Chapter 3

AIRBORNE PLATFORMS AND SENSORS

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AIRBORNE PLATFORMS AND SENSORS

Summary

This chapter surveys some of the types of airborne platforms and sensors that might be appropriate for agreed overflights and examines major issues for each. It also discusses how negotiations on operational issues can affect the success of an aerial surveillance regime.

The type of airplane or helicopter used in overflights must meet requirements for range, sensor payload, passenger room, safety, reliability, and negotiability. More exotic aerial surveillance regimes might use unmanned aerial vehicles (UAVs) or lighter-than-air craft.

A wide variety of imaging sensors, spanning the electromagnetic spectrum, could be employed during a cooperative overflight. Air samplers or sniffers and radiation detectors could be used to detect restricted chemical and radiological emissions. Signals intelligence (SIGINT) collection, passive acoustic devices, and magnetic anomaly detectors (MAD) might also be used to ferret out information. Sensors can be combined to provide 24-hour, all-weather effectiveness and to complicate attempts at concealing treaty-limited items (TLIs).

Operational considerations are also important. The number of flights relative to the area and composition of the overflown territory, the frequency and duration of overflights, and the amount of advance notice given must be appropriately matched to surveillance goals.

Introduction

Cooperative aerial surveillance involves flying one or more sensing devices (a sensor suite) over the territories of the signatories of an agreement. The platform flown could be an airplane or helicopter, but a case might be made for other craft, e.g., UAVs and lighter-than-air craft. The sensors carried might simply be the eyes of a human observer or more sophisticated cameras, signal gatherers, or air samplers.

The aerial platforms and sensors should be suited to their missions as defined by the overflight agreement. At the same time, the choice of platforms and sensors will likely be limited, primarily for reasons of cost and intrusiveness, to the minimum configuration needed to accomplish the goals of the accord. In the case of some potential agreements, e.g., Open Skies, the goals might be so broadly defined that no minimum configuration is readily apparent. However, in a regime meant to sample the pollutants near designated powerplants, loading a plane with SIGINT equipment would be clearly unnecessary. Similarly, operational criteria should be appropriate for the flights. If the agreement being negotiated calls for short-notice monitoring of some easily relocated TLIs, a prearrival notification period of 48 hours may render the overflights irrelevant. Likewise, an accord that allows the monitoring of troop movements might be undermined by territorial restrictions on overflights.

Airborne Platforms

Types of Platforms

Airplanes

Airplanes are especially useful for missions that require fast air speed, long durations, large sensor payloads, or film changing and sensor maintenance in flight. A wide variety of civil and military

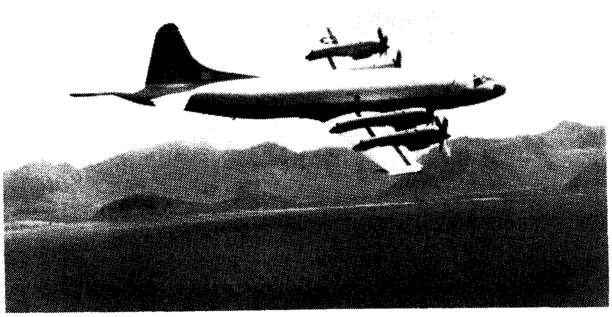

Photo credit: U.S. Navy contractor, released by Department of Defense

The P-3C Orion, a maritime patrol version of the Lockheed Electra, began service in the U.S. Navy in 1969 and has since found its way to many other countries. Its 10-person crew employ a variety of sensors to detect submarines. Note the magnetic anomaly detector protruding from the tail.

Photo credit: U.S. Air *Forces*

Helicopters might prove useful in agreements that seek to combine aerial surveillance and on-site inspections.

airplanes have already been modified for surveillance activities—horn sophisticated spy planes, like the TR-1 (descendant of the U-2), to transports, like the C-130. Even a two-seat, civil aircraft could be modified to play some role. Most agreements would probably require at least one representative of the overflown country to be on the plane as an escort, if not as the pilot and sensor operator.[1]

Helicopters

Provisions of the 1990 Vienna Document[2] permit observers in host-country helicopters in Europe to monitor large-scale conventional military activities. Generally of more limited speed and range than airplanes, helicopters might be particularly useful for missions exploiting their relative strengths: low-level flying, slow flying and temporary hovering, and close-quarter landing. Helicopters, like airplanes, could allow sensors to be adjusted or reloaded with film during flight.

Low-altitude flights would enable sensors to probe beneath all but the lowest cloud cover or fog. This might mitigate the need, in the daytime at least, for sensors more sophisticated than human vision or conventional photography. It might also improve the utility of sensors that need to get close to their targets to work efficiently (e.g., MADs). (But note that lowering altitude reduces the amount of territory visible to the sensors on board.)[3]

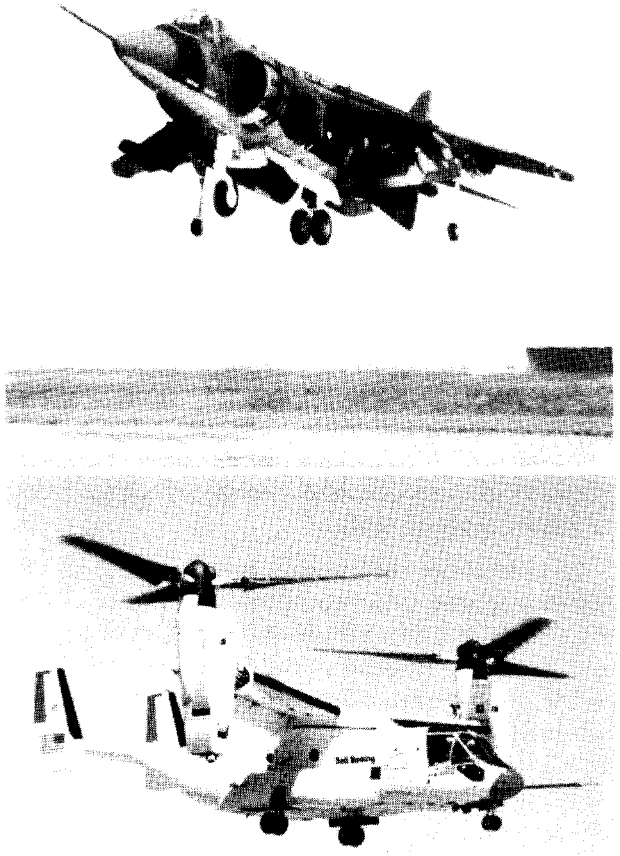

Photo credit: U.S. Department of Defense

The AV-8B Harrier jump jet (top) and the developmental V-22 Osprey tilt-rotor aircraft (bottom) are examples of platforms that share features of both airplanes and helicopters.

Similarly, slow flying[4] or hovering over a potential target or a declared site might permit more

[1] Although most scenarios include both inspecting and host country representatives on a plane, either party might be granted sole overflight authority.

[2] This product of the Conference on Security and Cooperation in Europe provides for aerid and ground observation of military exercises above a certain size.

[3] The line-of-sight to the horizon varies as the square root of the sensor height. For a helicopter flying at an altitude of 1 mile, the line-of-sight to the horizon is approximately 90 miles, For the same helicopter at an attitude of 1/4 mile, the distance to the horizon is approximately 45 miles.

[4] Slow air speeds (about 30 knots) minimize photographic image blurring and platform vibration. Higher speeds and hovering increase vibration. As cited in Allen V. Banner, Andrew J. Young, and Keith W. *Hall, Aerial Reconnaissance for Verification of Arms Limitation Agreements: An Introduction (New York, NY:* United Nations, 1990), p. 139. Maintaining minimal vibration may not be as important as hovering for some types of sensors.

sensitive instrument readings. It would also give the inspectors time to examine a suspicious object from a variety of altitudes, look angles, and sun angles.

Unlike most airplanes, a helicopter, however, can land without an airstrip. This enables a helicopter to combine the role of aerial monitor and on-site inspector. A sensor-bearing helicopter could detect an anomaly from the air and then land with inspectors who could document any violation.[5] All other modes of reconnaissance require that the sensor collect unambiguous evidence of violation directly (necessitating a more refined sensor) or that it cue other means of collecting evidence, such as ground-based, suspect-site inspection.[6]

Unmanned Aerial Vehicles

UAVs include "remotely piloted vehicles (RPVs), which require remote control by human pilots; autonomous aircraft (drones), which do not; and aerial vehicles which permit, but do not require, remote control by human pilots. ' UAVs may resemble either an airplane or a helicopter: some fly in a straight path, while others can hover. Most UAVs are small and have relatively short range; however, Boeing's recently demonstrated Condor can stay aloft above 65,000 feet for several days.[8] Because these aircraft are unmanned, there is no one on board to maintain sensors, reload film, or look out in a direction where the sensor is not pointing. At most, a human controller on the ground might be able to redirect and focus the sensors on board in real time. These characteristics make UAVs an attractive alternative to other platforms, because the potential for collateral information gathering can be reduced to an absolute minimum. Only that which is recorded by the sensors on the UAV or seen on a remote monitor is revealed to the inspectors on the ground. This information can be readily restricted by mechanical adjustment of the sensors. Covert sensors would also be difficult to hide on the relatively small vehicles.[9] Lastly, UAVs could monitor events that might be hazardous to human observers (e.g., chemical leaks and nuclear test venting) .10

Photo credit: U.S. Department of Defense

UAVs, equipped with television or forward-looking infrared sensors, collected reconnaissance and targeting information during Operation Desert Storm.

[5]Such landings would likely be subject to some numerical or time quota to lessen their intrusiveness and cost, as well as to safety constraints.

[6]Helicopters could also be employed t. land a quick-response team that would ring a suspect facility with rapidly deployable perimeter sensors to ensure that no mobile TLI escaped the facility while it was being prepared for an internalsuspect-site inspection. Note that this is not specifically an aerial surveillance task. The preparations required at a sensitive site can be quite extensive and time consuming. If the preparations were notallowed, the site might not be included in the accord for reasons of national security. A discussion of the trade-offs in on-site inspection systems can be found in U.S. Congress, Office of Technology Assessment, *Verification Technologies: Measures for Mom-toting Compliance With the START Treaty—Summary*, OTA-ISC-479 (Washington, DC: U.S. Government Printing Office, December 1990).

[7]U.S. Congress, Office of Technology Assessment, New *Technology for NATO: Implementing Follow-On Forces Attack,* OTA-ISC-309 (Washington, DC: U.S. Government Printing Office, June 1987), p. 230.

[8]Breck W. Henderson, "Boeing Condor Raises UAV Performan ce Levels," *Aviation Week and Space Technology,* Apr. 23, 1990, pp. 36-38.

[9]Many aircraft, other than current UAVs, could be converted for remote operation.

[10]Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Acrid Monitoring, " Occasional Paper #4, The Henry L. Stimson Center, Washington, DC, April 1991, p. 26.

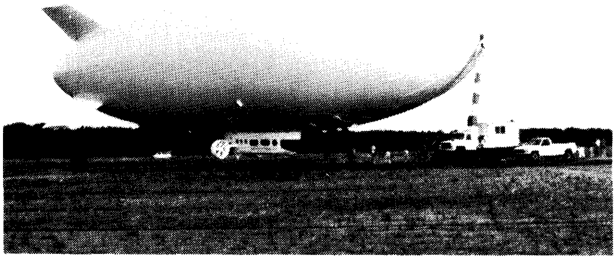

Photo credit: Westinghouse Airships, Inc.

Westinghouse Sentinel airship with its ground crew. Airships normally operate at 10,000 to 15,000 feet and at speeds in the tens of knots.

Lighter-Than-Air Craft

Dirigibles, balloons,[11] airships, aerostats, and blimps may be uniquely attractive for some purposes. Floating aerial platforms have the advantages of sensor stability (extremely low vibration), relative background silence for acoustic sensors, unrestricted access to sensors (on crewed craft), large payload capacity, endurance, and extended hovering.[12] The last attribute could enable tethered aerostats to provide an airborne sensor perimeter around a site (e.g., rocket motor plant) either for the term of an agreement or until preparations for an OSI were completed.

During the 1989 celebration of the French bicentennial, Paris police, stationed aboard a blimp, kept almost continuous vigil over the crowds and the comings and goings of world leaders. They professed the ability to identify an individual 1 mile distant.[13]

The chief disadvantages of these platforms are their slow air speed and vulnerability to severe storms. In particular, they would not be a good choice for searching for easily moved and hidden objects or for covering large areas of territory in a relatively short time.

Platform Issues

Aerial platform issues include: whose aircraft is used, who flies it, how many inspectors and host country escorts are on board, where can it land (refuel), what flight rules apply (perhaps those set by the International Civil Aviation Organization (ICAO)), and what will be the language of air traffic control.

Negotiators will also have to decide whether aircraft will be allowed to loiter over a particular spot, make repeated passes over the same territory, or change its flight plan during the flight (at a minimum, to avoid storm fronts). Moreover, minimum (and possibly maximum) altitudes may need to be codified.

Irregularities will also need to be considered: what if an aircraft crashes, what if the pilot intentionally strays off the mandated course,[14] or what if the plane fails a preflight inspection or safety check?

Overflown nations may be concerned that contraband sensors could be secreted aboard (or even in the skin of) the aircraft. If an accord disallowed a type of sensor or put limits on the capabilities of the agreed sensors, a preflight inspection of the platform and its sensor suite by the host country might be necessary. In all cases, except for some UAVs, this could be a fairly difficult and time-consuming endeavor. The provision of platform and sensor manuals and specifications may speed this process up. If the preflight inspection is too long, it may impinge on the ability of the aircraft to accomplish its mission (e.g., searching for easily relocated, mobile missiles). Keeping the aircraft under guard in the host country or some other agreed location after it had been cleared by inspectors might be one solution to this dilemma, because it would obviate the need to inspect the craft before every flight.[15]

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11 The French were the first t. use balloons for military reconnaissance in 1794. William E. Burrows, *Deep Black: Space Espionage and National Security* (New York, NY: Random House, 1986), p. 28.

12 Some lighter-than-air craft can also land without a prepared airfield, but unlike helicopters, they usually require the Presence of ground crews and a comparatively large clearing.

13 "The Blimp Is Back," *NOVA*, Public Broadcasting System telecast in Washington DC, Oct. 30, 1990.

14 A pilot might be tempted to divert his or her course to get a better look at a suspicious object or activity, or to gather collateral intelligence 011 some sensitive site in an exclusion zone.

15 On the other hand, the expense of having aircraft dedicated solely to an overflight regime might be too dear for smaller countries, while relying 011 aircraft provided by the larger countries might be politically unacceptable. (Private communication from Peter Jones, Contractor, Verification Research Unit, External Affairs and International TradeCanada, Ottawa, Canada, Mar. 25, 1991.)

Box 3-A—Types of Sensors

Imaging Sensors
- Human vision
  - Unaided
  - Binoculars
  - Optical transducers (night-vision goggles)
- Aerial photography
  - Optical
  - Infrared
  - Stereoscopic
  - Multispectral
- Electro-optical devices
  - Electronic still camera
  - Television (including low-level-light TV)
- Radar
  - Synthetic aperture radar (SAR)
  - Conventional radar
- Lidar (laser radar)

Nonimaging Sensors
- Signals intelligence (SIGINT)
- Air sampling and sniffing
- Radiation detection
- Acoustics
- Magnetic anomaly detector (MAD)

SOURCE: Office of Technology assessment 1991.

Sensors

Types of Sensors

Imaging Sensors

Human Vision—Although in many ways outmoded by modern technology, human vision remains a viable means of aerial surveillance. A confidence-building regime of purely symbolic overflights might have little reason for permitting more advanced sensors.

Human eyesight might have application in more rigorous monitoring systems as well. If the objects or activities being observed are suitably large and difficult to conceal, then unaided observations might be sufficient for the purposes of an agreement. Peacekeeping missions along desert borders, aerial inspections of missile silos, and observation of military exercises are examples of agreements where eyesight alone might provide satisfactory confidence. Moreover, human vision might cue other, mechanical sensors. For example, a crew member, having spotted a suspicious objector activity, could order the airplane to diverge slightly from its flight path (agreement provisions permitting) in order to photograph the anomalous object from a more advantageous distance or angle.[16] Likewise, the crew member could alter the sensors' scanning mode from a low resolution, wide-area search setting to a higher resolution mode focused on the object.

Under the proper circumstances, selected human beings can perform remarkable feats of visual detection. During World War II, General (then Lieutenant) Charles Yeager could spot German fighters at a range of 50 miles;[17] astronauts in orbit have sighted terrestrial objects as small as trucks in freak occurrences labeled the "hawkeye effect." Binoculars can extend human vision even further.

The detection capabilities of the human eye vary strongly with the angular size of the target (a function of the diameter of, and the distance from, the target), the size of the region in which it might be found, the contrast between the target and its background, the amount of time for which the detection opportunity lasts, and the level of alertness and training of the observer. The *shape* of the target is less important for detection alone.[18]

Some devices can extend human vision beyond the "visible spectrum" (see figure 3-l). Optical transducers, e.g., night-vision goggles, can enable users to see in the infrared portion of the spectrum. Exploiting the far infrared portion of the spectrum in which objects glow by virtue of their own warmth, infrared goggles allow the wearer to see in the dark.[19] Furthermore, because they depict objects according to their temperature, infrared vision systems also reveal phenomena not normally visible to the human eye, e.g., distinctions between conven-

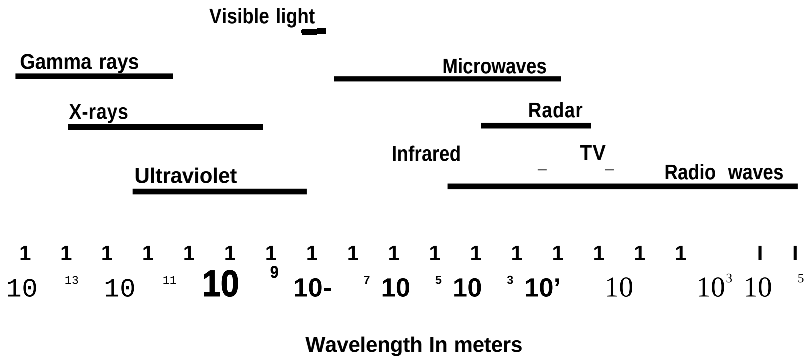
[16]B-2 advocates cite such decisionmaking by bomber crews in search of mobile missile launchers (which are also START TLIs) and other "look-shoot" and "relocatable" targets, though they may have in mind the human use of on-board radar or TV sensor equipment. See General John T. Chain Jr., "A Warrior's Perspective on the B-2, " *ArmedForcesJournal International,* September 1990, p. 78; and U.S. Senate, Committee on Armed Services, "Threat Assessment; Military Strategy; and Operational Requirements," Mar. 7, 1990, p. 873.

[17]Chuck Yeager and Leo Janos, *Yeager: An Autobiography* (Toronto, Canada: Bantam, July 1985), p. 56.

[18]For more information, including bibliographical references, on this topic, see app. E in Bernard Osgood Koopman, *Search* and Screening: *General Principles With Historical Applications (New* York, NY: Pergamon Press, 1980).

[19]With some modification, perhaps they could also be worn during *the* daytime.

Figure 3-1-Partial Electromagnetic Spectrum



SOURCE: Office of Technology Assessment, 1991.

tional camouflage netting and foliage of the same color and pattern; and images of relatively hot objects obscured by foliage, conventional camouflage, smoke, or fog. (Concealment measures that would be more effective are discussed below.) This latter ability to penetrate a leafy canopy would raise confidence that one was not missing TLIs simply because they had been driven into the woods before the aircraft flew over.

In addition, infrared vision systems can in some cases provide a short-term history of an object. For example, residual heat in the engine of a tank or missile transporter, or warm patches of taxiway heated by jet engines, would indicate recent activity that might have been prohibited by movement restrictions (a "freeze") in effect during an overflight or OSI. The heat signatures of overflown facilities might also assist on-site inspectors in deciding where to focus their search effort or reveal covert operations at supposedly closed-out facilities.[20]

For aerial monitoring purposes, it is worth noting that human vision is the one sensor system whose results cannot be recorded for postflight data processing or sharing. Inspectors making visual sightings might take notes or be debriefed after the flight, but they would lack concrete evidence of any wrongdoing.[21] Moreover, the human failing of boredom sets in quickly during a search for sparsely distributed targets, greatly degrading the searchers' effectiveness.[22]

Aerial Photography—Military aerial photography predates the airplane. In fact, placing photographers in intelligence balloons during the U.S. Civil War was considered, though never carried through.[23] It was not until the Spanish-American War that aerial photography first made its military debut in the form of a camera carried aloft by American kites.[24] Since that time, aerial photography has found a wide range of useful applications from strategic reconnaissance by supersecret spy planes to the documentation of local agricultural crops.

A variety of considerations bears on the quality of an aerial photograph. Of these, "resolution" is the most commonly cited parameter, though the ability of a camera to see in more than one part of the spectrum, or to create stereoscopic (three-dimensional) images, can also be important. Stereoscopic imagery aids in the interpretation of photographic reconnaissance data, discussed in appendix B.

Cameras carried aboard aircraft offer a great deal of freedom, affording views at a variety of altitudes, look angles, and sun angles.

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20 Infrared information about a site's operations might also be compared to the facility's material flow records (obtained through data exchanges) in order to uncover inconsistencies. Smithson and Krepon, op. cit., footnote 10, pp. 15, 23-24.

21 Unambiguous visual sightings would probably provide sufficient grounds for the overflying nation to take unilateral countermeasures, even if violations could not be "proved" to the other parties of an accord.

22 In the case of World War II airborne radar search for surfaced U-boats, analysis of sighting data showed that operator fatigue caused a marked decrease in sighting efficiency after only a half an hour. C.H. Waddington, *OR. in World War 2* (London, England: Paul Elek (Scientific Books) Ltd., 1973), pp. 138-139.

23 Thomas Crouch, The *Eagle Aloft* (Washington, DC: Smithsonian Institution Press, 1983), pp. 340-341.

24 The first American noncombat photographs were taken from a balloon in is@. See Burrows, op. cit., footnote 11, pp. 29-31.

Spectrum-The advantages of seeing in the infra-red, as opposed to the visible, part of the spectrum have already been mentioned above in the section on human vision. The most obvious disadvantage--fundamentally lower resolution[25] owing to the use of longer wavelengths of light--can be compensated for by a relatively lower sensing altitude, agreement permitting. One aircraft vendor's concept of aerial search operations includes infrared sensors, but specifies that they would be used during low-altitude segments (5,000 feet, lower than some regimes might permit) of the flight. At such an altitude, the "swath width" [26] of a notional infrared sensor is given as 5 kilometers, or 3 miles.[27]

Resolution—Resolution is often taken to be "ground resolution," the distance by which two objects on the ground must be separated in order to be distinguishable in a picture; this quantity depends on the altitude of the camera as well as its optical characteristics.[28] (This distance is often about twice the minimum size necessary for an object to appear at all.) More fundamentally, a camera's film has a resolution, ultimately determined by the grain of its emulsion. The ideal camera would project, in a distortion-free way, the image of the ground onto the image plane, where it would be captured. Actual cameras depart from the ideal and degrade resolution to a level somewhat below that which would be expected on the basis of the film alone.[29] As in the case of the human retina, the resolving power of the film depends on the contrast ratio between the target and the surrounding background.

Estimates of the ground resolution needed for various purposes differ from source to source. One commonly cited source[30] draws distinctions between the ground resolutions needed for detection, recognition, identification, and analysis. "Detection" refers to noting that the object is present at all; "recognition" to determiningg that it is a missile, vehicle, missile site, or aircraft; ''identiilcation" to determining what type of missile, vehicle, missile site, or aircraft it is; and ''analysis" to the performing of detailed technical analysis based upon the image at hand. Table 3-1 shows values for selected agreement-relevant items.

Another source[31] provides a nearly identical list of items and five levels of interpretation-detection, general identification, precise identification, description, and technical intelligence. Not surprisingly, the addition of a less exacting category widens the range of identifiably useful ground resolutions. A submarine, for example, can be 'detected," in the sense used by the latter source, given only a resolution of 100 feet (v. 25 feet).

A third source adduces digitized examples to show a tank at the picture element sizes (picture element, or pixel, sizes correspond closely to resolutions) at which it can be identified as an artifact, as a tank, and as a Soviet T-62. These resolutions appear to be approximately 16, 6, and 3 inches, respectively .32 Note the lack of close agreement with those values cited for a vehicle in table 3-1, typical of the way parameter estimates vary in this field.

A fourth source[33] introduces the Imagery Interpretability Rating Scale (IIRS) which is not based on resolution. Using subjective criteria, the IIRS sets up eight separate slots (labeled rating categories 1 through 8) into which targets are placed according to the aforementioned detection, recognition, identification, and analysis paradigm.

25A concept treated at length below.

26Theoretical sweep width, in our terminology; see ch. 6.

27John King, ' 'Airborne Remote Sensing for Open Skies: The Platform,'' in *Open Skies: Technical, Organizational, Operational, Legal, and Political Aspects, Michael* Slack and Heather Chestnutt (eds.) (Toronto, Ontario, Canada: Center for International and Strategic Studies, York University, 1990), p. 29.

28The basic expression of the resolution of a camera is its angular resolution, the angle subtended at the camera by two objects on the threshold Of appearing as one. 'Ground resolution" or "ground sample distance" is the projection of this angle on the ground. The term "ground sample distance" clarifies the point that resolution is an angle inherent in the camera-film combination whereas image interpretation depends upon the size of the ground sample subtending that angle.

29Atmospheric e&-~, such as moisture, pollution, and turbulence, can also degrade theoretically ideal resolution.

30''Minimum Ground Object Sizes for Imagery Interpretation,'' ASCC AIR STD 101/8, quoted in *the Reconnaissance Handy Book* (St. Louis, ‘: McDonnell Douglas, 1983), p.125.

31Jeffrey T. Richelson, *The U.S. Intelligence Community*, 2d. ed. (Cambridge, MA: Ballinger, 1989), p. 161.

32 David Hafemeister, Joseph Romm, and Kosta Tsipis, ''The Verification of Compliance With Arms-Control Agreements," *Scientific American*, vol. 252, No. 3, March 1985, p. 41. The number of shades of gray available in this digital presentation appears to have been either four or eight.

33' 'Open Skies Aircraft: A Review of Sensor Suite Considerations," The MITRE Corp., Bedford, MA, unpublished manuscript.

Table 3-l-Ground Resolution and Targets

Object	Detect (feet)	Recognize (feet)	Identify (inches)	Analyze (inches)
Missile	3	2	6	1.5
Vehicle	5	2	6	1.5
Nuclear weapon	8	5	12	0.5
SSM site	10	5	6	1.5
Aircraft	15	5	6	1.5
Submarine	25	15	6	1.0
Troop units	20	7	24	6.0

SOURCE: "Minimum Ground Object Sizes for Imagery Interpretation," ASCC AIR STD 101/8, quoted in the Reconnaissance Handy Book (St. Louis, MO: McDonnell Douglas, 1983), p.125.

For example, in rating category 5, the lettering on the wings of a large aircraft can be detected; command and control headquarters can be recognized; a tank can be identified as light or medium/heavy; and technical analysis can be made of airfield facilities. Interestingly, some surfaced submarines—though detectable in rating category l—have sufficiently similar overall dimensions[34] that they can be identified by type only in rating category 6. For example, the Soviet Romeo-class attack submarine can be distinguished from its Whiskey-class predecessor by the presence of a snorkel cowling.

Photographic film can have a resolution of about 1/5000 of an inch[35], so that a 10- by 10-inch picture similar to that produced by the Fairchild KC-lB framing camera[36] could capture a 50,000 by 50,000 field of resolvable units, the equivalent of 25,000 feet (or about 4 nautical miles) square at 6-inch resolution. This very approximate calculation suggests a sweep width of 4 nautical miles if the camera simply points straight down from, in the case of the Fairchild camera, an altitude of about 20,000 feet.

An Itek camera, derived from the Large Format Camera built for the Space Transportation System (the space shuttle) can resolve 1 meter or better from 12,000 meters.[37] From 20,000 feet, this camera could therefore resolve 20 inches or better, with a very wide field of view. The technology embodied in this camera, however, may make it unexportable and thus unusable in some cooperative aerial surveillance regimes.

The amount of search effort available per sortie is determined, in the case of many aircraft, by the amount of film in the camera. The Fairchild camera cited above carries about 400 feet of film, and could thus take almost 5004- by 4-nautical mile photographs. These photographs could easily be taken in sufficiently rapid succession to cover a swath 4 nautical miles wide and almost 2,000 nautical miles long; the film can advance through the camera at a rate of 3 inches per second, corresponding to 1.2 nautical miles of ground per second and thus almost 10 times faster than would be needed for perfect coverage of the swath. Some amount of overlap between adjacent pictures would be desirable from the standpoint of a photointerpreter. The aerial surveillance mission may differ enough from conventional military reconnaissance in that larger airplanes could be used, permitting the inflight replacement of film.

Electronic Still Camera—Though normally associated with TV-style ''moving picture' cameras, electro-optical technology can also be used in a still camera. Some such cameras use a ''push broom' technique, in which a linear array of detectors images thin slices of the scene and the motion of the sensor platform laminates these slices into a two-dimensional image. A 1979-vintage aerial device of this type could record a 3-mile-wide swath at a distance of up to 12 miles with enough resolution to allow counting of individual people and discrimina-

[34] The waterline length of a modern submarine is somewhat variable because the hull is pickle-shaped and the length of the exposed portion therefore depends upon the trim.

[35] *Reconnaissance Handy* Book, op. cit., footnote 30, p. 61. Values vary widely from film to film and depend greatly upon the contrast inherent in the scene itself.

[36] Ibid., p. 8. This camera's modest 6-inch focal length places it firmly in the ''medium-tech'' niche: export restrictions aside, a 72-inch focal length could readily be used instead, affording "the capability to performextraordinary feats" according to one expert. (prepared statement of Michael Krepon, President of the Henry L. Stimson Center, Washington DC, delivered before the Senate Foreign Relations Committee, Mar. 29, 1990.)

[37] ''Peaceful Watchdogs,'' *IEEE Spectrum, November 1989,* p. 31.

tion of different models of automobile.[38] More modern devices use staring arrays, making them completely analogous to TV cameras.[39] They can attain ground sample distances comparable to those of film cameras, and record 8 to 12 bits per picture element, enough to express from 256 to 4 million shades of gray.[40]

The large dynamic range of these systems—larger than that of the human eye[41]—allows post-processors to bring out latent details hidden amid shadows or glare. (Digital postprocessing of some film images can have the same effect, as *will* be seen in app. B.) Such postprocessing might be done on board the surveillance aircraft, allowing sites of interest to be revisited later in the flight after processing of imagery taken on the frost pass.[42]

Television—TV systems for aerial surveillance share some attributes of human vision and others of photographic and electro-optic systems. Like human vision, airborne TV can be analyzed in real time as the plane is flying, allowing for deviations from the flight path to examine interesting targets more closely or from a more advantageous angle.[43] Like photography and electro-optics, its results can also be recorded and it can operate outside the spectrum normally thought of as "visible." (The advantages offered by operating in the infrared portion of the spectrum are discussed above in the section on human vision.)

Whereas the screen of a digital TV system is divided into pixels (picture elements) whose pre-images on the ground readily define the system's resolution in terms of ground sample distance, the resolution of the conventional, analog, scanning TV system found in most homes is somewhat more complicated to determine. Such a TV system builds its image out of parallel lines scanned onto the screen. The spacing of the lines (512 of them in a conventional home set) determines, much like the number of pixels, the screen's resolution in the vertical dimension. The horizontal dimension's resolution is governed by the ability of the system to make intensity changes along a single scanning line, rather than from line to adjacent line as in the vertical dimension. A conventional 512-line TV image is refreshed 30 times per second; from its 4-megahertz input signal it can make 8 million meaningful samples per second, so each line would consist of 508 samples if none were lost to such "overhead expenses' as blank time between each image refreshment.[a] A realistic assessment of such losses could cut the number of samples per line to 400.[45]

As in film photography, the parameter of interest in TV systems is the ground resolution (and the effective ground sample distance), determined by the line spacing of the TV camera and screen. If 6-inch spacing on the ground were the standard required for aerial surveillance, the conventional 512-line home TV screen would depict a patch of ground ***256*** feet in length and approximately square. Even a substantially improved TV display would thus be a far cry from a film system in terms of the ability to cover ground (25,000 square feet in the film example above) at a given resolution.[46] Even a digital TV with a 1024- by 1024-pixel array, which could approximate the performance obtained by the combination of the human eye and state-of-the-art conventional optics, could do so only over a narrow field of view comparable to that of a submarine periscope.[47]

38Benjamin F. Schemmer, " 'Electronic Cameras' With Instantaneous Ground Read-Out Now Make Real-Time Precision Tactical Targeting Operationally Feasible," ***Armed Forces Journal International, November 1982.***

39'' *Communications,* Electronics, Scientific Advances Explode," *Signal,* September 1990.

40The MITRE Corp., op. cit., footnote 33.

41The human eye perceives about a million shades of gray in its photopic (cone-mediated) mode and another million in its scotopic and mixed (rod-mediated and rod-and-cones-together) modes. (See Koopman, op. cit., footnote 18, p. 322.) A periscope device described by Clark and Stevens likewise has a dynamic range of 60 decibels: its brightest bright is a million times brighter than ita dimmest dim. (See David Clarke and Eric G. Stevens, "High-Resolution Camera Provides Key to Electronic Periscope," Sea *Technology,* September 1990, p. *65.)*

42Assuming that the flight protocol permits real-time changes of flight plan or repeated overflights of the same area.

43Real-time analysis or redirecting of sensors has the drawback that on-board host country escorts may be able to witness what piques the interest Of the inspecting sensor technician, thus enabling the host country to perfect any attempts at camouflageconcealment, or deception (discussed below).

44Eight million samples per second divided by 30 images per second and by 512 *lines per image* **yields 508 samples per line.**

45This description drawn from Albert Rose and Paul K. Weimer, ''Physical Limits to the Performance of Imaging Systems," ***Physics Today,*** **September 1989, p. 30.**

46Low-light-level TV would be able to improve contrast due to haze or twilight. This could compensate to some extent for lower ground resolution.

47Clark and Stevens, op. cit., footnote 41, p. 63.

A special-purpose TV system, such as one to be used in aerial surveillance, might outperform the home set described above by a factor of five.

Synthetic Aperture Radar—Radar actively bounces radio waves off targets to determine their location and size. Airborne SARs use the motion of the airplane during the time that the radio pulses are in transit to and from the target to create the effect of having an antenna far larger than the one actually carried. The duration of the transit and the Doppler frequency shift of the returned signal are used to build up an image of the passing terrain. Because the process involves collation of returns and intensive computation, a SAR cannot produce an image in real time like a TV camera. High-end SARs can approach real time, but lesser SARs are often subject to a considerable delay. The resulting image has a somewhat photograph-like appearance and level of detail.

The along-track (azimuth) ground resolution in SAR is ultimately limited by the wavelength of the radar, but in practice the ability to resolve ground targets closely spaced in azimuth is a function of the physical aperture size (i.e., physical antenna size and thus physical antenna beamwidth) and the ability to remove motion-induced phase errors from the data while synthesizing the long virtual aperture. Phase errors are rinsed out through the use of antenna motion compensation and data processing. The crosstrack (range) resolution is limited by the bandwidth of the radar's transmitter/receiver. The ability to resolve ground targets closely spaced in range depends upon an ability to distinguish very precisely the closely spaced times of arrival of the echoes returning from these targets. This time-domain resolution is inversely related to bandwidth, so fine time resolution implies large bandwidths. With a large bandwidth and good data processing, a SAR image may approach the appearance of an aerial photograph. The filly focused SAR can see farther to each side and provide wider coverage than could the photographic system, and without loss of resolution at longer ranges.

Characterizations of SAR resolution vary and often depend upon unstated assumptions as to the quality of the SAR and the height at which the aircraft is flying. The U.S. Air Force cites the ability of the F-15 SAR to see ''a car in a driveway."[48] Another source cites a 12-inch ground sample distance for a SAR, but asserts that the difficulty of interpreting SAR images degrades their utility to that of photographs with twice that ground sample distance.[49] A third, writing in a context similar to the film and TV examples above, says that a SAR would have a ground resolution of 20 feet (v. 6 inches) .50

Yet another source addresses "sensor swath,"[51] citing a width of 25 kilometers (15 miles) for a notional SAR operating from an altitude of 25,000 feet.[52]

SARs contain advanced digital electronics, so they could be especially problematic from the standpoint of technology transfer. One extreme example is the Joint Surveillance Target Attack Radar System (JSTARS) that was created to support military operations by detecting force deployments and movements behind enemy lines, but could in principle be used for aerial monitoring as well. The Boeing 707-mounted system uses 154 computers, amounting to "the equivalent capability of three Cray supercomputers," to support its mission.[53] In addition to causing technology transfer concerns, such high technology could raise fears in the overflown country that the receiver might be illegally gathering signals intelligence (should such collection be banned by the aerial surveillance agreement). A SAR for cooperative aerial surveillance need not be nearly as complex as the JSTARS SAR: removal of moving-target-indicator, battle-management, and near-real-time capabilities could result in a system able to perform necessary aerial search tasks but palatable from the technology-transfer standpoint and incapable of performing illicit tasks.

Conventional Radar-Conventional, as well as synthetic aperture, radars could find an aerial surveillance application. Reportedly, Boeing's Ad-

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48 Quoted in *Interavia Aerospace Review*, vol. 45, August 1990, p. 649.

49 The MITRE Corp., op. cit., footnote 33.

50 ''U S Soviets Nearer t. Aerial Monitoring Deal, '' *Defense* News, Nov. 27, 1989, pp. 1 et seq.

51 Corresponding to ''theoretical sweep width'' as discussed in ch. 6 of this report.

52 King, op. cit., footnote 27, p. 9.

53 ''Surveillance Aircraft Tests Slated in European Scenario,'' *Signal*, September 1990.

vanced Technology Radar Project has demonstrated a 4.2-mile range for its millimeter wave radar designed expressly for use against relocatable targets, such as the SS-24 and SS-25 mobile missiles. This short range (projected to increase to over 6 miles) allows for a superb ground resolution (for radar) of about 18 inches. Because of the short timeline for attacking a ground target from a low-flying jet, Boeing's system uses automated pattern recognition to identify targets, placing icons, not images, on the user's display. This identification is aided by the automated use of information derived from other on-board sensors.[54] Such a system could be used in aerial monitoring to cue other sensors to focus on suspicious objects.

Radar, in both SAR and conventional variants, is also useful in defeating conventional camouflage and concealment measures. The relatively long wavelengths of radar allow it to pass unimpeded through clouds,[55] smoke, dust, thin foliage, conventional camouflage, and other visual obstructions. Moreover, radar can be used at night, giving the observer a round-the-clock, all-weather capability.

Lidar—Lidar, a laser cognate of radar, is analogous to conventional radar in many respects except that the laser light is of a much shorter wavelength. The shorter wavelength has the benefit of allowing a theoretically higher resolution, but the drawback of being blocked by weather, foliage, and other impediments.

Comparison of Airborne Imaging Systems

Table 3-2 compares the imaging systems considered thus far. Each has its own unique set of traits. In terms of those tabulated, there may seem to be little reason to adopt SAR. However, as discussed later in the sensor issues section, point-by-point comparisons of sensors omit important synergisms obtainable by using more than one sensor at a time.

Nonimaging Sensors

While imaging methods have received the widest attention in discussion of aerial monitoring and aerial reconnaissance in general-and will continue to be our primary focus in the remainder of this study-certain nonimaging means of information collection merit some mention. Two of these, air sampling and the use of acoustic methods, require that the sensor be within the Earth's atmosphere.

Signals Intelligence--SIGINT collects information through the interception of radio waves. In addition to communications and radar signals, airborne receivers might collect electromagnetic emanations from electrical equipment of all kinds.[56] Such receivers would so closely resemble SIGINT collection devices that a ban on SIGINT collection could effectively prohibit their use as well. Because of the large potential for collateral information collection during a SIGINT flight, the inclusion of SIGINT devices in an accord appears at this time to be unlikely. In fact, the only sensor technology that the United States ruled out for Open Skies was SIGINT.

Air Sampling and Sniffing-A variety of air sampling technologies might be applied to a cooperative overflight regime. Through air sampling or sniffing, aircraft could detect trace amounts of telltale chemical signatures of the production-and perhaps storage-of chemical weapons and missile fuels,[57] the venting of radioactive particles and gases from underground nuclear weapon testing, the release of outlawed pollutants, and other treaty-relevant or defense-related activities. The masking of some of these telltale aerosols or gases by legitimate effluents could complicate the matter of monitoring. Likewise, localizing the source of illegal emissions, particularly near a border, may cause difficulties. (See ch. 5 for a discussion of applications of air sampling and sniffing.)

Radiation Detection-Radioactive emissions from illegal tests or facilities in the form of telltale

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[54]Breck W. Henderson, "Boeing Developing Millimeter Wave Radar To Spot Soviet Union's Mobile Missile," *Aviation Week and Space Technology*, Oct. 8, 1990, pp. 55 et seq.

[55]If a treaty allows flights at lower altitudes, cloud cover could often be flown under, thus enabling any sensor to see below the clouds. However, this is not always the case and flying low resultsin a narrower swath width.

[56]For example, concern existed that the "racetrack" deceptive basing of the Peacekeeper missile (then known as MX) could be compromised by the detection of electromagnetic emanations resulting from transient loads on its power supply. U.S. Congress, Office of Technology Assessment, *MX Missile Basing*, OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 1981), p. 37.

[57]Ibid., p. 36. Concern existed that the "racetrack" deceptive basing of the Peacekeeper missile (then known as MX) could be compromised by the chemical detection of airborne emanations from itsfuel.

Table 3-2-Comparison of Airborne Imaging Systems

System	Real time	3-dimensional	Record	Color	Night	Resolution
Vision	Yes	some	No	Yes	infrared	Medium
Photo	No	Yes	Yes	Maybe	Infrared	High
Electro-optical still	Maybe	Yes	Yes	Maybe	infrared	High
I-v	Yes	No	Yes	Maybe	infrared	Low
Synthetic aperture radar	Almost	Yes[a]	Yes	No	Yes	High
Radar	Yes	Yes	Yes	No	Yes	Low
Lidar	Yes	Yes	Yes	No	Yes	High

a phase information allows recovery of a 3-dimensional image.
SOURCE: Office of Technology Assessment, 1991.

neutrons or gamma-rays might also be measured from aircraft carrying detectors. Lighter-than-air craft and helicopters might be particularly useful platforms for these sensors because of their ability to hover for more precise readings. Using these systems for uncovering small radioactive sources, e.g., nuclear weapons, however, may be seriously undermined by shielding and background radiation.

Acoustics-Though usually thought of in a submarine context, passive acoustic detectors can be used in the atmosphere instead of in the ocean. Development work has been pursued in this area.[58] Acoustic detection could be useful in special aerial monitoring tasks where a signature noise could be positively correlated with a monitored item. For example, concern existed that the location of the mobile Peacekeeper might be revealed by the sound of its cooling fans.[59] Of course, in this scenario, observers must be confident that the signature sound cannot be muted or altered to avoid detection.

Magnetic Anomaly Detector—Another sensor technology usually associated with submarines, MADs are designed to detect the presence of large ferrous objects by the size of their magnetic field relative to the background. Because detection of this field follows the inverse cube rule, the detector must get very close to find an object. It has been stated that a submarine can be discovered by an airborne (airplane or helicopter) MAD at about 1,000 yards.[60] Other possible TLIs that might be considered for MAD detection (e.g., mobile missile transporters and trains) are much smaller than submarines and would require higher sensitivities or closer proximity. The latter makes it more likely that helicopters would be the platform of choice.

Sensor Issues

If an aerial sensor suite is to be more than symbolic, it must be able to detector characterize its target reliably. To do this, its users need to consider the possibility that an overflown country may try to undermine the effectiveness of the sensor system through camouflage, concealment, or deception. Participating states should also assess the intelligence (and perhaps proprietary) costs of having similar sensors fly over their own sensitive facilities. Finally, the United States, in particular, has to decide whether a specific accord requires and is worth the technology-transfer cost of sharing advanced sensors.[61]

Target Characteristics

Effective aerial monitoring necessitates that the objects of attention be observable, either directly or indirectly, by the mutually agreed-on sensor package. For imaging systems this means that the observed item or activity must be resolvable enough to be detected, recognized, identified, or analyzed according to the goals of the accord. For example, a treaty that called for directly counting battle tanks would not be adequately served by a camera with a resolution too poor to distinguish a tank from a truck. Secondary characteristics, e.g., the formation of the tank-like objects, might, however, provide indirect evidence to support the treaty goals.

[58] The MITRE Corp., op. cit., footnote 33.

[59] U.S. Congress, Office of Technology Assessment, op. cit., footnote 56, p. 36.

[60] Kosta Tsipis, *Arsenal (New York*, NY: Simon& Schuster, 1983), p. 233.

[61] Some experts have stated that future accords might be worded with enough flexibility to allow for alterations or upgrades of the sensor suite as conditions change, technologies advance, or the parties become more comfortable with the regime. However, leaving the specifications of the sensor array deliberately vague or adopting standards that are currently inadequate with hopes of later adjustment may result in tensions (and possibly danger if the omitted sensors are needed for effective monitoring) if subsequent negotiations block any positive changes.

Nonimaging systems must also be selected with their target in mind. Insensitive chemical sniffers might pass over a tightly sealed, covert missile production plant. And SIGINT might yield no clues to the presence of covert facilities that practice strict emission control.

Moreover, looking at the target alone is not enough. The observed object must be put into context. (Remember that resolution is only one factor aiding detection: contrast is important too.) Acoustic and MAD sensors might be overwhelmed by background signatures if their targets were located in an urban area. The object's operating environment and habits need to be examined. Is it important to be able to monitor the object at night or in bad weather? Clearly, the smaller, more mobile, and less emissive an object is, the more difficult it will be for sensors to locate. If all these target characteristics have not been studied in advance of the sensor decision, and the sensor-target relationship not adjusted to the goals of the agreement, the monitoring system could be irrelevant (and indeed misleading).

False Alarm Rate

To the degree that sensors are to build confidence both internationally and domestically, the reliability of sensors becomes a critical issue. If a sensor detects targets that are not there, tensions could be raised for no good reason: one side would think it had detected a violation, the other would react to being falsely accused. In addition, if sensors are used to cue on-site inspectors, false alarms could quickly eat into that country's inspection quota (if there is one).

Camouflage, Concealment, and Deception[62]

Another critical issue for the sensor package decisions is the possibility of an observed party attempting to defeat the airborne sensors by camouflage, concealment and deception:

> Persuasiveness in camouflage consists of suiting the camouflage to the situation and of giving the enemy an impression of reality and probability. For example, when concealing objectives, it is necessary to make them blend in with the terrain or with typical local objects that do not attract attention. False objects should be created in those places where they fit into the setting; they must be similar enough to actual objectives not only in appearance but also in activity.[63]

Photo credit: U.S. Department of Defense

Camouflage net shields M1A1 Abrarns Tank from overhead observation during Operation Desert Storm. Such operational camouflage measures would not necessarily be banned by arms control agreements.

If a party's primary motivation for countering surveillance is to proliferate restricted TLIs, it might resort to camouflaging and concealing those TLIs above an agreed ceiling. Camouflage could consist of covering the TLI with leaves and branches cut from a tree, variegated four-color paint, or a camouflage net. Concealment could entail removing the TLI from view by moving it under the cover of another object (e.g., a shelter or the tree canopy) or masking it with fog-like smoke. As mentioned

[62] For some historical examples of CCD, see app. B.

[63] *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), p. 180.

above, some sensors can see through conventional camouflage and concealment measures. However, the manufacturers of camouflage and smoke have been busy creating new and improved products that are designed not only to obscure objects at visible wavelengths, but also at infrared, radio, and ultraviolet.[64]

Another objective of the cheating party might be deception. By applying deception in the form of decoys-of a TLI itself[65] or of the objects that one would expect to find near a TLI (i.e., an indirect indicator of the TLI)--this party could: 1) divert monitoring assets from true covert activities occurring elsewhere, 2) present a picture of compliance while preparing to break out of the agreement (e.g., the movement of troops out of a designated deployment area and toward the border), 3) dilute OSI quotas by sending inspectors on wild goose chases, and 4) undermine confidence in the reliability of the sensor suite (perhaps as a precedent should a real violation be discovered).

A final complicating factor is that some potential TLIs rely on CCD to survive in a conflict. These TLIs may be exempted from prohibitions on using normal CCD techniques, as is the case for TLIs in the Conventional Armed Forces in Europe (CFE) Treaty.[66]

Multiple Indicators

The best solution to the problem of CCD is to make the job of the violator as difficult as possible, if not impossible. Different imaging systems have different strengths and weaknesses. Configures of an aerial monitoring aircraft might want to combine complementary imaging systems for a maximum overall probability of achieving the goals of an accord; i.e., detecting the target regardless of countersurveillance measures.

Credible Evidence of a Violation and Data Storage

What happens if a violation of an agreement is discovered? Some would say that this alone would be just cause for abrogating an agreement. However, the history of compliance policy suggests that such black-and-white distinctions are extremely rare. More than one sighting from perhaps more than one source might be required for firm evidence of an intent to cheat.

If the overflight had made no permanent record of the discovery (e.g., visual observation) or the recorded data was ambiguous, the violator could claim that the accusation was a false and political provocation. Inspectors seeking to revisit the site (possibly in a quick-response helicopter) might not at-rive in time or might be rebuffed. If a record of the observation were made and the data were clear enough to interpret, the party could credibly argue that the violation spotted was simply an aberration, an accounting error that will be rectified immediately. Therefore, data storage can be important for supporting assertions of noncompliance.

However, stored data can also be a major source of collateral information that the parties might not want revealed. The task is to balance the informational requirements of an agreement against the cost of greater intrusiveness.

Depending to some extent on the sensor, data can be stored in either analog or digital form. In their digital manifestation, the raw data can be more easily processed by computer to bring out important details that might remain hidden in its analog counterpart. This, of course, helps increase the effectiveness of flights; however, it also increases the amount of collateral information lost by the overflown state. For this reason, restrictions might be placed on data storage: it could be limited to analog devices or prohibited entirely. Or, conceivably, the raw data could be passed through a computer

[64]Newly recolored, ultralight camouflage nets ordered for Operation Desert Shield (subsequently, Operation Desert Storm) in the Persian Gulf are designed to scatter radar in the 6-to 140-gigahertz range. ("Deployment of Saudi Tan,'' *Jane' s Defence Weekly,* Oct. 27, 1990, p. 805.) One company's camouflage netting-laced with metallic dipoles—reflects, scatters, and polarizes radar signals so that the returns approximate the background. It can also be given a foliage appearance or match the background in the near infrared. ("Camouflage Systems," company brochure, Teledyne Brown Engineering, Huntsville, AL.) See also Banner et al., op. cit., footnote 4, pp. 88-89.

[65]A TLI decoy might consist of another object that closely approximates the original at the sensitivity of the sensors involved *(e.g.,* a milk tanker for a mobile missile transporter or a set of radar corner reflectors). However, a decoy could also be an elaborate imitation that resembles the TLI in every way (visual, infrared, radio)—except that it can be dismantled and stowed before an inspection team arrives. See Teledyne, ibid.; and *Camouflage: A Soviet View,* op. cit., footnote 63, pp. 203-206.

[66]Article XV, paragraph 3.

program that filters out detail beyond that required by the accord. Lastly, the data gathered could be shared amongst all parties, even to the point of joint analysis.[67]

Sensors Targeting the United States

Aerial overflight agreements cut both ways. If they are effective in ferreting out useful collateral information about another country, they may reveal more information about your own country than you would like. If an agreement permitted sophisticated sensors with capabilities beyond those of NTM, aerial surveillance might undermine U.S. national security by adding considerably to the Soviet Union's (as well as other signatories') knowledge of the American defense and intelligence establishment.[68]

Even if agreed sensors were limited in their capabilities to prevent the collection of this extra information, the overflown country might still be concerned about the presence of covert sensors placed on the aircraft. This concern might be alleviated by preflight inspections of the aircraft.

If the agreed sensor suites were restricted to a capability equal to or below that of NTM, the United States, in particular, and the Soviet Union might have relatively little to gain by overflights beyond confidence building.[69] Instead, their monopoly on information would be broken by granting equivalent overflight rights to countries with limited independent NTM assets .70

Technology Transfer

Parties to an aerial surveillance regime might permit access to each others' aircraft and sensors. The primary reason for such access is the fear of the collection of collateral information. Aircraft inspections would verify the legitimacy of allowed sensors or check for covert instruments. In some cases, for reasons of equity as well as security, identical sensor suites might be shared among all the parties. Since many sensing technologies are on the cutting edge of U.S. technology, and since these sensors may have military and intelligence applications that are important for national security,[71] it maybe in the interest of the United States not to compromise them by putting them on an aircraft that will be inspected. In these cases, it may be best to rely solely on commercially available devices; in others, however, it may be worthwhile to give up some technical information in exchange for the benefits of an accord.[72] Of Course, settling for less capable technology may affect the ability of the sensor to serve the monitoring goals of an accord, and thus its utility. Only in regimes where there are no restrictions on overflight activity and no inspections of aircraft will the United States be likely to use its technology to the fullest.

Operational Concerns

Time: Notification and Duration

If the task is to monitor a region for certain objects or activities, time can be an important operational factor. This is particularly true for TLIs that are easily relocated or hidden. If a TLI can be removed from aerial view before a flight can reach it, then the overflight has questionable utility. (The time it takes to reach a TLI is the sum of the notification/preflight inspection period and the minimum flight time to the target.) If monitoring success does not necessitate reaching a TLI in a short time, then the length of the notification/preflight inspection period is irrelevant.

The duration of the actual flight is also a central issue in that it determines (when combined with air speed) the amount of territory a flight can cover. Except in the case of symbolic flights or flights to specific destinations, the ratio of the territory scanned to the total territory[73] can have an important impact on how confidently one interprets the data gathered.

67Opponents of data sharing argue that revealing this information would aid a potential cheater nation in perfecting iCCD measures.

68Conceivably, overflights could reveal proprietary and economic information as well, undermining economic security.

69As discussed earlier, even sensors inferior t. NTM might provide the superpowers with useful search capabilities, primarily because of the flexibilities of the platforms.

70See table 4-2 inch. 4 for a discussion of some of the regional and national asymmetries of such accords.

71As well as the national economy.

72This sharing of information implies some loosening of export control legislation.

73This might be the entire territory of a party or that part of it where the target in question would likely appear.

Flight Quotas

Similarly, the number and frequency of flight is important to the level of confidence one can invest in a monitoring regime. As will be addressed mathematically in chapter 6, the number of flights, combined with their duration, puts statistical bounds on certain types of monitoring, especially aerial search. Put simply, the more often and longer a country is overflown, the more confident is the observer in making statistically based judgments of compliance. Increasing the frequency of the flights (i.e., shortening the time between flights) builds confidence faster.

Methods offered to fairly apportion the number of flights for countries of varying size have been based on relative size of the countries' entire territory, their searchable territory, their military, and their population.

Territorial Restrictions

In the broadest of all aerial surveillance schemes, aircraft would be free to roam where they please. In the interest of flight safety, however, some restrictions might be deemed necessary. Active military exercise or test sites might have to be bypassed unless there were a mandated stand-down period. Severe weather systems might also have to avoided, although these could be predicted by the inspecting country in advance. Moreover, adequate air traffic control might not be available in some areas.[74] Restrictions could also be adopted to ensure the safety of overflown facilities and people. The Soviets have made this argument in the Open Skies negotiations over such sites as nuclear power plants and major cities (see ch. 4).

The Soviets also believe it is necessary to restrict flights over sensitive facilities, where aerial surveillance might be used to gather information contrary to Soviet national security. By setting up exclusion zones, the Soviet Union would try to shield secret military and intelligence installations from prying Western eyes. To varying degrees, many other states agree with these concerns over the collection of collateral information, but they have tried to deal with them through means other than territorial restrictions. For example, the United States agreed that including SIGINT sensors in Open Skies would be too intrusive.

In some accords, free-ranging flight might not even be considered necessary. For example, overflights might be made only over designated regions (e.g., mobile missile deployment areas) or over declared facilities (e.g., chemical plants).[75] In the narrowest of schemes, tethered aerostats could be anchored at a specific site in order to observe local activities or site perimeters.

Details

If the central issues of a cooperative overflight regime were settled, there would still remain a host of details to work out. There are personnel questions such as who can be selected as an inspector or escort, whether a nominee can be rejected by the other parties, the inspectors' diplomatic status, and whether the inspector can be subjected to a physical search. There are questions of which party is responsible for what costs, including aircraft servicing and aircrew accommodations. A joint consultative mechanism also needs to be established to handle concerns over compliance and gray areas of the agreements.

Conclusion

Negotiators of aerial surveillance provisions must determine which types of platforms and sensors would be both effective in achieving the goals of the accord and still mutually acceptable. If the overflights were intended to be purely symbolic, then perhaps only visual observations by the aircrew would be required. In contrast, if overflights were a major component of a monitoring regime, a wide variety of complementary sensors, spanning the electromagnetic spectrum, might be essential. Negotiators making the final selection of the sensor and platform package would have to balance the strengths and weaknesses of the various airborne equipment with the costs and benefits of the agreement as a whole.

[74] This may or may not be considered important. The United States itself has large areas that are not covered by air traffic control, but still permit flights.

[75] Restricting surveillance to designated sites undermines the *ability* of the flights to detect suspicious activities beyond these sites. In this sense, the flights begin to resemble some types of OSI: they can determine compliance at the designated site, and make cheating more difficult and expensive by shifting it elsewhere, but they cannot detect cheating off site.