Chapter 6

BROAD AREA SEARCHES FORM ARMS CONTROL TREATY VIOLATIONS

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Summary

Congress can reasonably expect quantitative assessments of the uncertainties inherent in arms control treaty verification. While such assessments are often provided, witnesses need to be clear about the assumptions and methods (if any--some quantitative statements are hunches or figure of speech, not a bad thing as long as the recipients understand the spirit in which the statements are made) by which they reach their assessments.

The arms control efficacy of aerial monitoring—whether as an anomaly detector, a violation deterrer, or a confidence builder-rests on the search capabilities of the aircraft and their associated equipment. Searches such as those entailed by aerial monitoring can be analyzed mathematically: simplistic analysis suggests that relatively heavy aerial monitoring alone would probably find some types of arms control treaty violation, if present, in a year. **Refinement of the analysis shows that considerable *prior* information--clues about where to look and for what—will be needed if aerial monitoring is to make a significant contribution to arms control verification.**

Introduction

The use of cooperative aerial surveillance in arms control agreements may be its most important task. Not only might overflights tend to build confidence in an accord, but aerial monitoring flights may fulfill a search, warning, inspection, cost-raising, or deterrent function by observing compliance with specific provisions of an agreement. Information from monitoring can also be used to support other verification methods, particularly on-site inspections (OSIs).[1] For example, aerial surveillance in an arms control context might:

- observe military exclusion zones or disputed borders to deter, detect, and warn of the illegal presence of restricted forces;
- inspect conditions at declared bases or facilities to observe compliance, to monitor movement or other restrictions, or to assess the need for and prepare for an OSI;[2]
- confirm the destruction of declared facilities, equipment, or weapons;
- search for indications of noncompliance that require other methods of verification for final confirmation;
- by virtue of an increased chance of detection, force a cheater to expend more effort and money to violate the treaty or deter him or her completely;[3] or
- search for treaty violations distributed over some large area being surveyed.

This chapter applies a quantitative search analysis method to the last role, searching large areas for violations. Focusing on this one mission will serve several useful purposes. First, it will allow us to illustrate how quantitative methods can be applied to the larger problem of estimating confidence levels in our ability to find arms control treaty violations if they exist. Second, the analysis shows how comparisons could be made among various monitoring options to produce more cost-effective monitoring regimes. Third, examining the potential and limits of aerial search underscores the importance of applying multiple, complementary instruments to monitoring tasks.[4]

1~e various utilities of aerial surveillance are discussed in detail in ch. 2.

2For example, sensor information and photographs might be used to create a map of the site and indicate the most important locations to inspect. Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper No. 4, The Henry L. Stimson Center, Washington DC, April 1991, pp. 14,21-22.

3Ibid., p. 3. Amy Smithson and Michael Krepon state, "Aircraft overflights could marginally increase deterrence if approved flight plans and sensors increase the likelihood of detection or the possibility of follow-up investigations."

4Note that aerial warning is closely related to aerial search and that many of the same lessons apply.

Quantification

Congressional demand exists for quantification of answers to questions regarding compliance,[5] though the urge to quantify verifiability is not universal.[6] The expression, in the Intermediate-Range Nuclear Forces (INF) Treaty hearings, of such matters in round numbers suggests that Members and witnesses understand that great precision is neither possible nor needed. However, testimony and colloquy in the INF case also indicate an absence of consideration of important factors which should enter into an assessment-quantitative or otherwise-of the verifiability of a treaty: the length of time allowed for detection of the violation, the difference between verifying compliance with the treaty as a whole and verifying compliance with any one subset of its provisions (e.g., in the INF case, those pertaining to SS-20s), the significance of the violation, and the difference between the probability of detecting the presence of a covert force and the probability of detecting any single missile therein.

Congress needs to decide how much to invest in verification measures, and quantitative analysis can indicate how much additional confidence might be obtained as a benefit of increased spending. This report discusses the quantifiable aspects of aerial search at some length, not only for their own sake, but as a good example of certain statistical issues arising in treaty verification. Inasmuch as most verification assets, especially those subsumed under the heading national technical means” (NTM) of verification, monitor more than one treaty at once, a complete analysis of treaty verification would simultaneously embrace all treaties and all verification assets. The simple examples explored in this report are thus intended as models for discussion and analysis, not as the last word on the utility of aerial search.

Even if one does not resort to quantification when interpreting data from aerial search flights, an important lesson of the approach we will examine--that lack of evidence must be interpreted in light of the likelihood that evidence would have been obtained were it to exist-retains its validity.

The Limitations of Aerial Search

As discussed in chapter 3, the aerial monitoring provisions of particular treaties will set limits on the number of flights, their duration, the equipment that may be carried, and the freedom to fly anywhere at any time. These constraints limit the effectiveness of aerial monitoring. Even without them, however, aerial monitoring would remain subject to certain limitations inherent in most treaty-monitoring or intelligence-gathering means.

The most general trait of these limitations is the everyday finding that we notice things far more readily if we are looking for them. Treaty-monitoring efforts to date show distinct signs of this limitation: for example, the monumental radar near Krasnoyarsk (a treaty-limited item (TM) of the Anti-Ballistic Missile (ABM) Treaty) went unnoticed for many months despite its detectability by NTM, because the managers of NTM had no reason to examine its particular locale for SALT I TLIs.[7] In another example, efforts to find and destroy Iraqi Scud launchers during the Persian Gulf War were impeded by the use of launchers other than the expected Soviet-made transporter-erector-launchers (TELs). These examples and others suggest that aerial monitoring may be most efficiently applied if specialized: such specializations might include the monitoring of declared deployments or the inspection of particular locations. When used more generally, aerial search (like any other means of collection) benefits greatly from the use of *prior information* as to where to look and for what to look (a point addressed more fully below)

[5] Witnesses and Senators in the hearings on the Intermediate-Range Nuclear Forces Treaty variously stated that the ‘‘intelligence community . . . pUt the potential for verifying compliance somewhere in the lo-or 20-percent region,’’ that “the chances of the United States detecting covert SS-20’s is [sic] about 1 in 10,” tbat “we can detect 1 in 10” SS-20s, that therefore if “we suddenly detect 5 [SS-20s], . . . the Soviets could have a viable force of up to 50inhiding,” that “given the entire verification package, includingnational technical means,. . .we have high confidence in the ability to verify the provisions of the treaty,” and that “high confidence’’ means “well above 50 percent.’’ (See U.S. Congress, hearings before the Senate Foreign Relations Committee, *The ZNF Treaty,* 100th Cong., 2d sess., Part 3, p. 35; Part 5, pp. *8&96 passim.*)

[6] Another witness at the same hearings contested the claim that the intelligence community had produced the the 10- to 20-percent figure On the grounds that the intelligence community does not assess verifiability at all, and does not express estimates in terms of percentages. The witness also stated that the U.S. Arms Control and Disarmament Agency would not use percentage terms either. (Manfred Eimer, Assistant Director of the Bureau of Verification and Intelligence, U.S. Arms Control and Disarmament Agency, Ibid., Part 5, p. %.)

[7] Malcolm Wallop and Anthony Codevilla, The *Arms Control Delusion* (San Fransisco, CA: ICS [Institute for Contemporary Studies] Press, 1987), p. 65.

Box 6-A-Search Effort, Width, and Rate

The following **example introduces the concepts of search effort, search width, and search rate.**

Consider a l-hour search for mobile missile launchers, conducted **from** an aircraft flying at 200 rniles/hour. The *effort* devoted to the search is the hour of flying; the output will be the number of launchers spotted

For simplicity's sake, we will make the assumption (soon to be dropped) that the vision of the observers and equipment in the aircraft operates in a completely deterministic fashion: they see any launchers within 2.5 miles of the airplane's ground track If we knew a priori that launchers inhabit the territory with a density of one launcher per hundred square miles, we would expect that an hour of searching would discover 10 launchers. The aircraft will examine a swath 200 miles long by 5 miles wide for a total of 1,000 square miles, and

200 miles X 5 miles X .01 launchers/square mile= 10 launchers.

If we were uncertain as to the capabilities of the observers but knew a posterior that they had seen ten launchers, we could view this result as confirmation of their stated capability to examine the territory 2.5 miles to either side of the airplane:

10 launchers seen@ 0.01 launchers/square mile= 1,000 square miles seen

and

1,000 square miles/200 miles flown= 5 mile "sweep width."

Relaxing the assumption of determinestic sighting, let us suppose that we recognize that luck will play a role in the sighting of missile launchers-some launchers near the ground track of the airplane will be overlooked, while others located a distance away will be spotted by chance. Still aware that launchers have been spread out at an average density of one per ten square miles, we discover that 10 launchers have been sighted and interpret the result to mean that the crew and equipment can see an *average* of 2.5 miles away from the airplane. We will therefore **say that the aircraft has an effective sweep width[1] of** *5 miles,* computed by the two equations above. This width, multiplied by the speed of the aircraft, leads to the sweep ***rate:*** 1,000 square miles/hour.

The effective sweep width is related to, but different from, the *theoretical sweep width--the* width of the swath in which the sensor *could* detect a target. The effective sweep width cannot possibly be greater than the theoretical sweep width, and is likely to be considerably less, The disappointingly low ratio of the effective sweep width to the theoretical sweep width was one of the first findings of the investigation of aerial search for (German submarines in the Second World War. Even after discounting the theoretical sweep width in proportion to the fraction of the time that U-boats spent submerged, a factor-of-two discrepancy remained, explicable only in terms of human factors.[2]

[1] Called operational sweep width in the search theory literature.

[2] Philip Morse and George Kimball, Methods *of Operations Research* (Washington, *DC:* Department of the Navy, 1946), p. 43.

Most important, monitoring is more effective when multiple means of monitoring can be used **to cue one another. (The second part of this** chapter addresses this point.) Aerial monitoring would thus rely on other monitoring methods, e.g., OSI and NTM, but this reliance ought not to **be construed as a defect, because the other methods would rely on aerial monitoring in turn.**

This chapter begins with an introduction to search theory; it then offers concrete examples of the application of that theory to hypothetical aerial searches for Soviet SS-24 and SS-25 intercontinen**tal** ballistic missiles, missiles that would be limited under the proposed Strategic Arms Reductions Talks (START) Treaty.[8]

"Search as an Operation in Practical Life"[9]

Reflection on our everyday experiences of search reveals some important characteristics of searches:

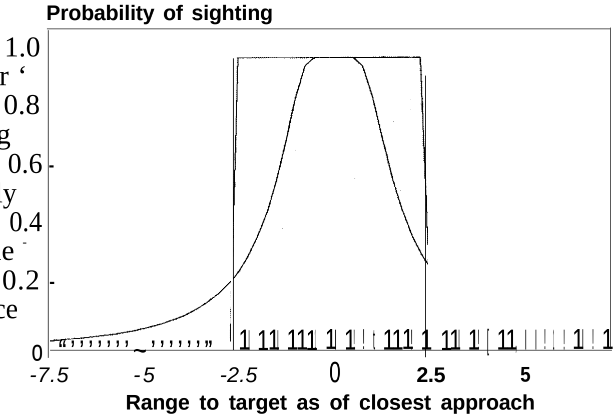
[8] Aerial surveillance is not contemplated for inclusion in the START Treaty, and Open Skies surveillance is not officially linked with arms control treaty monitoring as such. Nevertheless, the question of how Open Skies-like surveillance would perform in searches for these START TLIs is an instructive one to answer.

[9] Bernard Osgood Koopman, a pioneer in the mathematical development of a theory of search, used this phrase as a section heading in his book. (Bernard Osgood Koopman, *Search and Screening (New* York, NY: Pergamon, 1980), p. 12.)

Box 6-B—Lateral Range Curves

The "sweep width" assessment of search effectiveness merits some scrutiny. It seems plausible in a bottom-line sense: the searcher has spotted as many launchers as it would have if it could see perfectly out to the 2.5-mile limit and not an inch beyond. Moreover, , the crew has missed a launcher within 2.5 miles for ' each that it spotted beyond 2.5 miles. Thus the interpretation of 2.5 miles as an average[1] spotting distances reasonable and useful, even though it treats all sightings as occurring when the launcher is directly abeam of the airplane, which is certainly not the case: many targets, perhaps all, will be detected some time before or after they pass abeam of the aircraft.[2] Keeping track of the targets according to their distance when they pass abeam of the aircraft is, however, a useful accounting convention, according to which we *can* form a *lateral range curve,* plotting the probability that a launcher is spotted as a function of its distance from the ground track of the airplane.

Lateral Range Curve and Equivalent "Cookie-Cutter"



The arch-shaped lateral range curve depicts the probability that the target will be detected as a function of the searcher% distance of closest approach. There is some chance that nearby targets will be missed and, conversely, that a distant target might be seen. The rectangular curve represents a %ooide-cutter" deterministic lateral range curve, guaranteed to see the target if it passes within 2.5 miles and to miss it otherwise. The two curves are equivalent In the sense that, assuming a random distribution of targets, each searcher will detect the same number.

SOURCE: Office of Technology Assessment, 1991.

The lateral range curve contains far more information about the characteristics of the searcher than does the sweep width. In particular, it keeps explicit the point that, given an imperfect searcher, no amount of searching can guarantee that a target will be found. The "effective sweep width" characterization of the imperfect search of a broad width as a perfect search of a narrower width can give a misleading impression of how the efforts of many such searchers (or the repeated efforts of one such searcher) combine: the temptation to take the sweep width concept literally and imagine a lawn spreader-like application of perfect search to the region of interest must be avoided. Mathematically correct ways of assessing searchers' combined or repeated efforts exist and will be presented below. The sweep width, however, retains its utility as a one-number fig&e of merit suitable for use in practical calculations.

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[1] In the sense that calculation based on the use of this fixed distance would result in the same number of sightings as are actually experienced.

[2] The ranges at which such launchers get spotted are thus underestimated.

the role of luck, our ability to make statements about the difficulty of the search, the utility of coordination of the search effort in the (usual) case that it is performed by more than one searcher, and the question of efforts on the part of the target to stay hidden. (See also box 6-A.)

Luck plays two major roles. In the case of a search for a moving target, e.g., an escaped pet, the searcher and the target move about in the same area and only encounter one another by chance. Even in the case of a stationary target, e.g., a mislaid set of keys, the searcher might approach the keys very closely without finding them, perhaps later exclaiming, "But I looked right there!" when somebody else locates the keys. The first example shows the role of luck in bringing a searcher-target encounter about; the second shows the role of luck in determining whether an encounter results in a sighting. (See also box 6-B.)

The role of chance notwithstanding, assessments of a search's difficulty or likelihood of success can be made in advance. A set of keys misplaced somewhere in the house is one thing; a contact lens lost during a fast break on the basketball court is quite another. The likely outcome of the search is determined by the effectiveness of the searcher (how good he or she is at searching), and by innate characteristics of the target of the search, the size of

Box 6-C-Coordination of Search Efforts

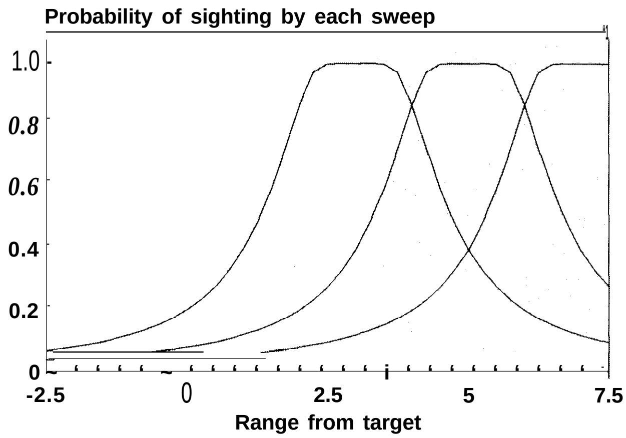
Suppose that we wish to use airplanes of the type considered in boxes 6-A and 6-B to sweep a 5,000 square mile region clean of treaty-banned missile launchers.[1] The effort required would thus seem to be the searchable area divided by the sweep rate:

5,000 square miles ÷ 1,000 square miles per hour= 5 hours,

This **calculation** (despite its dismaying implications for a Soviet Union of roughly 6,500,000 square nautical miles) is, in fact, overoptimistic. The reason becomes apparent when we try to decide on the correct search pattern to fly: despite the 5-mile sweep width, simply spacing adjacent sweeps 5 miles apart won't do because the 2.5-mile sighting range is an average, not a guarantee. Five-mile spacing is good (apart from any exploitation of terrain and or other prior information), but not good enough: in fact, the nondeterministic nature of the search ensures that no search pattern or allocation of search effort can be certain to see all targets. Given the notional lateral range curves shown here, for example, the target has an 88-percent chance of being missed by the sweep that passes 2.7 miles away, a 92-percent chance of being missed by the sweep that passes 5 miles away, and a %-percent chance of being missed by the sweep that passes 7 miles away, for a combined 78-percent (0.88X 0.92X 0.96) probability of being missed completely and thus a 22-percent chance of being sighted

[1] That is, for missile launchers obligingly left out in the open. Later we will take up the question ofsearching for targets that might be concealed.

Sighting by Successive Sweeps at Ranges of 3,5, and 7 Miles From Target



Like crop-dusters, searchers can coordinate their flights so as to compensate for a somewhat uneven application of search effort. These overlapping lateral range curves show how even distant passes contribute to the overall probability that the target will be detected.

SOURCE: Office of Teetinology Assessment, 1991.

the region in which the target is located, the search effort available, the presence of any prior knowledge as to the target's whereabouts, and how well the search effort is coordinated.

Multiple Searchers and/or Targets

Coordination of the search effort can help a great deal if the amount of search effort available is comparable to that needed for a complete search of the region of interest. A dragnet search, perhaps for a child lost in the woods, is conducted with searchers walking shoulder-to-shoulder---clearly a superior approach to the uncoordinated alternative of simply turning the same number of searchers loose in the woods for the same amount of time. Coordination ensures that no location goes unstarched while another is oversearched. (In the lost-child example, coordination can also ensure that the child does not wander from an area that has not been searched into one that already has. See also box 6-C.) If only meager search resources are available, no amount of coordination can confer a high probability of success; a plethora of searchers, on the other hand, can do a good job without particularly coordinating their efforts. (See also boxes 6-D and 6-E.)

Thus far we have assumed that the searcher seeks a unique target. Many searches, however, would be satisfactorily concluded if they were to find any single target out of a large population. For example, a hungry cat searching for mice is not particular as to which mouse it catches. Similarly, many would consider the search for treaty violations to end if even one violation were found, inasmuch as that is

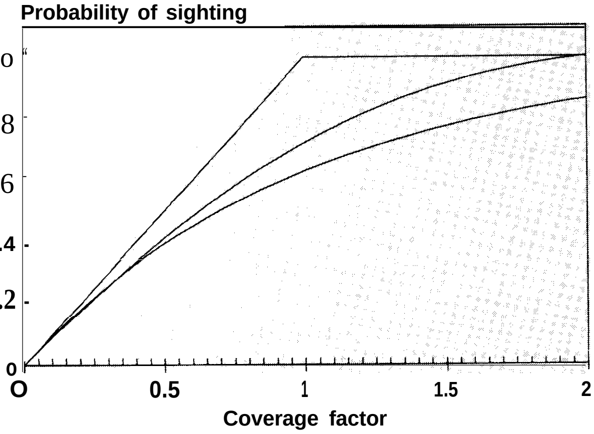
Box 6-D--Coverage Factor

Detailed lateral range curve information such as that used in the example is rarely available: an analyst is likely to be asked what to make of a given search situation given only the search effort, an estimate of the sweep rate and perhaps a rough idea of the shape of the lateral range curve. In this situation, the analyst can state some bounds on the probability that a given target will be sighted. Each starts with the *coverage factor, the* product of the search effort and the sweep rate, This quantity can be thought of as the numberof square miles searched: the question is how these square miles are applied to the square mileage of the territory to be searched. In the case at hand, the coverage factor is equal to unity.

The upper bound is that given by the optimistic calculation cited above: 100-percent probability of sighting the target given 5 flying hours of effort, a 5-mile sweep width, a 200-mile/hour speed, and 1,000 square miles of searchable area. This upper bound treats the 5-mile sweep width as a guarantee instead of as an average, and assumes that the airplane can fly so as to search every point in the searchable region: 1,000 square miles' worth of searching have been laid neatly, like 5-mile-wide wallpaper, on 1,000 square miles of territory.

The lower bound, recognizing that the 2.5-mile sighting range is a mathematical construct[1] assumes that the 1000 square miles' Worth of search effort are laid down like confetti instead of like wallpaper. Absent any assumption that the pilots are intentionally suboptimizing the search, this assumption of a completely haphazard search results in the lowest possible value for the probability that a target will be detected because it gives the searchers no credit for organizing their efforts. Some parts of the region are oversearched at the expense of others. In the case at hand, with 1,000 square miles' worth of coverage factor distributed confetti-style on 1,000 square miles of searchable region, a target has a 63-percent chance of being sighted. Doubling the coverage factor would raise the probability of detecting a target to 86 percent.

Probability of Sighting as a Function of Coverage Factor



Perfect coordination of completely deterministic sighting would lead to a sighting probability (as a function of the coverage factor) shown by the upper curve. Completely haphazard application of search effort leads to a, sighting probability shown by the lower curve. Real-world cases. often lie near the curve in between: note that 100-percent coverage does not In such cases, guarantee a sighting.

SOURCE: Bernard Osgood Koopman, *Search and Screening* (New York, NY: Pergamon, 1980), p. 78.

[1]Reflecting, again, the fact that as many targets are sighted beyond that range as are missed within it.

all that is required to brand the other side as a treaty violator.[10]

Treatment of Target Concealment

Many—if not most—INF, START, and Conventional Armed Forces in Europe (CFE) TLIs, e.g., airplanes, mobile missile launchers, and tanks, could be driven into buildings, caves, or tunnels and thus hidden from aerial searches.[11] In fact, these treaties allow concealment according to normal operational procedures. For example, mobile missile launchers can be camouflaged, even though fixed silos cannot be, because camouflage is customary for military vehicles. Is aerial search then useless for assessing compliance with these treaties?

[10]The ultimate sanction against a country caught cheating would be abrogation of the treaty itself. The United States prepared a contingency plan for the resumption of atmospheric testing in the event of a Soviet breach of the Limited Test Ban Treaty. (Michael Krepon, *Arms Control—Verification and Compliance,* headline series No. 270 (New York, NY: Foreign Policy Association 1984), p. 16.) Henry Kissinger saw the consequences of a revealed violation as spilling over from treaty to treaty: "Any country that contemplates a rupture of the treaty or a circumvention of its letter and spirit must now face the fact that it will be placing in jeopardy not only a limited arms control agreement, but a broad political relationship. " (Quoted Wallop and Codevilla, op. cit., footnote 7, p. 89.) Historically, recourse to treaty abrogation in the event of violation has rarely, if ever, been carried out when an instance of violation has been discovered.

[11]For a treatment of camouflage, concealment, and deception, see ch. 3.

Box 6-E--Use *of Imaging Systems in Concert*

Clearly the chance of detecting a target is improved if additional imaging systems are brought to bear. The question is best addressed through the paradigm of lateral range curves and sweep **widths. Indeed** it is in this sort of calculation that the sweep width comes into its own as a simple and useful one-number summary of the searcher's efficacy.

Suppose that a visible-light photography system records a 4-mile swath with, after interpretation is complete, an 80-percent chance of detecting a treaty-limited item (TLI) within that swath; suppose further that a synthetic **aperture radar** records an 8-mile swath but because of a lower resolution, has only a 40-percent chance of seeing TLIs within that swath. (Note that each of these systems has a 3.2-mile sweep width.) We wish to know the combined effect of the two systems, i.e. the effective sweep width of an airplane carrying both.

A target within the camera's field of view has a 20-percent chance of being missed by the camera and a 60-percent chance of being missed by the radar. Thus, assuming that detection by one system is statistically independent of detection by the other,[1] it has a 12-percent (because 0.2 X 0.6= 0.12) chance of being missed by both, for a complementary 88-percent chance of being detected by one or the other or both. The two 2-mile strips to either side of the camera's field of view are seen only by radar, with its 40-percent chance of detecting a target therein. Therefore the combined sweep width of the two detectors is

2 x 0.4+4x 0.88i"2 x 0.4 = 5.12 miles.

This is a considerable improvement over the 3,2-mile sweep width offered by either system alone, but somewhat less than the 6,4-mile sweep width which one might naively have thought would result from their combination.

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[1] This assumption makes sense if the main source of detection uncertainty for targets within the two systems' fields of view is the interpretation step. These interpretations will be conducted separately, and probably by different people. If actual target characteristics, e.g. orientation contribute to the probability of not being seen, then the assumption of independence would breakdown. There is reason to think that orientation has little to do with probability of detection (seeKoopman, op. cit., footnote 9) and we may note for the presentexample that many other target characteristics, e.g. relative brightness compared to the background, will be different for the two systems and thus unlikely sources of correlation between the two detection probabilities. Lack of correlation would itself be a desirable quality for candidate pairs of detection mechanisms; inverse correlation would be even better, because with inverse correlation each sensor would be especially good at seeing the targets with respect to which the other sensor was especially bad.

Of course, aerial searches might still see the buildings, tire tracks leading to caves, and so on, so that suspicions could be aroused even if no actual violations were perceived during the flight. In this way, the overflights could aid other inspection procedures allowed for in the particular treaties, including the use of NTM.

Nevertheless, one might suppose that a system of deliberate TLI concealment, even one that worked well, would not work perfectly. The scramble (perhaps nationwide, depending upon the treaty protocol implementing the aerial search proposal) of the TLIs for cover when an overflight was announced would on occasion be marred by some units not getting the word, units breaking down on their way to the concealment facility, and so on. Thus deliberate concealment measures could degrade the performance of the overflights, but not necessarily vitiate them completely. (See also box 6-F.)

Simple Aerial Monitoring Calculations: Aerial Search for SS-24 ICBMS

The Soviet SS-24, a rail-mobile intercontinental ballistic missile (ICBM) physically comparable to the U.S. Peacekeeper, is powered by solid fuel and delivers 10 reentry vehicles.[12] Unlike the proposed rail-mobile version of the Peacekeeper, SS-24s frequently deploy to the rail net in peacetime. The Soviet Union has over 145,000 kilometers of track to which SS-24 can deploy.[13] This figure overstates the difficulty of finding the SS-24 because it includes considerable amounts of dual trackage (though not as great a proportion as would be found on other rail nets, e.g., that of the United States). A more accurate figure for the total amount of *roadbed*

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[12] U.S. Department of Defense, *Soviet Military Power 1990* (Washington DC: U.S. Government Printing Office, 1990), P. 52.

[13] *World Factbook* 1990 (Washington, DC: U.S. Government Printing office, 1990), P. 217.

> ### *Box 6-F—Treatment of Deliberate Target Concealment*
>
> Deliberate target concealment, like any other degradation of search effectiveness, can be characterized mathematically as a reduction (perhaps a very large reduction) of the aircraft's sweep width. For example, if each TLI had a 99-percent chance of reaching cover when bidden to do so, an aircraft with a 3.2-mile sweep width would find its width reduced to 0.032 miles. That is to say, an aircraft with a 4-mile wide photographic field of view, backed up by a staff which finds 80 percent of the TLIs present in the photographs would-if confronted by an opponent who successfully concealed his TLIs 99 percent of the time-see on the average as many TLIs as an aircraft which exerted perfect scrutiny, with no possibility of concealment, on a strip 0.032 nautical miles (or about 200 feet) wide.
>
> The above statement should not, of course, be construed as a (ludicrous) statement that concealment measures somehow restrict the camera's field of view to a narrow strip; to reiterate, concealment lowers the number of targets seen to that which would be seen if scrutiny were perfect and the field of view were so narrowed. In fact, of course, the scrutiny is imperfect (with much of the imperfection introduced by the targets' concealment), and the field of view is much wider. The narrow strip, however, proves to be a useful mathematical construct, as will be seen below.

in the USSR would be 100,000 kilometers, or 68,000 nautical miles. Moreover, logistical and communications considerations may constrain the SS-24 force from using the entire rail system.

An aerial search by a single vehicle could perhaps overfly 3,000 nautical miles of roadbed, suggesting a 4-percent (i.e., 3,000 divided by 68,000) chance of seeing *any particular SS-24* train. If mobile ICBMs were completely banned by some arms control agreement, this simple calculation suggests that each flight's chance of detecting a violation would be roughly 4 percent *per deployed train*.[14]

Most refinements to the above simplistic calculation---other than those modifying the assumption that the search is performed by an unassisted aircraft-tend to lower the estimated probability of

Photo credit: U.S. Department of Defense

Artist's conception of rail-mobile SS-24 missiles on maneuvers in a dual-tracked section of the Soviet railroad system.

finding a violation. (See also box 6-G.) For example, not all extant trains would be deployed at all times, and the aerial search task is complicated by the presence of ordinary trains--perhaps one every 50 miles.[15] The missile-carrying trains would have to somehow be discriminated from the ordinary trains, and caution about accusing the Soviets of a violation would introduce a benefit-of-the-doubt effect by which some SS-24 trains could escape identification. These considerations could lower the flight's chance of finding a violation from 4 percent per train to 2 percent overall.

With 10 warheads per missile and more than one missile per train, and in an environment of reduced strategic arsenals, only a handful of trains would be needed to constitute what could plausibly be deemed a militarily significant force. If considerations such as those raised in the preceding paragraph were to lower the overall chance of finding a violation to 2 percent per flight, 50 flights (nominally a year's worth) would have only a 63-percent chance of finding a violation even if they were all dedicated to the search for illegal rail-mobile missiles.

Simple Aerial Monitoring Calculations: Aerial Search for SS-20 IRBMS and SS-25 ICBMS

The SS-20 is a three-warhead, intermediate-range ballistic missile (IRBM), deployed on land-mobile launchers by the Soviet Union. It is an item banned

[14]The chance of finding at least one out of n trains is $1 - 0.96^n$. For small values of n, $1 - 0.96^n$ is about@ to $0.04 \times n$.

[15]Based on *World Factbook 1990*, op. cit., footnote 13, figures for total trackage and total ton-miles hauled, and some estimates Of train speed, number of ears, and tons per car.

Box 6-G-Calculation of Sighting Probabilities

This box explains how overall sighting probabilities can be calculated given the search effort, the size of the region to be searched, and an assumption about how the search effort is organized. These probabilities result from consideration of the problem in terms of the Poisson probability distribution, whose density parameter ***p* is the** coverage factor, sweep rate times effort per area searched, The probability of a target being sighted ***n*** times is then $p^n e^{-p}/n!$. Substituting $n = 0$ gives the probability e^{-p} of the target not being sighted at all, for a complementary probability $1-e^{-p}$ of it being sighted.

The upper bound for the probability of sighting, then, results from considering the search as perfectly coordinated and is the coverage factor or unity, whichever is the lesser:

$$P(\text{sighting}) = \min(\text{coverage factor}, 1).$$

The lower bound results from considering the search as splattering coverage over the searchable area confetti-style:

$$P(\text{sighting}) = 1 - e^{-\text{coverage factor}}$$

The truth will lie somewhere between these two extremes. Differing assumptions as to exactly how well the searchers can coordinate their efforts lead to differing values for the probability that a target will be sighted as a function of the coverage factor. One commonly used function is

$$P(\text{sighting}) = \text{cnorm}(\text{coverage factor}),$$

where 'cnorm' represents the cumulative normal distribution. This (rather startling) appearance of the cumulative normal distribution can be derived from a widely applicable expression for probability of sighting as a function of true-not lateral-range, and has the advantage of being easily looked up in commonly available tabular form or as a "canned" function on a computer or calculator.

Note that the three functions agree for very small coverage factors and for very large ones: the exact degree of coordination only matters for medium values of the coverage factor because very sparse coverages run little risk of redundant overlapping and very dense ones can afford the wasted effort.

In a case in which the coverage factor is based on an effective sweep width drastically reduced by sensor imperfections or target concealment (see box 6-J?), the instances of sighting will be so randomized that the confetti-style equation for probability of sighting should be used.

by the INF Treaty, and the Soviets are obliged under the INF Treaty to destroy their existing SS-20s and not build any more. The SS-25 is a single-warhead, land-mobile ICBM physically comparable to the proposed U.S. Midgetman. Unlike the proposed ''garrison-mobile' Midgetman, SS-20s and SS-25s deploy to the countryside in peacetime.

The Soviet Union has 1.6 million kilometers (1.1 million nautical miles) of roads.[16] The SS-25 TEL is billed as off-road-capable, so it would not (except perhaps during mud season) be restricted to the 800,000 miles of hard-surfaced road. However, the SS-25 TEL is not considered to be *as* off-road capable as the proposed U.S. Midgetman TEL. We might therefore assume that operational SS-25s would operate on unimproved roads and even off the road, but would not stray far from the road. A simplistic calculation would then suggest that a 3,000-nautical-mile flight would have a 0.37-percent (i.e., 3,000 divided by 1.1 million) chance of seeing a particular SS-25.

Refinements to this calculation include consideration of the fact that more than one section of road would be visible at a time, raising the probability of detecting the launcher. Other refinements, like those suggested above in the case of the SS-24, reduce the estimated probability of seeing a launcher: not all launchers are out of their garrisons at any one time and the reluctance to cry ''wolf' at the sight of any large truck with a cylindrical cargo would tend to mask some actual sightings. In particular, aerial search for illegal SS-20s would be greatly complicated by the presence of legal SS-25s, whose launchers are outwardly similar. Chances of finding any particular illegal SS-20 or SS-25 on a road would be worse than those of finding a particular rail-mobile SS-24. Compared to the SS-24, the small number of warheads per missile on the land-mobile systems would require that 10 times as many be

16 *World Factbook 1990,* op. cit., footnote 13, p. 217.

Photo credit: U.S. Department of Defense

In an artist's conception, road-mobile SS-25 ICBMs take to the field in a remote area of the Soviet Union. The mobility of such systems increases their survivability, but also complicates verification of any numerical limits placed on them.

deployed to reach a given level of military significance. However, the lower chance per missile of finding a violation counteracts this effect.

SS-20s and SS-25s can also leave the roads and roam the countryside. The arable land and meadowlands of the Soviet Union total 1.8 million square nautical miles,[17] and another 2.7 million square nautical miles of the Soviet Union is covered by forest. Arable lands and meadows generally support tractors, and thus can be considered capable of supporting the off-road capability of the SS-25 launcher. In addition, these launchers could penetrate the forested and mountainous regions of the Soviet Union[18], as well as operating on nonarable tundra, even if they could not negotiate each and every square meter of such territory. Thus one might credit the SS-25 with creating an 'uncertainty area' of at least 5 million square nautical miles.[19] (The entire landmass of the Soviet Union is about 6 1/2 million square nautical miles.) The calculations performed in the previous chapter thus apply roughly to this case: an overflight might see, on the average, a mile-wide swath throughout its 3,000-mile flight, leading to a 0.06-percent chance per missile that a single flight would find a violation.

As will be discussed later, knowledge of Soviet infrastructure could help. For example, there might not be enough bases to serve TELs spread out over the whole 5 million square nautical miles, in which case the inspections could concentrate on regions near bases.

Discussion

Many important considerations do not appear in the simple calculations described above. A more complicated calculation could take these into account, but for now we will simply point them out. Some make the calculation look pessimistic while others make it look optimistic. (See also box 6-H.)

For example, the inspecting side would not necessarily know which mode of violation the violating side had chosen, and would thus not know whether to concentrate a year's worth of flying on road, rail, or countryside search. Effort would be diluted by the need to address all of these regions. Other searches would be required too: for example, the 4,530 usable and 2,360 nonusable airfields of the Soviet Union[20] would provide cover and some amount of infrastructure for deployment of mobile ICBMs, and examination of these airfields would use up flying time which might otherwise be allocated to searching roads, rails, or countryside. Finally, a breakout deployment would occur gradually over a period of time (perhaps a year). At the beginning of that period the force is very small, and thus almost impossible to detect; only at the end of the period is the force of the "militarily significant"

[17] Ibid., p. 216.

[18] They are depicted operating in rough wooded country in U.S. Department of Defense, Soviet *Military Power 1988* (Washington, DC: U.S. Government Printing Office, 1988), p. 47.

[19] Attempts to define an "@vtdent uncertainty area" of a road network or otherwise deal with the problem of searching a combination of two-dimensional and one-dimensional regions (e.g., fields and roads) have in general been disappointing because the equivalency depends upon whether or not multiple roads can be captured in the same view, and thus upon what sensor is in use.

[20] *World Factbook 1990*, op. cit., footnote 13, p. 217,

Box 6-H—Satellites v. Aircraft

Because satallites pass over so much territory so frequently, as compared to aircraft, one might wonder whether they would be cheaper platforms for overhead surveillance. An analysis shows that this is not necessarily the case.

One may compare the $10/square mile figure for airborne photography (see in box C-F') with the costs derived for a notional MediaSat newsgathering satellite based roughly on the French SPOT commercial satallite.[1]

MediaSat pictures would cost, all told, from $35,000 to $73,000 each depending upon how various design choices between the austere and the desirable were made and assuming a demand of approximately 1,000 pictures per year. Towards the desirable (and thus more costly) end of the design regime, pictures would each cover an area of 15 by 15 miles and thus cost in the neighborhood of $300/square mile. Thus these pictures cost about 30 times more than their aircraft-obtained counterparts. Their 5-meter resolution is not even close to the resolutions identified as necessary for aerial monitoring of treaties, so one would infer that satellite photography suitable for treaty-monitoring would be even more costly than the MediaSat estimates would indicate.

If the treaty-monitoring effort could benefit by collection of more pictures,[2] economies of scale would make satellites more cost-competitive. While 1,00015- by 15-mile pictures cover an area comparable to the 50 flights' worth of 5- by 1,000-mile strips we have considered in several examples so far, most of their cost is the investment cost of building and launching the satellite. Extra satellite pictures would be almost free. The investment cost of aerial surveillance, on the other hand, is but a small part of the total, so amortization of that cost over a larger number of pictures would not greatly lower the cost per picture.

Of course, satellite-derived pictures could be worth their extra cost because of other possible advantages of satellites, e.g. more frequent revisit times, than would be allowed to aircraft in a treaty context. One must be careful, however, in drawing facile comparisons between such different systems: where the partisan of satellites points to frequent revisit times, for example,his or her airplane-favoring oppositenumberpoints to the greater unpredicability of airplanes' flight plans.

1See U.S. Congress, Office of Technology Assessment, *Commercial Newsgathering From Space—A Technical Memorandum,* OTA-TI-ICS-40 (Washington DC: U.S. Government Printing Office, May 1987), especially pp. 25,39-41.

2As ~@ well be the case if many treaties were to be monitored by the same satellite.

size according to which detection probabilities are normally computed, but by then it is too late: the militarily significant force is already in place and there is no time to make an appropriate response.[21]

Concealment, camouflage, and deception (CCD) could all lessen the probability that a TLI would be sighted even if an aerial monitoring aircraft flew by. On the positive side, other arms control monitoring and intelligence sources (as well as cogent use of previous results of aerial monitoring) could provide valuable clues facilitating the air search for treaty-l.imited objects. Aerial monitoring assets could then concentrate on the most likely regions, increasing their effectiveness. The interplay of CCD and intelligence on the other is quite complex: a study of the search for mobile Scud-B launchers in Iraq would hold important lessons for those who plan to search for illicit SS-20s and SS-25s.

So far we have considered only searches for items totally banned by treaties. START or other treaties might limit, but not ban, such weapons as the SS-24 and SS-25. Aerial search would then need to count TLIs rather than simply look for them. This important topic is treated in appendix A.

The United States and the Soviet Union had atone time reportedly agreed on restricted deployment areas of 125,000 square kilometers (36,400 square nautical miles) for road-mobile ICBMs in a START context.[22] Assuming no wasted effort, a 3,000-nautical-mile flight with a l-mile sweep width as described above would have a 8-percent chance of seeing any particular TLI Inspection of the deployment areas is an important minimum requirement, and not an easy

21 R- Scott Strait of Lawerence Livermore National Laboratory has pointed out the importance of this ramp-up effect on the detection Of breakouts. He has further noted the convenient mathematical facthat, assuming a constant deployment rate, the average detectability of the force is half of the maximum detectability attained when the force is fully deployed.

22Dunbar Lockwood, "Verifying START, From Satellites to Suspect Sites, ' *Arms Control Today*, vol. 20, October 1990, p. 18.

one to fill if the aerial monitoring process is supposed to verify a nonzero limit. Nevertheless, it would be a mistake to assess one's inspection capability on the basis of inspections of designated deployment areas. To do so is to run the risk of accepting a verification regime that will work only if the other side does not cheat.

Simplistic calculations portray a comparatively heavy aerial search schedule as offering only slightly more than even odds of finding a nominally sized treaty violation in a year. Most refinements of these calculations, e.g., consideration of CCD, the difficulties presented by the task of discriminating illicit TLIs from legitimate ones, and the desire to detect a treaty-violating deployment before it is complete, lessen the chances that aerial search will function as hoped. One important consideration, however, has the opposite effect: the use of *prior information* about the TLIs' likely whereabouts—perhaps gained by NTM, or by previous aerial monitoring flights—can focus the attention of the aerial search assets upon those regions most likely to contain items of interest.

Sources and Exploitation of Prior Information

As the preceding sections of this chapter suggest, an aerial search program that had no prior information as to where to look would be an unguided tour or photographic ramble of the target country. It would not be much more focused than the random searches of the GENETRIX project, in which automatic cameras drifted across the Soviet Union beneath weather balloons. (See also box 6-I.) Even complete photographic coverage, were such to be available given treaty constraints, would not provide a practical solution. As we have seen in chapter 3, photographic equipment used in aerial monitoring might resolve a ground sample distance of 6 inches, imaging those 6 inches as a 5,000th of an inch: in that case, the 6.5 million-square-nautical-mile Soviet Union would lead to a quarter of a million square feet of photographs. If these were assembled into a single photograph of the Soviet Union, it would cover more than five football fields and require a microscope for detailed analysis. Some means of directing the search is needed.[23] Potentially useful kinds of *such prior information* include: terrain characteristics, target-associated infrastructure, results of previous searches, knowledge of the inspected side's operational habits, and other intelligence data.

Terrain

In most areas, terrain sharply limits the possibilities for the locations of many kinds of TLIs. Land-mobile SS-20 or SS-25 missile launchers, for example, might not be able to enter swampy land. More generally, land-mobile missile launchers are likely to be found in regions where accessible terrain is not only available but plentiful, because the concept of operation of such launchers calls for them to be able to disperse and create enough uncertainty as to their whereabouts to stymie an attack by ballistic missiles. This consideration would lessen the area of the region in which launchers might be found. However, as mentioned earlier, such launchers might use roads to enter and move about in a region of difficult terrain.

Infrastructure

Infrastructure can provide many valuable clues to the location of reconnaissance targets. A photointerpreter's account of how she found the German V-1 cruise missile during the Second World War shows her use of infrastructure clues. (See app. A.) More recently, a British analyst of Soviet earth-resources satellite *Soyuz Karta* stereoscopic pictures discerned a 750-meter-long building, new roads, embankments, and signs of possible excavation at a site in Iraq; these clues (taken together with information collected by Kurdish separatists in the region) led the analyst-a mineralogist by training—to conclude that the Iraqis were developing the site as a ''uranium mine' or a nuclear weapon production plant.[24]

In general, the tracks made by troops and vehicles "are the most important and obvious signature of any military activity."[25] Not only do some military vehicles create tracks unlike any civilian vehicle, but the presence of such military-related infrastructure can be given away by tracks: the presence of barbed

[23] In the case of a much smaller country, some 25 linear miles of film were shot by U-2s and low-flying aircraft in the course of the Cuban Missile Crisis. (Robert Kennedy, *Thirteen Days (New* York, NY: W.W. Norton, 1971), p. 46.)

[24] ''Satellite Reveals 'Uranium Mine',' *Jane's Defence Weekly, Nov. 31990,* p. *879.*

[25] *Imagery Analyst*, Soldier's Manual STP 34-96D1-SM (Washington, DC: Headquarters, Department of the Army, November 1987), p. 2-456.

Box 6-I—The GENETRIX Project

The GENETRIX project presents, in purest possible form, an airborne search undertaken without any recourse to existing knowledge of important targets' locations.

During the mid-1950s, the U.S. Strategic Air Command launched a program of balloon-borne reconnaissance of the Soviet Union and the People's Republic of China. High-altitude balloons bearing automatic cameras would float East from Europe across the Soviet Union and the P.R.C. to Arctic recovery areas in the Pacific. In January and February of 1956,516 balloons were launched, of which fewer than 10 percent were recovered. These furnished almost 14,000 100-square mile exposures of Soviet or Chinese territory, accounting for about 8 percent of those countries' area. The utility of the pictures was characterized as suitable only for "pioneer" work, and the Soviet reaction-which included a press conference featuring many fallen balloons-was vehement.[1]

"Pioneer reconnaissance" was elsewhere defined at that time as a resolution of 20 to 400 feet; pictures taken at such resolutions would not be useful to military photointerpreters.[2] The balloons may have performed at the better end of this range. They carried pairs of cameras whose fields of view slightly overlapped-with a then-readily-attainable film resolution of 10 lines per millimeter and optics to match, the resulting 9- X 9-inch images[4] would, if showing a region 10 statute miles on a side, attain a ground resolution of

(5,280 X 10)+(9X 25.4X 10)=23 feet.

From a mapping standpoint, however, the pictures were quite usable, and the program was characterized as a suceessful and even cost-effective mapping mission.[5]

The militarily disappointing results of the GENETRIX program are instructive because they stem in large measure from the scattershot nature of the search. Not only were the users unable to target the balloons (some even missed the Soviet Union altogether), but their first order of business upon receipt of the product was to determine where the balloons had been. The principal lesson of the project is the price it paid for its inability to capitalize upon existing information as to the whereabouts of interesting targets.

1This account from Thomas Crouch, *The Eagle Aloft* (Washington, DC: Smithsonian Institution Press, 1983), *PP.* @44547.

2Merton E. Davies and William R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space* Technology (Santa Monica, CA: The RAND Corp., 1988), pp. 26-27. French SPOT and U.S. Landsat pictures fail in the "pioneer reconnaissance" category according to this standard.

3Ibid., p. 11,

4Ibid., p. 60.

5Ibid., p. 61. At just under $50/_ mile, GENETRIX collected mapping data on the Soviet Union more cheaply than any other means then in use for mapping the United States.

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wire (a difficult photographic target), for example, can be deduced by observing the otherwise inexplicable convergence of tracks.[26]

Soviet SS-20 and SS-25 mobile missiles deploy to prepared sites consisting of turnouts and berms.[27] To assure survivability, the Soviets have doubtless prepared far more of these sites than there are missiles, but the sites, and the regions surrounding them, are still likely places to look for mobile missile launchers.

Between deployments, SS-25s (and SS-20s, to be eliminated under the provisions of the INF Treaty) occupy unique sliding-roof buildings. Clandestinely deployed missiles would probably not be based in buildings of the same appearance as those housing the overtly deployed force, but the sliding- roof feature (which enables the missile to be launched without moving the TEL outdoors) might be retained.

Despite their off-road capability, SS-20 and SS-25 missiles are more mobile on roads than off, and therefore an aerial monitoring search for these missiles or their shelters could be guided by the road network. Bridges would channelize missile launcher traffic (along with all other traffic), making them and their vicinities especially likely places to find TELs.

Rail-mobile SS-24 missiles are constrained by an even more obvious item of infrastructure: railroad

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'*Ibid.*, p. 2-457.

27As shown *in Soviet Military power,* various issues.

tracks. Railroad tracks seem to be important for Soviet silo-based ICBMs as well: the existing fields string out along the Trans-Siberian Railway. As is well-known, most of the Soviet Union's rail network is broad-gauge (5 feet): the SS-24 operates on this broad-gauge track.[28] Some western regions of the Soviet rail network have the same standard-gauge (4 foot, 8.5 inches) track as the neighboring European countries. The standard-gauge sectors would merit some surveillance, lest the Soviets exploit U.S. overreliance on this particular infrastructure cue and clandestinely produce illegitimate SS-24s deployed in standard-gauge railcars.

In general, railroads are such an important part of the Soviet infrastructure that an aerial search for almost any kind of facility could sensibly be begun on the assumption that the facility would have handy access to a railroad.

Illicit TLIs, especially small numbers of them, might well be found mixed in with legitimate TLIs or even non-TLIs. For example, SS-23s (TLIs banned by INF) were found amidst the treaty-unconstrained missiles of an East German Scud-B unit.[29] As mentioned in chapter 6, an aerial monitoring aircraft searching railroad tracks for SS-24 trains would also see many ordinary trains, probably seeing one in motion every 50 miles or so and many others stopped at sidings or in railyards. These trains would have to be judged missile-free. Discrimination of missile-carrying trains from ordinary ones might not be easy: the United States plans to disguise its Peacekeeper-carrying trains as ordinary ones,[30] so the Soviets could do the same without incurring charges of the use of 'deliberate concealment measures" to defeat NTM.

Certain treaty provisions could have the effect of mandating infrastructure. "Designated deployment areas, regions expressly designed to simplify detection without so constraining weapon deployment as to constitute a threat to survivability, have been proposed for mobile ICBMs under START. Conversely, designated test areas are designed to

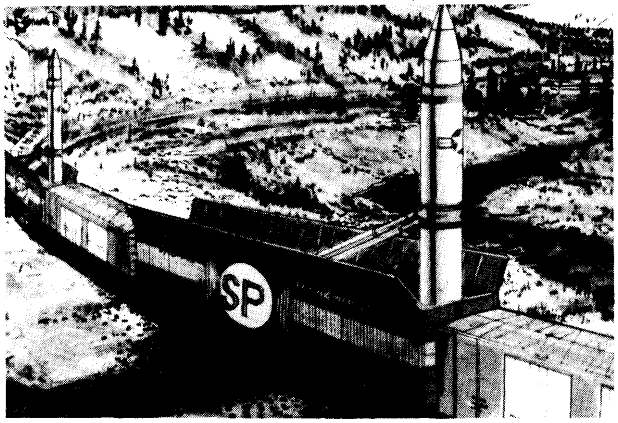

Photo credit: U.S. Department of Defense

Plans for possible rail-mobile deployment of the U.S. Peacekeeper ICBM call for the use of normally marked trains.

assure the verifier that weapons found within their limits are not deployed, but are merely test items. The SALT I ABM Treaty codifies infrastructure in this way. Finally, the intended purpose of a deployment may be established by its location: the ABM Treaty requirement that putative early warning radars face outwards from positions on the perimeter of their countries establishes that they are not proscribed battle management radars.[31] Not only do such mandated details of infrastructure facilitate the counting of deployed weapons; they also simplify the decisionmaking process in case a TLI is sighted outside an allowed region: "detection of a single item in proscribed places or times would constitute a violation. '[32]

Finally, and most simply, TLIs are likely to be found near other TLIs, and other military hardware. Even targets such as mobile missile launchers, which try to spread themselves out for survivability's sake, spread out only on a tactical level and not on an national one. If total bans on weapon systems, like total bans on operating certain weapon systems outside of designated deployment areas, are especially verifiable because "if we see even one then we'll know they're cheating," then having seen

[28] *Soviet Military power* 1990, op. cit., footnote 12, pp. 51-52.

[29] *Washington Times*, May 4, 1990, P. 6.

[30] Applying commercial emblems, authentic-looking amounts of dirt and rust, and even blending in a few real freight cars. Remaining functionally related observable differences include the number of axles on the missile-carrying cars and the undercarriage of the fuel car. ("U.S. Plays Cloak-and-Boxcar," *Chicago Tribune*, June 14, 1989, p. 1.)

[31] The famed Krasnoyarsk radar violates this condition.

[32] Ivan Oelrich, "The Verification of Conventional Arms Limits, " in *New Technologies for Security and Arms Control*, Eric H. Arnett, ed. (Washington, DC: American Association for the Advancement of Science, 1989), p. 192.

more than one would help clinch the case. Thus searchers who find a target might do well to modify their search plan and look for more targets in the same region.

Previous Searches

In a search for a stationary target, e.g., a clandestine factory, the results of all searches can be considered simultaneously, amounting to one big search. In dealing with mobile targets, e.g., mobile missile launchers, one must keep in mind the possibility that a target has moved to the site of an earlier picture, so that it can evade detection even after the entire region has been photographed.

Studies addressing the search for mobile, or ‘‘relocatable,’ ’[33] surveillance targets, e.g., mobile missile launchers, often contain assumptions about such targets’ movement habits based upon current practice. Because these habits may be as much a matter of policy as of necessity, they could perhaps be changed—say, by making movement more frequent—if necessary to elude detection by a newly deployed surveillance asset or a newly introduced program of aerial monitoring. (See also box 6-J.)

Other Sources of Prior Information

Other sources of prior information include analysts’ assessment of what developments to expect, previous sightings of the same item, and the fruits of other intelligence collection means.

Unaided by previous sightings or collection by other means, an intelligence collection effort can be aided by an awareness of the operations of one’s own side’s forces. For example, the British discovery of a German V-2 intermediate-range ballistic missile at Blizna (see app. B for an account of this) may have been aided by the analyst’s having seen a V-2 before, in a picture of Peenemunde. Similarly, the initial Allied discovery (also described in app. B) of the German V-1 ground-launched cruise missile was owed partially to the photointerpreter’s having been briefed on the possibility of pilotless aircraft and the ramps needed to launch them: these cues were the result of other means of intelligence collection.

Radio direction-finding can contribute strongly to the a priori information available to searchers. Most observers believe that an aerial monitoring agreement will not include collection of electronic intelligence by the flights themselves, but the planners of the flights could capitalize on electronic intelligence obtained by other sources.

Other sources of intelligence could also be of great use to planners of aerial monitoring searches. The search effectiveness of U-boat skippers prowling the Atlantic during the Second World War, for example, was doubled when they had access to radio intercepts revealing the intended routes of Allied convoys.[34]

Box 6-J--Mobile Targets

In looking for a fixed facility such as a factory, one can at least count on the fact that that the target will not move between searches. Searches for *mobile* **targets, such as Soviet SS-25 ICBMs, are complicated by the fact that the target might move during the search. In an aerial monitoring search, in which the target country is examined in installments, even cumbersome “relocatable” targets might move between installments of the search. The contrast between searching for mobile targets and immobile ones bears some resemblance to the** contrast between sampling with **replacement and sampling without replacement in, for example, a reentry vehicle on-site inspection (RVOSI) context.**

In calculating the probability of finding a target (assuming some known target density], the case of mobile targets can be handled by the confetti-search formalism described above. In what might be called “the (mathematically) ideal worst case,” in which the targets are constantly moving about and the fact that a target has not been seen at a particular place has absolutely no bearing on whether or not there might be a target there the next instant, the expected number of targets found is

$$\text{total} \times (1 - e^{-\text{effort/area}}).$$

(see box 6-G) instead of

$$\text{total} \times (\text{effort/area})$$

The probability of finding at least one target is still

1- ~-totd X efforttarea

as in the case of randomly located stationary targets.

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[33]The term connotes something less than full mobility; usually the inability to operate on the move, and perhaps even the need to spend setup time between cessation of movement and onset of operations, and teardown time between cessation of operations and onset of movement.

[34]Operations Evaluation Group Report No. 533, available from the Center for Naval Analyses, Alexandria, VA.

The Problem of Misleading Prior Information

Prior information, or simply predisposition, can reduce the probability of detection as well as raise it. R.V. Jones recounts that the "ski" or "catapult" V-1 launchers at Peenemunde (on one of which Flight Officer Constance Babington-Smith was later to discover the V-1 itself):

> were, for example, interpreted as "sludge pumps," a theory perhaps coloured by the interpreter's previous experience as an engineer with a river Catchment Board after his Cambridge Ph.D. thesis on classical hydraulic engineering[.][35]

Jones does not mention that a long-term land-reclamation project going on at Peenemunde was another source of confounding false clues as to the true nature of the launchers. (See also app. A.)

In the case of the V-2, search for launching sites in France was originally planned on the basis of an assumption that launchers would be sited close to rail lines.[36] Only later was a V-2 recognized in a photograph of Peenemunde on what would today be called a TEL, disassociated from any rail line, leading to the realization that the search for rocket launchers near rail lines-and indeed the search for freed rocket launchers at all-was fundamentally misconceived.

Prior Information and the Assumption of Rationality

Most of what we have called 'prior information' regarding the placement of rocket launchers and so on contains, to greater or lesser degree, reasoning as well as facts. Much of this reasoning concerns what the other side would or would not do, typically based on an assumption that they are reasonable people. For example, advocates of the INF Treaty-while admitting that illicit SS-20s would be very difficult to detect--discounted fears that the Soviets would hide illicit SS-20s in SS-25 canisters on the grounds that doing so would simultaneously deprive the Soviets of the military benefits of having a missile that could reach the United States and the political benefits of having a missile demonstrably targeted at Europe:

> If they wanted to cheat on the INF Treaty, I would give them a little more credit than taking an SS-20 and putting it in an SS-25 canister. . . . The problem is, you would have to ask why they would do it. The purpose of the SS-20, in my opinion, was to provide a political threat to Europe. An SS-20 which is covert, hidden, or an SS-20 which is in an SS-25 canister would not represent that political threat.[37]

Some may question any such argument based on perceived lack of Soviet incentives or lack thereof. It is true that such reasoning can sometimes lead the analyst astray, but the error so induced is rarely larger than the penalty paid by the other side for its failure to act rationally.

For example, the British detection of the V-2 was considerably retarded by the belief that a militarily effective ballistic missile of sufficient range was either impossible to build or ludicrously uneconomical. In particular, once the V-1 program was understood, those who believed in the existence of a V-2 program had to weather the argument that the Germans would not go to the trouble of building a ballistic missile simply to deliver the same size warhead as was carried by their V-1 cruise missile. As it turned out, the V-2 missile did in fact deliver a warhead only slightly larger than that of the V-1, and with much greater trouble and expense. Those in Britain who doubted the existence of the V-2 program on the grounds that Germany would have no incentive to build two weapons for one mission neglected the considerations of improved penetration, interservice equity,[38] and technological romanticism[39] that compelled the German authorities to allow the Wehrmacht and Luftwaffe each to develop its own system.[40]

Though the British were *surprised* by the V-2 project, they were not *dismayed: they* were correct in their belief that the weapon would be a grossly

[35] R.V. Jones, *Most Secret War* (London, England: Hamish Hamilton, 1979), p. 433.

[36] Constance Babington-Smith, *Air Spy (New York, NY:* Harper and Brothers, 1957), P. 215.

[37] Testimony of Major General William F. Burns, *The INF Treaty*, hearings before the Committee on Foreign Relations, U.S. Senate, Part 5, 100th Cong., 2d. sess., p. 89.

[38] Though this motivation was anticipated by some in Britain. (Jones, op. cit., footnote 35, PP. 456-457.)

[39] Ibid., pp. 573.575; and Michael J. Neufeld, "Weimar Culture and Futuristic Technology: The Rocketry and Spaceflight Fad in Germany, 1923- 1933," *Technology and Culture,* vol. 31, No. 4, October 1990, especially the concluding paragraph.

@See also David Irving, The Mare's Nest (London, England: William Kimber & Co. Ltd., 1964).

inefficient use of German resources and erred only in believing that the Germans would abandon the project accordingly. The German war effort needlessly bore the burden of ballistic missile production, with each V-2 representing a debit to the Germans of many V-IS' worth of resources and thus a saving to the British of many V-is' worth of damage. Analogously, advocates of the idea that the Soviets would not place SS-20s in SS-25 canisters might well (and in some cases do) take the attitude that "if the Soviets did that, they are sort of playing into our hands. "[41]

The assumption of rationality is simply an instance of the usual worst-case planning: the worst case is that the other side behaves rationally and in one's own worst interest. This standard is sometimes equated to the more dangerous ''mirror-imaging" assumption that the other side behaves rationally and in what we see as its own best interest, which may not be the same thing.[42] For example, U.S. analysts' consistent underprediction of the growth of the Soviet ICBM force in the 1960s has been ascribed to mirror-imaged imputations of the costs and benefits to the Soviets of building ICBMs.[43] Interestingly, it has been pointed out that mirror-imaging would have correctly predicted the growth of the Soviet ICBM force if the U.S. civilian analysts had imputed to Soviet military planners the mindset of their uniformed U.S. counterparts, not that of U.S. civilian analysts.[44]

One could undertake a program of aerial monitoring without any recourse whatsoever to assumptions about the other side's rationality. Searches in such a program would be scoped only by the physical constraints under which the other side operated: aircraft would not search for ships in the middle of deserts or for missile silos in quicksand. However, the need to search for silos in the desert and ships in the quicksand would deprive the searching side of any means by which to cut down on the raw area it needed to search. A better aerial monitoring program would impute rationality to the other side, but also hew to the assumption that the other side was—rationally-pursuing the most damaging possible course of action.

Searches in such a program would respect physical constraints and, to some degree, fiscal ones as well; searches for isotope separation plants, for example, would be concentrated in regions plentifully supplied with hydroelectric power plants. The "if they want to, let them" principle would be observed: occasional searches of inappropriate or unlikely terrain would be performed, but the principal search effort would be allocated to the regions most likely to contain the objects of the search. The theoretical ideal would be to create a situation in which the costs of committing a violation—including the difficult-to-quantify cost of being caught—were equalized over all locations in the other side's territory.[45] Any other allocation Of search effort would create favorable locations for cheating and thus allow it at too low a cost.

[41] Testimony of Major General William F. Burns, op. cit., footnote 37, p. 90.

[42] The special case of deterrence deserves mention because of its importance in U.S. planning. To be deterred may be in the adversary's best interest, but for him or her to fail to be deterred is in one's own worst interest. As in the case of Pearl Harbor, the would-be deterrers' eventual victory does not assuage the dismay they feel when the target of their deterrence fails to see the light and executes a worst-case attack.

[43] Walter Laqueur, *A World of Secrets: The Uses and Limits of Intelligence* (New York, NY: Basic Books, 1985), pp. 190-194.

[44] Bruce D. Berkowitz and Allan E. Goodman, *Strategic Intelligence for American National Security* (Princeton, NJ: Princeton University press, 1989), pp. 91-93. Such insights can be exploited on the tactical level as well. During the Cuban Missile Crisis, when aerial photography revealed that "the Russians and Cubans had inexplicably lined Up their aircraft wing tip to wing tip on Cuban airfields, making them perfect targets, [President John F. Kennedy] requested General [Maxwell] Taylor to have a U-2 fly a photographic mission over our fields in Florida. 'It would be interesting if we have done the same thing,' he remarked. We had. He examined the pictures the next day and ordered the Air Force to disperse our planes." (Robert Kennedy, op. cit., footnote 23, pp. 37-38.)

[45] Similarly, the air search effort for U-boats in the Second World War was apportioned overnight and day so as to make surfacing equally hazardous at all times. See Brian McCue, *U-Boats in the Bay of Biscay* (Washington, DC: National Defense University Press and the U.S. Government Printing office, 1990).