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Conventional Arms Control and Disarmament in Europe: A Model of Verification System Effectiveness

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The cover graphic is based on an ancient Egyptian hieroglyph representing the all-seeing eye of the powerful sky god, Horus. Segments of this "eye in the sky" became hieroglyphic signs for measuring fractions in ancient Egypt. Intriguingly, however, the sum of the physical segments adds up to only 63/64 and, thus, never reaches the equivalent of the whole, or perfection. Similarly, verification is unlikely to be perfect.

Today, a core element in the multilateral arms control verification process is likely to be the unintrusive "eye in the sky," or space-based remote sensing system. These space-based techniques will have to be supplemented by a package of other methods of verification such as airborne and ground-based sensors as well as some form of on-site inspection and observations. All these physical techniques add together, just as the fractions of the eye of Horus do, to form the "eye" of verification. Physical verification, however, will not necessarily be conclusive and there is likely to remain a degree of uncertainty in the process. Adequate and effective verification, therefore, will still require the additional, non-physical, element of judgement, represented by the unseen fraction of the eye of Horus.

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Abstract

This paper examines the problem of verification system effectiveness in monitoring compliance with a conventional arms reduction agreement. As background, a chronology of conventional arms control proposals from 1985 to 1989 is presented, highlighting measures variously suggested for an MBFR or CFE verification regime. The paper then briefly discusses military and civilian surveillance technologies available for wide-area coverage, i.e., aerial and spaced-based monitoring systems. Finally, a verification model derived from the binomial probability distribution is introduced. This model demonstrates the relationship between various operational factors and the effectiveness of overhead systems in detecting inadvertent yet militarily significant treaty violations. As the operating parameters for many of these factors will be defined by treaty, it is essential that negotiators understand their relationship to verification system effectiveness.

Résumé

Le présent document traite de l'efficacité du système de vérification prévu dans le cadre d'un accord de réduction des armements conventionnels. En toile de fond, il présente une chronologie des propositions faites entre 1985 et 1989 sur le contrôle des armements conventionnels, d'où ressortent les diverses mesures proposées en vue de l'instauration d'un régime de vérification des « Réductions mutuelles et équilibrées des forces » ou des forces armées conventionnelles en Europe. Il aborde ensuite brièvement les techniques militaires et civiles de surveillance disponibles pour la couverture de vastes étendues de territoire, c'est-à-dire les systèmes aériens et basés dans l'espace. Il présente enfin le modèle de vérification dérivé de la distribution de probabilité binomiale. Ce modèle montre les rapports qui existent entre les divers facteurs opérationnels et l'efficacité des systèmes aériens pour ce qui est de la détection des violations involontaires mais militairement significatives du traité. Étant donné que les paramètres d'application de bon nombre de ces facteurs seront définis dans le traité, il est essentiel que les négociateurs comprennent le lien qu'ils ont avec l'efficacité d'un système de vérification.

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List of Abbreviations

ATTU	Atlantic-to-the-Urals
AVLB	Armoured Vehicle Launched Assault Bridges
AWACS	Airborne Warning and Control System
CCD	Charge-coupled device
CFE	Negotiation on Conventional Armed Forces in Europe
CSCE	Conference on Security and Co-operation in Europe
FBIS SU	Foreign Broadcast Information Service *Daily Report Soviet Union*
HLTF	High-Level Task Force
IRIS	Integrated Radar Imaging System
MBFR	Mutual and Balanced Force Reductions
NATO	North Atlantic Treaty Organization
NGA	NATO Guidelines Area
NNAs	Neutral and nonaligned countries
PEEP	Permanent entry and exit point
PRON	Patriotic Movement for National Rebirth
SAR	Synthetic aperture radar
SED	Socialist Unity Party
SLAR	Side-looking airborne radar

SPOT	Satellite pour l'observation de la terre
TLE	Treaty-limited equipment
TLI	Treaty-limited item
WTO	Warsaw Treaty Organization
YCISS	York Centre for International and Strategic Studies

Introduction

On 6 March 1989, the opening plenary session of the Negotiation on Conventional Armed Forces in Europe (CFE)[1] was held in Vienna, with its aim to "strengthen stability and security in Europe."[2] The CFE represented the culmination of efforts, beginning with Soviet leader Mikhail Gorbachev's offer in April 1986 to discuss force reductions from "the Atlantic to the Urals," to organize a new forum for conventional arms control and circumvent the 16-year stalemate in the Mutual and Balanced Force Reduction (MBFR) negotiations. The talks opened amidst guarded optimism that a politically and militarily significant reductions agreement was, for the first time, within reach. However, the participants[3] were under no illusions that the task facing them was simple. Disagreements on the scope and extent of reductions were inevitable. In addition, one of the more contentious issues promised to be, as in past negotiations, the specifics of the verification regime.

In an attempt to better understand the complexities likely to be encountered when negotiating the structure of the regime, this paper offers an introductory examination of three important dimensions of conventional arms control verification:

(1) the elements of a possible CFE verification regime;

(2) verification technologies; and

(3) operational factors influencing the effectiveness of verification systems.

In terms of the first, various conventional arms control verification measures have been proposed in recent years, meeting with varying degrees of acceptance by members of NATO and the Warsaw Treaty Organization (WTO). From these proposals, it is possible to identify the elements likely to receive close consideration as the details of the verification regime are discussed. Consequently, in the first section of this paper, major MBFR, conventional arms reduction, and CFE proposals from 1985 to the present are surveyed to highlight these elements.

As apparent from the survey, most proposals stress the importance of on-site inspection for confirming treaty compliance. Equally important, however, are the overhead monitoring systems used for wide-area surveillance. Part 2 summarizes some military and civilian technologies available for aerial and spaced-based surveillance.

The paper then examines the question of system effectiveness for wide-area coverage. One concern of the participants as they consider the elements of the verification regime will be to identify the operational factors that influence effectiveness in the routine deterrence of inadvertent yet militarily significant treaty violations. A model, derived from the binomial probability distribution, is presented in the third section of the paper, in which the relationship of key factors to overhead monitoring system effectiveness is explored.

Certain terms mentioned in this respect require further elaboration. The first is "verification system effectiveness." As used here, "system" refers to monitoring instruments and procedures that function as a combined and self-contained whole. Thus, the focus is not with particular sensors, e.g., aircraft-mounted Synthetic Aperture Radars (SARs), but rather with complete systems of surveillance, including, in this example, aircraft and sensor coverage, sortie rates, data analysis, etc.

"Effectiveness" is a somewhat nebulous concept, a composite of both operational technical factors and political judgments. In the model, it is expressed as a detection standard specifying a probability of detection and a search interval. Both represent, ultimately, a political judgment of what is required to deter an inadvertent, militarily significant treaty violation. The standard is summarized in statements such as,

> *"the verification system must have a 50 per cent chance of detecting an inadvertent treaty violation within five days of its occurrence"; or,*
>
> *"the verification system must have a 95 per cent chance of detecting an inadvertent treaty violation within ten days of its occurrence."*

The particular standard for verification system effectiveness is determined, in the end, by what political authorities feel they can accept in the post-reductions world.

Finally, there are two aspects to a treaty violation. First, it is "militarily significant." The definition of this term derives from a related measure offered for consideration in a CFE agreement — prenotification of out-of-garrison activities. This proviso requires participants to provide advance notice of military activities undertaken outside designated garrison areas. The unauthorized presence of unit formations, e.g., brigades, divisions, armies, etc., outside these areas constitutes a violation. This definition is used to distinguish violations related to operational military formations with significant combat capability from less-threatening "technical" violations such as small breaches of weapons ceilings.

Second, the violations most often encountered during the life of the treaty are likely to be "inadvertent." It is reasonable to assume that participants enter a treaty based on a positive appreciation of the resulting security environment for their national interests. While it is possible that some may try to use the treaty as a ruse to gain a temporary military advantage, the tremendous risks of such a strategy, e.g., loss of international credibility, coupled with, at best, fleeting strategic benefits, make this a highly improbable contingency. Thus, in all but extreme circumstances, the signatories to a treaty will be acceptably reliable and will not, as a matter of habit, intentionally try to circumvent the treaty. However, this does not preclude infractions arising from negligence, loose organizational control, etc. Violations may occur that are unintentional but, nevertheless, disrupt the treaty environment.

Thus, the objective of the verification regime is to deter on a routine, daily basis such inadvertent yet militarily significant treaty violations. The model presented in later sections of the paper offers some insight into the operational factors that influence the effectiveness of verification systems in meeting this objective. But first, the elements of a possible CFE verification regime, derived from a survey of recent conventional arms control proposals, will be described.

Notes

1. The Negotiation on Conventional Armed Forces in Europe is one of two sets of discussions proceeding within the Conference on Security and Co-operation in Europe (CSCE) process, the second being the Negotiations on Confidence- and Security-Building Measures. The former concentrates on strengthening stability in Europe through reductions in conventional armed forces, the elimination of force disparities, and the elimination of capabilities for surprise attack and initiating large-scale offensives. The latter focuses on confidence-building measures that reduce the risk of military confrontation in Europe. Although procedurally separate, the substance of the two negotiations is closely linked, and progress in one (or the lack thereof) will inevitably reverberate in the other. Both will be reviewed in the Helsinki Follow-Up Meeting beginning 24 March 1992.
2. Mandate for Negotiation on Conventional Armed Forces in Europe," in *CSCE: A Framework for Europe's Future* (Washington, D.C.: U.S. Information Agency, 1989), p. 44.
3. Twenty-three countries are represented in these discussions: Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, France, the German Democratic Republic, the Federal Republic of Germany, Greece, Hungary, Iceland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, the Soviet Union, Spain, Turkey, the United Kingdom and the United States.

Part 1: Verification — A Survey of Key Proposals (1985-89)

Chronology

On 14 February 1985, the WTO tabled a proposal at the MBFR negotiations calling for reductions in Soviet and American forces stationed in Central Europe as a first stage leading to a comprehensive force reduction agreement. This plan proposed reciprocal withdrawals of 20 000 Soviet and 13 000 American troops and their equipment within a one-year period. Associated measures for verification included the designation of three to four observation points to monitor departing units. Beyond this, Soviet spokespersons claimed that satellite surveillance would be sufficient to monitor compliance.[1]

The West responded in December 1985 with a counterproposal presented by the head of the United Kingdom delegation, Ambassador Michael Alexander, in the 413th plenary session of the negotiations. In a press conference following the session, Alexander publicly described the proposal. Although the Eastern interim proposal suffered from many serious flaws, including the lack of a prior data exchange, Alexander indicated that NATO had no objections to a limited first-stage reduction, having itself proposed a similar measure in 1979. Consequently, NATO proposed reductions of 11 500 Soviet and 5 000 American troops over a one-year period (with removal of equipment left to each side's discretion), followed by a three-year "no-increase" commitment on all direct participants' ground and combined ground/air forces in the reduction area.

Along with the proposed reductions, NATO included a detailed verification package. The package included four elements:

(1) conversion of observation points into permanent entry/exit points through which all forces leaving or entering the reductions area would pass;

(2) the exchange of disaggregated information down to battalion level after the completion of the initial reductions, thereby providing a data base for verifying compliance with the no-increase commitment;

(3) on-site inspections to verify withdrawals as well as post-withdrawal force levels, including the right to 30 inspections per year in each of the three years following completion of initial reductions; and,

(4) creation of a Consultative Commission to clarify ambiguities and settle disputes.

In anticipation of Eastern objections to such stringent verification measures, Alexander offered several counter-arguments. In particular, he explained that the proposal for 30 on-site inspections[2] per year was commensurate with the task at hand:

> *The West will be trying to verify force levels in the order of a million men spread over more than half a million square kilometres in more than 2,000 camps and barracks in three large areas. Against that background a proposal for 30 inspections per annum is fully in accord with the nature and scope of the agreement.*[3]

Eastern negotiators were, in fact, critical of the verification provisions of the proposal. The Soviet head of delegation, Ambassador Valerian Mikhaylov, said in a Foreign Ministry press briefing held in Moscow on 25 March 1986:

> *As to verification and control, the NATO representatives simply lose all sense of proportion and reasonable realism...[The data exchange and on-site inspection provisions] are not at all commensurate either with the nature and content of planned agreement, or with real needs for the ensurance of its implementation, or with specific features of [the] present day military and political situation.*[4]

Within three months of the Western proposal, the WTO tabled a new draft treaty incorporating elements from its June 1983 draft treaty and February 1985 interim proposal, as well as revisions to the latter offered on 6 February 1986. The new draft treaty, presented on 20 February, called for the withdrawal of 11 500 Soviet and 6 500 American troops in the first stage of the agreement. In terms of verification, the treaty accepted joint monitoring at three to four permanent entry and exit points ("PEEPs") in the post-withdrawal period (this had been foreshadowed in Mikhail Gorbachev's disarmament speech of 15 January); allowed on-site inspection "on justified request" (with its implied veto power for the inspected party); sanctioned data exchanges on each country's army and air force, though not disaggregated to the battalion level; and, provided for a Consultative Commission.[5] NATO negotiators did not respond favourably to the draft treaty. They regretted not being given the opportunity to fully explain their December 1985 proposal, and criticized the East's continuing reluctance to embrace their comprehensive verification package.[6]

The complexion of conventional arms negotiations changed radically on 18 April 1986. In a speech before the Socialist Unity Party (SED) Congress in East Berlin, Mikhail Gorbachev proposed "substantial reductions in all the components of the land forces and tactical air forces of the European states and the relevant forces of the United States and Canada deployed in Europe" in an area stretching from the Atlantic Ocean to the Ural mountains.[7] He hoped that broadening the scope of the question would cut the ever-tightening knot in which the two alliances found themselves in Vienna. In this speech, he also included a statement of principles for the associated verification regime:

> *The question of dependable verification at every stage of this process is natural. Both national technical means and international forms of verification, including, if need be, on-site inspection, are possible.*[8]

Accepting the Soviet leader's challenge to pursue new directions in conventional arms control, NATO created the High-Level Task Force (HLTF) on Conventional Arms Control, announced at the foreign ministers' meeting in Halifax, Canada, 29-30 May 1986. The ministers' closing statement explained the objective of the conventional arms reduction process: "[o]ur objective is the strengthening of stability and security in the whole of Europe, through increased openness and the establishment of a verifiable, comprehensive and stable balance of conventional forces at lower levels."[9] The HLTF was to submit an interim report to the Council in October 1986 and a final report to the foreign ministers in December of that year.

While NATO became mired in often divisive procedural and substantive debates within the HLTF,[10] the WTO retained the public-relations initiative. On 11 June 1986 at the WTO Summit in Budapest, Hungary, the collected East-bloc leaders issued an "appeal" to NATO members and all European states. According to their final statement, the objective of the disarmament process was three-fold: (1) eliminate weapons of mass destruction; (2) substantially reduce armed forces and conventional armaments; and, (3) lower states' military expenditures. To achieve these objectives, three stages were necessary. First, each alliance would demobilize 100 000 to 150 000 troops within one to two years.[11] Second, land forces and tactical strike aviation would be reduced approximately 25 per cent from present levels by the early 1990s; this step alone would result in the combined reduction of over one million troops. In the final stage, reductions would continue with other European states (i.e., the neutral and nonaligned countries [NNAs]) joining the process.

The verification provisions included in the appeal did not stray greatly from those in previous proposals. The WTO statement recognized the need for both national technical means and international procedures including on-site inspection. Specifically,

> *on-site verification of the reduction of armed forces, destruction or storage of armaments could be implemented, when needed, with the involvement of representatives of the international consultative commission [with members from NATO, WTO and NNA states]. Check-points staffed by representatives of the international consultative commission could be set up for such control at large railway junctions, at airfields, in ports.*[12]

On the question of data exchange, the WTO heads of state agreed to supply data on the total numerical strength of land forces and tactical strike aviation within the reductions area. In addition, data on the units to be reduced — unit designation and deployment, troop strength, and equipment numbers (for treaty-limited armaments) — and the units remaining after reductions would be provided separately.

Despite this latest WTO proposal, NATO did not advance the HLTF's December 1986 deadline so it might respond rapidly with its own position on reductions. In fact, it could not. Opposing viewpoints had prevented an early consensus,[13] and only a last-minute meeting between U.S. Secretary of State George Schultz and French Foreign Minister Jean-Bernard Raimond produced a compromise before the deadline. This compromise was embodied in the "Brussels Declaration," issued at the foreign ministers' meeting 11-12 December 1986. The Declaration proposed discussions on a new negotiating mandate for conventional arms control covering Europe from the Atlantic to the Urals. Discussions would take place concurrently within two distinct negotiations — the first building upon the achievement of the Stockholm Conference on confidence and security building measures; the second seeking to eliminate conventional force disparities between NATO and the WTO.

No concrete verification proposals were included; the Declaration itself was a statement of principles rather than a specific negotiating proposal. However, the verification principle underlying NATO's conventional arms control proposals in the past was once again repeated: "an effective verification regime (in which detailed exchanges of information and on-site inspection will play a vital part) [is needed] to ensure compliance with the provisions of any agreement, to guarantee that limitations on force capabilities are not exceeded."[14]

Negotiations between NATO and the WTO on a new conventional arms control mandate began 17 February 1987 at the French Embassy in Vienna. While the discussions continued, a new reductions plan was suggested 5 May 1987 by Polish leader Wojciech Jaruzelski in a speech at the second PRON (Patriotic Movement for National Rebirth) Congress. The "Jaruzelski Plan" as it became known contained the following elements:[15]

(1) withdrawal of short-range nuclear missiles, "nuclear-weapon-carrying" aircraft, nuclear artillery and charges (e.g., bombs and mines);

(2) withdrawal of those weapons most suited to offensive conventional operations — strike aircraft, tanks, armed helicopters, long-range and rocket artillery;

(3) joint discussions of military doctrines, aimed ultimately at the mutual adoption of strictly defensive doctrines; and,

(4) agreement on confidence-building measures covering land, naval and air force activities.

The plan covered nine countries in Central Europe — Belgium, Czechoslovakia, Denmark, East Germany, Hungary, Luxembourg, the Netherlands, Poland and West Germany. However, it recommended that negotiations on disarmament in Europe proceed on three territorial levels — the zone of direct contact between the two alliances, Central Europe and the Atlantic-to-Urals region.

The verification regime proposed in the Plan did not differ substantively from that found in the "Budapest Appeal." These measures included: international control commission(s) with NATO, WTO and/or third party participation; information exchanges; notification and observation of the start and completion of withdrawals; exit points for withdrawing forces, and control points at major railway junctions, airfields and ports.

No comprehensive reductions proposals were publicly offered in the next 18 months as both alliances focused their efforts on the mandate talks in Vienna.[16] The discussions were more protracted than many had anticipated. Inter- and intra-alliance divisions on issues such as the inclusion of tactical nuclear weapons and air forces, the handling of dual-capable systems, the relationship of the negotiations to the CSCE, and the geographic definition of the reductions areas and sub-areas, were not easily overcome. Finally, however, consensus was reached on the mandate,[17] and it was included as an Annex to the Concluding Document of the Vienna follow-up meeting of the CSCE, published 17 January 1989.

As stated in the CFE mandate, the objectives were threefold:

> *...to strengthen stability and security in Europe through the establishment of a stable and secure balance of conventional armed forces, which include conventional armaments and equipment, at lower levels; the elimination of disparities prejudicial to stability and security; and the elimination, as a matter of priority, of the capability for launching surprise attack and for initiating large-scale offensive action.*[18]

These objectives were to be achieved by means of militarily significant measures, such as reductions, limitations, redeployments, etc., applied to the whole area, with provision for regional differentiation. The process itself would proceed in a step-by-step manner, ensuring that the participants' security was not adversely affected at any stage. In terms of the scope and area of application, the mandate included the region from the Atlantic to the Urals. Dual-capable equipment was not excluded nor was it to be dealt with separately. Naval forces and chemical weapons, however, would not be discussed.

While the negotiations would take place within the framework of the CSCE, only the participants themselves would determine the procedures and results of the talks, or effect changes in the mandate. Information and views were to be exchanged with other countries within the CSCE.

In terms of verification, the mandate specified that compliance be monitored through "an effective and strict verification regime," including on-site inspection by right and information exchanges in sufficient detail to allow meaningful inter-force comparisons and verification of compliance. The details of the regime would be determined during the course of the negotiations.

With the mandate concluded, both alliances prepared their opening proposals for presentation at the inaugural meeting of the CFE. For the WTO, Soviet Foreign Minister Eduard Shevardnadze introduced a three-stage plan for reductions.[19] The first stage, lasting two to three years, would see each side reduce its armed forces and conventional weapons to levels 10 to 15 per cent below the level of the lower side. In addition, a nuclear-free zone of reduced armaments along the line of direct contact would also be established. In the second stage, armed forces — personnel and equipment — would be cut by a further 25 per cent. Finally, in the third stage, the participant's armed forces would be restructured along strictly defensive lines.

NATO's proposal,[20] presented by British Foreign Secretary Sir Geoffrey Howe, called for overall limits on tanks (20 000), artillery (16 500) and armoured personnel carriers (28 000). No one country would be permitted to have more than 30 per cent of the combined total for both alliances in these categories. Active weapons deployed by each side on allied territory would be limited to 3 200 tanks, 1 700 artillery and 6 000 armoured troop carriers. As with the WTO proposal, no detailed provisions for verification, beyond the statement of principles contained in the mandate, were included.

While the two sides elaborated on their opening proposals in Vienna, the West finally gained the public-relations momentum on 29 May when President Bush announced a new four-point initiative in conventional arms reductions at the NATO summit meeting in Brussels. The initiative called for:

(1) locking in the WTO's acceptance of ceilings on tanks and armoured personnel carriers, and exploring a mutually acceptable limit on artillery;

(2) reducing attack and assault helicopters and all land-based aircraft 15 per cent below the level of the lower side;

(3) reducing American forces in Europe by 20 per cent with a resulting ceiling of 275 000 on Soviet and American ground and air forces stationed outside national territory in the Atlantic-to-Urals region; and,

(4) accelerating the CFE timetable to seek agreement within six months or a year.[21]

From a verification perspective, however, the most interesting element of the Bush initiative was mentioned in a speech he gave at Mainz, West Germany two days after the Brussels summit. In his address, Bush reintroduced the "open skies" policy,[22] calling upon the Soviet Union and its allies to "open their skies to reciprocal, unarmed aerial surveillance flights, conducted on short notice, to watch military activities."[23]

Building upon the Bush initiative, NATO completed its comprehensive arms package and submitted it to the negotiations on 13 July, two months before the scheduled 7 September deadline. The proposal established ceilings on aircraft and helicopters alluded to in Bush's speech at the Brussels summit. Each side would be limited to 5 700 combat aircraft — aircraft designed for air-to-ground bombing and air-to-air combat — and 1 900 combat helicopters. According to NATO figures, the Warsaw Pact would have to eliminate 3 900 aircraft while the Alliance would destroy 1 000 aircraft or 15 per cent of its inventory.[24] Again, attention focused on the nature of the proposed reductions; few details of an associated verification regime were discussed.

The second round of talks ended on 13 July. During the two-month summer recess, the HLTF prepared a position paper outlining measures for information exchange, stabilization, verification and non-circumvention. The proposal was scheduled for release at the opening of the third round on 7 September. However, its completion was delayed by differences within the Alliance. Greece, for example, rejected the 40 000-troop-limit for prior notification of force concentrations, maintaining that it did not adequately constrain the activities of its eastern Mediterranean rival, Turkey.[25] France and the United Kingdom were concerned that measures to monitor production of treaty-limited items might leave their defence industries open to industrial espionage.[26] Finally, the United Kingdom and the Federal Republic were uneasy over restrictions on armed helicopters. West Germany feared these restrictions would frustrate their efforts to build an air cavalry, while Britain worried they would thwart plans to purchase American Apache attack helicopters.[27] These obstacles were overcome, or at least sidestepped, in the following two weeks. On 11 September in Washington, U.S. Secretary of State James Baker and British Foreign Secretary John Major reached a compromise on the buildup of arms along the Atlantic-to-the-Urals (ATTU) periphery, while dodging the production monitoring issue.[28] Eight days later, Greece withdrew its opposition to the stabilization package. With the last Alliance hurdle removed, NATO introduced its proposal in Vienna on 21 September.

This proposal represented the most extensive package of supporting measures officially presented to date.[29] They were separated into four categories: exchange of information, stabilizing measures, verification provisions and non-circumvention measures. From the verification perspective, the information exchange and verification packages were of particular interest:[30]

(1) Exchange of information —

Each participant would provide information on the command organization of its land, air, and air defence forces in the area of application down to the battalion and squadron level. Furthermore, the normal peacetime locations and holdings of treaty-limited items (TLI) — main battle tanks, artillery pieces, armoured troop carriers, combat aircraft, combat helicopters (collectively referred to as "treaty-limited equipment"(TLE)), and armoured vehicle launched assault bridges — would be supplied for the following:

(a) headquarters components and units with treaty-limited equipment and/or Armoured Vehicle Launched Assault Bridges (AVLB);

(b) monitored storage depots;

(c) non-unit assigned TLE not in monitored storage;

(d) other sites where TLE may be present on a regular basis, e.g., repair depots, training areas, etc.;

(e) AVLB in monitored storage and elsewhere;

(f) TLE not subject to treaty limitation, e.g., produced but not in service with national forces, or equipment held by paramilitary forces.

In addition, locations and personnel levels would be given for low-strength units, and American and Soviet ground and air force personnel stationed on allied territory. Locations of sites holding TLE after 1 January 1989 and subsequently withdrawn would be identified as well.

This information would be exchanged upon signature of the treaty, on the date it becomes effective, on 15 December of the year in which it is signed, and upon completion of reductions. Thereafter, the exchange is to take place on 15 December annually.

Notification of the permanent reorganization of existing unit structures or the introduction of new units into the area of application would be required 42 days in advance. Participants would have to report changes of 10 per cent or more in unit strength or TLE holdings in the preceding annual exchange or as they occur.

(2) Verification measures —

As set out in the proposal, the verification regime must (1) provide confidence that treaty provisions are being obeyed; (2) deter violations of those provisions; and, failing that, (3) provide timely detection of the infractions. To these ends, the tasks are to validate the baseline data, monitor reductions and confirm compliance with the treaty after reductions. On-site inspections are to be used in part to perform these tasks. At declared sites, inspections can be requested on short notice with no right of refusal. Quotas would be set, expressed in terms of the number of days each participant must permit inspection teams on its territory. The intensity of inspections would be greater in the first months of the treaty in order to validate the baseline data; during this period, the armed forces of the participants would not be required to stand-down. The inspector has the right to determine the sites visited and the number of days spent on the inspected state's territory. However, the time spent at any one site would be limited, as would be the number of teams accepted on the inspected state's territory at any given time.

At non-declared sites, the inspected state has the right of delay and ultimate refusal of a request. Again, inspections are to be limited by quota.

The second task involves monitoring the destruction of equipment and the withdrawal of Soviet and American personnel. Equipment in excess of treaty limits is to be destroyed according to an agreed timetable, with prior notification and on-site inspection without quotas or right of refusal. Similarly, timetable and monitoring provisions are to be arranged for American and Soviet troop withdrawals.

In addition to on-site inspections, provision would be made for aerial inspection and the use of National and Multinational Technical Means. "Tagging" of combat aircraft and combat helicopters was also a possibility the Alliance felt deserved further study.

Other measures included the creation of a joint consultative group, and general considerations regarding inspection rights, the composition of inspection teams, the transfer of unused quotas and limits to inspections accepted from the same participant. While details in many instances were deferred to later negotiation, this document represented significant progress toward a comprehensive CFE verification regime.

At the close of the third round on 19 October, the WTO tabled two working papers on stabilization, information exchange and verification measures.[31] The proposals for the data exchange differed from the Western position in only three respects. First, the WTO suggested data be provided for land, air and air defence forces down to the regimental rather than battalion or squadron level. Second, no reference was made to the need for data on TLI not subject to treaty, e.g., equipment for export or held by paramilitary forces. Finally, they recommended that armed forces personnel levels be supplied for all participants rather than only Soviet and American stationed forces and units with treaty-limited items.

Likewise, the verification measures differed only slightly from the Alliance's proposal. NATO had raised for further study the possibility of "tagging" combat aircraft and combat helicopters. For its part, the WTO called for treaty-limited aircraft to be placed in the open upon request for inspection. Furthermore, inspection teams would have the right of free access to aircraft and their weapon systems at inspected airfields. In addition, the WTO reintroduced the idea of entry/exit points established along and inside the area of application. Finally, provision was made for verifying temporary breaches of the limits due to routine replacement and other reasons.

As the fourth round of the CFE negotiations opened on 9 November, verification was one of the items receiving highest priority for discussion. Although many technical details of the regime had yet to be determined, the prospects for success seemed promising. As demonstrated in their respective working papers, the two alliances agreed in principle on many issues. This common ground should serve as the basis for continued progress toward an effective CFE verification regime.

Notes

1. *The Arms Control Reporter 1985* (Brookline, Massachusetts: Institute for Defense and Disarmament Studies, 1985), p. 401.B.83-84.
2. The 30 challenge inspections included 25 ground and 5 air/ground inspections; notification had to be given 12 hours in advance, with the inspection beginning 24 hours after this notice (*The Arms Control Reporter 1986*, p. 401.A.7).
3. *The Arms Control Reporter 1985*, p. 401.D.12.
4. Foreign Broadcast Information Service, *Daily Report Soviet Union* (hereafter FBIS SU), 8 April 1986, p. AA7.
5. FBIS SU, 21 February 1986, p. AA1.
6. *The Arms Control Reporter 1986*, p. 401.B.103.
7. FBIS SU, 18 April 1986, p. F8.
8. Ibid.
9. "Statement on the Ministerial Meeting of the North Atlantic Council at Halifax, Canada, on 29 and 30 May 1986," *NATO Review* 34 (June 1986): 30.
10. See Jonathan Dean, "Can NATO Unite to Reduce Forces in Europe?" *Arms Control Today* 18 (October 1988): 11-18, for an excellent survey of the concerns that divided NATO members in the months prior to the opening of the CFE negotiations.
11. Forces would be eliminated by formation, with personnel demobilized and equipment destroyed, stored at depots on national territory, or converted to peaceful purposes. Nuclear charges would be destroyed.
12. "Warsaw Pact Appeal to the NATO States and All European Countries Concerning a Program for Armed Forces and Conventional Arms Reductions in Europe," reproduced in Joachim Krause, *Prospects for Conventional Arms Control in Europe*, Institute for East-West Security Studies Occasional Paper Series No. 8 (Boulder, Colorado: Westview Press, 1988), p. 67.

13. The principal actors in the internal disagreements were France and the United States. For example, in procedural matters, France insisted upon NNA participation in the negotiations and, thus, an explicit link to the CSCE. The French government wished to avoid the bloc-to-bloc approach that had characterized the MBFR discussions; it feared that a formal NATO proposal would create the impression that France had indirectly reentered NATO's integrated command, thereby disrupting the domestic right/centre/left defence consensus (Dean, "Can NATO Unite to Reduce Forces in Europe?" p. 17). For its part, the American government wished to avoid linkage to the CSCE. For one reason, the Administration felt that it had been pressured to accept a less-than-satisfactory agreement at Stockholm under the pressure of the CSCE schedule, and, consequently, it did not want to have the same CSCE-related time pressures interfere with the new negotiations (*The Arms Control Reporter 1986*, p. 401.B.123).
14. "Brussels Declaration on Conventional Arms Control by Ministers at North Atlantic Council Session," *NATO Review* 34 (December 1986): 27-28.
15. "Memorandum of the Polish People's Republic on Arms Reduction and Confidence-Building in Central Europe, Transmitted on 17 July 1987 to the States Participating in the Conference on Security and Cooperation in Europe by the Ministry of Foreign Affairs of the Polish People's Republic," in Krause, *Prospects for Conventional Arms Control in Europe*, pp. 77-9.
16. The most significant event in conventional disarmament during this period was Mikhail Gorbachev's announcement before the United Nations General Assembly on 7 December 1988 that the Soviet Union would unilaterally reduce its armed forces by 500 000 men over the next two years. Six tank divisions would be removed from the German Democratic Republic, Czechoslovakia and Hungary by 1991, totaling 50 000 men and 5 000 tanks. Combined with reductions in the European U.S.S.R., force reductions in the region from the inter-German border to the Urals would amount to 10 000 tanks, 8 500 artillery systems, and 800 combat aircraft (*Speech by Mikhail Gorbachev at the UN General Assembly*, News Release no. 97, Press Office of the U.S.S.R. Embassy in Canada, 8 December 1989, p. 21).
17. The mandate talks were almost derailed in the final hours by a dispute arising between Greece and Turkey on the definition of the southern boundary of the CFE area. Soviet and Turkish negotiators had agreed on a line that excluded the port of Mersin on the Mediterranean coast. The Greek government objected to this exclusion, however, since Mersin was used to supply Turkish forces in Cyprus. Nevertheless, the mandate was signed on 14 January after NATO offered to resolve the dispute internally in later talks (*The Arms Control Reporter 1989*, p. 407.B.115-17).
18. "Mandate for Negotiation on Conventional Armed Forces in Europe," in *CSCE: A Framework for Europe's Future*, p. 44.
19. Michael Gordon, "Cutting Arms in Europe: It's Down to the Details," *The New York Times*, 9 March 1989, p. 6.
20. Ibid.
21. *The Arms Control Reporter 1989*, p. 407.B.176.
22. This policy was originally proposed at the Geneva summit conference in July 1955 by President Eisenhower. The proposal was intended to reduce the risks of surprise nuclear attack through a comprehensive exchange of information on each side's military forces and facilities combined with a system of aerial reconnaissance and ground inspection. The Soviet Union rejected the proposal, maintaining that the plan was "nothing more than a bald espionage plot" (Jerome H. Kahan, *Security in the Nuclear Age: Developing U.S. Strategic Arms Policy* (Washington, D.C.: The Brookings Institution, 1975), p. 56).
23. "Proposals for a Free and Peaceful Europe," speech by President George Bush, *Current Policy* no. 1179 (Washington, D.C.: United States Department of State, Bureau of Public Affairs, 1989), p. 3.
24. Thomas Friedman, "NATO's Proposal on Aircraft Cuts Ready, Baker Says," *The New York Times*, 13 July 1989, p. 1.

25. *The Arms Control Reporter 1989*, p. 407.B.215.
26. *Trust and Verify: The Bulletin of the Verification Technology Information Centre*, December/January 1990 (London, England: Vertic, 1990), p. 1.
27. *The Arms Control Reporter 1989*, p. 407.B.219.
28. Ibid.
29. *Chapter III: Measures of Information Exchange, Stabilization, Verification, and Non-circumvention*, Conference paper, Negotiation on Conventional Armed Forces in Europe, 21 September 1989, pp. 1-14.
30. A distinction should be drawn between "verification measures" and "measures facilitating verification." Data exchanges assist the verification process. Compliance with weaponry ceilings cannot be confirmed in the absence of a verifiable data base, including such information as unit numbers and types, weaponry stocks, etc. Strictly speaking, though, this is not a "verification" measure; it differs fundamentally from measures specifying the means by which treaty-related activities are physically observed, e.g., on-site inspections or surveillance overflights. In the same vein, overhead surveillance using National Technical Means, i.e., earth-orbiting satellite systems, should be classified as a verification measure, while non-interference with NTM is more properly a verification-facilitating measure (it sets the environment in which NTM can operate with maximum effectiveness). To attempt a definition,"verification measures" are the means or modalities by which treaty-regulated activities are physically observed and monitored; while "facilitating measures" are actions, norms and procedures enhancing the operational effectiveness of monitoring systems.
31. *The Arms Control Reporter 1989*, p. 407.D.43.

Part 2. Verification Technologies

NATO's September 1989 verification package referred to the use of three surveillance methods: on-site inspection, national and multinational technical means and aerial surveillance. While it described the terms governing on-site inspections at some length, the latter two were discussed in considerably less detail. Nevertheless, both have a vital role to play in monitoring a reductions agreement. What capabilities are available for spaced-based and aerial surveillance?

National Technical Means[1]

The American military reconnaissance satellite KH-11 (Keyhole 11), operational since December 1976, has the ability to monitor the Soviet Union and Eastern Europe in "real time" using a technology known as charge-coupled devices (CCDs). Developed in 1970 at the AT&T Bell Laboratories, the CCD is an array of thousands of very small light-sensitive sensors or picture elements ("pixels"). These pixels store electrons in proportion to the intensity of the light received. The number of electrons is then tallied and transmitted in digital form, along with the position of the pixel in the grid, via a communications satellite to the CIA satellite imagery centre located at Fort Belvoir, Virginia. Computers at the ground station receiving this digital information recreate the original image within minutes of the KH-11's overflight. On the satellite, the pixels are drained of their electrons and are once again ready for use, the entire procedure being completed within milliseconds. This technology frees satellite reconnaissance from the restrictions of photographic film and increases their operational life to two to three years depending upon fuel supplies.

The KH-11 is currently being replaced by the latest in the Keyhole series, the KH-12. This satellite, with a ground resolution of approximately 10 cm, is so large that only the space shuttle or Titan 34D7 booster rocket can carry it into orbit. The KH-12 is the first satellite with sufficient sensitivity for thermal infrared imaging, allowing it to "see" in the dark.

Future developments in the American military satellite reconnaissance program will focus on a technology known as the synthetic aperture radar (SAR). The resolution of satellite-borne conventional radars is restricted by the diameter of the receiving antenna; to increase resolution, the antenna must be physically enlarged beyond all reasonable practical limits. The SAR, however, expands the effective size of the antenna to one many kilometres in length through the selective combination of radar signal echoes by its computer. This technique increases the length of the synthetic antenna (without increasing the physical size of the antenna) equal to the distance travelled by the satellite during the time the signals are processed, with dramatic increases in ground resolution. Once satellite-borne SAR becomes operational, the United States will have a high-resolution surveillance capability that can "see" through both darkness and cloud cover.

Verification of arms control treaties using space platforms is no longer limited to the American military satellite reconnaissance program. An increasing number of commercial satellites may enable other nations to independently monitor treaty compliance to some extent.[2] The best-known of these is the French SPOT ("satellite pour l'observation de la terre") launched in February 1986. This satellite has a 10 m resolution for black-and-white images and 20 m resolution in colour. Moreover, it can move its mirrors up to 27 degrees to the right or left, allowing it to produce stereoscopic images. SPOT is not the only independent commercial satellite to have entered earth orbit in recent years. Japan orbited an ocean satellite, the MOS-1, with a 50 m resolution in March 1987; the Soviet Union launched India's IRS-1 satellite (36 m resolution) in 1988; in September of that year, Israel launched its experimental OFFEQ-1.

One of the technical problems blocking the use of commercial satellites for arms control verification has been their relatively low ground resolution. However, the next generation of satellites planned for the early 1990s may overcome this problem. The Japanese ERS-1, with an anticipated 1992 launch-date, has a SAR with an 18 m resolution. Canada's Radarsat, planned for launch in 1994, will have a SAR with a resolution under 10 m.[3] Other countries, including Brazil, China and the United Kingdom, are also pursuing independent commercial satellite programs for the coming decade. Next-generation commercial satellites will have the technical capabilities to open space-based remote sensing for treaty verification to nations other than the United States and Soviet Union. The operational and political implications of this are the subject of continuing research and debate.

Aerial Surveillance

Several reconnaissance aircraft may have relevance to the CFE-verification role. The American U-2 was the first high-altitude strategic reconnaissance aircraft, introduced in 1956.[4] The present version, the U-2R, has a range of 5 000 km flying at a maximum speed of approximately 1 000 km per hour at 12 200 m (40 000 ft.), with an operational ceiling of 21 300 m (70 000 ft.). It carries a package of infrared spectrometers, optical cameras and side-looking airborne radar (SLAR). Although once the mainstay of the American strategic reconnaissance program, it has since been replaced in most tasks by the SR-71 Blackbird and/or reconnaissance satellites. However, it is still used to monitor some regions including Central America and the Carribean basin.

The SR-71 Blackbird began operations on 7 January 1966. It has a speed of Mach 4 at 38 100 m (125 000 ft.), and can film a 155 000 km^2 area every hour flying at an altitude of 25 900 m (85 000 ft.). It, too, carries a varied sensor package

Figure A-1. Overall Detection Probability — Interval Length = 5 Days

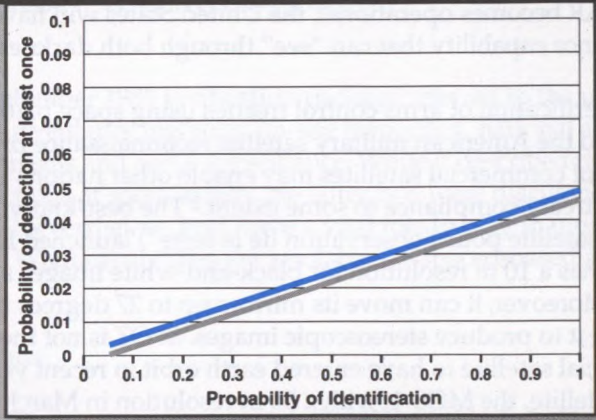

Figure A-2. Overall Detection Probability — Heightened Sortie Rate

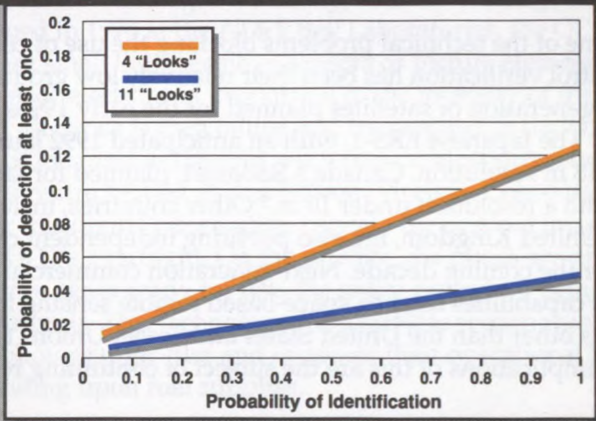

Figure A-3. Overall Detection Probability — Satellite Surveillance

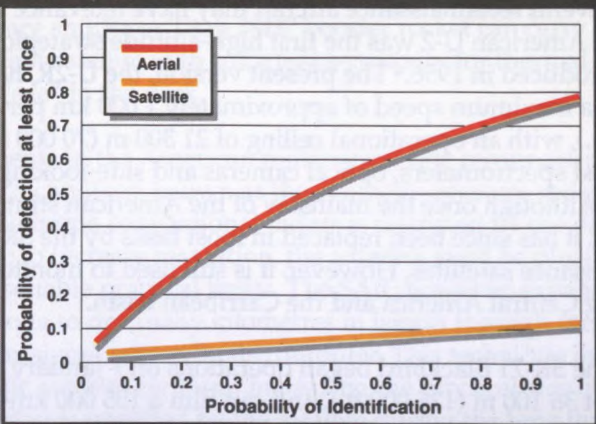

Figure A-4. Overall Detection Probability — East European Sub-region

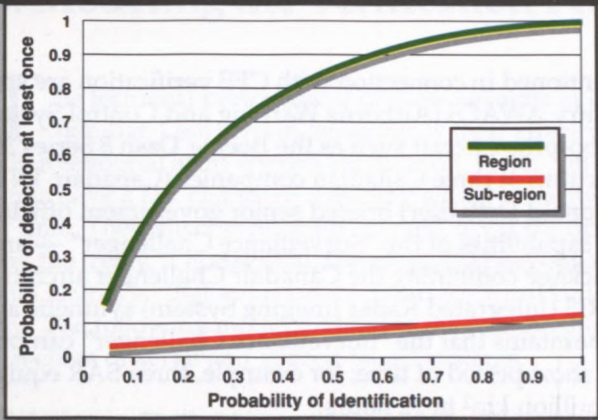

Figure A-5. Overall Detection Probability — Interval Length = 10 Days

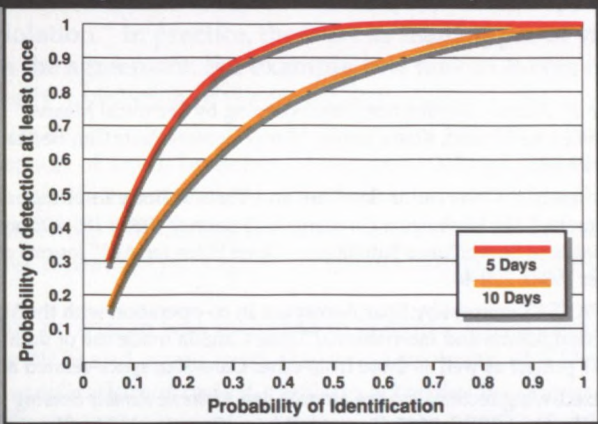

Figure A-1 summarizes the hypothetical probability of detecting an unauthorized out-of-garrison military unit at least once assuming four aircraft sorties are flown over a five-day search interval.

Figure A-2 compares the overall detection probability in the base case to the probability of detecting a treaty violation assuming 11 sorties are flown over the same search interval.

Figure A-3 compares the detection probability in the "heightened sortie" case to that for a surveillance satellite system taking 11 "looks" in the eastern ATTU region over the five-day interval.

Figure A-4 compares the detection probability in the "heightened sortie" case to the probability of detecting a violation in the Central European region assuming the 11 aircraft sorties over the five-day search interval are restricted to East Germany and Czechoslovakia.

Figure A-5 compares the overall detection probability in the "heightened sortie/East European sub-region" case to that for 22 aircraft sorties over a 10-day search interval in the same sub-region.

including SLAR[5] with a slant range of 100 km and SAR for high-altitude night imaging.

Other aircraft mentioned in connection with CFE verification are specially modified Boeing E-3 Sentry AWACS (Airborne Warning and Control System) and extended-range turbo-prop aircraft such as the Boeing Dash 8 Series 300. In December 1989, a consortium of three Canadian companies (Canadair, INTERA Technologies and MacDonald Dettwiler) briefed senior government officials in Ottawa on the technical capabilities of the "Surveillance Challenger" — an airborne surveillance package combining the Canadair Challenger aircraft and MacDonald Dettwiler IRIS (Integrated Radar Imaging System) synthetic aperture radar. The consortium maintains that the "Surveillance Challenger" can provide wide-area coverage in a short period of time; for example, three-SAR equipped aircraft can cover three million km^2 in 12 hours.[6]

Notes

1. See, for example, John A. Adam, "Verification: Peacekeeping by Technical Means," *IEEE Spectrum* (July 1986): 42-56; and, Kosta Tsipis, "Arms Control Pacts Can Be Verified," *Discover* (April 1987): 79-93.
2. Hugh De Santis, "Commercial Observation Satellites and Their Military Implications: A Speculative Assessment," *The Washington Quarterly* 12 (Summer 1989): 185-200; and, Johan Swahn, "International Surveillance Satellites — Open Skies for All?" *Journal of Peace Research* 25 (September 1988): 229-44.
3. Development of the PAXSAT concept by Spar Aerospace in co-operation with the Verification Research Unit of External Affairs and International Trade Canada made use of data produced under the RADARSAT project as well as those from other Canadian space-related activities.
4. For a description of fixed-wing reconnaissance aircraft, see *Airborne Remote Sensing for C.F.E. Verification: The Platform*, SER-8-2295 (Toronto: Boeing Canada, de Havilland Division, 1989); Jeffrey Richelson, "Technical Collection and Arms Control," in *Verification and Arms Control*, ed. William C. Potter (Lexington, Massachusetts: Lexington Books, 1985): 169-216; and, "Verification: Peacekeeping by Technical Means," pp. 42-56.
5. SLAR may use either synthetic aperture or real aperture radars.
6. *Airborne Surveillance: A National Sovereignty Requirement*, Presentation given by INTERA, Canadair and MacDonald Dettwiler representatives, Ottawa, Canada, December 1989.

Part 3. Modeling the Verification Problem

The technical performance of these systems in routine operations is familiar. Less certain, however, is their effectiveness in the unfamiliar world of conventional arms control verification. Here, "effectiveness" requires that systems have a fair chance of detecting a treaty violation within a reasonable period of time. Their success depends, in part, upon the operating environment defined by the treaty. It is essential, therefore, that negotiators recognize these operational factors so that appropriate parameters can be incorporated into the agreement. The following model highlights the relationship of such factors to the effectiveness of aerial and spaced-based systems.

Treaty Violation — Definition

Effectiveness cannot be considered, however, without first defining a "treaty violation." In practice, there are as many types of violations as limiting clauses in the agreement. For example, one tank in excess of a 20 000-tank limit is technically a violation of the treaty, although not one to which a great deal of military importance is attached. In the model presented here, the concern is not with detection of small breaches of weapon ceilings, but rather with detection of militarily significant violations. The definition of "militarily significant" is shaped by the following "stabilizing measure" that could be included as part of a CFE supporting measures package — prenotification of out-of-garrison activities.

This provision was included in NATO's MBFR proposal tabled in December 1979 and again in its stage-one proposal of 5 December 1985.[1] It required notification of out-of-garrison activities by one or more "division formations"[2] within the area of reductions — the NATO Guidelines Area (NGA)[3] — and the western military districts of the Soviet Union. A schedule of these activities would be published in an annual calendar with supplemental information provided no later than 30 days prior to the activity.[4]

The September 1989 supporting measures package included provisions for prior notification of the movement of ground treaty-limited equipment exceeding (within a two-week period) 600 main battle tanks, 400 artillery, and 1 200 armoured troop carriers. Written notice would be required 42 days in advance, including the purpose of the movement, the numbers involved, their normal peacetime locations, and the intended destination and length of stay.[5] Similarly, notification would be required at least 12 months in advance for the one military activity involving over 40 000 troops or 800 main battle tanks allowed each participant over a two-year period.[6]

As these examples demonstrate, the concept of pre-notification for out-of-garrison activities is not without precedent in past conventional arms control proposals. Moreover, this stabilizing measure greatly eases the task of monitoring treaty compliance. Post-reduction forces remain, as a matter of course, within designated garrisons. All out-of-garrision activities, e.g., for training exercises and unit rotation into or out of the area of application, are reported in advance, including such information as timing, duration, location, participating units, etc. The presence of unauthorized military formations, i.e.. those for which no notification has been given, outside the garrison areas constitutes a violation of the treaty.

The Objective

The objective of the verification exercise is to detect a militarily significant, inadvertent treaty violation:

(1) "Militarily significant" treaty violation —

The unauthorized presence of a unit formation(s) — brigades, divisions, armies, etc. — outside the designated garrisions, that is, unit(s) engaged in out-of-garrison activities for which no advance notification has been given. The following examples presented in the "Analysis" assume the presence in the coverage area of only one such "target," consisting of one unit formation or, alternatively, several units operating together. However, the model can accommodate multiple targets involving many independently operating units.

(2) "Inadvertent" treaty violation —

In general, infractions of the treaty can be categorized as either intentional or inadvertent depending upon the violator's intent. In the former, the violator consciously attempts to circumvent the terms of the treaty, for example, to assist preparations for an offensive; assuming it is the intention to preserve strategic and tactical surprise, the violator will try to hide these activities from the scrutiny of the treaty monitoring systems. The latter, on the other hand, represents an unintended and, hence, unconcealed contravention of the treaty, for example, the unsanctioned actions of a "rogue" unit commander, or careless co-ordination of unit rotation through the area of application. This is the case to which the following model applies.

The verification regime, then, is designed to deter a militarily significant, inadvertent (i.e., observable) treaty violation, and, thus, strengthen routine compliance with the treaty. Why is this important? The detection of violations, even those lacking malicious intent, can disrupt the stability of the treaty environment, leading to recriminations and, in the extreme, abrogation of the treaty.

Moreover, it can destroy confidence in the honest intentions of others, with effects extending beyond the treaty to the broader political relationship. Assuming they entered it in good faith, no participant wants to disturb the treaty relationship through negligence. With an effective verification regime that the participants believe able to uncover virtually any observable infraction, greater pains will be taken to minimize inadvertent events. In this manner, an effective regime reinforces treaty discipline among the participants, creating a stabler security environment.

The Binomial Experiment

The verification problem is modeled in terms of a binomial experiment. In general, the binomial experiment has the following properties:[7]

(1) It consists of "n" identical trials ("n" being a positive finite number).

(2) Each trial results in one of two outcomes — success or failure.

(3) The probability of success — p(s) — for a single trial equals the value "p" and is the same for each trial. Conversely, the probability of failure — p(f) — equals one minus the probability of success [1 - p] or the value "q."

(4) The trials are independent.

How do these properties translate to the verification problem? We examine each in turn:

Property (1) — One "look" by the monitoring system in the coverage area represents one "trial." Moreover, all "looks" are assumed to be identical. That is, the operating parameters for each observation are the same — sensor type, target resolution, sensor range, pointing error and instability, imperfections in optics, etc.

Property (2) — Each trial or "look" results in one of two outcomes — the violation is detected (success) or it is not (failure). Operationally, no such dichotomy exists; the technical evidence of a possible violation is often ambiguous, in which case the event in question is monitored until its meaning becomes apparent and/or a request for clarification is made. However, its use here refers to the broader political context in which questions of compliance are decided. "Success" (a violation is detected) implies that the technical evidence from one "look" of the monitoring system is conclusive; that is, the political authorities are satisfied that, on the basis of this evidence, a violation has taken place and an accusation to this effect can be supported (although other considerations may argue against actually making such an accusation). Alternatively, the technical evidence may be ambiguous, leading the political leadership to conclude that there are insufficient grounds to confront the potential violator. Both this contingency and the one in which no untoward activities have been uncovered represent "failure" (a violation is not detected) for a given trial.[8]

Property (3) — The probability of detection for each "look" equals the ratio of the area searched (the "swath") to the coverage area. With current technologies, the coverage area cannot be constantly watched in its entirety, i.e., the "swaths" for satellite and airborne sensors are not conterminous with the area to be monitored.[9] Thus, the area is surveyed in a series of "looks," each examining some part of the region. This is analogous to shining a flashlight on a large table — each "look" of the sensor system represents a circle of light illuminating a portion of the table. The probability that the target falls within this "circle of light" is simply the ratio of the area searched to the total area of the monitored region. For example, assume the coverage area includes all of Eastern Europe and the western Soviet Union (5.96 million km^2 from the inter-German border to the Urals) and that the swath cut by a satellite-borne surveillance system in this region is 777 000 km^2 (2 400 x 320 km). The ratio of the swath to the coverage area is approximately 1:8. Thus, the probability that the target will be in the area observed in one "look" of the sensor system equals 1/8.

Property (4) —It is assumed that the monitoring area is searched at random and there is no restriction on the number of times a region within this area can be surveyed, i.e., examining a region in one "look" does not preclude its being searched in subsequent "looks." Strictly speaking, no surveillance system's search pattern is completely random. The locations it monitors are spatially related to each other; the system's position at time "t+1" invariably depends upon it's position at time "t." Nevertheless, the flexibility of movement for aircraft allows them to approximate most easily a random search pattern. Satellite-borne sensors are somewhat more problematic since they normally follow regular and predictable orbital paths; in some instances they can be manoeuvred but this is done only at a cost to the operational life of the satellite, e.g., in the depletion of fuel supplies. For wide-area coverage, however, the relatively high frequency of visits over time renders the satellite search pattern effectively random in the long-term. Thus, the model can also be applied to the satellite surveillance case.

As defined here, the verification problem — detection of militarily significant, inadvertent treaty violations — can be interpreted in terms of the binomial experiment. Although admittedly an abstraction from reality, the essential elements of the problem correspond to the properties of the experiment.

The Verification Model

The elements of the model can now be defined. These include the following:

(1) The Probability of Detection —

The probability of detection depends upon two factors:

(i) The probability of observation

As discussed above, technological limitations do not allow the monitoring area to be kept under continuous surveillance. Thus, the probability that the target falls within the swath of the surveillance system for each "look" is given by:

$$p(o) = s/c$$

where $p(o)$ = probability of observation;
s = swath area;
c = coverage area.

An illustrative calculation for this variable was presented in the discussion of Property (3).

(ii) The probability of identification

Although the target may fall within the swath searched by the sensors, identifying the unauthorized unit(s) is not guaranteed. Various factors may interfere with sensor performance. Environmental conditions may hamper the operation of particular sensors and/or monitoring systems. Photoreconnaissance satellites, for example, are unable to operate in darkness or in cloud cover (thermal and radar imaging sensors can overcome these obstacles). Similarly, heavy fog, severe storms, or other atmospheric conditions can delay or ground surveillance aircraft.

Of particular importance for satellite systems, the ground resolution of the sensor may not permit precise identification of the unit(s) detected. Table 1 summarizes the resolution requirements for interpretation of various targets.

With a resolution of 20 m, for example, a reconnaissance satellite can detect a troop unit or bivouac. However, a resolution of .3 m is required to describe the target in detail, an important discrimination capability especially if the target is collocated with units participating in permitted out-of-garrison activities. High resolution and greater discrimination is not without cost. As target resolution is

Table 1

Ground Resolution Required for Treaty Verification and Crisis Monitoring (in metres)

Object	Detection	Recognition	Identification	Description
Troop Units or Bivouacs	20.0	2.1	1.2	0.30
Headquarters	3.0	1.5	0.9	0.15
Supply Dump	1.5	0.6	0.3	0.03
Vehicles	1.5	0.6	0.3	0.05
Artillery and Rockets	0.6	0.3	0.15	0.05

Source: Dietrich Schroeer, Science, Technology, and the Nuclear Arms Race *(New York: John Wiley and Sons, Inc., 1984), p.376.*

increased, more data is transmitted to ground stations, requiring greater expenditures of electrical energy drawn from the satellite's solar cells. Moreover, data management is complicated by receipt of many finely detailed images, a problem to which the discussion now turns.

Difficulties may be experienced in the analysis and interpretation of data received from the monitoring systems. One problem that bedeviled interpretation in the past was the quality of the images, particularly the clarity of photographs from overhead sensors. With the use of advanced computer enhancement techniques — spatial filtering and contrast enhancement, for example — the problem of blurred or highly degraded photographs has been largely overcome.

The greatest obstacle to timely interpretation, however, remains the system's ability to handle ever-increasing quantities of data with limited human and material resources. To illustrate the magnitude of the problem, 10 000 to 100 000 person-years would be needed to examine one complete picture of North America at a ground resolution of 10 cm.[10] To eliminate some of the data burden, coverage of areas in which illegal activities are not expected may be less exacting; for example, the resolution of satellite-borne sensors may be lowered over seemingly "safe" areas. This practice, however, can lead to "surprises" when forbidden activities are first discovered at locations only superficially monitored before.

In general, evasion and concealment also hampers target identification. However, the incorporation of these factors within the framework of this model is problematic. Evasion refers to the co-ordination of the movements of the unauthorized unit(s) with the anticipated search pattern of the surveillance system so as to remain outside the "swath" at any given time. A violator intentionally attempting to circumvent the treaty is likely to try to evade detection in order to preserve strategic and tactical surprise. In these circumstances, the model does not apply. This situation is better modeled by a two-person game with various search and evasion strategies for the inspector and the inspectee respectively.[11]

Concealment refers to passive measures taken by the violator to conceal the presence of the target from the surveillance system. The target does not avoid the system's search pattern; rather, camouflage and other concealment techniques are used to degrade the ability of the monitoring system to recognize the target as it passes overhead. Concealment, then, effectively reduces the acuity of the surveillance system, hence reducing the probability of identification. However, the inclusion of this factor raises a logical inconsistency in the analysis. The problem as originally defined assumed that the treaty violation was inadvertent, an unintended infraction likely caused through negligence or lax organizational control and co-ordination. To assume that the violator attempts to hide the offending units implies an awareness that its actions are in contravention of the treaty. Thus, the violation could not be inadvertent. For consistency in the definition of the problem, the model assumes that no effort at concealment is made.

To summarize, although further refinements in sensor technologies, data processing and management, computer-assisted interpretation, etc. will continue, the interpretation task will never become perfect. In other words, there remains some chance that the system will not provide timely identification of a treaty violation even though the surveillance system has passed in its vicinity. Probability estimates for identification, therefore, must be incorporated in the calculation of the overall probability of detection.

The probability of detection, then, is a conditional probability dependent upon the intersection of two events:

Event A. The target falls within the area searched by the sensor;

Event B. The sensing/interpretation system identifies the violation.
According to the Multiplicative Law of Probability, the probability of the intersection of these two events is

$$p(ab) = p(a) \times p(b|a)$$

That is, the probability that both events occur equals the probability of the first multiplied by the probability of the second given that the first has already occurred.[12] In this model, the probability of detection is

$$p(d) = p(o) \times p(i)$$

where $p(d)$ = probability of detection;
$p(o)$ = probability of observation;
$p(i)$ = probability of identification given that the target is observed.

To illustrate, assume that the probability of observation is 1/8 or .125 (see above). If the probability of identification is .95 (i.e., given that the target lies within the swath searched by the surveillance sensors, the monitoring system identifies it 95 per cent of the time), the probability of detection equals .125 × .95 or .119 — each "look" has approximately a 12 per cent chance of detecting the violation.

(2) The number of "looks"

The number of "looks" taken by the surveillance system depends upon the interval length and the "look" rate:

$$L = t \times r$$

where L = number of "looks;"
t = interval length;
r = "look" rate per unit time.

For example, assume that the surveillance system searches a swath of the coverage area three times daily. Further assume that the interval length is 10 days. The number of "looks" taken by the system in 10 days, then, is 30.

The variables of the model have now been defined. The probability of detecting a violation at least once[13] for a given interval can be calculated using the binomial probability distribution:[14]

$$p(D) = 1 - [1 - p(d)]^L$$

where p(D) = probability of detection at least once.

Returning to the example, the probability of detection for each "look" was .119 and 30 "looks" were taken over a 10-day period. Therefore, the probability of at least one detection of the target is .9777. That is, there is a 98 per cent chance that the violation will be detected within the 10-day period.[15]

Analysis

Before proceeding with the analysis, it must be emphasized that the overall detection probability estimates presented here are illustrative only. The model from which these estimates are derived is a simplification of reality and, consequently, cannot capture all the operational factors that bear upon this reality. Hence, the estimates are, at best, reflective of actual detection probabilities. Nevertheless, the following analysis highlights the relationship of key variables in the verification problem to the likelihood of detection. It is the exploration of these relationships rather than the precise estimation of detection probabilities that recommends the binomial model when examining the verification problem.

The example here assumes the monitoring task is performed by an aerial surveillance system using a SAR.[16] Airborne remote sensing for conventional arms control verification has received special attention in recent months, as evident in President Bush's "open skies" proposal. These systems possess many operational and political advantages over satellite systems especially relevant to CFE verification. Operationally, the flight frequency, profile, routing and coverage of fixed-wing aircraft can be easily changed; short-notice inspections can be conducted throughout the coverage area; observer teams can be transported without losing surveillance capability; sensors can be quickly repaired or replaced; and, life-cycle costs are lower than those for satellite systems.[17] Politically, aerial surveillance opens the verification process to all participants. Exclusive reliance on National Technical Means limits verification to those states with the technical and financial resources to maintain space-based surveillance systems; with airborne systems, the process becomes truly multilateral. With growing awareness of the advantages of aerial surveillance, it is instructive to examine the verification problem primarily in terms of these systems (as noted above, the model applies to satellite surveillance as well).

In the model, the following assumptions are made. The coverage area (from the NATO perspective) includes Eastern Europe and the western regions of the Soviet Union to the Ural mountains, an area of approximately six million km^2. An aerial survey of the entire region is completed every three months. One aircraft sortie covers 3 000 km at 7 620 m (25 000 ft.) in 9.3 hours with a radar (SAR) swath of 25 km.[18] Defining the verification problem in this manner, the research question is as follows:

How can one increase the likelihood that the aerial surveillance system will detect a treaty violation — unauthorized out-of-garrison unit(s) — in the coverage area at least once during a given interval length (assumed initially to be five days)?

The values for the two variables in the model — the probability of detection [p(d)] and the number of "looks" [L] — are calculated based upon these assumptions. Initial calculations, representing the base case for the analysis, are presented in Table 2.

The overall detection probabilities are estimated substituting these values into the binomial model defined above; the results are found in the Appendix, Table A-1, and are presented graphically in Figure A-1. To reiterate, no practical significance should be attached to these estimates themselves; rather, attention should be given to the direction of the relationship between the overall probability of detection and the model variables and parameters.

From Figure A-1, the first relationship may be discerned: the probability of at least one detection increases with the probability of identification, given that the probability of observation remains constant. Recall, the probability of

Table 2

Base Case Assumptions and Calculations

Assumptions:

1. Coverage area = 5 965 044 km²
2. Frequency of coverage = Once every three months *
3. Aircraft and coverage = 3 000 km in 9.3 hrs at 7 620 m (25 000 ft.)*
4. Sensor coverage (Radar) = 25 km swath at 7 620 m *

Calculations:

1. Probability of Detection [p(d)]
   Aircraft coverage per sortie *
   at 7 620 m = 3 000 km × 25 km = 75 000 km²
   $p(o) = \frac{s}{m} = \frac{75\,000}{5\,965\,044} = .012$
   Therefore,
   p(d) = p(o) × p(i) = .012 × p(i)
   for p(i) = (.05 → 1.0) in .05 increments

2. Number of "Looks" [L]
   Number of sorties required $= \frac{5\,965\,044}{75\,000}$
   = 79.53 per quarter
   = 318.12 per year

   "Look" rate $= \frac{318.12}{365} = .87$ per day

   Interval length = 5 days
   Number of "looks" = t × r = 5 days × .87 per day
   = 4.35 ≈ 4 "looks"

* *Source:* Airborne Remote Sensing, *pp.17-19.*

identification represents the likelihood that the monitoring system recognizes a treaty violation given that the target lies within the swath of the airborne sensor. For example, p(i) = .05 denotes a 5 per cent chance that the target will be identified assuming the sensor platform has passed in its vicinity; alternatively, p(i) = 1.0 indicates that the system always identifies the target if it has been observed. As the probability of identification increases, that is, as the ability of the monitoring system to recognize a treaty violation improves, the probability of detecting a militarily significant violation at least once during the required search interval also increases.

Next, consider changes in the "look" rate. Assume the aircraft sortie rate [r] is increased 2 1/2 times to 2.18 sorties per day (the number of flight hours on surveillance missions is increased from 8.1 to 20.3 hours per day; these operational demands could be met through an expanded fleet and/or higher utilization rates for currently tasked aircraft). This higher sortie rate translates into a higher number of "looks" by the airborne sensor during the five-day search interval; in this instance, approximately 11 sorties are flown [L = 11]. Figure A-2 compares the overall detection probabilities calculated assuming this heightened sortie rate with the base case presented in Figure A-1. As illustrated here, the higher "look" rate raises the overall detection probability at each level of system sophistication.

Alternatively, the area of the search swath may be expanded by using wider-area sensors and/or systems. For a satellite-borne sensor monitoring a 777 000 km^2 swath (2 400 km x 320 km) on each orbital pass, the probability of observation equals 777 000/5 965 044 or .13 (the ratio of the search area to the coverage region). The probability of detection, then, for each "look" is higher than in the base case across the range of values for p(i). Figure A-3 compares satellite surveillance with "heightened-sortie" aerial surveillance discussed above. The number of "looks" are assumed to be the same for both systems. Differences in the overall detection probability estimates, then, result from differences in the values calculated for the probability of observation. The figure illustrates that the overall probability of detection for the wider-area search system is greater at corresponding levels of system sophistication.

It has been argued that satellite systems, with their wider surveillance swath, compound the data analysis problem, producing an overwhelming amount of data that, in many instances, prevents timely interpretation. These arguments do not recognize that data analysis is only a secondary task in the deterrence process; it is done primarily to reassure the inspector that deterrence is "working," not to deter the inspectee. From the inspectee's perspective, the deterrent effect of the surveillance system lies in the act of monitoring itself. It cannot be predicted with confidence whether all, some, or none of the data are actually scrutinized. What is certain, however, is that activities within the coverage area are being monitored and that an inadvertent violation will likely be observed within a relatively short time. It is this ongoing threat of observation that reinforces compliance with the treaty. Whether all the data from these observations are analyzed is virtually irrelevant from a deterrence perspective; as long as the potential violator believes some of it is analyzed, he cannot risk assuming that what is observed will not be identified. Consequently, he will take greater pains to guard against inadvertent violations. Thus, the data problem becomes less imposing for wider-area search systems, arguing for their continued usefulness in monitoring extensive coverage areas.

This, however, does not negate the usefulness of airborne sensors in CFE verification. Aerial surveillance can be very effective when operating within smaller geographic zones. Consider, for example, a coverage area limited to the "frontline" East European states — the German Democratic Republic and Czechoslovakia (herein referred to as the "East Europe sub-region"). Their combined area is 236 068 km^2 or approximately 4 per cent of the coverage area in the base case. Recall the probability of observation equals the ratio of the search swath [s] to the coverage area [c]. Aircraft coverage per sortie using a SAR is unchanged at 75 000 km^2; therefore, the probability of observation equals 75 000/ 236 068 or .32 (in the base case, p(o) = .012). That is, there is a 32 per cent chance that the search swath of the airborne sensor will pass over a target located in the critical East Europe sub-region. In Figure A-4, the overall detection probabilities calculated for the East Europe sub-region are compared with the full-region, "heightened-sortie" case. The figure illustrates that aerial detection capabilities increase dramatically as the coverage area becomes smaller. Moreover, the number of "looks" taken by airborne sensors during the five-day interval need not be affected by restrictions on coverage-area size, whereas the frequency of satellite overflights falls as the size of that area is reduced.

Finally, the overall probability of detection can be raised by relaxing the requirements on interval length [t], thereby increasing the number of "looks" taken by the monitoring system. For example, assuming a heightened sortie rate of 2.18 sorties per day [r], the aerial surveillance system searches some part of the coverage area 11 times in a five-day period. However, extending the search interval to ten days, for example, allows the system to take 22 "looks" in the same coverage area. Figure A-5 compares the overall detection probabilities for five- and ten-day search intervals in the East Europe sub-region. Not surprisingly, detection probabilities are higher (given the level of system sophistication/efficiency) as the monitoring system "looks" more often at the coverage area.

To this point, the analysis has focused on means to enhance the overall probability of detection, implicitly assuming that the higher the detection probability, the greater the deterrent effect of the verification regime. What, however, are the lower limits that satisfy the demands for effective deterrence beyond which increases in detection probabilities are superfluous? In other words, what are the minimum detection standards needed to deter inadvertent treaty violations? Understandably, the inspector wants to maximize verification system performance to reassure himself that no violation will go undetected. Thus, the demands on the verification system often approach standards on the order of a 95 per cent chance of detecting a militarily-significant violation within a five-day interval, for example. Assuming the coverage area is limited to the East Europe sub-region, this standard [p(D) = .95] demands a heightened sortie rate [L = 11] and relatively high system sophistication/efficiency [p(i) = .75] (see Appendix, Table A-4). However, does the standard overstate what is needed to deter an inadvertent violation? In other words, is a lower standard sufficient to reinforce compliance with a treaty the participants believe to be in their mutual best interests, evident by their signing of the agreement.[19] Assume that the standard necessary to instill greater discipline among participants already committed to the treaty regime is lower than that discussed above, e.g., a 25 per cent chance of detection within five days [p(D) = .25]. For the same coverage area, the sophistication/efficiency demands on the system are substantially lower — p(i) falls to 8 per cent from the original 75 per cent. Alternatively, assume system efficiency remains unchanged at 75 per cent. The lower deterrence standard is still satisfied even when the number of "looks" is reduced to only one sortie every five days. There is a danger that such infrequent observation may, in fact, weaken the incentive for strict compliance. To overcome this problem while continuing to meet the deterrence standard, the surveillance system can take 11 "looks" in each five-day interval, but analyze the data for only one randomly selected "look." Thus, lowering the standard for the verification system to the minimum needed to deter the inspectee rather than that needed to reassure the inspector allows for reductions in the operational demands placed on the verification system.

Notes

1. The proposal called for prenotification of out-of-garrison activity by one or more "division formations" within the area of reductions and the European U.S.S.R.; notice would be provided in an annual calendar, to be supplemented, if necessary, by additional detail no later than 30 days prior to the activity. An annual schedule of troop movements into the reductions area was also suggested (*The Arms Control Reporter 1986*, p. 401.A.7).
2. "Division formations" include headquarters, command and control, and operational units but excludes service support units (Ibid.).
3. The NGA includes Belgium, Czechoslovakia, the Federal Republic of Germany, the German Democratic Republic, Luxembourg, the Netherlands and Poland.
4. The WTO argued that this provision unduly favoured the West; NATO had larger garrison areas and, hence, did not need to leave its garrisons for exercises as often as the WTO. As well, Eastern negotiators objected to the inclusion of the western Soviet Union within the prenotification area (*The Arms Control Reporter, 1986*, p. 401.B.106, 401.B.115). Although the Soviet Union and its allies rejected this proposal when presented four years ago, their recent willingness to agree to stringent and intrusive arms control verification measures may bode well for its eventual acceptance. At the very least, the new negotiating climate demands a reexamination of the merits of this proposal.
5. *Chapter III: Measures of Information Exchange, Stabilization, Verification and Non-circumvention*, p. 5.
6. Ibid., p. 8.
7. William Mendenhall and James E. Reinmuth, *Statistics for Management and Economics* (North Scituate, Massachusetts: Duxbury Press, 1978), pp. 145-59.
8. Oftentimes, the evidence from one "look" is not, in itself, conclusive, while the cumulative evidence from a series of "looks" at the same event over time is decisive. For simplicity, this model only considers "success" or "failure" as it relates to each independent "look."
9. Satellites in geosynchronous orbit could provide the wide-area coverage to maintain constant surveillance of the Atlantic to Urals region. However, the technology for "close-look," high-orbit reconnaissance using adaptive optics — a system of deformable mirrors, wavefront

sensors, and wavefront processors that compensate for waveform distortions caused by irregularities and misalignment of large optical surfaces — has yet to be proved [J. Richard Vyce and John W. Hardy, "Adaptive Optics: Potential for Verification," in *Arms Control Verification: The Technologies That Make It Possible*, ed. Kostas Tsipis, David W. Hafemeister, and Penny Janeway (Washington, D.C.: Pergamon-Brassey's International Defense Publishers, 1986), pp. 97-103].

10. Herbert F. York, "Reconnaissance Satellites and the Arms Race," in *Arms Control and Technological Innovation*, ed. D. Carlton and C. Schaerf (New York: John Wiley, 1976), p. 229. At one time, the United States planned to develop a system of satellites that would permit daily global coverage (designated "KH-X"). However, the idea was apparently discarded due to the system's projected processing and analytical demands (Adam, "Verification: Peacekeeping by technical means," p. 51). According to one estimate, 3 468 individual photographs, each covering an area 450 km by 1 000 km at a resolution of 20 m (sufficient for general detection of troop units only), taken by two shuttle-launched reconnaissance satellites would provide complete global coverage. One mile of film would be required to record the photographs (Schroeer, *Science, Technology, and the Nuclear Arms Race*, p. 377).

11. Brams and Kilgour model the verification problem as a game of treaty compliance: the inspectee may comply with or violate the treaty, while the inspector may accept or challenge the inspectee's stated compliance [Steven J. Brams and D. Marc Kilgour, *Game Theory and National Security* (New York: Basil Blackwell Inc., 1988) pp. 143-168]. This view of the problem is different from the search and evasion game referred to here.

12. Events A and B are dependent, i.e., the probability of Event B depends upon whether Event A has occurred. For example, if the sensors "look in the right block," the probability of identification equals .95. However, if the sensors "look" elsewhere, the probability of identification is zero (one cannot identify what is not observed). Thus, the probability of Event B changes depending upon the occurrence of Event A.

13. Note the probability estimate refers to the detection of the violation "at least once." In other words, the concern is not with the probability of detecting the violation once and only once. From the defender's perspective, it does not matter whether it is seen one or many times, so long as it is detected. Thus, the estimate defined here is a cumulative probability — p(one detection) + p(two detections) + ... + p(L detections).

14. See the Appendix, p. 39, for the derivation of this equation from the binomial probability distribution.

15. In fact, the violation will most likely be seen three times during the detection period — the probability of three detections equals .2236.

16. Assumptions regarding aircraft and sensor characteristics are found in *Airborne Remote Sensing for CFE Verification: The Platform*, SER-8-2295 (Toronto: Boeing Canada, de Havilland Division, 1989).

17. Ibid., pp. 6-7.

18. Ibid., p. 17

19. Admittedly, a state may sign an arms control agreement with the intention of subsequently circumventing the treaty and gaining a military advantage, however slight or fleeting. In such circumstances, though, the treaty violation is not inadvertent, and the routine deterrence scenario posited here, and the binomial model describing it, would not apply.

Conclusion

This paper examined various conventional arms reduction proposals presented over the past four years, a period during which the Mutual and Balanced Force Reduction (MBFR) talks gradually yielded to the Conventional Armed Forces in Europe (CFE) negotiations. Although many proposals stressed the importance of an effective verification regime, the NATO and WTO proposals tabled in the third round of the CFE negotiations were the first to discuss in some detail the measures needed in the regime.

Following a survey of overhead surveillance technologies, the paper examined system effectiveness in terms of deterring a militarily significant inadvertent treaty violation. A model derived from the binomial probability distribution was introduced to illustrate several factors that must be considered as the operating parameters for a multilateral aerial monitoring system are negotiated. Specifically, the model demonstrated that to increase overall detection probabilities, the inspector should:

- operate monitoring systems of greater sophistication and/or efficiency (increase p(i));
- increase the "look" rate for the systems (increase r);
- operate monitoring systems with wider search swaths, i.e., satellite systems, for wide-area surveillance (increase s);
- Assign aerial systems to coverage of critical sub-regions (reduce m); and
- Increase the search interval length (increase t).

Finally, the paper asked the question "How much is enough?" when considering the detection standard needed to reinforce treaty compliance among those already committed to the agreement. In many instances, the demands placed upon the system far exceed what is necessary to encourage treaty discipline among the participants. Accepting that the participants do not want to jeopardize the stability and certainty of the treaty environment through their own negligent actions, the standards for system operation can be relaxed. Extensive observation of the coverage area should continue as the monitoring function itself carries with it the greatest deterrent effect. However, there is greater latitude in committing financial, technical and human resources to later stages of the verification process, especially data analysis, while preserving the standards sufficient for routine deterrence.

This analysis represents an introduction to the study of verification regime effectiveness. Further areas of research suggested by the preceding include:

(1) A game-theoretic examination of the search-and-evasion game, exploring the requirements for deterring intentional treaty violations; and

(2) The deterrent effect of verification system synergisms, i.e., mutually reinforcing satellite, aerial and ground-inspection system overlap.

Consideration of these dimensions of verification regime effectiveness could build upon and expand the conclusions noted in this study.

Appendix

Derivation of the Binomial Probability Model[1]

The binomial probability density function is:

$$P(x) = \frac{n!}{x!\,(n-x)!} p^x (1-p)^{n-x} \qquad \text{(i)}$$

where x = number of successes;
n = number of independent trials;
p = probability of success in each trial.

The binomial probability model presented on p. 30 calculates the probability of **at least one** detection of a treaty violation. In other words,

$$\begin{aligned} P(\text{at least one detection}) &= 1 - P(\text{no detections}) \\ &= 1 - P(0) \end{aligned}$$

For P(0), Equation (i) becomes

$$P(0) = \frac{n!}{0!\,(n-0)!} p^0 (1-p)^{n-0}$$

$$= \frac{n!}{n!} (1-p)^n \qquad [0! = 1;\ p^0 = 1]$$

$$= (1-p)^n \qquad \text{(ii)}$$

Therefore,

$$\begin{aligned} P(\text{at least one detection}) &= 1 - P(\text{no detection}) \\ &= 1 - (1-p)^n \qquad \text{(iii)} \end{aligned}$$

Note

1. I am grateful to Mr. Ed Emond, Directorate of Mathematics and Statistics, Department of National Defence, Ottawa, Canada for his explanation of the binomial probability model and the derivation presented here. Responsibility for the application of this model to the verification problem in conventional arms control rests solely with the author.

Table A-1

Probability of Detection At Least Once During the Detection Interval (5 days)

p(i)	p(o)	p(d)	p(D)
0.05	0.012	0.0006	0.0024
0.10	•	0.0012	0.0048
0.15	•	0.0018	0.0072
0.20	•	0.0024	0.0096
0.25	•	0.0030	0.0119
0.30	•	0.0036	0.0143
0.35	•	0.0042	0.0167
0.40	•	0.0048	0.0191
0.45	•	0.0054	0.0214
0.50	•	0.0060	0.0238
0.55	•	0.0066	0.0261
0.60	•	0.0072	0.0285
0.65	•	0.0078	0.0308
0.70	•	0.0084	0.0332
0.75	•	0.0090	0.0355
0.80	•	0.0096	0.0379
0.85	•	0.0102	0.0402
0.90	•	0.0108	0.0425
0.95	•	0.0114	0.0448
1.00	0.012	0.0120	0.0471

Note:
p(i) = Prob. (Identification)
p(o) = Prob. (Observation)
p(d) = Prob. (Detection) [Each Trial]
p(D) = Prob. (Detection At Least Once)
Number of Trials = 4

Table A-2

Probability of Detection At Least Once During the Detection Interval (5 days) — Heightened Sortie Rate

p(i)	p(o)	p(d)	p(D)
0.05	0.012	0.0006	0.0066
0.10	•	0.0012	0.0131
0.15	•	0.0018	0.0196
0.20	•	0.0024	0.0261
0.25	•	0.0030	0.0325
0.30	•	0.0036	0.0389
0.35	•	0.0042	0.0452
0.40	•	0.0048	0.0516
0.45	•	0.0054	0.0578
0.50	•	0.0060	0.0641
0.55	•	0.0066	0.0703
0.60	•	0.0072	0.0764
0.65	•	0.0078	0.0825
0.70	•	0.0084	0.0886
0.75	•	0.0090	0.0947
0.80	•	0.0096	0.1007
0.85	•	0.0102	0.1066
0.90	•	0.0108	0.1126
0.95	•	0.0114	0.1185
1.00	0.012	0.0120	0.1244

Note:
p(i) = Prob. (Identification)
p(o) = Prob. (Observation)
p(d) = Prob. (Detection) [Each Trial]
p(D) = Prob. (Detection At Least Once)
Number of Trials = 11

Table A-3

Probability of Detection At Least Once During the Detection Interval (5 days)—Satellite Surveillance

p(i)	p(o)	p(d)	p(D)
0.05	0.130	0.0065	0.0692
0.10	•	0.0130	0.1341
0.15	•	0.0195	0.1948
0.20	•	0.0260	0.2516
0.25	•	0.0325	0.3047
0.30	•	0.0390	0.3544
0.35	•	0.0455	0.4009
0.40	•	0.0520	0.4442
0.45	•	0.0585	0.4847
0.50	•	0.0650	0.5226
0.55	•	0.0715	0.5578
0.60	•	0.0780	0.5907
0.65	•	0.0845	0.6213
0.70	•	0.0910	0.6499
0.75	•	0.0975	0.6765
0.80	•	0.1040	0.7012
0.85	•	0.1105	0.7242
0.90	•	0.1170	0.7456
0.95	•	0.1235	0.7654
1.00	0.130	0.1300	0.7839

Note:
p(i) = Prob. (Identification)
p(o) = Prob. (Observation)
p(d) = Prob. (Detection) [Each Trial]
p(D) = Prob. (Detection At Least Once)
Number of Trials = 11

Table A-4

Probability of Detection At Least Once During the Detection Interval (5 days) — East European Sub-region

p(i)	p(o)	p(d)	p(D)
0.05	0.320	0.0160	0.1626
0.10	•	0.0320	0.3008
0.15	•	0.0480	0.4179
0.20	•	0.0640	0.5169
0.25	•	0.0800	0.6004
0.30	•	0.0960	0.6705
0.35	•	0.1120	0.7293
0.40	•	0.1280	0.7783
0.45	•	0.1440	0.8192
0.50	•	0.1600	0.8531
0.55	•	0.1760	0.8811
0.60	•	0.1920	0.9042
0.65	•	0.2080	0.9231
0.70	•	0.2240	0.9386
0.75	•	0.2400	0.9511
0.80	•	0.2560	0.9613
0.85	•	0.2720	0.9696
0.90	•	0.2880	0.9762
0.95	•	0.3040	0.9814
1.00	0.320	0.3200	0.9856

Note:
p(i) = Prob. (Identification)
p(o) = Prob. (Observation)
p(d) = Prob. (Detection) [Each Trial]
p(D) = Prob. (Detection At Least Once)
Number of Trials = 11

Table A-5

Probability of Detection At Least Once During the Detection Interval (10 days)

p(i)	p(o)	p(d)	p(D)
0.05	0.320	0.0160	0.2987
0.10	•	0.0320	0.5111
0.15	•	0.0480	0.6611
0.20	•	0.0640	0.7666
0.25	•	0.0800	0.8403
0.30	•	0.0960	0.8914
0.35	•	0.1120	0.9267
0.40	•	0.1280	0.9509
0.45	•	0.1440	0.9673
0.50	•	0.1600	0.9784
0.55	•	0.1760	0.9859
0.60	•	0.1920	0.9908
0.65	•	0.2080	0.9941
0.70	•	0.2240	0.9962
0.75	•	0.2400	0.9976
0.80	•	0.2560	0.9985
0.85	•	0.2720	0.9991
0.90	•	0.2880	0.9994
0.95	•	0.3040	0.9997
1.00	0.320	0.3200	0.9998

Note:

p(i) = Prob. (Identification)
p(o) = Prob. (Observation)
p(d) = Prob. (Detection) [Each Trial]
p(D) = Prob. (Detection At Least Once)
Number of Trials = 11 [Five Days)
= 22 [Ten Days)

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