at sea[60], could conceivably be seen by civilian satellites equipped with Synthetic Aperture Radar. Though the radar waves themselves can penetrate seawater only a little, their presentation of disturbances on the surface, potentially including submarine wakes, would allow them to detect submarines indirectly.[61] Diverse alternate traces of submarines' passage, such as changes in the water's temperature or even its plankton population, have received intermittent attention over the years.[62] Conceivably some such phenomenon could someday be detected by a civilian satellite. Surfaced submarines would be almost as readily detectable as ships of the same size.

The principal drawback of civilian satellite sensing systems (and, indeed of most systems!) for broad area search is the large number of pictures needed to complete the search. This large number, in turn, translates into time and money.

For example, the former Soviet Union covered about 10 million square miles. A complete search of that territory by Landsat would require about 1,000 pictures, obtained at a cost of $1 million over many pciture months.[63] The subsequent analysis of the Pictures would add more time and cost to the project. SPOT pictures are less expensive per image, but cover less area (albeit at a higher resolution). Use of SPOT pictures would more than double the price: it takes nine SPOT scenes to cover a single Landsat scene.

These daunting figures suggest that true broad area search might not be done very often. More likely, a focused search, based on *prior information* such as the locations of cities, rivers, and coastlines, would be performed. Even so, a Landsat survey of the over 4,500 airfields in the former Soviet Union would, with one

56 Skorve, op. cit., footnote 27, p. 90.

57 Ibid., p. 86.

58 Ibid., p. 48.

59 Craig Covault, ' 'USAF Urges Great Use of SPOT Based on Gulf War Experience, " *Aviation Week and Space Technology,* July 13, 1992, p. 65.

60 The modern defense literature contains numerous descriptions of the dramatic change that would come about if 'the oceans were made transparent. " In most cases, the authors have broad area search, not support of combat operations, in mind-they are concerned that ballistic-missile launching nuclear submarines (S SBNS), whose deterrent mission rests on the other side's ignorance of their whereabouts, would become locatable.

61 Craig Covault, ' 'Soviet Radar Satellite Shows Potential to Detect Submarines,' *Aviation Week and Space Technology,* Oct. 8, 1990, pp. 22-23,

62 See Thomas Stefanick, *Strategic Antisubmarine Warfate and Naval Strategy*, (Lexington, MA: Lexington Books, 1987), especially app. 3.

63 While Landsat would require only weeks to orbit over each scene, it could take months or even years to collect a complete set Of clear-weather daylight pictures. Recall Skorve's experience in imaging the Kola Peninsula.

picture each, cost $18 million.[64] In this case, use of SPOT would be more economical, because an airfield would fit inside a single scene, negating SPOT's disadvantage of having a smaller scene size: the SPOT version of this search would cost only $4.5 million.

Searches at sea highlight another problem as well. Not only would an Almaz search of the 400,000-square-mile Sea of Japan (an antisubmarine warfare arena of modest size) have required 640 25x25-km scenes at a total pre-analysis cost of about a million dollars, but it would have taken at least a week to complete[65]—too long to be of use in many antisubmarine warfare scenarios.

A new broad-area search mission has arisen with increasing military involvement in countering the narcotics trade: searching for fields of illegal drugs. According to a United Nations report,

> . . . it would be feasible to develop a global system for locating cultivation of illicit narcotic crops by space-borne remote sensing devices but that preliminary activity would need to include inspection on the ground at selected test sites to verify the accuracy of information interpreted from satellite photography.[66]

Presently, there is great interest in detecting coca (from which cocaine is derived) planted in South America. Created as a land-use sensor, Landsat would seem ideal for this mission, However, coca turns out to be a difficult crop to monitor. MSS and TM differentiate between vegetation and other features by detecting key substances such as chlorophyll, other pigments, color in general, water content, and even leaf structure:[67] It turns out that the contrast from the minor chlorophyll differences among coca and other local plants such as citrus fruits is small.

Not only is coca's multispectral signature similar to that of other plants in the area, but the agricultural practices of the coca growers can stymie detection: they interplant coca with other crops, and even grow it in patches covered by a tree canopy. Coca tends to be produced in small plots, commonly a half a hectare to two hectares-so small-sized plots would be too small to dominate a pixel,[68] increasing the probability that surrounding features will overshadow evidence of coca. Also, other interfering features (e.g., smoke, clouds) can interfere with satellite detection. Large marijuana fields, however, generally create an easier Landsat target.

Indications and Warning—The indications and warning mission (I&W) is very demanding, and policy makers would certainly like to be able to spread it among as many systems as possible. Table C-6 lists a variety of targets similar to those that might be routinely imaged in the performance of the I&W mission.

While aircraft are visible in Banner's SPOT pictures of Kabul airport, they become much more apparent when one panchromatic image of the airport is overlaid on another, with false color added to highlight differences. Then the moved aircraft-which appear only in one image or the other and are hence brightly colored-become quite obvious not only through their color and shape but through their placement on ramps and runways where any large movable object would be presumed to be an aircraft.

Banner's SPOT-aided discovery that trucks had left a military encampment near Kabul deserves special note for two reasons. First, Banner's knowledge that the site was a military camp, and that it housed the Soviet 108th Motorized Rifle Division, was not gained via satellite imagery: it was *collateral information,* openly available, that aided him in his photointerpretation. Second, the size of an individual vehicle

64 Assuming that no two airfields are close enough to fit into the same picture. In fact, near cities two or three airfields might exist in the same Landsat scene. However, this effect is not strong enough to alter the conclusions of this calculation. Skorve's 17-picture Landsat Kola atlas shows an average of only slightly more than one airbase per picture (not counting duplicate views of the same base in overlapping pictures) even though Kola is a very militarized region and even though some pictures show as many as four or five bases.

65 Almaz facts from *Aviation Week and Space Technology,* Oct. 8, 1990; area of the Sea of Japan from 1990 World Almana c. Almaz's image processing facility in Moscow is projected to be able to handle about 100 images per day.

66 UN International Narcotics Control Board Report for 1990, 1/91.

67 Kennedy, op. cit., footnote 38.

68 A hectare is 10,000 square meters, or about 2.5 acres. An 80 x 80 meter pixel is thus 0.64 hectares in area, and its boundaries would not necessarily be aligned with those of the planted plot. Even adjacent small coca plantings may not add up to a discernible target because they are owned by different growers, who cultivate them in different ways. Thus the signature of an unharvested field may be diluted by that of an adjacent harvested field.

Table C-6-Civilian Satellite Images of I&W-Type Targets

Target	Location	Satellite	Source
SSBN base w/SSBN	Zapadnaya Litsa, former USSR	SPOT	Skorve, p. 99
Naval base w/ships	Severomorsk, former USSR	SPOT	Zimmerman, p. 39
Naval base w/carrier	Severomorsk, former USSR	SPOT	Skorve, p. 67
Airbase w/aircraft	Kabul, Afghanistan	SPOT	Banner, p. 17
Encampment w/vehicles	Kabul, Afghanistan	SPOT	Banner, p. 18
Pentagon parking lots	Arlington, VA	SPOT	suggested by P. Zimmerman

SOURCE KEY:

Banner = Allen V. Banner, *Overhead Imaging for Verification and Peacekeeping Studies: Three Studies*, prepared for the Arms Control and Disarmament Division (Ottawa, Ontario, Canada: External Affairs and International Trade Canada, 1991), pp. 7-8.

Skorve = Johnny Skorve, *The Kola Image Atlas*, Oslo, the Norwegian Atlantic Committee, 1991.

Zimmerman = Peter Zimmerman, "A New Resource for Arms Control," *New Scientist*, Sept. 23, 1989.

would make one think that a system with SPOT's resolution could not see vehicles, but Banner detected their departure by the fact that they had been parked together, aided by change analysis. In his own words:

> Using SPOT imagery, with its spatial resolution of 10 m or more, all but the largest military vehicles will be smaller than even a single image pixel. Nevertheless, imagery of this quality might provide some limited evidence of large-scale migration of vehicles from an area. . . . The red areas in the change image [an "after" picture subtracted from a ''before' picture-OTA] are indicative of dark-toned features that existed in 1987 but not in 1988. The thin lines . . . and smaller features . . . might be vehicles parked in rows and next to a building. The thicker red areas . . . might be vehicles parked several rows deep. Although the spatial resolution of SPOT imagery is clearly insufficient to detect individual vehicles, it might be able to detect changes in orderly rows of vehicles. At the same time, other possible explanations for the changes are apparent in the imagery. For example, it could be tents or packing crates that have been moved.[69]

For many purposes, the sudden departure of large objects from a military base would be of great interest even if one could not establish whether the objects were crates, trucks, or tents. While Banner's interest is the verification of troop withdrawals amid the outbreak of peace, the same technology and logic could be applied to see troop arrivals, or the departure of troops from their customary bases. This last item takes on particular salience in the context of the indications and warning mission. Perception of these aircraft and vehicles at such low resolution would be vulnerable to deceptions in which dummy equipment is substituted for the real thing.[70]

Sensors capable of piercing clouds or darkness, such as thermal infrared and radar sensors, could provide the timely coverage that is particularly vital in the I&W task This consideration is hardly second-order; the Kola peninsula, for example, widely cited during the Cold War in such terms as "the largest concentration of military installations and hardware anywhere in the world"[71] and therefore rating intensive I&W coverage, experiences overcast conditions 80 to 90 percent of the time. Four-fifths of the peninsula lies above the Arctic Circle and thus experiences round-the-clock darkness part of the year. With "prevailing bad luck' some targets in the peninsula went through a whole year without presenting themselves to be photographed by J. Skorve's civilian satellite survey .72

Combat Intelligence-Unlike the shipyards, airfields, and other targets of broad area search, the targets of combat intelligence occupy sharply delimited areas-the battlefield and its environs. Thus when Air Force planners looking at combined SPOT and Landsat

69 Allen V. Banner, *Overhead Imaging for Verification and peacekeeping: Three Studies*, prepared for the Arms Control and Disarmament Division (Ottawa, Ontario, Canada: External Affairs and International Trade Canada, 1991), pp. 20-21.

70 R.V. Jones, *Reflections on Intelligence* (London, England: William Heinemann Ltd, 1989), p. 123. In their Second World War battle at El Alamein, the British deployed dummy artillery and fooled the Germans, who eventually caught on only to be fooled again when real artillery replaced the dummies!

71 Johan Jorgen Hoist, in his preface to Skorve's *The Kola Satellite Image Atlas*, p. 6.

72 Skorve, op. cit., footnote 27, pp. 54-55.

Table C-7—Civilian Satellite Images of Combat Intelligence-Type Targets

nstallation	Location	Satellite	Source
Ships	off California, U.S.	Seasat-A	*MX Basing*
Damaged reactor	Chernobyl, former USSR	SPOT, Landsat	*SMP 1987*, p. 115
Bombed bridges	Baghdad	SPOT	*ES*, p. 13
Naval base	Vladivostok, former USSR	SPOT	*SMP 1988*, p. 84

SOURCE KEY:

SMP 1987 = *Soviet Military Power*, U.S. Department of Defense, Washington, DC, 1987.

SMP 1988 = *Soviet Military Power*, U.S. Department of Defense, Washington, DC, 1988.

MX = *MX Missile Basing*, United States Congress, Office of Technology Assessment, OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 1981).

ES = *Electronic Spies*, by the editors of Time-Life Books (Alexandria, VA: Time-Life Books, 1991).

pictures of a fertilizer plant in Al Qaim (Iraq) saw antiaircraft installations around it and deduced that they should bomb it,[73] they were performing combat intelligence, not broad area search. The antiaircraft example also illustrates how the utility of non-resolvable or barely resolvable images can be enhanced by combining them with better images.[74] For example, the SMP 1987 picture of Chernobyl combines SPOT panchromatic imagery and Landsat thermal imagery, creating a useful view of the overheated reactor. Remarkably, many U.S. military units, even low-level commands, have the ability to combine imagery in this way.[75]

Though, as mentioned above, Landsat often cannot see roads, DIA has stated that 'during preparations for the ground war during Operation Desert Storm, 30-meter Landsat could have revealed ground scars and track activity indicating the thrust into Iraq west of Kuwait. ' '[76] It has been claimed that both sides in the Iran-Iraq war purchased SPOT images as a means of gaining combat intelligence,[77] so such concerns *are* hardly misplaced. In the case of Desert Storm, however, U.S. and French vendors did not sell to Iraq after hostilities began.[78]

Use of even coarser resolution images may be possible. A Singapore-based civilian aviation journal has reported that:

> Pictures from the domestically developed IRA-lA B remote sensing, and INSAT-D weather satellites are being used for photo-processing and weapon targeting under a high priority defence project that is ushering India into the era of satellite reconnaissance and communication. When fully commissioned, this system will increase India's capability for targeting its cruise and ballistic missiles for counter-base and counter-force operations, as well as giving the country's armed services a near real-time theater reconnaissance and battle-damage assessment capability.

In modem warfare, **part** of combat intelligence is the preparation of fighting men for particular missions. The Air Force's successful attempt to staunch the massive Kuwaiti oil leak perpetrated by Saddam Hussein near the end of the Gulf War was rehearsed in simulators using SPOT data.[79] Formulation of databases to drive simulations used for training and mission planning represents an emergent use of remotely sensed civilian data. DIA has shown mem-

73 Chenard, op. cit., footnote 40, p. *4. This is* probably the same well-protected 'fertilizer plant' mentioned by Gordon on p. 30 of the June 26, 1992 testimony. For more on the fascinating art of photointerpretation, see OTA'S *Verification Technologies: Cooperative Aerial Survelliance in International Agreements.*

74 In principle, an image's resolution could *be* improved by combining it with another image of equal quality, as long as the pixel boundaries fell in different places on the two images (as would be almost guaranteed to happen.)

75 D, Brian Gordon, Chairman, Tactical and Military Multispectral Requirements Working Group, Defense Intelligence Agency, testimony of hearings before the House Committee on Science, Space and Technology and the Permanent Select Committee on Intelligence, 102d Congress, 1st session, June 26, 1991. Scientific, Mititary, and Civilian Applications of the Landsat Program, p. 29.

76 Ibid., p. 56.

77 Chenard, op. cit., footnote 48, p. 5.

78 Gordon, op. cit., footnote 75, written response to questions inserted fOr the record, p. 57.

79 Ibid., p. 31.

bers of Congress a few minutes of video tape portraying a simulated pilot's eye view of a flyaround of Kuwait City and the neighboring Faylakah Island. Landsat, SPOT, and Resurs-F images were combined to create this tape.[80] A published example shows how an original SPOT picture of Baghdad can be turned into a pilot 's-eye view of the approach to a target, complete with antiaircraft guns and annotations showing the locations of sites to avoid hitting, such as schools and mosques.[81]

An important part of combat intelligence relates to MC&G: the creation of databases for guidance systems. While the creation of map patches used by TERCOM, for example, could well be categorized as MC&G, the scenes used by the pilot or DSMAC (Digital Scene Matching and Correlation) properly belong to the realm of combat intelligence.

As mentioned in the description of the nascent Indian capabilities, the combat intelligence mission continues after the attack is made. *Bomb damage assessment* must be performed to see if the target merits another attack. The entry in table C-7 regarding the damaged reactor at Chernobyl represents a possible bomb damage assessment mission, but the reader should be aware that bomb damage assessment is notoriously difficult even with the best of sensors, and that civilian satellites are unlikely to play any appreciable role in bomb damage assessment in the foreseeable future. [82]

In performing the combat intelligence mission during coalition warfare such as that prosecuted by our side during the war with Iraq, civilian satellites have the advantage that their product can be released to foreigners allied with the United States.[83] It can also be distributed near the front without fear of compromising the capabilities of highly classified systems if combat intelligence documents are captured.

Arms Control Agreement Monitoring—''Politics, ' as Prince Bismarck said, ''is the art of the possible. "[84] For this reason, arms control agreements are, to a large degree, crafted so as to be verifiable at the limits of available technology .85 The SALT arms control agreements[86] dealt with large objects such as submarin es and missile silos. President Jimmy Carter said, during the SALT era, that "Photoreconnaissance satellites have become an important stabilizing factor in world affairs in the monitoring of arms control agreements. '[87] Increased arms control ambitions and improved verification technology (as well as the newfound acceptability of on-site inspection) now combine to create agreements such as START, in which constraints are applied to the payloads of missiles deployed underground.

Present-day civilian satellites seem hardly capable of verifying even yesterday's arms control agreements. For example, SALT specified that an intercontinental ballistic missile (ICBM) would be deemed to be of a "new type" if its dimensions (or, more accurately, the dimensions of its silo launcher) differed from those of its predecessor by more than 5 Percent.** Such a tolerance---less than 1 meter[89]cannot be measured

---

80 Ibid., p. 37.

81 Covault, Op. cit., footnote 59, pp. 61, 63.

82 Secretary of Defense Dick Cheney, Conduct *of the Persian Gulf Conflict: An Interim Report to Congress, p. 14-2,* and *Conduct of the Persian Gulf War: Final Report to Congress,* pp. C-14 to C- 16.

83 Gordon, op. cit., footnote 75, p. 28.

84 Th, *Oxford Dictionary of Quotations, 4th* edition, Angela Partington (ed.) *(oxford,* NY: Oxford University press, 1992), p. 84.

85 Ideally, technology would be developed with an eye to making verifiable those agreements that were desirable for other reasons. See U.S. Congress, Office of Technology Assessment, *Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures,* OTA-ISC-488 (Washington DC: U.S. Government Printing Office, May 1991).

86 From today's perspective SALT I includes the signed and ratified ABM Treaty and the Interim Agreement on Offensive Arms. SALT II was signed but never ratified. All continue to figure in today's arms-control compliance debate, even though time spans stated in the Interim Agreement and SALT II have now elapsed. START, signed but not yet ratified, subsumes many of the SALT provisions that have lived on past their official lifetimes.

87 Speech by President Jimmy Carter, at the Kemedy Space Center, Oct. 1, 1978.

88 Later, considerable contention would arise over the quesiton of whether this proviso referred to linear dimensions Or to volume. In the present context, this important consideration is irrelevant.

89 Not because 5 percent of the diameter is less than a meter, but because the difference between an allowable 5 percent change and an illegal 6 percent change is less than 1 meter. This important point is made by Zimmerman, op. cit., footnote 22, p. 41.

by today's civilian satellites, though they could see the construction equipment present during silo modification if they looked at the right time.

However, civilian remote sensing satellites are not without utility in arms control verification (table C-8). They can, for example, locate facilities deserving greater attention from other treaty-monitoring systems, including onsite inspection. Jasani's analysis of SS-25 sites in the former Soviet Union brings to light several discrepancies between the site plans submitted by the Soviet side and the actual layouts of the sites. The INF Treaty protocol allows for the revision of data submitted in the data exchanges (Article IX.3), and SPOT-derived indications that such revision was in order could be freely shown to CIS representatives.

The View From the Other Side

So far this analysis has been one-sided, addressing only the benefits the U.S. military could derive from civilian remote sensing satellites. In this section we shall turn to the view from the other side—ways in which an adversary could diminish the utility of these satellites to the United States military, and ways in which he could avail himself of their services to the military detriment of the United States.

CAMOUFLAGE, CONCEALMENT, AND DECEPTION (CC&D)[90]

Sun-Tzu Wu, the ancient Chinese military writer, maintained that deception was the cornerstone of successful military planning. More recently, the erstwhile Soviet military emphasized the role of *maskirovka,* a military art grouping under one tarpaulin the Western notions of camouflage, concealment, and deception.[91] The Soviets' confederated successors and Third-World understudies doubtless attach similar importance to these dissimulative practices.

"Camouflage is the technique of hiding from view that which is physically present,"[92] and includes the mottled paint and nets festooned with fresh-cut branches familiar to us from war movies and television, and other techniques of making the objects of interest blend in with the ground.

"Concealment" includes other means of avoiding detection. In the case of radar satellites such as Almaz, concealment could be accomplished by jamming—beaming junk radio waves of the correct frequency at the satellite. Such jamming would ''appear as dark static interference on imagery and [would] usually cover the entire section of imagery in the area of coverage. '[93]

"Deception is the technique of making what is physically present appear to be something different. '[94] It includes the use of dummies and decoys. ''Dummies are imitations of actual objects or installations, usually composed of dummy weapons, emplacements, vehicles, and equipment, They are designed to simulate real activity and draw fire away from camouflaged or concealed activities. Decoys are lures located in logical military positions but far enough from actual targets to prevent fire directed against them from hitting the real sites, ' '[95] Interestingly, a decoy or dummy must—for realism's sake-be camouflaged, though not so well as to prevent it from being seen!

Military applications of civilian remote sensing that use the sensors' utmost spatial resolution and rely heavily on the deductive powers of the end user could be deceived by the crudest of CC&D operations: 10-meter resolution could hardly hope to discriminate a decent dummy from the real thing. However, civilian satellites' *spectral* resolution could come to the rescue: painted-on foliage might look realistic in the visible-light portion of the spectrum, but only the fanciest camouflage nets maintain their deception into the near infrared. Thermal infrared provides yet another view, one very difficult to mask. The detection of these, and of CC&D efforts in general, is aided greatly if *comparative covers* (multiple images of the same region) are available: comparison of a current image to an archive picture taken much earlier immediately

---

90 See also OTA's *Verification Technologies*, op. cit. footnote 19, especially ch. 3 and app. B.

91 See, for example, *Camouflage: A Soviet View, Soviet Military Thought*, no. 22, translated and published under the auspices of the U.S. Air Force (Washington, DC: U.S. Government Printing Office, 1989). This volume is comprised of two Soviet books on maskirovka.

92 Soldier's Manual Skill Level I, op. cit., footnote 21, p. 2-298.

93 Ibid., p. 2-484.

94 Ibid., p. 2-298.

95 Ibid., p. 2-236.

Table C-8-Civilian Satellite Images of Arms-Control Targets

Installation	Treaty	Satellite	Source
Semipalatinsk Test Site, USSR	LTBT	SPOT, Landsat	Zimmerman, plate2
Kahuta Enrichment Plant, Pakistan.	NPT*	SPOT 1	Zimmerman, plate 5
Pakistan			
Large radar, USSR	ABM	SPOT	*SMP 1987*, p. 49
Large radar, Krasnoyarsk, former USSR	ABM	SPOT	Zimmerman, p. 41
Dimona reactor, Israel	NPT*	SPOT 1	Zimmerman book, plate 6
IRBM base, France	NF*	SPOT	Zimmerman, plate 8
Yongbyon nuclear plant, North Korea	NPT	Landsat Thematic Mapper	*NK*, page 61
Uranium Mine, Iraq	NPT	Resurs-F	*JD* 4/3/1990, p 879
SSBN base w/ Typhoon	SALT, START	SPOT	Skorve, pp. 98-99
SS-25 Base	SALT, INF, START	SPOT	Jasani, pp. 382-383
U.S. Air Force base	SALT, START	Resurs-F	*ES*, page 36

These sightings are not evidence of treaty violations. They do, however, bear on the issue of treaty compliance. For example, the Pechora radar would, if not facing out from the perimeter of the former Soviet Union, be a violation of the ABM Treaty.

* Indicates that the country imaged is not a signatory of the treaty in question: nevertheless, the target is physically typical of the items that those nations that did sign the treaty pledged to limit.

TREATY KEY:

ABM = SALT I "Antiballistic Missile Treaty"
LTBT = Limited Test Ban Treaty
NPT = [Nuclear] Non-Proliferation Treaty

SOURCE KEY:

ES = *Electronic Spies*, Time-Life Books, 1991.
Jasani = "Satellites and Arms Verification" Bhupendra Jasani, *Jane's Intelligence Review,* August 1992, pp. 380-383.
JD = *Jane's Defence Weekly.*
NK = *North Korea: The Foundations of Military Strength*, Defense Intelligence Agency, October 1991.
Skorve = Johnny Skorve, *The Kola Satellite Image Atlas* Oslo, the Norwegian Atlantic Committee, 1991.
SMP 1987 = *Soviet Military Power*, U.S. Department of Defense, Washington, DC, 1987.
Zimmerman book = *Civilian Observation Satellites and International Security*, Peter Zimmerman (eds.) et. al.
Zimmerman article = Peter Zimmerman, "A New Resource for Arms Control," *New Scientist*, Sept. 23, 1989.
Zimmerman = Peter D. Zimmerman, *The Use of "Open Market" Satellites for the Monitoring of Multilateral Arms Control Accords*, prepared for the United Nations Department of Disarmament Affairs.

focuses attention on those features that are different, alerting the interpreter to the fact that they might be parts of a CC&D operation. The U.S. Army's manual for the beginning image analyst counsels: "Be suspicious of everything in the photograph that does not have an explanation."[96]

SPYING ON AMERICA

Under current policies, vendors will sell satellite pictures of the United States to anybody who has the money. While one can imagine various ways in which such information could be used in the realm of economic competition (prediction of crop yields, for example), it is at first difficult to imagine ways in which satellite imagery could further a military effort against the United States. Information about the United States is relatively easy to come by, and few potential enemies have the ability to reach U.S. territory with anything but a terrorist attack. (Even so, terrorist attacks against the United States to date have occurred at foreign airports, bases, or embassies. Additionally, some of these attacks have required information that could not be obtained by satellite, such as the internal layout and security procedures of airline terminals.)

However, remotely sensed data from civilian imaging satellites could be used in certain ways inimical to the United States.

Obtaining Accurate Location of Target-In the near future, even a technologically unprepossessing foe may be able to fit primitive cruise missiles (perhaps no more complicated that the German V- 1s of 50 years ago) with inexpensive, and yet highly accurate, guidance equipment using the universally accessible Global

96 Ibid., p. 2-281, as welt as numerous other pages.

Positioning System (GPS).[97] Such accurate guidance engenders a need for accurate knowledge of the target's location, because otherwise the accurate guidance is wasted. A typical target would be a building on a military base. A SPOT or other image with good metric data would allow for accurate GPS-based navigation of the missile to the target.

Testing **CC&D Methods-The practitioner of CC&D, especially that directed against civilian imaging satellites, could test the efficacy of his methods by requesting imagery of test targets, in his own territory, incorporating his CC&D methods. In this way he would be spying not on America's territory, but on her civilian detection capabilities vis-a-vis his denial techniques.**

Observation of Denied Areas---Despite America's overall character as an open society, there exist many good-sized military reservations to which access is denied. These could be probed through the use of satellite photography.

Market Motives and Military Missions

Technical progress is possible in all facets of remote sensing technology+ specially in the four basic parameters, spatial and spectral coverage and resolution—but civilian satellites' designs are based on tradeoffs among these and other desirable characteristics. These tradeoffs are made on the basis of civilian science and commercial demands. Assuming that the design of future systems is not shaped by military requirements recycled into the commercial marketplace, will civilian satellites, through technical progress, become ever-more suited to military missions?

Almost any technological improvement in civilian remote sensing technology will have some military benefit, but the principle defect of civilian satellites for military remote sensing-their untimely responsiveness—is unlikely to be remedied unless the designers of civilian satellites accede explicitly to their military customers' demands. In the civilian world, timeliness measured in days or weeks is perfectly acceptable for most applications: geology and topography aren't going anywhere, and pictures of crops, evanescent though their subjects may be, can often be scheduled far in advance because planting and harvesting occur on strict schedules.

Interestingly, arms control missions-in which civilian satellites do not now perform conspicuously well because of their limited resolutio~may be very well-served by the civilian satellites of the future. Market forces will almost certainly push satellites to finer resolutions, and the arms control mission requires no greater a timeliness than do many civilian missions because arms control verification takes place on a diplomatic, not a military, time scale. However, the high resolutions desired by the arms<ontrol customer would have little use for nonmilitary missions and would pressure the satellite's design away from the broad-area coverage desired for the nonmilitary missions.

Might a satellite optimized for military uses be built and launched as a commercial venture? Such a "mercsat' is already in the advanced planning stage: a U.S. company has proposed to build, launch, and operate a satellite for a foreign customer, providing data with l-meter resolution[98] and other such deals have been contemplated.[99] This arrangement is not an export of anything but the data, because the foreign customer would at no time lay hands on the satellite or its controls.

Findings

1. Civilian satellites such as Landsat, but most notably SPOT and Resurs-F, have considerable military utility. Imagery from these assets can and has been used to support military operations. Their utility for arms control is limited. Technical progress, especially in spatial and spectral resolution, continues to improve the military utility of successive generations of these satellites.
2. Civilian satellites' use to date for military reconnaissance suggests that post-processing, skilled interpretation, and the use of collateral information can make even fuzzy pictures informative. For this reason, the civilian satellites' in reconnaissance exceeds that which might be expected on the basis of ground resolution—a simplistic, though custom-

~ Kosta Tsipis, *New York Times,* Apr. 1, 1992, p. A25.

98 "Emirates Want To Buy U.S. Spy Satellite," *Space News,* vol. 3, No. 43 (Nov. 16-22, 1992), p. 1.

99 William J. Broad, "3 Nations Seek To Buy Spy Satellites, Causing a Policy Rift in U.S.,' *New York Times, Nov. 23,* 1992, p. A7.

ary, measure of capability-and the highly conservative rules of thumb normally used to relate it to suitability for particular reconnaissance tasks.

3. However, reconnaissance missions' requirements for timeliness often exceed the current capabilities of civilian satellite systems. Because civilian missions' timeliness requirements are relatively lax compared to military ones, civilian satellite systems will continue to fall short in this regard unless they begin to cater expressly to the military market.
4. Foreign ownership of the most capable civilian remote-imaging satellites brings into play the usual foreign-source considerations: the United States could be denied access to imagery for political reasons, and the assets could well be operated in ways inimical to U.S. interests, and so on. Restoration of U.S. technical dominance in the commercial remote-imaging field could allay these fears.
5. Though the possibility of using Landsat, SPOT, and Resurs-F data to sense enemy forces springs most readily to mind when one speaks of military uses of civilian sensing, the military needs accurate meteorological data as well. These, too, come from civilian satellites as well as from the military's own weather satellites.
6. Mapping—including precise measurement of the geoid itself—is a civilian mission with important military applications. These applications include simulation, training, and the guidance of automated weapons. Mapping to date falls short of what most people might imagine, both in terms of coverage and of precision. A more capable system, perhaps a interferometric SAR, would remedy this shortfall.
7. Many uses, civilian and military, of remotely sensed Earth data require that one be able to mix, match, compare, contrast, combine, add, or subtract data from different sources. While such operations are hampered by the plethora of different formats and media in which the data are collected and stored, this lack of standardization poses no insuperable obstacles-data from such diverse sources as Landsat, SPOT, and even the Russian Almaz are routinely combined once an initial learning period has passed. Moreover, in recent action by the executive branch, the Secretary of Defense and the Director of Central Intelligence have chartered a new Central Imagery Office.[100] Specifically included in its responsibilities are the areas of imagery formats, standardization, and interoperability.

Issues for Congress

1. **Standardization:** Is there need for Federal action to regularize Earth data reporting formats and media? If so, ought action to be taken by the executive or the legislative branch?
2. Competitiveness: Civilian satellites such as Landsat, but most notably SPOT and Resurs-F, have considerable military utility. Imagery from these assets can and has been used to support military operations. Is potential loss of this military market, by EOSAT to foreign suppliers a national competitiveness concern?
3. **Threats to Security: The** United States could be denied access to imagery for political *reasons,* and the assets could well be operated in ways inimical to U.S. interests. Putting the shoe on the other foot, other countries could use civilian images of the United States or its foreign military deployments to plan their attacks. Can the U. S., **through its Landsat program, take action to prevent or deter** such operation?
4. **Entanglement:** Foreign belligerents can, and probably have, buy Landsat pictures (or use GPS data) to further their wars against each other. They might even buy them to prepare for a war (or terrorism) against the United States or its allies, fulfilling Lenin's prophecy that the capitalist would sell the rope that would be used to hang him. How should the United States respond to indications that such activity might be in the offing? Could the United States detect that such use of Landsat images was being made?

[100] Department of Defense Directive 5105.56, May 6, 1992.