Self-Defense Zones in Space

Albert Wohlstetter and Brian G. Chow

July 1986

Contract Number: MDA903-84-C-0325

Contract Expiration Date: June 15, 1986

Short Title of Contract: Integrated Long-Term Defense Strategy

Name of Contractor: Pan Heuristics
R & D Associates
4640 Admiralty Way
Marina del Rey, CA 90295

Project Directors: Albert Wohlstetter
Fred Hoffman

Phone Number: (213) 822-1715

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

Self-Defense Zones in Space

Albert Wohlstetter and Brian G. Chow

July 1986

Contract Number: MDA903-84-C-0325

Contract Expiration Date: June 15, 1986

Short Title of Contract: Integrated Long-Term Defense Strategy

Name of Contractor: Pan Heuristics
R & D Associates
4640 Admiralty Way
Marina del Rey, CA 90295

Project Directors: Albert Wohlstetter
Fred Hoffman

Phone Number: (213) 822-1715

ACKNOWLEDGEMENTS

We would like to thank Col. Brock Strom of the Air Force Space Division, and Samuel Tennant and Wesley Mann of the Aerospace Corporation for their help as well as that of their staffs during the initial phase of our study. Their briefings and technical discussions were most valuable. We would like in particular to thank Sidney Kash, V.A. Chobotov, Paul Jorgensen, J. S. Leung, Michael Lew, Robert Mercer, Julian Reinheimer and John Travis. We are indebted also to many colleagues at PAN Heuristics and at RDA. At PAN to Fred Hoffman, Richard Brody, Zivia Wurtele, Paul Kozemchak and David Blair. At RDA to Horace Ory, Charles Stowe, Bernard Moller, Ralph Gilbert, Gary McLeod and Roger Speed. We are grateful for the programming assistance of Nancy Virts. We owe a large debt to Jerry Cayford. He not only provided us with excellent research assistance, but also served as both an advocate and critic of our ideas. Finally, we benefited greatly from talks with Paul Nitze.

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

TABLE OF CONTENTS

ABSTRACT ix

I. USING, ATTACKING AND DEFENDING SATELLITES 1

Introduction 1
A Comprehensive Ban Would Not Ban Soviet ASATs 4
A Comprehensive Ban Would Prohibit Our Active Satellite Defense 10
Unilateral Efforts for Satellite Mission Survival 14
Soviet Incentives to Negotiate and Agree on SDZs 27

II. A PROPOSED SELF-DEFENSE ZONE AGREEMENT 29

Three Key Features of our Proposal 29
Role of Self-Defense Zones 33
Satellite Distribution by Mission and Orbit 38
Impact of Satellite Distribution on SDZ Design 45
A Proposed Agreement on Self-Defense Zones in Space 53

III. IMPLICATIONS OF SELF-DEFENSE ZONES 63

Aiding Satellite Defense 63
Slight Reduction in Geostationary Slots 68
SDZs Do Not Restrict Third Countries' Access to Space 73
A Multi-national SDZ Agreement 74
Why an SDZ Agreement Now? 74
Number of Geostationary Satellites Needing to be Repositioned . . 75
Transition Rule has Little Effect on Satellite Operations 76

APPENDIX A: SELF-DEFENSE ZONES IN LOW EARTH AND HIGHLY ELLIPTICAL ORBITS 79

APPENDIX B: DETERMINATION OF MAXIMUM NUMBER AND TIME OF ALLOWABLE TRANSITS 85

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

LIST OF ILLUSTRATIONS

FIGURE II-1: SELF-DEFENSE SECTORS AT GEOSYNCHRONOUS ORBITS 31

FIGURE II-2: SELF-DEFENSE SHELLS AT SEMI-GEOSYNCHRONOUS ORBITS 32

FIGURE II-3: TYPES AND CHARACTERISTICS OF SATELLITE ORBITS 39

FIGURE II-4: CURRENT DISTRIBUTION OF OPERATIONAL SATELLITES IN GEOSYNCHRONOUS ORBITS 47

FIGURE II-5: EARLY 1990s DISTRIBUTION OF OPERATIONAL SATELLITES IN GEOSYNCHRONOUS ORBITS 48

FIGURE II-6: GEOSYNCHRONOUS SPACE OCCUPIED BY WESTERN ZONES ATTACHED TO CURRENT SATELLITES 49

FIGURE II-7: GEOSYNCHRONOUS SPACE OCCUPIED BY WESTERN ZONES ATTACHED TO EARLY 1990s SATELLITES 50

FIGURE II-8: SELF-DEFENSE ZONES AT GEOSYNCHRONOUS ORBITS WITH CURRENT SATELLITE DISTRIBUTION 56

FIGURE III-1: SELF-DEFENSE ZONES AT GEOSYNCHRONOUS ORBITS WITH EARLY 1990s SATELLITE DISTRIBUTION 70

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

LIST OF TABLES

TABLE 1: CURRENT AND PROJECTED DISTRIBUTIONS OF OPERATIONAL SATELLITES 41

TABLE A-1: USSR/U.S. SATELLITE ENCOUNTERS WITHIN 2000 KM 81

TABLE A-2: USSR/U.S. SATELLITE ENCOUNTERS WITHIN VARIOUS DISTANCES . . 82

TABLE B-1: INPUT ASSUMPTIONS FOR DETERMINATION OF ALLOWABLE NUMBER OF ZONE TRANSITS 89

TABLE B-2: SELECTED ORBITAL CHARACTERISTICS OF STANDARD LOOPERS 91

TABLE B-3: EXPECTED TIME INTERVAL BETWEEN ORBITAL ADJUSTMENTS TO AVOID SIMULTANEOUS TRANSITS EXCEEDING AN AGREED NUMBER . . . 92

TABLE B-4: TYPICAL TRANSIT TIME THROUGH SELF-DEFENSE SHELL 94

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

ABSTRACT

A space agreement can facilitate, not replace, our unilateral efforts to protect critical satellite missions. The proposed Self-Defense Zone (SDZ) agreement would clarify what are considered menacing configurations of space objects. It would also make clear that the owner of a vital satellite system would take defensive actions when such a configuration seriously threatens a surprise destruction of the system--just as the United States did against Libyan missile boats which came too close to our carriers in the international waters of the Mediterranean. The SDZ agreement would thus encourage effective enforcement and thereby avoid some of the principal difficulties about compliance that trouble the present debate over arms control.

This paper also details the specifics of the agreement including the number, size and location of SDZs, and the maximum number and time of allowable transits through the other side's zones. Two key design features are i) that many of these SDZs are not attached to specific satellites but are regions in space which are fixed with respect to the earth, and ii) that SDZs are to protect critical satellite missions instead of every satellite which serves these missions. The first feature makes it much easier to adjust the orbits of one's satellites for treaty compliance, to recognize dangerous incursions, and to coordinate future satellite placements. The second feature allows for a few transits through SDZs by the other side's satellites. Even the destruction of some satellites resulting from these transits would not interrupt the mission performance of a system with built-in redundancy. The allowance of transits would permit much larger and more useful SDZs without significantly interfering with routine satellite operations.

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

I. USING, ATTACKING AND DEFENDING SATELLITES

Introduction

The Soviet Union and the United States have each been using space for their military purposes for over 25 years and almost certainly will continue to do so. Seventy-five percent of all Soviet space payloads involve direct military missions and another 10 percent are for both military and civilian uses.* Others have estimated that 90 percent of Soviet satellites have some military function.** Since their military goals and long-term political purposes are partially at odds, the Soviet Union and the United States (as well as their allies) will continue to compete in their satellite and other space activities.

This competition, however, is not the same as a feverish "exponential race" in space budgets. Rather, both sides are likely to increase their use of space for a variety of military purposes to replace functions performed less effectively or more expensively on the ground or in the air. Both sides will use satellites to gather and communicate information about the weather and other parts of the environment relevant to a potential military conflict, and about the disposition of their own and their adversary's military forces in time of peace or in transition to or during a nonnuclear or nuclear war. They will also use their navigation satellites for much more accurate initialization and guidance of airplanes, ships and, later, missiles. This means that each side will have strong reason to interfere with the other's hostile use of such information and

---

* Stephen M. Meyer, "Space and Soviet Military Planning," in _National Interests and the Military Use of Space_, edited by William J. Durch, Ballinger Publishing Co., 1984, p. 61.

**Barry R. Schneider and Colin S. Gray, "The Soviet Military Space Program," _Signal_, December 1984, p. 69.

to protect its own satellite and space activities from interference by the other side. In short, each side surely will use satellites and will have very strong incentives to try to disable adversary satellites and to defend its own. Thus, monitoring, verification and prevention of creep-out and break-out are crucial in any space agreement, particularly those whose success hinges on the modification of the behavior of both sides.

We believe that there are space agreements that could usefully supplement our unilateral efforts to preserve Western autonomy without war. However, we should not have an illusion that there exists an enforceable agreement which would ban all potential anti-satellite activities. Some argue tautologically that the satellites could not come under attack if there were no ASAT weapons to attack them. But there will always be weapons that can attack satellites so long as there are satellites. Believing in the feasibility of an effectively total ASAT ban or in the feasibility of preventing hostile action against space objects would lead us to the worst outcome--the Soviets will continue to develop means of attacking or disrupting satellites while we expose ourselves invitingly to such attack by failing to protect our satellites by unilateral means.

Any bilateral space agreement is likely to be illusory if it is thought of as a way of compensating for unilateral neglect of the problem of protecting satellite missions. If the operation of a satellite system depends on a few critical nodes, no agreement is likely to assure the survival of those nodes and, thus, to protect the mission performance of the system. Too many forms of anti-satellite activity can use systems that have innocent other uses as well. So long as the attacker only needs to destroy a few targets, a surprise attack could be staged by taking advantage of the unavoidable ambiguities between innocent close encounters arising from normal satellite operations and calculated prepositioning of his ASAT capable satellites. These ambiguities would make enforcement worse than doubtful.

On the other hand, an adaptive system with multiple substitutable nodes such as a Multiple Satellite System for essential communications (which will be discussed later) could degrade very slowly. An adversary would have to position in peacetime a great many space objects which have no plausible other use than a surprise attack to destroy such a system. The system might function adequately without the benefit of a bilateral or multilateral agreement governing peacetime behavior. Furthermore, its very robustness would place less of a crucial burden on arms agreements. It would make possible agreements which would improve further the possibilities of self-defense. Such agreements could clarify what are considered menacing configurations of space objects. And, by making clear that defensive actions would be taken in the event of a configuration of space objects that seriously threatened a vital satellite system, such agreements would encourage effective enforcement. This may avoid some of the principal difficulties about compliance that trouble the present debate over arms control.

In this chapter, we will first explain why no ASAT ban would effectively ban Soviet ASATs and how the Soviets could develop their ASATs even under an ASAT ban agreement. Second, we argue that a comprehensive ban would prohibit our development and deployment of active satellite defense. The ban advocates have never shown that the net result of a comprehensive ban would enhance the survival of critical satellite missions. Third, we discuss a new approach that the United States needs to consider for satellite mission survival. Fourth, we discuss the Soviet incentives to negotiate and agree on Self-Defense Zones (SDZs).

In the following chapters, we describe the utility and implementation of SDZs.

A Comprehensive Ban Would Not Ban Soviet ASATs

No total ASAT ban would be workable. Both civilian and permitted military systems could be covertly modified into ASAT weapons. The Soviets have already performed many tests of their ground-launched ASAT interceptors against low-altitude satellites. Could a comprehensive ASAT ban prevent them from developing a capability against our high-altitude satellites such as the Global Positioning System (GPS) navigation satellites at the 20,000 km semi-geosynchronous orbits, and the Defense Support Program (DSP) early warning satellites and communication satellites at the 36,000 km geostationary orbits?*

A nuclear ASAT capability against the high flyers could be readily and covertly developed by the Soviets even under a total ban. The Soviets have been regularly using their SL-12 missiles to launch communications satellites (under Raduga, Ekran, Gorizont and Kosmos Programs) to the geosynchronous orbits. They could house a nuclear warhead inside a satellite and might even make it appear as a normal communication satellite. Currently, in a typical launch, a satellite first goes to a low-earth parking orbit, then is boosted to 90° East at the geostationary

*Geostationary orbits and geosynchronous orbits are used interchangeably in this report. Many satellites are placed at the equatorial belt of these orbits to take advantage of their stationary (apparent-) positions to fixed earth observers.

orbit, and finally is drifted with propulsion at an observed speed of up to 10 degrees per day to its assigned slot.* It takes about an hour to get to parking orbit, an additional 5 1/2 hours to the 90° East location, and, depending on distance, a week or two to the final slot. A nuclear space mine could follow the same route to get to and stay near its prey. The nuclear lethality is more than ample to compensate for the positioning inaccuracy, and a targeted satellite's operational capability would be irreparably damaged by the nuclear effects (x-rays and fission electrons). Moreover, the Soviets are fully capable of launching directly a satellite or a payload to its final destination and, hence, significantly reducing its flight time to a few hours with precise time depending on their willingness to sacrifice payload weight for speed. This would make a ground-launch direct-ascent nuclear ASAT weapon.

Admittedly, this type of directly-adopted ASAT capability against high-altitude satellites is rudimentary. Would the Soviets be concerned about a Soviet nuclear ASAT weapon's damaging their own satellites or the international outcry of violation of the Outer Space Treaty by placing nuclear weapons in orbit if nuclear space mines were discovered by malfunction or our inspection? The damage could be significantly reduced by selecting the right warhead design and place of detonation. What little collateral damage there would be to their own satellites could be small compared to our losses--particularly in view of their greater capacity for replenishing satellites. The treaty violation would be a minor side issue if they were about to launch an attack, especially a nuclear one. We

*Private communication from Nicholas L. Johnson, Teledyne Brown Engineering, Colorado Springs Office, February 12, 1986.

must, therefore, be prepared for this type of nuclear ASAT attack.

Worse yet, the Soviets could also develop an all-altitude conventional ASAT capability under a comprehensive ban. To be more specific, let us study how civilian and permitted military satellite activities can be used to develop a nonnuclear space mine capability, particularly against geostationary satellites. Already in many of those 20 ASAT tests conducted between 1968 and 1982 at an intercept altitude between 230 and 1630 km, the Soviets succeeded in using a radar homer to get co-orbitally within a short distance of the target and destroy it with shrapnel fragments. In three of the failed tests, a more accurate infrared homer was used. The Soviets could continue to develop their terminal homing capability at higher altitudes by picking one of their own satellites as a practice target and repositioning another satellite along a flight path that intersects the practice target. To us, it is repositioning; to them, it is testing how close one satellite can get to another. However, this type of non-destructive test, if practiced repeatedly, might become suspicious. The Soviets could simply argue that these tests are for civilian and non-ASAT military applications. And we could not stop them. Furthermore, especially at the geostationary orbit, a replacement satellite often goes to the same assigned slot as the old satellite. Even operational satellites using different frequency bands often occupy the same slot. A practice of rendezvous and docking with these extremely nearby neighbors would be much harder to discover.

Other activities, such as acquisition and tracking of satellites, orbital maneuvering, rendezvous and dockings, ground command and control of satellites, and reactivation after long-term dormancy are readily transferrable to space mine operations. The Soviet Union has already publicly tested a series of rendezvous and dockings between the Progress spacecraft and the Salyut space station. Some people might argue that the success of these activities cannot be equated to a conventional space mine capability because both objects are huge, with the spacecraft weighing 15,500 lbs., and because these activities are conducted with the space station (target) cooperating.* But the point is that these ASAT applicable activities are perfectly legitimate and will remain so even under a comprehensive ban agreement. The Soviets could argue that docking between two satellites has important non-ASAT applications. For example, one might want to replenish a satellite with expendables such as fuel for life extension as Progress now does to Salyut. Anticipating similar refueling needs, the United States has also conducted relevant tests with the space shuttle. Or, one might want to send a satellite close by for inspecting and photographing the degree of damage on another satellite. Or, one might decide to repair or attach a booster to a satellite in order to reposition it to a newly assigned orbit or to boost it to a stable higher orbit or a less crowded orbit at the end of its service life.

The nuclear reactor of a RORSAT, for example, is programmed to be separated from the rest of the spacecraft and boosted to a higher orbit at the end of its life. However, due to malfunctioning, the reactors of Cosmos 954, in 1978, and Cosmos 1402, in 1983, plunged into the atmosphere instead. Some of the debris of the former which fell over Canada was

---

*However, at least on one occasion, Salyut's cooperative rendezvous transponder system was inoperative and a new, autonomous optical rendezvous aid was used in the approaching spacecraft Soyuz instead. Nicholas Johnson, <u>The Soviet Year in Space 1985</u>, Colorado Springs Office, Teledyne Brown Engineering, p. 54.

extremely hazardous and Canada was forced to conduct a multimillion-dollar debris search and recovery operation, for which the Soviet Union eventually paid partial compensation.* The Soviets could very well argue that if they had had a satellite-to-satellite docking capability, they could have attached another booster to the whole spacecraft or its reactor. With plausible reasons or excuses such as these, the Soviets could openly test rendezvous and docking between satellites. These types of tests have obvious applications to space mines and other ASAT operations.

They could use ground command to guide the spacecraft to the vicinity of the target and, for nonnuclear kill, use an on-board sensor for terminal guidance. Better yet, the ground control center could simply give predicted target coordinates to the spacecraft which would then travel autonomously to the vicinity of the target and use its on-board sensor, say an LWIR sensor, for terminal homing. This more autonomous mode of operation would reduce tie-up time on the ground facilities and, thereby, facilitate operations of simultaneous, multiple attacks on our critical satellites.

On September 28, 1984, the Soviets launched a new, massive electronic intelligence gathering vehicle.** Our interest here lies in the extensive maneuvering undertaken in reaching its final orbit because, while these substantial maneuvers are clearly not required for the placement of a spacecraft in orbit, they certainly have ASAT applications. However, the whole incident was not considered an ASAT demonstration apparently because, at the end, a spacecraft was placed in orbit. Once more, we have

---

* Craig Covault, "Soviet Nuclear Spacecraft Poses Reentry Danger," Aviation Week & Space Technology, January 10, 1983, pp. 18-19.

**"Soviets Orbit Large New Military Electronic Intelligence Satellite," Aviation Week & Space Technology, January 14, 1985, pp. 19-20.

an illustration of the double character of space activities and the consequent difficulties of banning ASAT development.

Once the Soviets achieve a satellite-to-satellite docking capability, they also automatically achieve a conventional ASAT capability. This is well recognized by the Soviets, as observed by Yevgeniy Velikhov, Vice President of the USSR Academy of Science:

> If we can dock with a satellite, then clearly, we can dock with an American satellite, but a bit carelessly, and thus destroy it.*

An unpublished study by General Research Corporation estimates that a Soviet SL-12 launch vehicle can place two 1150kg (380kg warhead, 450kg electronics, 160kg propulsion and 160kg structure) mines at geosynchronous orbits, each with the capability of destroying any non-maneuverable satellites.** More advanced mines can be developed with a lethal capability against even maneuverable satellites.

Moreover, the Soviets terminal maneuver and homing capabilities developed for space mines are applicable to other space-based and ground-based ASAT systems, and also satellite defensive systems (DSATs).

Some might argue that the United States could also develop a similar ASAT capability under a comprehensive ban. But, first, even our possession of ASATs would not make our satellites survivable because we might be asymetrically dependent on satellites in some very important contingencies and the Soviets might choose to trade off their satellites for ours. Second, our open society would hinder our ASAT development much more than the Soviet Union's closed society would hinder theirs. Imagine the public outcry if the Pentagon were discovered secretly testing some

---

* Interviewed on Moscow Radio in English to North America on 26 May 1984. Foreign Broadcast Information Service Daily Report: Soviet Union, 6 June 1984, p. AA12.

**Quoted in R.B. Giffen, U.S. Space System Survivability, National Defense University Press, 1985, p. 63.

ASAT weapons in the face of an ASAT ban. Ironically, we might even curtail some legitimate performance characteristics in our other weapon systems because they also happen to have potential treaty-prohibited applications and these characteristics, even treaty-permitted, might "upset" the Soviets.

A Comprehensive Ban Would Prohibit Our Active Satellite Defense

Some could argue that, while a comprehensive ASAT ban cannot completely eliminate ASAT weapons, it could make our unilateral efforts for satellite mission survival easier and more effective. This conceivably might be true, but proponents of the ban such as the Union of Concerned Scientists and the Soviets have nowhere presented the necessary evidence.* In any case, we need to recognize that a comprehensive ASAT ban would prohibit our active satellite defense. It would necessarily include active satellite defense (DSAT) weapons because they can be used for ASAT purposes. After all, an active DSAT supposedly is used to destroy an ASAT platform or weapon. If it can do this, it can destroy a satellite. So the ban would force us to forego both ASAT and active DSAT development. Thus, while the Soviets in a closed and centrally controlled society could continue to develop their ASAT and DSAT systems, the West could end up with neither or be far behind.

Worse yet, even if we somehow developed some active DSATs, the ban would forbid such DSATs' physical placement in space. Yet, to be of any

---

*Union of Concerned Scientists', The Fallacy of Star Wars, Vintage Books, 1984, Appendix B: A Treaty Limiting Anti-Satellite Weapons. Office of Technology Assessment, Anti-Satellite Weapons, Countermeasures, and Arms Control, September 1985, Appendix A: Soviet Draft Treaty on the Prohibition of the Use of Force in Outer Space and From Space Against the Earth (August 22, 1983).

use, the deployment must precede the actual attack. Under an ASAT ban, these DSATs would not be available for the protection of our satellites against a surprise Soviet attack. In other words, we would have to rely solely on passive means for satellite defense until our DSATs were developed and/or deployed in the midst of war. Would passive defense alone be adequate for satellite mission survival?

Many comprehensive ASAT ban proponents assume explicitly or implicitly that the answer is in the affirmative. Yet, practically all the existing critical satellites and those planned for deployment are very expensive.* Thus, an attacker can afford to design ASAT weapons which can defeat a defense based on passive means alone. To begin with, no feasible hardening is strong enough to withstand a direct hit or an arbitrarily close explosion, especially a nuclear one. An attacker can design a space mine which cannot be evaded by the satellite's maneuvering and is also cheaper than its expensive target. A space mine has the advantage of dedicating the bulk of its weight, volume and fuel for trailing while a satellite cannot divert a large fraction of its resources from the

*There is a trend in the United States toward deploying higher performance and more expensive satellites. New military satellites cost several tens of millions of dollars and up. A GPS (Global Positioning System) navigational satellite costs about $40 million and a DSCS III (Defense Satellite Communications System Phase III) satellite costs $150 million each. (Jane's Spaceflight Directory 1985, pp. 249 and 247.) A "UHF follow-on" to FLTSATCOM (Fleet Satellite Communications System) and LEASAT will cost about $100 million each. (David A. Boutacoff, "Steering a Course Toward Space," Defense Electronics, March 1986.) The total price tag for MILSTAR will be $6-10 billion including $2 to $6 billion for 4,000 mobile earth terminals. (James Fawcette, "Milstar: Hotline in the Sky," High Technology, November 1983, p. 62.) Even if we assume the development cost to be half of the remaining $4 billion, each of eight satellites would still cost $250 million each. Worse yet, the cost of the MILSTAR program has recently been quoted at $10-20 billion (Fred Hiatt, "Building a Force for World War IV," The Washington Post, July 27, 1986). A DSP (Defense Support Program) satellite costs probably around $250 million also.

performance of its intended mission to evasive maneuvering. Nor can the users of expensive satellites afford to rely on replacement. Moreover, a space mine can conserve fuel by shadowing its prey only from time to time or even only when needed. Without active defense, we cannot rely on decoys either because the attacker would have the time on his side for discrimination from close range. In sum, passive defense alone could not cost-effectively protect any mission performed by satellites which cost much more than does attacking them.

Although we agree with much of what Michael May says about the vulnerability and protection of U.S. military space systems, we would comment on his statement that

> The high-altitude satellites needed for warning and communications in particular could be vulnerable to prompt destruction by certain space-based systems and, in the future, possibly by ground-based high power lasers. A combination of passive countermeasures and arms control agreements could give these satellites some protection against such attack. Deployment of strategic defensive systems with the capability to reach far into space would invalidate this approach.*

For the reasons given in the paragraph before last, we are very pessimistic that "some protection" without an active defense component at all would be sufficient to save these expensive satellites. May himself qualifies the last sentence in the quote by reference to reaching "far into space." We would emphasize that qualification because effective strategic defensive systems do not need a lethal range reaching far into space. Those in low-earth orbits (say, less than 3,000 km in altitude) might be effective against ballistic missiles in boost phase and mid-course but ineffective against satellites, for example, at semi-

*Michael M. May, "Safeguarding Our Military Space Systems," Science, 18 April 1986, p. 232.

geosynchronous altitudes (20,000 km) and above.

However, the role of active defense can be significantly reduced if we can design our space systems in a drastically new way. For certain applications, such as communications for the execution of essential strategic and tactical missions, there is a good possibility that satellites could be made so cheap and so numerous that they could not be effectively attacked. We should actively investigate this new system architecture for mission survivability of not just communications but of all types of space sensors and systems. In the extreme, no defense, active or passive (except replacement), would be needed for cheap satellites. We could simply replace the destroyed satellites, if it would be cheaper for us to replenish them than for our adversary to shoot them down. On the other hand, if we are concerned that our adversary would place space mines or other space-based ASAT platforms next to nearly every satellite in the system and that a simultaneous attack would cause an interruption in mission performance, we can send up on-orbit spares as soon as they send up space mines. This scheme would work as long as space mines are more expensive than individual satellites and space mines cannot hop around cheaply to threaten different satellite systems.

We will discuss later that a satellite in the Multiple Satellite System (MSS) for essential communications might be cheaper than a space mine. But, it is too early to know whether satellites for other missions can also be cheaply proliferated and, if so, whether i) different missions could be performed from the same satellite system, ii) systems for different missions would occupy similar or well separated altitude bands and iii) the cost of an individual satellite is less than that of moving a space mine from the vicinity of one system to another. It is quite possible that we could not afford to add satellites of every type while our adversaries maneuvered their space mines from one system to another. On the other hand, a DSAT whose capability in destroying a space mine is similar to a space mine's capability in destroying a satellite should also have a cost similar to a space mine. These DSATs might also be repositioned in response to changes in the threat environment. Their uses in conjunction with replenishment could cost-effectively thwart the space mine threat while replenishment alone could not. This illustrates that even the survivability of a well-proliferated system with reasonably cheap components might still require active defense. A comprehensive ASAT ban would certainly foreclose that option. A limited ASAT ban might not have to, but it would face the same array of difficult problems of enforcement and prevention of creep-out and break-out.

<u>Unilateral Efforts for Satellite Mission Survival</u>

It is now apparent that we cannot rely on any space agreement to completely eliminate the threat to our space assets. Nor has anyone demonstrated that a comprehensive or limited ASAT ban would reduce the ASAT threat so much that it compensates for foregoing active defense as an element in designing our satellite mission survivability program. So how do we keep our space missions surviving?

Some argue that a mutual assured destruction of space assets would keep our satellites alive. They start with a pessimistic assessment that, even with the best defenses, satellites could not survive an ASAT onslaught. Offense always dominates defense in space. However, they contend that this mutual vulnerability could be used advantageously as a deterrent to keep both sides' satellites intact in the transition to and during a war. This assumes erroneously that both sides would prefer to have satellites in the sky under all contingencies. Most of our allies and friends are located around the Soviet's Eurasian periphery. At time of war there, transoceanic satellite communications would certainly be much more important to us than to the Soviets who could rely heavily on means over land. They might decide that destroying our satellites, even at the risk of losing their own, would be to their net advantage. Moreover, the Soviets in recent years have made about five times as many space launches per year as we have. We compensate by building longer-lived satellites. But, then, survivability of in-orbit satellites is much more important to us because the Soviets could replace their destroyed satellites faster.

Rapid advances in the product of transmitting rate and the distance which the signals can travel without amplification as well as cost reductions are making fiber optics economical, both for land lines and submarine cables, but the latter are hard to protect. There are essentially two ways in which they might conceivably serve as a backup to transoceanic satellite communications. First, fiber cables could be laid after the outbreak of war and used during a protracted conflict. Although the Soviets could not freely and leisurely search for these cables because we might attack their surface ships and submarines, the United States could not know how well these optic communications could be protected. Second, fiber cables could be covertly laid during peacetime, and used if our communication satellites were destroyed. This is even a tougher job, because the Soviets would have ample time to search for these cables and we are not likely to attack trawlers severing our cables in time of peace. (We have not). Moreover, finding the cables in peacetime without cutting them would be sufficient to make the system unreliable for backup. There appears to be no obvious way that we can get the robustness underseas that is possible with land lines laid in the form of a mesh with packet switched nodes. Even if some parts of the cable were buried under the ocean floor (for example, on the continental shelf), it would not give the cable as a whole robust protection against location and destruction by the Soviets. Therefore, in the foreseeable future, we have to depend on satellites for transoceanic communications, and we need to protect them since they are essential in controlling and efficiently employing our forces.

Moreover, with submarines carrying conventional and nuclear land-attack cruise missiles and their growing role in serving conventional and limited nuclear contingencies, it is becoming even more important that messages can be sent to submarines anywhere and at operating depth. The land-based ELF (extremely low frequency) system uses 84 miles of antenna stretching across parts of Michigan and Wisconsin, and transmits at an extremely low data rate. It takes 15 minutes to transmit a mere half-dozen letters or numbers.* On the other hand, a blue laser system can transit at a much higher data rate. To provide global coverage, space-based transmitters or reflecting mirrors would be required. Again, our much heavier reliance on sea power dictates that we cannot afford to rely on mutual abstinence.

*Malcolm W. Browne, "In Battle of Wits, Submarines Evade Advanced Efforts at Detection," New York Times, April 1, 1986.

Satellite mission survival should not hinge on bilateral or multinational space agreements or mutual abstinence, but on our own unilateral actions. In the past and in the current space plan for the future, the United States has concentrated on the deployment of high performance satellites capable of performing peacetime military functions over many years. These have tended to be increasingly large, complex, and expensive, requiring a very large launch vehicle such as the shuttle or the Titan 34D. While some of our systems, like the GPS navigation system at semi-geosynchronous, involve a large number of satellites and might degrade slowly under attack, many involve only a few satellites* with very long delays possible and very high costs for replenishment in peacetime. These would have almost no opportunity for reconstitution during a war. The recent disaster to the shuttle due to a defective O-ring, and the explosions on the launch pad of the last two Titan 34Ds suggest the hazards of relying so extensively on such systems in time of peace. But even more, they indicate potential vulnerabilities in time of war. In recent years there has been much useful effort to reduce the vulnerability of our satellites. But we should not assume that satellites in the high semi-geosynchronous or geosynchronous orbits are immune to attack, for example, by space mines.

The Soviets, on the other hand, have followed a different course. They have satellites of lower quality, including many communication satellites in low earth orbit where we have none. Their satellites have a much shorter mean-time between failures and they replace them much more

---

*Our DSP (Defense Support Program) for early warning consists of only several satellites. The MILSTAR (Military Strategic Tactical and Relay) for essential communications will be composed of eight satellites.

frequently. They have to launch many more satellites a year just to maintain their systems. On the other hand, this difference in their satellite program has given them the capability of launching satellites on short notice and this gives them a substantial flexibility for both crises and war. They have already used this capability to advantage during the crisis over the Falkland Islands† and various Middle East crises. The capability of replenishment during a war would be very useful for maintaining mission performance throughout a conflict. The Soviets have also improved the survivability of their communications satellites themselves by multiplication. They have established a network of up to 24 very small (about 90 lbs.) satellites in almost circular orbits of 1500 km altitude and an inclination of 74°. Each satellite can pick up messages from a sending location and, when it passes another location designated to receive it, retransmit the message. These 1500 km satellites complement a constellation of three satellites orbiting at 800 km in orbital planes spaced 120° apart and operating in a similar "store and dump" mode.*

We need systems that do not depend excessively on a very few, potentially vulnerable elements, and, in particular, we need distributed systems that would degrade gracefully in the event that they conceal some unexpected mode of failure through random events or unanticipated vulnerabilities to enemy attack.

Let us illustrate these desirable traits with the packet switched Multiple Satellite System (MSS) now under study by DARPA and Rome Air Development Command. Similar to MILSTAR (Military Strategic Tactical and Relay) which is expected to be deployed in the early 1990s, MSS could

*Nicholas L. Johnson, The Soviet Year in Space 1984, p. 18 and The Soviet Year in Space 1985, p. 20.

† "Sky Spies," Time, May 17, 1982.

provide communications for the execution of essential strategic and tactical missions. On the other hand, while the MILSTAR system will consist of four low-inclination geostationary and four other satellites, MSS would use 240 small satellites in 350 to 400 nautical mile orbits at three different inclinations, and perhaps 1,000 ground terminals, some mobile.* Each satellite would cover only about 2 percent of the earth's surface to provide global coverage for voice as well as data transmission with data rates varying between 100 megabits and 100 kilobits per second, depending on the number of satellites still surviving and the environment, which might be jammed and nuclear. Low earth orbital dynamics (with periods near 100 minutes) would mean that if individual satellites failed, communication in a given region would be quickly healed by other satellites coming rapidly into view. In any case, the packet switching would automatically bypass nonworking satellites: each individual satellite could communicate at a high data rate with immediate neighbors and at lower data rates with distant satellites. Even with individually unreliable satellites, the network would be reliable.**

The manufacturing costs of individual satellites should be intrinsically cheaper because (a) they need not be individually highly reliable and one could avoid "gold plating," (b) they are smaller and also (c) they are less complex since their stabilizing, station-keeping, pointing and tracking requirements are relaxed, and (d) the large numbers of satellites permit serial production, automation, and the benefits of the learning

---

* Gowri S. Sundaran, "U.S. Military Satcom Programs," International Defense Review, 5/1985, p. 709. John Capetanakis, program manager, Multiple Satellite System Study, M/A COM LINKABIT, Inc. for Defense Advanced Research Projects Agency, February 1985, pp. 2 and 46.

**Note that some, though not all, of these desirable traits might be obtained at higher orbits.

curve. J. Lehman and his colleagues at TRW* estimated the average cost of an MSS satellite (250 lbs.) in a 250-unit production run to be $370 thousand in 1982 dollars. The marginal cost for an additional 250 units is $315 thousand each. In one design which was discussed earlier, a space mine equipped with warhead, electronics and propulsion weighs 1,150 kgs or 2,540 lbs. It is ten times as heavy as an MSS satellite and would likely cost more. Thus, it is possible that the spare or replacement cost of an MSS satellite is lower than the cost of attacking it. On the other hand, we would expect a space mine to be cheaper than our existing and planned satellites. A MILSTAR satellite would probably cost a few hundred million dollars.

Moreover, launch costs should be low because of the light weight of the satellites and the low orbits to which they would be lifted. And a variety and multiplicity of launch vehicles could do the job. Therefore, the costs and difficulties of replenishment during peacetime would be greatly reduced. Most important, it would be feasible to replace satellites during wartime.

The capability of quickly replenishing a satellite system in small increments helps to maintain steady mission performance. A production run of a large number of satellites would reduce the number of man-hours for the assembly of a replacement satellite. For satellite survivability and replacement considerations, man-hours for the last satellite in the space system is more pertinent than the average man-hours. ESL analysts

*J. Lehman, et al, Multiple Satellite System (MSS) Requirements and Performance Analysis, ESL, Inc., a subsidiary of TRW, 15 June 1983, pp. 1-5 and 2-26. The average cost for 500 units is given to be $343 thousand each. We translate it to $315 thousand each for 250 additional satellites.

estimated that a planned large production run would lower the man-hours for the assembly of even the first unit, because a much more efficient production design can be used.* The man-hours for the assembly of the first satellite in a large production run are only 1,431, as opposed to 4,515 for the current type of limited production run.** This amounts to a factor of three (i.e., 4,515/1,431).

Moreover, the man-hours for the 100th satellite are further reduced to 383 with an assumed 82 percent learning curve. They assumed a 98 percent learning curve thereafter. This brings the man-hours for the last of 240 satellites in MSS to 373.*** In contrast, the man-hours for the assembly of the last of an 8-satellite system**** (assuming a 90 percent learning curve and 4,515 man-hours for the assembly of the first satellite) are 3,291. Thus, the combined effect of lower first unit and learning curve reduce the number of man-hours by a factor of 9 (i.e., 3,291/373).

The MSS would use an order of magnitude more satellites than the Soviet network at 1500 km and, of great importance, the packet switched satellite-to-satellite burst communications would make it unnecessary for an individual satellite both to receive a message from a sending station and wait until its orbit path permits it to retransmit the message to a

---

* Reduction in man-hours, however, is not obtained for free. Presumably, one would need a higher initial capital investment for such items as automation.

* Lehman, et al, <u>Multiple Satellite System</u>, <u>op. cit</u>., pp. 2-18 to 2-23.

** ESL gave the man-hours for the 250th satellite to be 360. It is slightly, but insignificantly, different from our number, probably because of different interpolation assumptions. Our calculated man-hours for the 250th satellite are 372.76 and those for the 240th satellite are 373.20. Therefore, it also does not matter whether we use the figure for the 240th or 250th satellite.

****MILSTAR will consist of 8 satellites including one in-orbit spare. Sundaram, "U.S. Satcom," <u>op. cit</u>, p. 709.

receiving station in another location on earth. The Soviet "store and dump" network stores a message from an earth station for as long as an hour and a half if the satellite can complete the retransmission within one orbit, or for as long as 11 hours if it needs to wait for the earth's rotation to bring the receiving station, such as one at sea, within line of sight. The average transmission time from one satellite to another in MSS is just milliseconds. The total cycle time between transmission and reception by users is designed to be a tenth of a second or less. In sum, if the program is successful, it would seem to have precisely the desirable characteristics of an adaptive, distributed communication network.

The problem of getting sensors that can keep functioning or be reconstituted in time of war has been at least as neglected as the problem of getting durable communications. And the possibilities for dealing with the problem parallel in important respects the alternatives we have discussed for communications. We would need to receive at least gross continuing information on the status of military forces and civil society on both sides. The appropriate information rate and the degree of resolution would vary with the contingency (an initial small selective exchange of nuclear weapons growing out of a conventional conflict on a flank of NATO, large but selective exchanges of nuclear fire in the course of a conventional invasion in the European center, etc.); and with the use to be made of the information: detection, acquisition and tracking of military forces on the ground or at sea for purposes of maneuver and directing fire; or of aircraft and missiles in the air to enable interception; or of reentry vehicles as distinct from decoys in space, etc. Take three examples of the possibilities in various stages of research, development, acquisition and deployment: space-based nuclear detectors, phased array radar satellites, and satellites with staring focal plane arrays.

Integrated Operational Nuclear Detection Systems (IONDS) packages of sensors for detecting visible light, X-rays and the electromagnetic pulse associated with a nuclear explosion are programmed to be distributed on some of the 21 GPS navigation satellites (including 3 spares) we are in the process of deploying at semi-geosynchronous altitude. IONDS so distributed would degrade rather slowly and could be distributed further by piggybacking on other systems besides GPS, and so further improved in mission survivability.

Space-based radars can greatly reinforce the information derived from electronic intelligence. From time to time in the last 12 years, the Soviets have had one or two active, primitive radar satellites (RORSATs) in low earth orbit to perform the function of wide area ocean surveillance. They also have a few electronic ocean reconnaissance satellites (EORSATs) which passively use electronic emissions to locate and target U.S. and allied naval forces for destruction by anti-ship platforms. Both the U.S. Air Force and the U.S. Navy have at least since the 1970s been considering systems involving several phased array radar satellites at three-tenths geosynchronous altitude. The Navy considered a system of 12 satellites for ocean surveillance, the Air Force six for air defense over the U.S. And a joint Air Force-Navy system of a dozen satellites, proposed for almost as long, would work over land as well as sea to enable the detecting and targeting of aircraft and ships worldwide. So far, it has met the usual fate of such joint projects. However, under the stimulus of SDI and the attention it has focused on the problem of survivability in space, much more advanced, more distributed, agile and powerful systems of radars are now under study. And the state of the art has advanced substantially. The Air Force, in its Project Forecast II, proposes to investigate the possibility of placing extremely large phased arrays in space with major parts of the arrays on separate satellites without any rigid connection to each other. If phase coherence among these widely separated components could be achieved by electronic means, the system would degrade very slowly and elements of it could be replenished or added in time of peace and possibly in wartime. The project is in the idea stage and is clearly at most a prospect only for the long run.

The technology of focal plane arrays, on the other hand, has been under rapid development. Its wide range of potential applications varies from guided conventional submunitions in ground warfare to potential miniature homing vehicles for kinetic energy weapons in space to airborne optical sensors for acquiring and tracking reentry vehicles in midcourse to satellite-based sensors for detecting or tracking other satellites, missiles, aircraft, ships or moving tank divisions to imaging features of the terrain. A staring mosaic sensor may consist in the future of millions of detectors densely packed in a focal plane. Such optical systems with much shorter wavelength are capable of resolutions several orders of magnitude better than that of UHF radar with the same aperture size. Staring mosaics in which each detector looks at its portion of the field of view continuously have several advantages in sensitivity compared to scanning sensors. The staring permits longer integration times than scanning and, since signal to signal accumulates linearly while random noise fluctuation accumulates only as the square root, the sensitivity of the staring sensor increases roughly as the square root of the integration time. Also, it is more efficient than scanning sensors in eliminating background clutter against moving targets. From the standpoint of increasing the survivability and reconstitutability of our systems for acquiring information, the most relevant points are that such sensors should permit large weight reductions for a given performance and the possibility of reducing the size of satellites with the associated possibilities of multiplying the numbers of satellites, reducing their launching costs, and increasing the possibilities of replenishment. For example, focal plane arrays might allow us to move away from our reliance on a small number of DSP satellites for early warning from space.

In thinking about satellite mission survivability we need to look at programs not only individually but as a whole for ways in which they might reinforce each other. There are two key points:

1) individual programs not only complement each other, but are also partial substitutes--the loss of radar information on the movement of ships might be replaced for some purposes by information obtained through signals intelligence; and

2) these individual programs can be designed much more than they have been to take advantage of opportunities offered by related programs. Specifically there is considerable scope for more extensive piggybacking of the functions of some military satellites on other military satellites, as we have done with nuclear detectors and some transponders. And, using the model of the civil reserve air fleet, it should be possible to exploit the growing number of power-

ful civilian private and public computing centers and communications nets and satellites to improve capabilities for survival or reconstitution.

In sum, in the design of satellites and their constellations, the United States should have placed more emphasis on systems composed of larger numbers of cheaper satellites that could degrade gracefully if some satellites were destroyed. In fact, the rapid advances in sensing technologies, data processing and component miniaturization have opened even better opportunities for designing this type of adaptive, distributed system. A proliferated system of inexpensive components would greatly reduce an adversary's incentives to place ASAT weapons in space. It would also make replenishment a viable component of our satellite mission survival program. Graceful degradation would also buy time for the activation of earth-based backup systems, if needed.

While these unilateral efforts would not critically depend on any space agreement for success, there are space agreements that would help to avoid conflicts arising from misunderstanding and to facilitate self-defense.

A Self-Defense Zone agreement would make both sides agree to avoid menacing activities. The "death line of Sidra" illustrated that a military confrontation can arise between the claims of a unilaterally declared keep-out zone and those of freedom of navigation. Most interesting, self-defense zones in space are useful under practically all circumstances: with ASATs, or under a limited or comprehensive ASAT ban. This feature should draw widespread political support for the negotiation and implementation of SDZs.

Soviet Incentives to Negotiate and Agree on SDZs

The Russians say frequently that they are concerned about a possible NATO or U.S. surprise attack. Many in the West, including some Sovietologists, think their fear is real, whether or not it is justified. If so, the Soviets should be interested in negotiating an agreement which makes a surprise raid on a critical proportion of their satellites much more difficult and defense against it easier.

The Soviets, of course, also deny that they have any interest in obtaining the capability for making an unprovoked surprise attack on NATO or the U.S.

It's quite possible that the Soviets aren't really worried about a NATO surprise attack. Or, at least, not very worried. If so, and if they also have no interest in being able to conduct an unprovoked surprise attack themselves, they may nonetheless find it useful to conduct a negotiation whose object is to make it clear to the rest of the world that they want it to be hard to conduct a surprise raid effectively on a critical number of satellites.

If they are not worried about a NATO surprise attack, and want to have a capability to conduct a surprise raid of their own, this is hardly the sort of thing that they can proclaim in public as a way of winning friends and influencing people. And the West certainly cannot afford, in that case, to negotiate a space agreement that doesn't hamper surprise attacks simply because the Soviets would find it unacceptable to be prevented from conducting such an attack on the West.

A good many advocates of arms control in recent times have taken the tack that we should not try for agreements which are not "negotiable" with the Soviets. If "negotiability" includes bowing to the Soviet insistence on preserving their capability to conduct a successful surprise attack--a possibility considered above--those in the West who insist on our advancing only "negotiable" proposals have a criterion problem.

The process of negotiating this agreement would offer an excellent forum for making clear some of the essentials of useful arms control measures as distinct from ones that are merely negotiable.

A self-defense zone agreement may be concluded provided that the Soviets are willing to negotiate without insisting on achieving or maintaining a capability for surprise attack. If they do insist, negotiations of any space agreement are not likely to be of great utility to the West.

Finally, there is much to negotiate about the number, location, size and transit of self-defense zones, some of which are analogous to frequency allocation in the field of communications. Such negotiations could be substantive and of positive utility. That would distinguish them from some arms control negotiations that have actually hampered Western self-defense.

II. A PROPOSED SELF-DEFENSE ZONE AGREEMENT

The first requirement of an effective satellite defense is adequate warning time. No such defense is feasible against an attack from close range. Some designated zones for each side would not only provide warning for active and passive defenses of satellites but also allow better and additional preparation against an attack on earth that could follow the ASAT attack. We call these self-defense zones (SDZs).

Three Key Features of Our Proposal

Before describing the proposal in detail, we would like to contrast ours with the previous "keep-out zone" proposals. They differ in three essential aspects. First, previous ones, in effect, often attempted to protect every satellite which serves a critical mission, instead of the critical missions themselves. To achieve the former objective, no Soviet satellite could be allowed in a U.S. zone since the Soviets could take advantage of a close transit to mount a deadly attack. But the already sizable number of satellites in space and the criterion of keeping the probability of any transit low would often result in zone size ranging only from 1 to 100 kilometers. Such a small size would greatly limit the utility of a keep-out zone. In our proposal, redundancy is considered as an essential feature of the satellite mission survivability program, and thus the destruction of a few satellites would not lead to mission interruption. Consequently, a small number of Soviet transits at any given time through our zones could be allowed. This provision permits us to choose zone sizes as large as thousands of kilometers and to provide much longer warning time for defense and other responses. At the same time, it also permits peacetime inspection and collection of information about the other side's satellites from close range.

Second, in previous proposals the zones were attached to satellites. Then only smaller zones were feasible for satellites at the crowded but important geosynchronous orbits. Instead, we take advantage of the fact that the very purpose of placing satellites there is to be geostationary, and create very large sectors (3,700 km radius) that revolve in an orbit synchronzied with the Earth's rotation (Figure II-1). For semi-geosynchronous orbits (Figure II-2) and above geosynchronous orbits (similar to Figure II-2 but at different altitudes and of a different thickness), the zones would take the shape of spherical shells. These sectors and shells will be described in detail later. They are larger in size and provide better warning. But, perhaps even more important, these geostationary sectors and altitude shells make each side better able to control its satellites and to monitor others, because these zones do not move around with respect to the earth. Also, since they define the allowable regions in space for not only current but future satellites of both sides, the proposed arrangement permits orderly planning and mutually beneficial utilization of space.

Third, previous proposals are either silent or ineffective in dealing with violations. We consider an essential element in the agreement to be the right to inspect, expel or otherwise render harmless invading satellites (should they exceed a mutually agreed safe number), without first passing through the sluggish Standing Consultative Commission.

FIGURE II - 1
SELF-DEFENSE SECTORS AT GEOSYNCHRONOUS ORBITS

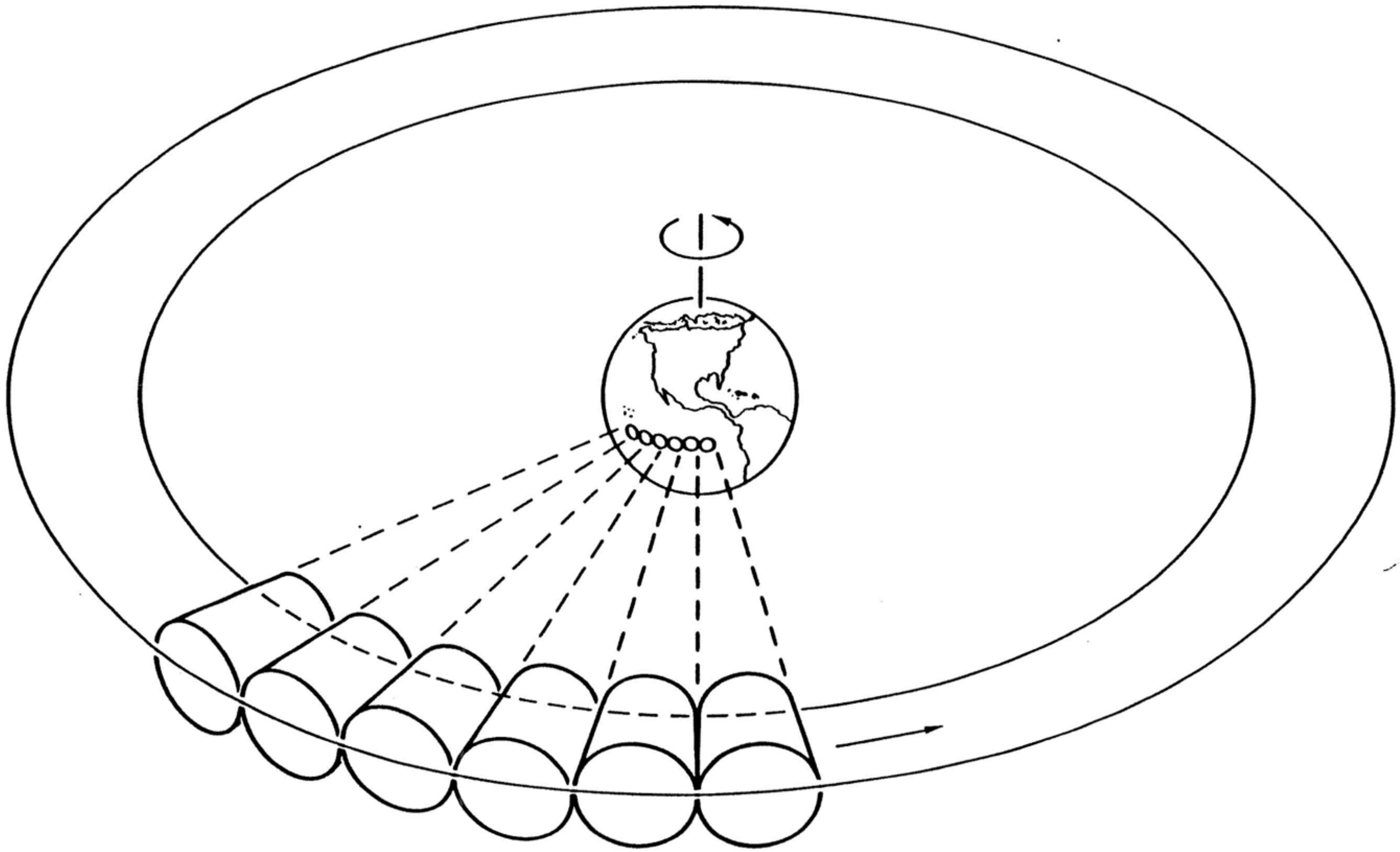
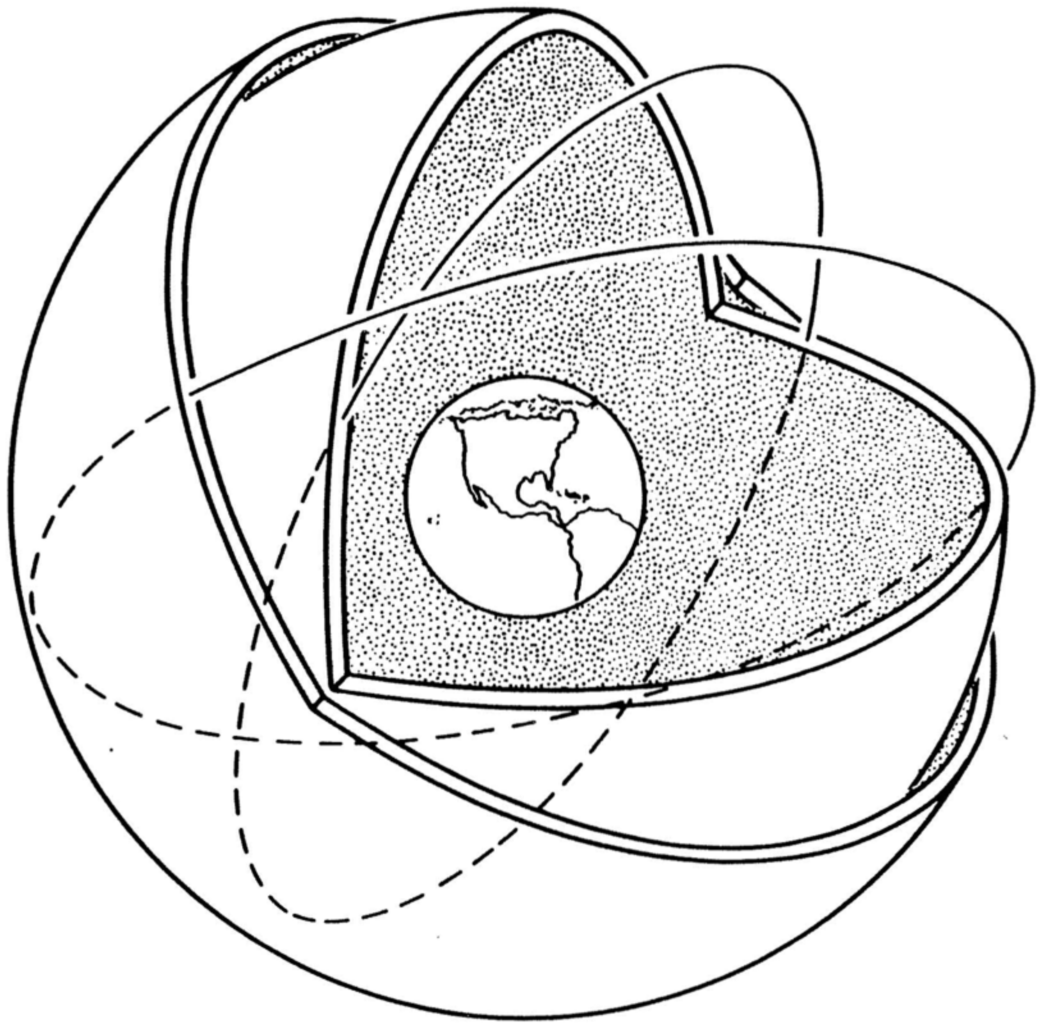


FIGURE II - 2
SELF-DEFENSE SHELLS AT SEMI-GEOSYNCHRONOUS ORBITS



Role of Self-Defense Zones

Self-defense zones are designed to counter surprise attack. The attack does not have to be a "bolt-from-the-blue." A tactical surprise would do. Too much emphasis has been placed on the Soviets' ground-launched ASATs to the exclusion of space mines. In fact, space mines are often not even considered one of the credible ASAT weapons in the space community. We readily agree that ground-launched ASATs do not have to be pre-deployed in space and might well be the system of choice when tactical surprise no longer exists. But space mines, and in the future space-based ASAT weapons, would be the only way that an attacker could destroy a large number of satellites simultaneously in a sudden initial attack. The sudden total collapse of a system frequently causes much more adjustment difficulties than a gradual degradation.

Let us illustrate the space mine threat and the role of self-defense zones with the contingency of a growing crisis between the Warsaw Pact and NATO in Europe. Assume that the situation at geostationary orbit is pretty much the same as today and our critical satellites there have not been or cannot be replaced by a much larger number of satellites at the same or other altitudes. In Case (1), no SDZ agreement has been signed between the two sides. The Soviets are steadily positioning an increasing number of satellites, possibly space mines, next to our critical satellites. If these activities are not stopped, over a period of a month, the 20 or so U.S. and allied critical satellites at geostationary orbit will have threatening neighbors. These critical satellites include early warning DSP satellites and military communications satellites: DSCS (Defense Satellite Communication System), FLTSATCOM (Fleet Communication Satellites), LEASATs and NATOs (NATO Communication Satellites). Their missions are to provide the earliest warning of a Soviet ballistic missile attack and the trans-atlantic communications needed to control and employ our forces. These Soviet prepositioning activities have some resemblance to their naval maneuvers in crises. During the October 1973 Arab-Israeli war, they increased the number and intensity of their shadowing operations by putting an anticarrier group near every major task group in our Sixth Fleet. They trailed the amphibious group as well as the usual aircraft carrier groups--a move without precedent in previous Mediterranean crises.* So we cannot count on the Soviets not to take threatening or unprecedented actions against our satellites. Nor can we count on such actions as giving unambiguous warning of a planned Soviet attack.

First, suppose that the West had not developed and deployed active satellite defenses because we did not see the need or it was prohibited by a signed total ASAT ban. Against expensive satellites, the Soviets could afford to design more capable space mines which could defeat passive defenses. Whenever the Soviets wished to carry out the attack, those targeted satellites would be destroyed because passive defenses alone could not do the job. In the meantime, all the West could do would be to protest about the Soviets' provocative actions, demand the removal of these unwelcome companions and, at the same time, make preparations for the possible loss of our satellites.

The Soviets might counter our accusation by saying that the United States is claiming sovereignty over space and is denying other nations free

*"The October 1973 Arab-Israli War," by Stephen S. Roberts in Soviet Naval Diplomacy, edited by Bradford Dismukes and James McConnell, Pergamon Press, 1979, p. 206.

access to space, both of which actions are prohibited by the Outer Space Treaty of 1967. Of course, they would conveniently forget to mention the respect of "inherent right of self-defense" in Article 51 of the United Nations Charter. Some prominent people in the West might argue that the Soviets have not violated any treaty: those Soviet objects were for close monitoring and could not be space mines because the Soviets had not tested them or because they were prohibited by the signed total ASAT ban. The earlier suggested paths for developing space mines under a total ban are considered incredible by these observers. They even turn the naval examples around and argue that no shot has ever been fired by the Soviets at our carriers in the course of shadowing. So the United States' going to a higher alert would be unnecessary and could provoke the Soviets into an actual attack in space and/or on the ground. The military, unsure about the Soviets' ultimate intent, would make some half-hearted preparations. In any case, they could not know when the actual attack would come and would take no readiness or emergency measures that could not be sustained indefinitely.

Next, suppose that the West had deployed active satellite defenses but that there is still no self-defense zone agreement. Again, as the Soviets are positioning these near-by objects, a heated debate erupts in the West. Of particular concern are the consequences of our "escalatory" actions in attacking Soviet satellites although they are threatening ours. We are unsure as to when, if ever, we would take defensive actions to neutralize these menacing near-by objects.

This is the same D-day shoot-out problem facing the Navy. In times of crisis, the Soviets often use combatants to "tattletale" our carriers at the scene. Moreover, on occasion they moved their ships within firing range to the carriers. For example, during the Jordanian crisis of September 1970, their shadowing anticarrier groups had the capability to cause great harm to our task groups in a surprise attack.* The U.S. and Soviet agreement on Prevention of Incidents On and Over the High Seas, which was signed in 1972 and had the right intention, is nowhere nearly effective in preventing the intermingling of the two fleets because the Agreement does not specify keep-out distance, allowable transit numbers and unilateral enforcement right. As discussed earlier, the Soviets continued to use anticarrier groups to shadow every one of our major task groups in the Mediterranean during the 1973 Arab-Israeli war. On the other hand, the Soviets also attempt to control the threat posed to U.S. forces. But, it is hard to strike the desired balance when both sides' forces are intermixed. After analyzing the behavior of the navies of the two superpowers during acute international crises since the mid-1960s, Stephen Roberts and his colleagues concluded that

> A violent exchange between the superpower fleets (whether the result of deliberate choice, accident, misperception, or the actions of third parties) could not have been ruled out.**

In space as well as at sea, just having the self-defense assets is insufficient. Both sides need first to make clear and, much better yet, to agree upon what configurations of threatening platforms would be considered intolerable and would invite proper counter-actions.

In Case (2), an SDZ agreement has been signed in peacetime and well before the crisis. If a total ASAT ban is also in force, we could not have developed active defenses, without which these critical satellites

---

* Ibid., p. 211.
**Ibid., p. 158.

could still be destroyed. On the other hand, if we did not sign a total ban, a defensive capability against space mines could have been deployed. While space mines are deadly if the victim can be surprised, they are relatively bulky, slow and not very maneuverable. The DSAT requirement in countering them is correspondingly low and should be attainable within the same time frame as space mines.

Some might argue that the zones plus the enforcement feature amount to the establishment of dangerous free-fire zones. This misunderstands the SDZ concept. With or without SDZ, if we did not need to fire, we would not fire. The difference lies in the consequences of firing when we need to fire. With the Soviets' prior acknowledgement of such a right in an SDZ agreement, escalation would be much less likely if we did fire. Moreover, with an unambiguous understanding of the right to clear out invaders, the Soviets would have much less incentive, and thus be less likely, to send ASAT weapons or platforms into our zones in the first place, because we would take appropriate measures and they would not accomplish their military objective with these invaders. On the other hand, if they still decided to invade our zones, they would have to pay a much higher political cost by violating a formal agreement at time of crisis when it is supposed to count. And we would know better about their intentions when they did. As the Soviet invaders exceed the prior-agreed safe number, we would render them harmless by methods ranging from inactivation of their sensing or control system to total physical destruction. It is much more appropriate and less escalatory to directly neutralize the threat posed by these violations instead of retaliating against the adversary's other assets in space and on the ground.

Satellite Distribution by Mission and Orbit

Before we discuss the specifics of our proposal, it is necessary to study the current and projected worldwide satellite distribution. An ideal SDZ agreement would be one which clarifies and prohibits threatening actions without unduly restricting and burdening space use and activities.

Later, when we design self-defense zones, we will try to take advantage of the satellites' different population densities and orbital characteristics at different orbits. One key reason that previous keep-out zone proposals fail to gather momentum is that they do not go beyond the basic concept and tailor the design to fit the actual space environment. In Figure II-3, various types of satellite orbits and their characteristics are shown.*

We found it most convenient to design SDZs according to the following classification of satellite orbits:

(A) Above geosynchronous orbits are those with apogee and perigee at or above 40,000 kilometers (km);

(B) Geosynchronous orbits are those with apogee and perigee at or above 30,000 km but below 40,000 km;

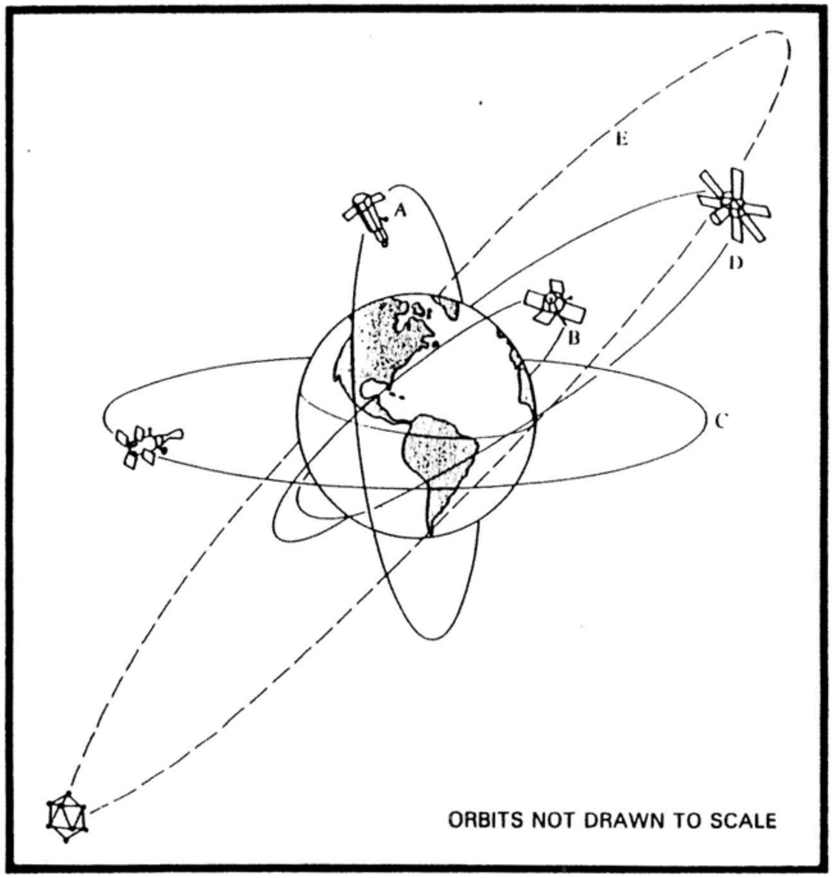
(C) Intermediate earth orbits are those with apogee and perigee at or above 3,000 km but below 30,000 km;

(D) Low earth orbits are those with apogee and perigee below 3,000 km, and;

(E) Highly elliptical orbits are those not belonging to any of the above groups.

*For more details, see, for example, Aston B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," International Security, Spring 1986, pp. 46-98.

FIGURE II - 3
TYPES AND CHARACTERISTICS OF SATELLITE ORBITS



Selected satellite	Altitude (km)	Orbital inclination*	Type of orbit
Reconnaissance			
Photographic			
US Big Bird	180–290	97°	A
US KH-11	240–530	97°	A
Cosmos	180–350	62°, 72°, 82°, 67°	B
Electronic			
US	480	97°	A
Cosmos	500	74°	B
	650	82°	B
Ocean surveillance			
US	1 100	63°	B
Cosmos	250	65°	B
Early warning			
US	36 000	0°	C
Cosmos	688 × 39 000	63°	D
Nuclear explosion detection			
US	110 000	35°	E
Meteorological			
US	36 000	0°	C
Meteor	900	81°	B
	610	98°	A
Communications			
US SDS DSCS	250 × 39 000	64°	D
US FLTSATCOM	36 000	0°	C
Molniya	440 × 40 000	63°	D
Cosmos	1 400	74°	B
Navigation			
US	20 000	64°	B
Cosmos	1 000	83°	B

*The angle between the plane of the orbit and the equatorial plane.

SOURCE: BHUPENDRA JASANI AND CHRISTOPHER LEE, COUNTDOWN TO SPACE WAR, STOCKHOLM INTERNATIONAL PEACE RESEARCH INSTITUTE, 1984, FIGURE 3 ON PAGES 16-17.

In Table 1, the current and projected distributions of operational satellites among these five groups of orbits are shown. They are mostly active satellites and a few of them are spares. We have gone through considerable difficulties in preparing the table and need to comment on it.

First, to our knowledge there does not exist a data base from which one can derive all the entries in Table 1. We were forced to combine several sources of different dates and to use our own judgment to reconcile the inconsistencies and update the data. Nicholas Johnson* provided the best estimates of current Soviet operational satellites in all orbits. Ironically, for our own U.S. satellites on which we should have much better information, there does not exist a similar consistent analysis. We rely on Fairchild Space Company's map for current and future non-Soviet geostationary civil communications satellites and for future Soviet communications satellites. We use John Pike's estimates for U.S. entries in low earth and highly elliptical orbits. We also found the NORAD unclassified satellite data base (although it does not specify satellites' operational status: alive or dead), the Federal Communications Commission's geostationary data base, and <u>Jane's Spaceflight Directory</u> useful in cross-referencing and in helping to determine the rest of the entries in the table.

Second, the current U.S. and USSR satellites in aggregate shown in Table 1 are in excellent agreement with those numbers in the authoritative <u>Soviet Military Power</u> where the Department of Defense states that,**

> The U.S. and USSR currently maintain about the same number of operational satellites in orbit, 110 to 120.

---

* All data references can be found immediately following Table 1.
** Department of Defense, <u>Soviet Military Power</u>, 1984, p. 46.

Table 1: Current and Projected Distributions of Operational Satellites

Orbit	Our Altitude Grouping (km) A = Apogee P = Perigee	Typical Satellite Altitude (km)	Mission	Current (End of 1985) Western Alliance US	Current (End of 1985) Western Alliance Others	Current (End of 1985) Soviet Bloc USSR	Current (End of 1985) Rest	Early 1990s Western Alliance US	Early 1990s Western Alliance Others	Early 1990s Soviet Bloc USSR [9]	Early 1990s Rest
Above Geosynchronous	40,000 ≤ A,P		Nuclear Detection	2 [6]	0	0	0	0	0	0	0
			Early Warning & Others	0 [8]	0 [8]	0 [8]	0	0 [8]	0 [8]	0 [8]	0
				2	0	0	0	0	0	0	0
Geosynchronous	30,000 ≤ A,P < 40,000	36,000	Early Warning	3 [3]	0	0 [2]	0	3 [3]	0	3 [3]	0
			Electronic Intelligence	4 [3]	0	0 [2]	0	4 [3]	0	0 [3]	0
			Communication, Military	15 [13]	3	26 [2,14]	0	15 [4]	3 [4]	61 [1,9,14]	0
			Communication, Civil	45 [1,7]	20 [1]	- [14]	9 [1]	104 [1,10]	50 [1]	- [14]	32 [1]
			Meteorology	4	3	0 [2]	0	4 [4]	3 [4]	4 [11]	0
				71	26	26	9	130	56	68	32
Intermediate Earth	3,000 ≤ A,P < 30,000	19-20,000	Navigation	7 [5]	0	10 [2]	0	21 [3]	0	10 [4]	0
Low Earth	A,P < 3,000	< 3,000	Communication	0 [3]	0	27 [2]	0	0 [3]	0	27 [4]	0
			Navigation	5 [3]	0	10 [2]	0	0 [3]	0	10 [4]	0
			Electronic Intelligence	12 [3]	0	9 [2]	0	14 [3]	0	9 [4]	0
			Meterology	4 [3]	0	5 [2]	0	4 [3]	0	5 [4]	0
			Radar Surveillance	0 [3]	0	2 [2]	0	0 [3]	0	2 [4]	0
			Photo Reconnaissance	4 [3]	0	1-5 [2]	0	2 [3]	0	1-5 [4]	0
			Manned	1 [3]	0	1 [3]	0	1 [3]	0	2 [3]	0
			Others	1 [3]	8 [12]	7-10 [2]	3 [12]	1 [3]	8 [4]	7-10 [4]	3 [4]
				27	8	62-69	3	22	8	63-70	3
Highly Elliptical	Others	400 x 40,000	Early Warning	0 [3]	0	9 [2]	0	0 [3]	0	9 [4]	0
			Communication, Military	2 [3]	0	16 [2,14]	0	2 [3]	0	16 [4,14]	0
			Communication, Civil	0 [3]	0	- [14]	0	0 [3]	0	- [14]	0
			Others	1	13 [12]	2 [2]	1 [12]	1 [4]	13 [4]	2 [4]	1 [4]
				3	13	27	1	3	13	27	1
				110	47	125-132	13	176	77	168-175	36

Sources and Notes to Table 1: All unmarked entries are our estimates.

(1) Map of Geostationary Communication Satellites, Fairchild Space Company, Fairchild Industries, 1 June 1984. We use the following additional sources to update, adjust and confirm their data:

a) NORAD Unclassified Satellite Data Base as of December 31, 1985. Courtesy of Messrs. Robert Mercer and Michael Lew, Aerospace Corporation.

b) Data base (as of December 17, 1985) on geostationary satellites, Treaty Branch Office of Science and Technology, Federal Communications Commission. Courtesy of Mr. Anthony Rutkowski, FCC.

c) Jane's Spaceflight Directory 1985, edited by Reginald Turnill.

d) TRW Space Log, various annual issues.

e) Aviation Week and Space Technology, Forecast and Inventory Issue, March 18, 1985, pp. 170-171.

(2) Nicholas L. Johnson, The Soviet Year in Space 1984 and 1985, Colorado Springs Office, Teledyne Brown Engineering, particularly p. 3 of the 1984 issue and p. 79 of the 1985 issue.

(3) John Pike, "Anti-Satellite Weapons," Federation of American Scientists Public Interest Report, November 1983.

(4) Assumed to be unchanged from current satellite constellation or network.

(5) NORAD unclassified satellite data base and private communication with Dr. J. S. Leung of Aerospace Corporation on February 14, 1986.

(6) Bhupendra Jasani and Christopher Lee, Countdown to Space War, Stockholm International Peace Research Institute, 1984, p. 15; and Paul B. Stares, "Space and U.S. National Security" in National Interest and the Military Use of Space, edited by William J. Durch, 1984, p. 48.

(7) Including 15 INTELSATs.

(8) Satellites for these missions and in this orbital group, if they exist, are highly classified.

(9) Including one Cuban satellite at 84° W.

(10) Including 55 INTELSATs.

Sources and Notes to Table 1 (continued):

(11) Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," International Security, Spring 1986, p. 67.

(12) Mostly research satellites.

(13) Five Phase II DSCS, two Phase III DSCS, five FLTSATCOM and three LEASAT.

(14) Civil communication satellites are included in the count of military communication satellites.

The total number of U.S. satellites in Table 1 is 110 and the Soviet number is between 125-132.* However, the excellent match might have exaggerated the quality of the individual entries in Table 1; some sensitive military satellites might be classified and dropped from less-aggregated lists where their missions and orbits would have to be specified. Moreover, whether some old satellites are spares or dead is highly uncertain.

Third, for future operational satellites at the important geostationary orbit, we essentially use, via Fairchild's data, information supplied to the International Frequency Registration Board (IFRB) by the members of the International Telecommunications Union. In addition to the current satellites, we include all satellites presently being coordinated by IFRB and those given advance publication. Coordinated ones are often placed in their geostationary slots in a few years. Moreover, countries normally submit their plan of geostationary launches for the next five years to IFRB for advance publication.** However, it is difficult to determine how many of these new satellites will actually go into orbit and when and to what degree they are replacements of some older-generation satellites which should be deleted from the future list of operational satellites. There is also the uncertainty of the impact of the Challenger loss--one of the four U.S. space shuttles--on launch delay and policy.***

---

* The Soviets had 108-120 operational satellites in 1984 in excellent agreement with the Department of Defense estimate in 1984. By the end of 1985, our time of reference, the Soviets had about 12 to 17 additional operational satellites.

** Private communication with Mr. Anthony Rutkowski, Science and Technology Office, Federal Communications Commission, February 4, 1986.

***NASA Administrator James Fletcher said on July 14 that the next space shuttle launching originally set for July 1987 has been rescheduled to early 1988 at best. (Michael Wines, "Next Shuttle Flight Delayed Until '88," Los Angeles Times, July 15, 1986.) Moreover, we think that President Reagan might not allow another manned shuttle flight during his term through January of 1989.

We assume as a best estimate, then, that these 286 satellites or about twice the current number (132), will populate the geosynchronous orbits by the early 1990s.

Impact of Satellite Distribution on SDZ Design

Satellite population and their orbital characteristics would affect the design of self-defense zones. Let's consider their impact on each of the five groups of orbits.

(1) Above Geosynchronous Orbits

There are very few satellites ever launched into earth orbits above geosynchronous altitudes. Between 1963 and 1970, the United States launched twelve Vela satellites into orbits of about 110,000 km altitude for detecting nuclear explosions. Two are still working. However, they are being replaced by the much more advanced sensors known as Integrated Operational Nuclear Detection Systems (IONDS) carried by the GPS satellites in 20,000 km orbits. In the 1960s and 1970s, there were several U.S. scientific satellites launched into 60,000 km and 120,000 km near-circular orbits for the study of solar flares and radiation. Other countries had placed few satellites there.

However, these high orbits have been considered from time to time for in-orbit satellite storage and backups to critical satellites. For example, an Advanced Warning System (AWS) at three times geosynchronous radius and a Strategic Satellite (STRATSAT) at five times radius, proposed in the past, would help us to diversify our sole reliance on geostationary DSP satellites for the critical early warning mission from space.

Since orbits in this group are sparsely populated, we can design some large, separate altitude shells for the Western Alliance and the Warsaw

Pact.* In each shell, a lower and an upper altitude bound are specified. Satellites in that shell would have their whole orbits (i.e., apogees and perigees) confined between those two bounds. The other side's satellites are not allowed to stay in the shell beyond a mutually agreed number and transit time.

(2) Geosynchronous Orbits

In Figures II-4 and II-5, we plotted the current and future satellite distributions at the geosynchronous orbits. We often hear the comment that these orbits are too crowded and the implementation of keep-out zones of any useful size is impractical there. These people are thinking of keep-out zones attached to satellites. To illustrate this, we attach a zone with a 2,000 km radius to every satellite belonging to the Western Alliance (Figures II-6 and 7). Indeed, these zones would occupy too large a portion of space and leave only 1/3 presently and 1/4 in the future of the geostationary belt to the Soviet Bloc. It is unreasonable to expect that they would be willing to settle for such a small fraction.

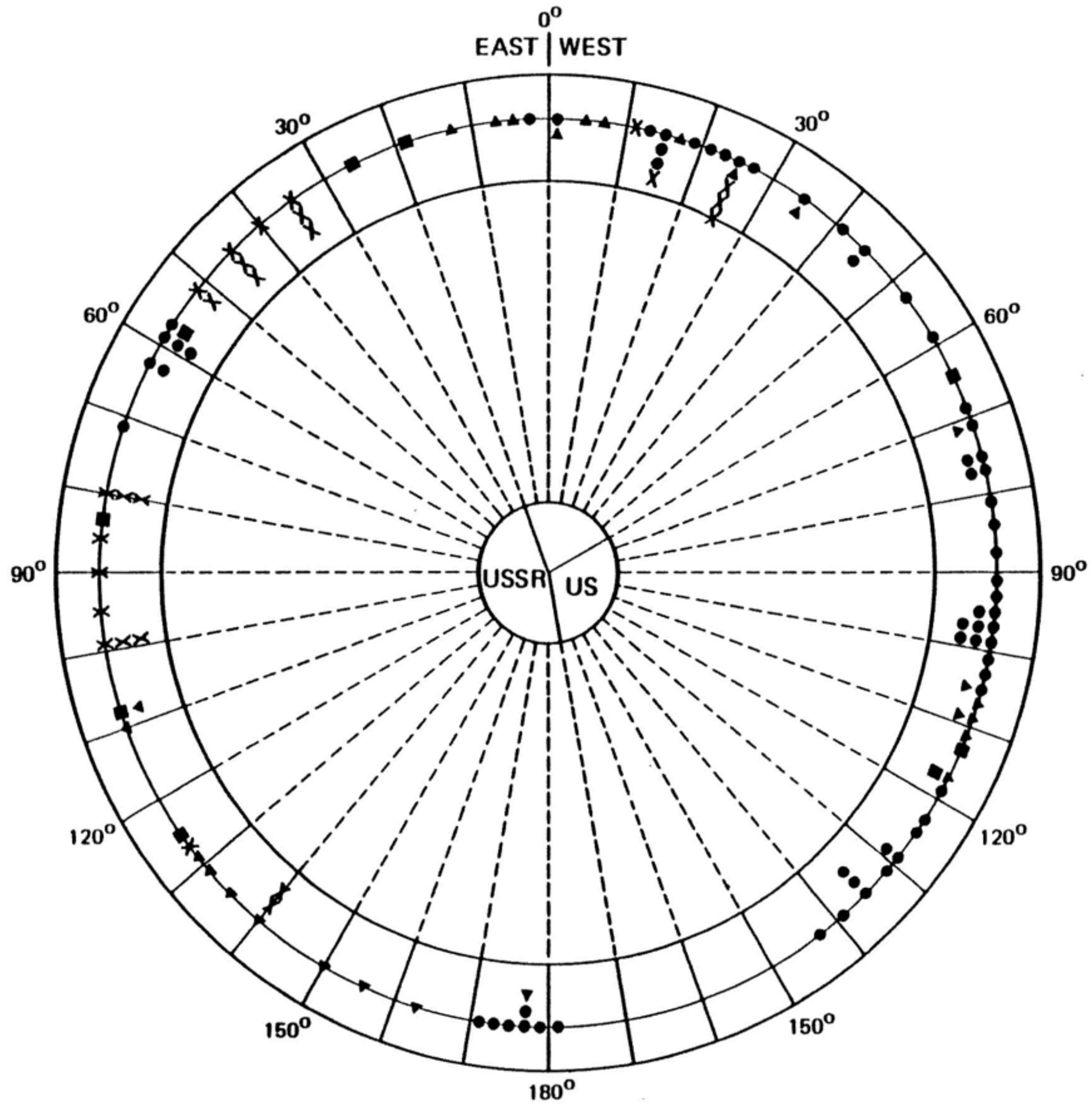
There are three ways to reduce the self-defense space for each side. First, use a smaller zone. But, there is practically no upper limit on the desirable zone size, above which no additional useful warning is provided. In other words, we should try to get the largest zone that does not appreciably affect normal satellite operations. Reducing zone size is not our preferred choice. Second, every satellite need not be placed in one of its side's zones; it's unnecessary since our objective should be the protection of critical satellite missions and not every satellite.

*We will discuss third-country satellites later. Their locations are essentially unrestricted.

FIGURE II - 4

CURRENT DISTRIBUTION OF OPERATIONAL SATELLITES IN GEOSYNCHRONOUS ORBITS
(AS OF DECEMBER 31, 1985)

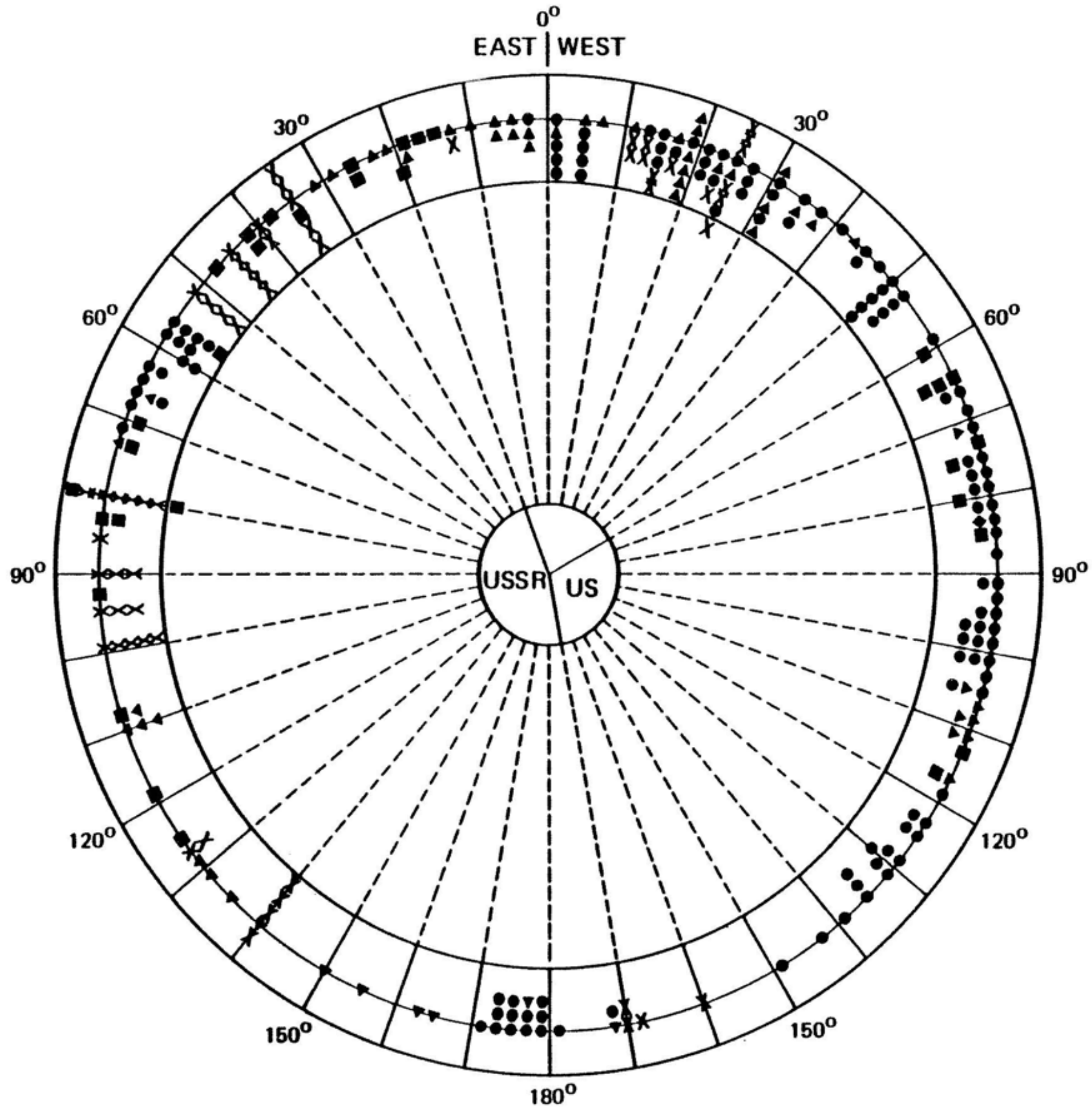
			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	64
	OTHERS	▲	26
SOVIET BLOC	USSR	X	26
	OTHERS	♦	0
REST		■	9
			125



NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED.

FIGURE II - 5
EARLY 1990s DISTRIBUTION OF OPERATIONAL SATELLITES IN GEOSYNCHRONOUS ORBITS

			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	123
	OTHERS	▲	56
SOVIET BLOC	USSR	X	60
	OTHERS	♦	1
REST		■	32
			272



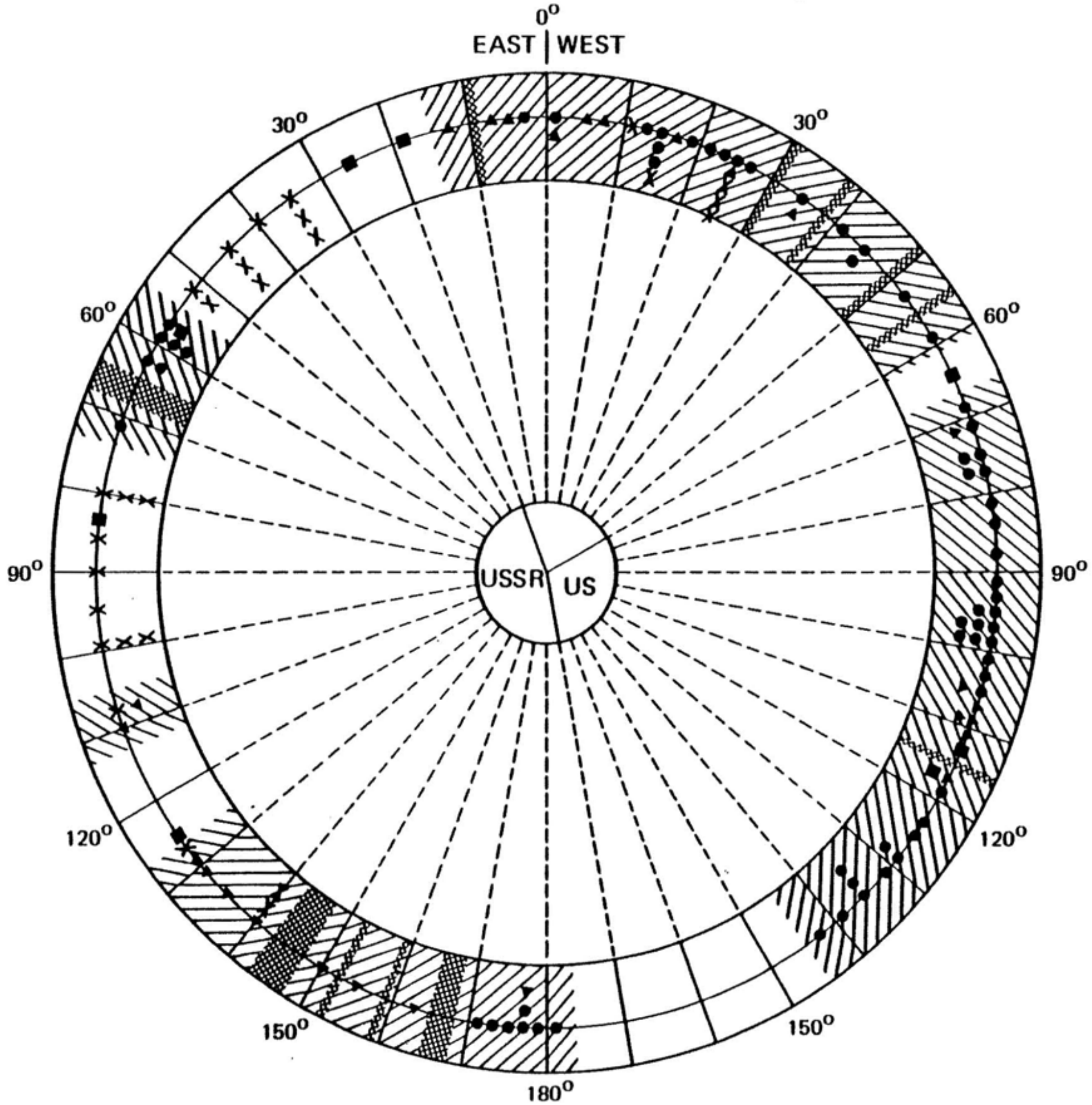
NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED. 3 USSR EARLY WARNING SATELLITES, WHICH WILL BE CLASSIFIED, ARE ALSO NOT SHOWN OR COUNTED. NOR ARE 4 USSR METEOROLOGY SATELLITES WHOSE LOCATIONS ARE YET TO BE DETERMINED.

FIGURE II - 6

GEOSYNCHRONOUS SPACE OCCUPIED BY WESTERN ZONES ATTACHED TO CURRENT SATELLITES
(AS OF DECEMBER 31, 1985)

	GEOSTATIONARY ARC COVERED ANGULAR	%
WESTERN OCCUPIED	220°	61
TOO SMALL FOR SOVIET BLOC OCCUPATION	19°	5
AVAILABLE TO SOVIET BLOC SATELLITES	121°	34
	360°	100

			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	64
	OTHERS	▲	26
SOVIET BLOC	USSR	X	26
	OTHERS	♦	0
REST		■	9
			125

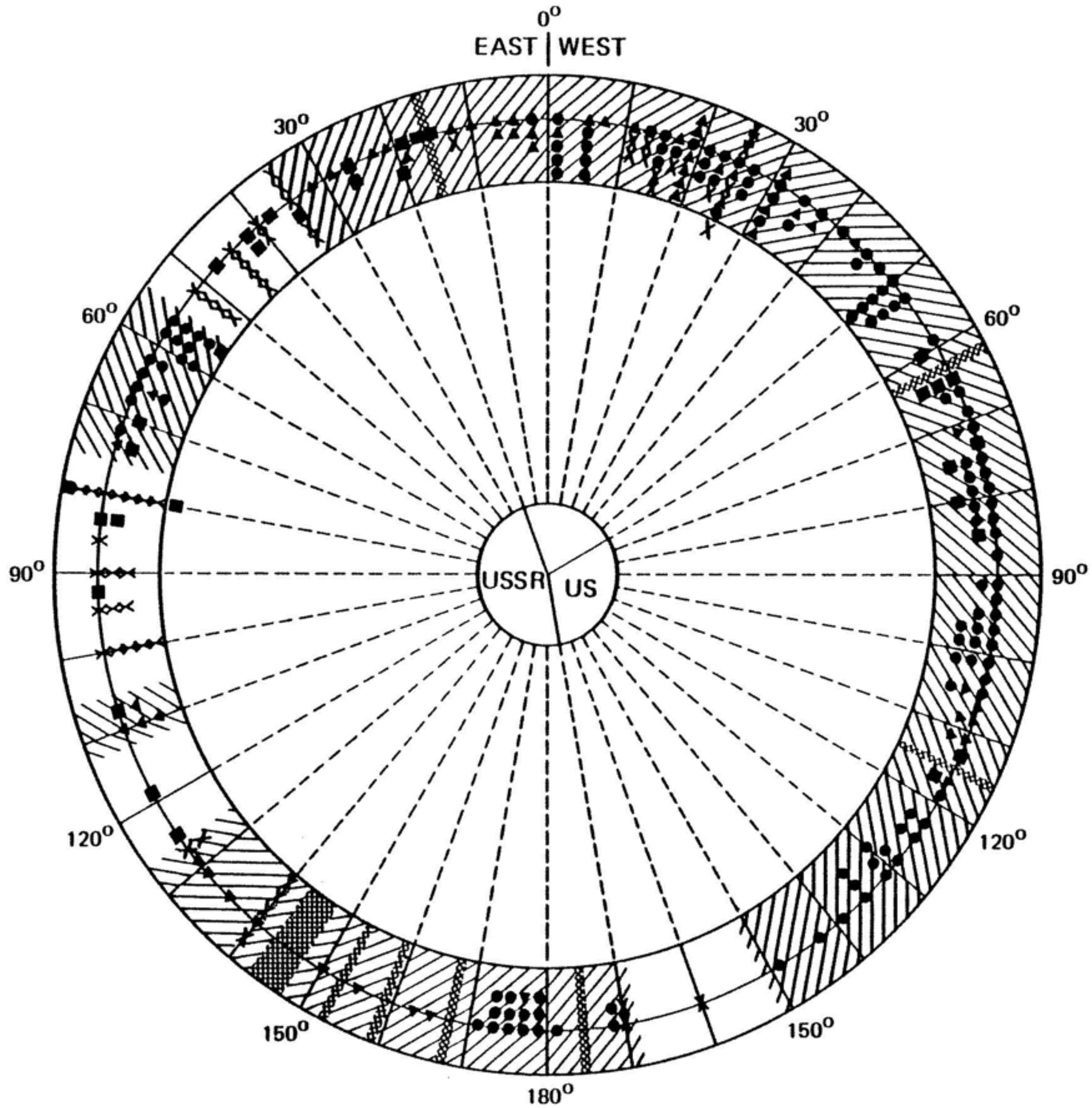


NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED.

FIGURE II - 7
GEOSYNCHRONOUS SPACE OCCUPIED BY WESTERN ZONES ATTACHED TO EARLY 1990s SATELLITES

		GEOSTATIONARY ARC COVERED: ANGULAR	%
WESTERN OCCUPIED	(hatched)	265°	73
TOO SMALL FOR SOVIET BLOC OCCUPATION	(stippled)	13°	4
AVAILABLE TO SOVIET BLOC SATELLITES	(blank)	82°	23
		360°	100

			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	123
	OTHERS	▲	56
SOVIET BLOC	USSR	X	60
	OTHERS	♦	1
REST		■	32
			272



NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED. 3 USSR EARLY WARNING SATELLITES, WHICH WILL BE CLASSIFIED, ARE ALSO NOT SHOWN OR COUNTED. NOR ARE 4 USSR METEOROLOGY SATELLITES WHOSE LOCATIONS ARE YET TO BE DETERMINED.

Thus, some of the satellites could be placed in neutral zones where both sides' satellites can stay without restriction. Third, group satellites so they can share the common protection of a single zone. Instead of attaching zones to satellites, assigning geostationary angular sectors or zones which revolve in an orbit synchronized with the Earth's rotation would allow large zones while reducing the total space required for self-defense by each side. We will specify the details of the geostationary arrangement in a later section.

Moreover, satellite-attached keep-out zones, as proposed by others, require more complicated monitoring and planning. One needs to predict the locations of the other side's satellites in order not to infringe their keep-out zones. One also needs to ascertain that his orbits under planning do not conflict with those of the other side. On the other hand, as first publicly outlined in July 1985,* our angular sectors are not attached to satellites and are fixed with respect to the earth. That makes it much easier to adjust the orbits of one's satellites for treaty compliance. That also makes it simpler to recognize dangerous incursions. These sectors also allow planners to easily select and plan future orbits which would not involve frequent accidental trespass. Finally, picking a sector fixed with respect to the Earth, rather than a zone attached to a satellite, makes it unnecessary to announce the locations of one's satellites at the geosynchronous orbits--which in turn offers useful opportunities to improve the protection of possible unspecified and silent satellites in one's own self-defense zones. Altitude shells for other orbits also have similar advantages. But, these advantages are of a lesser

*Albert Wohlstetter and Brian Chow, "Arms Control That Could Work," Wall Street Journal, editorial page, July 17, 1985.

extent because, as explained later, we need to declare the positions and orbital characteristics of some of the satellites there.

(3) Intermediate Earth Orbits

This group includes the important semi-geosynchronous orbits. Thus far, the U.S. has launched eleven GPS navigation satellites into orbits with apogees and perigees lying between 19829 km and 20532 km. Six of them work as expected and an additional one works with a degraded capacity. On the other hand, the Soviets have their counterpart, GLONASS, at lower altitudes of 19002 km to 19194 km.* This separation should be maintained and formalized for purposes of self-defense. During the last decade, few other satellites were launched into these intermediate earth orbits by any nation. Altitude shells similar to those in the above-geosynchronous orbits but of different thicknesses could be arranged for these intermediate orbits above and below the semi-geosynchronous shells.

(4) Low Earth Orbits

Currently, the U.S. has 27 operational satellites in these orbits and the rest of the Western Alliance has 8. The Soviet Union has 62-69 and the rest of the Soviet Bloc has none. Other countries have 3 satellites there. These satellites come near each other from time to time (see Appendix A). Moreover, the highly elliptical orbits of 44 operational satellites intersect the low earth orbits. Our simulation of satellite movements and their relative positions indicates that many low earth orbit satellites have companion satellites belonging to the other side within 2000 km at any given time (see Appendix A). If a satellite system

*NORAD Unclassified Satellite Data Base as of December 31, 1985.

consists of a small number of satellites and its mission performance would be impaired by the destruction of a few of them, a practical SDZ size would probably be limited to the order of 50 km. This also assumes that both sides are willing to coordinate their orbit selections to avoid co-orbital and counter-orbital satellites. Even a 50 km keep-out distance could be useful against a simultaneous surprise attack by nonnuclear space mines. Moreover, as discussed in Appendix A, there are several ways to increase the effective size of SDZs. A different approach is to design satellite systems which consist of a large number of substitutable satellites. Then, a much larger number of simultaneous zone transits and a much larger zone size can be allowed. In any case, the difficulties in monitoring and enforcement lead us to recommend that the initial SDZ negotiation, and even the initial agreement, should not include satellites in low-earth orbits. These low orbits have the additional problem of coming fairly close to potential earth-based interceptors.

(5) Highly Elliptical Orbits

As discussed above, satellites in these orbits constantly bring themselves into the vicinity of low-earth orbit satellites. Again, we recommend that these orbits not be included in the initial agreement.

<u>A Proposed Agreement on Self-Defense Zones in Space</u>

For specificity, we will suggest the number, size and locations of SDZs and the maximum number and time of allowable transits. However, there is ample room for negotiation without affecting the basic usefulness of SDZs in space. Moreover, we will leave the precise wording of the agreement to the lawyers.

The States Parties to this Agreement,

Recognizing that the utilization of space should be coordinated,

Believing that a clarification of what configurations of space objects are threatening would avoid confrontation arising from misunderstanding,

Have agreed on the following:

Article I

1. A number of self-defense zones (SDZs) as specified in Article II.2 are assigned to the states in the Western Alliance (WA) and a number of separate SDZs to the states in the Soviet Bloc (SB).

2. Each side has the right to decide which of the other side's satellites and under what conditions, such as ground inspection, are allowed to stay in its zones. The prohibition of all of the other side's satellites with only a few exceptions is a distinct possibility.

3. Each side has the right to inspect, expel or otherwise render harmless invading satellites exceeding a mutually agreed number and transit time set forth in Article II.3.

Article II

1. For the purpose of describing the locations and boundaries of SDZs, satellite orbits around the earth are divided into five categories:

i.	Above geosynchronous orbits	--	Apogee and Perigee $\geq$ 40,000 km
ii.	Geosynchronous orbits	--	30,000 km $\leq$ A,P < 40,000 km
iii.	Intermediate earth orbits	--	3,000 km $\leq$ A,P < 30,000 km
iv.	Low earth orbits	--	A,P $\leq$ 3,000 km
v.	Highly elliptical orbits	--	Others

2. The number and configuration of WA and SB SDZs are given below:

i. Above geosynchronous orbits:

--Three spherical shells which occupy space between altitudes 55,000 to 60,000 km, 75,000 to 80,000 km and 105,000 to 110,000 km are assigned to WA.

--Three spherical shells which occupy space between altitudes 65,000 to 70,000 km, 85,000 to 90,000 km and 115,000 to 120,000 km are assigned to SB.

ii. Geosynchronous orbits--As shown in Figure II-1, the boundary of a geostationary zone projected on the equatorial plane is formed by two earth-centered radii 10^{o} apart and the circumferences of two earth-centered circles with radii of 30,000 km and 40,000 km. The three-dimensional zone boundary is generated by the rotation of the above described boundary around an earth-centered radius on the equatorial plane bisecting the 10^{o} angle. Twelve such zones each are assigned to WA and SB as indicated in Figure II-8. Either side's satellites can stay without restriction in the remaining twelve neutral zones.

iii. Intermediate earth orbits: These orbits can be subdivided into semi-geosynchronous orbits and other intermediate earth orbits.

a) Semi-geosynchronous orbits--A spherical shell which occupies the space between 19,800 and 21,100 km is assigned to WA and one which occupies space between 18,000 and 19,300 km is assigned to SB. Moreover, neither side may place a satellite between 19,300 and 19,800 km without the other side's approval. No satellite may be placed between 21,100 to 21,600 without WA's approval and

FIGURE II - 8
SELF-DEFENSE ZONES AT GEOSYNCHRONOUS ORBITS WITH CURRENT SATELLITE DISTRIBUTION

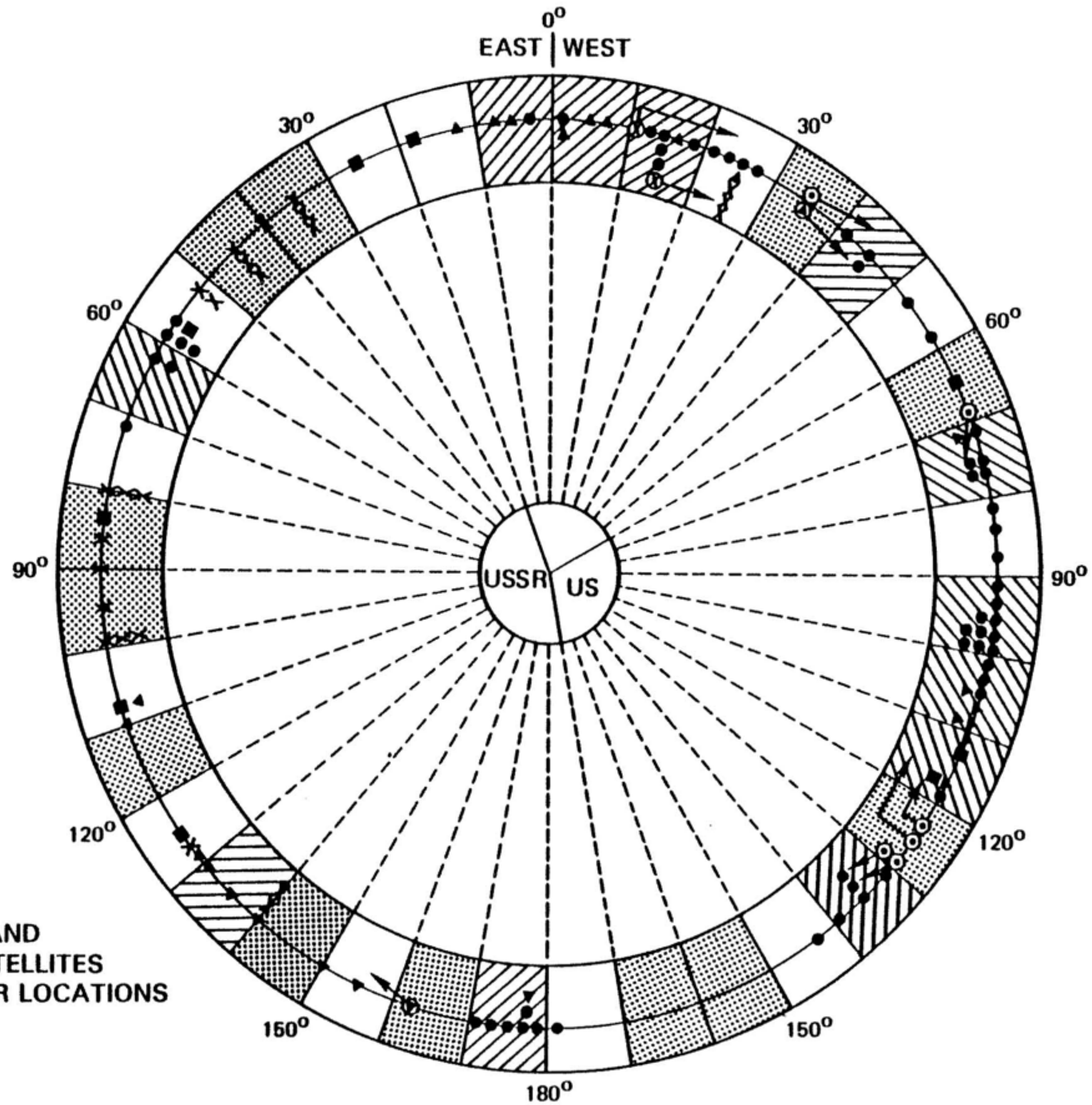
NUMBER OF SATELLITES IN OTHER SIDE'S ZONES

WESTERN ALLIANCE	8
SOVIET BLOC	2
	10

SDZ DESIGNATION

- WESTERN ALLIANCE (hatched)
- SOVIET BLOC (dotted)
- NEUTRAL (blank)

			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	64
	OTHERS	▲	26
SOVIET BLOC	USSR	X	26
	OTHERS	♦	0
REST		■	9
			125



NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED.

no satellite may be placed between 17,500 and 18,000 km without SB's approval.

b) Other intermediate earth orbits. The arrangement for these orbits is more flexible than that in the semi-geosynchronous ones because few satellites are currently at or planned for these orbits. Option 1: Three shells to each side. For example,

--three spherical shells which occupy space between altitudes 3,200-4,500, 8,400-9,700 km and 13,600-14,900 km are assigned to WA.

--three spherical shells which occupy space between altitudes 5,800-7,100 km, 11,000-12,300 km and 16,200-17,500 km are assigned to SB.

Option 2: One shell to each side. For example,

--one spherical shell which occupies space between altitudes 3,000 and 8,000 km is assigned to WA.

--one spherical shell which occupies space between altitudes 8,000 and 13,000 km is assigned to SB.

iv. Low earth and highly elliptical orbits:

Self-defense zones in these orbits are to be determined in subsequent agreement. (Suggestions are shown in Appendix A).

3. The maximum number and time of allowable transits by WA and SB satellites through the other side's zones are given below. But, one single or multiple payload launch is exempt from the transition rule. The number of such satellites in each launch type will have to be specified. For example, three Soviet semi-geosynchronous GLONASS satellites are

typically carried as a triplet by a single launch vehicle.

i. Above geosynchronous orbits--No more than one satellite is allowed to have its transit time exceed four hours in any specific altitude shell of the other side. Moreover, in each shell, no more than two satellites at any given time are allowed to come within 2000 km of the other side's declared satellites. For example, three satellites within 2000 km of three different declared satellites of the other side is a violation. So is three satellites within 2000 km of the same declared satellite. The distance from the transitting satellite to the declared satellite is determined by assuming the latter would continue to move along its declared orbit. The characteristics of a declared orbit can be updated on a regular basis but must be announced well before they become effective for the purpose of implementing transition rules.

ii. Geosynchronous orbits--No more than two simultaneous transits are allowed through any number of the other side's geostationary zones. This means, for example, that one transit in each of three of the other side's geostationary zones is a violation. So is three transits in one zone. However, any number of satellites which penetrate the other sides' zones by less than $1/2^{\circ}$ or 370 km are not treated as transits and, therefore, not governed by the transition rule.

iii. Intermediate earth orbits:

a) Semi-geosynchronous orbits--No more than one satellite is allowed to have its transit time exceed 30 minutes in the other side's shell and its two adjoining 500 km shells. Moreover, no more than three satellites at any given time are allowed to come within 500 km of the other side's declared satellites.

b) Other intermediate earth orbits--Option 1: No more than one satellite is allowed to have its transit time through any specific shell of the other side exceed 15 minutes. Moreover, no more than three satellites at any given time are allowed to come within 500 km of the other side's declared satellites. Option 2: No more than one satellite is allowed to have its transit time exceed 45 minutes. Moreover, no more than three satellites at any given time are allowed to come within 500 km of the other side's declared satellites.

Article III

1. Satellites that are declared dead are not counted toward the number of allowable transits. But they are at the other side's disposal when they are in the other side's zones. All satellites not declared dead are treated as operational.

2. Each party agrees to the treatment of its operational satellites that are currently in the others' zones. Except those that are grandfathered, the rest are to be repositioned outside prohibited zones, according to a stipulated time schedule.

Article IV

1. The WA and SB States Parties agree not to circumvent the Agreement via third parties. Moreover, third-party satellites that are to be

launched by a State Party and placed or possibly later repositioned into the other side's zone are subject to ground inspection. Uninspected third-party satellites launched by the other side, unless grandfathered or expressly permitted, are treated as if they were the other side's satellites. This condition will be part of the launch or satellite sale contract with any third party.

Article V

1. The Parties undertake to hold periodic consultations to consider questions and possible amendments relating to transition rules, SDZ number, size and location, and further implementation of the purposes of this Agreement, especially those arising from the changes in satellite attack and defense technologies and satellite population and distribution. Special sessions can be called for the adoption of those amendments which must be made promptly in order not to frustrate the purposes of this Agreement. Other amendments will be dealt with in conference as proposed under Article VI.2.

Article VI

1. Each party shall, in exercising its national sovereignty, have the right to withdraw from the Agreement, if it decides that events, related to the subject matter of this Agreement, have jeopardized the interests of its country. It shall give notice of such withdrawal to all other Parties to the Agreement and to the United Nations Security Council three months in advance.

2. To stay in force, the agreement must be renewed every five years by unanimous vote. Well before its renewal date, a conference shall be

convened to deliberate on the practicality and utility of the Agreement with necessary amendments as identified under Article V.

(THIS PAGE IS INTENTIONALLY LEFT BLANK)

III. IMPLICATIONS OF SELF-DEFENSE ZONES

With the SDZ provisions now specified, we can examine how they would aid us in obtaining warning and in facilitating defense, and how they would affect satellite operations and space utilization.

Aiding Satellite Defense

Any viable SDZ must satisfy two potentially conflicting criteria--that it is large enough to generate adequate warning and that it is small enough to avoid significantly hindering normal satellite operations. The proposed SDZ arrangement could accommodate both.

However, it must be clear that any specific agreement will be applicable for only a limited time. Periodically, there will have to be redefinition of the agreement in terms of the number, size and arrangement of SDZs and the number and time of allowable transits, in order to accommodate changes in satellite population and attack and defense technologies. Continuation of previous limits may often be appropriate, but that would require positive mutual reaffirmation if the agreement is to be extended.

At geosynchronous orbits, the proposed SDZ arrangement generates a keep-out distance of typically 2,000 km and up to about 3,300 km.* An advanced space mine with a relative velocity capacity of 1 km/sec would need 17 minutes to travel 1,000 km. The defender would have at least that much time to detect the invasion and defend his satellites even against a nuclear mine with a lethal radius measured in hundreds of kilometers. The fact that both the Soviets and the U.S. can launch satellites to

*3,700 km minus 370 km (resulting from permissible $1/2^{o}$ zone penetration. See Article II.3.ii).

geostationary orbits and maintain them at any position within at least $\pm$ 0.1° accuracy implies that either country would have a nuclear space mine capability by equipping or replacing a satellite with a nuclear payload. Since ASAT weapons can serve as DSAT, the U.S. ground-launched interceptor with miniature homing vehicles (MHV) currently under development could later be extended in range to reach all altitudes and be used to intercept Soviet space mines or suspicious objects that exceed the permitted number or time in our SDZs. Although ground-launched DSAT could still be useful, it would be much more timely if DSATs were space-based and prepositioned within our SDZs. Our MHV and its supporting technologies would be equally applicable to space-based DSAT systems. Therefore, the current Congressional ban on ASAT tests against objects in space actually delays our efforts to develop DSATs. Because of space mines' limited capability, corresponding active DSAT could be developed within the same time frame as space mines. In truth, we might also need to pursue passive defensive measures such as hardening, redundancy, maneuvering, decoys, replenishment and jamming for an efficient satellite mission survivability program.

By the time that the Soviets deploy space-based homing vehicles, we should have developed similar systems for satellite defense. A hit-to-kill vehicle with a relative velocity capability of 7 km/sec still requires about 5 minutes to reach the targeted satellite from 2,000 km away. Even against a space-based laser which is typically assumed to have a range of 1,000 km or so, a 2,000 km keep-out distance would be adequate. We would not necessarily enlarge the SDZs, even when more powerful lasers are deployed in space. Satellite hardening and other countermeasures would have the effect of shortening the lasers' lethal range. Moreover, if we can proliferate the number of satellites more cheaply than laser platforms, the lasers might not be able to destroy enough satellites to severely disrupt the mission in a surprise attack. Alternatively, if and when the lethal range of directed energy weapons is still too long, there is the possibility of banning objects at geostationary orbits that are above a certain weight and have certain physical dimensions or shapes, provided that such a ban on deployment would be verifiable and its violation would generate useful warning. Even if advances in ASAT capabilities were to conclusively outstrip defenses and to render SDZ's useless in the future, the agreement would have served a useful purpose during the interim. That is already a lot to expect from any arms agreement. Moreover, this extreme situation of offensive domination over defense would alter fundamentally our space policy. We would no longer depend on satellites for the performance of critical missions in transition to and during war. On the other hand, as long as we depend on satellites for any such mission, SDZs would be useful.

At above geosynchronous orbits, an SDZ shell of 5,000 km thickness would generate a typical keep-out distance of 2,000 km (not all the satellites have to stay at the middle of the shell) and a maximum of 2,500 km. Such SDZ shells can help to counter threat levels similar to those discussed above for geosynchronous orbits.

At semi-geosynchronous orbits (categorized under the group of intermediate earth orbits), formalization of current U.S. and USSR satellite arrangements would yield a keep-out distance of at least 500 km. This should be adequate to counter nonnuclear space mines. The Soviets would face at least one problem in deploying nuclear space mines. The Outer

Space Treaty prohibits States Parties to the Treaty "to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction." And we can deploy devices in space which can detect on-board nuclear materials, perhaps even distinguishing those in a warhead from those in a reactor. Also, nuclear space mines are not as versatile as conventional ones in various contingencies. They would be subject to attack in contingencies that start as conventional conflicts. Moreover, space mines, if deployed, would generally be positioned in the same orbit with the target satellite. But the proposed SDZ agreement would make the whole shell inaccessible to the attacker. Instead, he would have to place space mines in lower or higher orbits, which would bring them 500 km or so from the target satellites only at various times rather than continuously and simultaneously. That would make simultaneous attacks much more difficult and defeat one key strength of space mines in being crude and cheap but effective. In any case, if the concerns about nuclear space mines and other space-based ASAT weapons were to become very serious, the separation of the Western Alliance shell and the Soviet Bloc shell could be increased to 2,000 km or even more. Satellites there can perform the same missions at higher and lower orbits.

At low earth orbits and highly elliptical orbits, satellite orbital characteristics preclude any SDZ arrangement that would provide keep-out distances in thousands of kilometers to even tens of satellites without allowing a large number of simultaneous transits (see Appendix A). On the other hand, small SDZs in tens of kilometers attached to satellites might be feasible even if one insists on a small number of simultaneous transits. Small SDZs would still complicate simultaneous, multiple attacks with cheap nonnuclear space mines. We can also adopt some additional provisions in the agreement to complicate attacks with nuclear space mines and other space-based ASAT weapons (see Appendix A).

But, more fundamentally, we need to redesign our space systems, especially at these orbits, for mission survivability. For reconnaissance, one way is to develop some shorter-lived and cheaper satellites as the Soviets have done. Then, by the time the satellite is tracked, targeted and attacked, it has already performed its mission. Our Big Bird satellites for both area-survey and close-look functions weigh over 13,000 kg each and last for about 6 months. The Keyhole satellites used to photograph some of the highest priority intelligence targets have even a longer lifetime of 1 to 2 years. The Navy's Ocean Surveillance Satellites (NOSS) have a suggested operational life of 3 to 5 years.* In contrast, the Soviets regularly launch photographic reconnaissance satellites that last for only about two weeks each. Of course, they supplement these satellites with others of longer duration: many have about a 47 day lifetime and some last up to six months.**

For space systems which cannot rely on short-lived satellites, we need to consider adaptive systems composed of a large number of inexpensive satellites for enhanced mission survivability. Current discussions of porcupines, which could be used to intercept ballistic missiles in boost phase and mid-course, and to defend other ballistic-missile-defense platforms, have already indicated a shift from the earlier configuration of a small number of space-based platforms, each carrying a large number

* Turnill, Jane's Spaceflight Directory, 1985, op. cit., pp. 242-244.
**Johnson, Soviet Year 1984, op. cit., pp. 11-17.

of KEWs to one of a large number of platforms, each carrying a small number of KEWs.*

Slight Reduction in Geostationary Slots

One is justifiably concerned that any rules-of-the-road agreement would accentuate the satellite crowding problem at the geostationary orbit. But our SDZ proposal simply allows an orderly arrangement and separation of the two sides' satellites; just as placing documents on different topics in different folders in a filing cabinet does not reduce the holding capacity of the cabinet.

Some assume falsely that any keep-out zone arrangement would necessarily make some space inaccessible to the other side and thereby reduce the number of available slots. In fact, those slots unavailable to the other side can, instead, be made available to the first side. Then, two sides are essentially swapping slots without reducing the total number of geostationary slots. The proposed earth-fixed SDZ arrangement has this advantageous characteristic. In contrast, the traditional satellite-attached keep-out zones did reduce the total number of slots. That is because if one side wants to use the slots in the space inaccessible to the other side, those newly occupied slots would create their own keep-out zones and exclude some new space to the other side. Our arrangement solves this dilemma. To visualize this, one can imagine that an earth-fixed zone (EFZ) is equivalent to many satellite-attached zones (SAZs) whose sizes vary according to the satellites' positions in the EFZ. The size of an SAZ is largest for a satellite placed at the center of an EFZ

*Gregory H. Canavan, "The Survivability of Strategic Defensive Concepts," LA-UR-April 85-1583, Los Alamos National Laboratory, April 25, 1985.

and it shrinks to zero for a satellite at an EFZ's edge (assuming that the neighboring EFZ belongs to the other side). Since we would try to place critical satellites near the center of an EFZ and non-critical ones near the edge, our proposed SDZ arrangement is, in effect, offering large SDZs to the critical satellites and, at the same time, not reducing the available geostationary slots.

However, the proposed SDZ arrangement could generate some small negative effects on the number of available slots. Since some Soviet Bloc SDZs are placed over the CONUS and some Western SDZs over the USSR (Figure III-1), it is conceivable that while the early warning satellites and other satellites for global coverage could be placed there, the future demand for them would still be far below the number of slots available in those zones. On the other hand, had there been no SDZ agreement, these zones could be much better utilized. Let us assume that the U.S. could use to fuller capacity two of the SB zones, that are directly above CONUS, for our civilian communications satellites. And the Soviets could similarly better utilize two WA zones. If we further assume that all four zones would be at half capacity with the proposed SDZ agreement but otherwise would be at full capacity, that would be equivalent to a loss of two zones out of 36 zones or 5.6 percent. Considering the critical importance of protection to early warning and global C^3I to both sides, we believe that the price is acceptable. Moreover, while these zones are not accessible to the other side, they are available to third-countries.

Another small effect which is correctable has to do with the possibility that under an SDZ agreement both sides might not want to place satellites too near the edges of the other side's zones. Otherwise,

FIGURE III - 1
SELF-DEFENSE ZONES AT GEOSYNCHRONOUS ORBITS WITH EARLY 1990s SATELLITE DISTRIBUTION

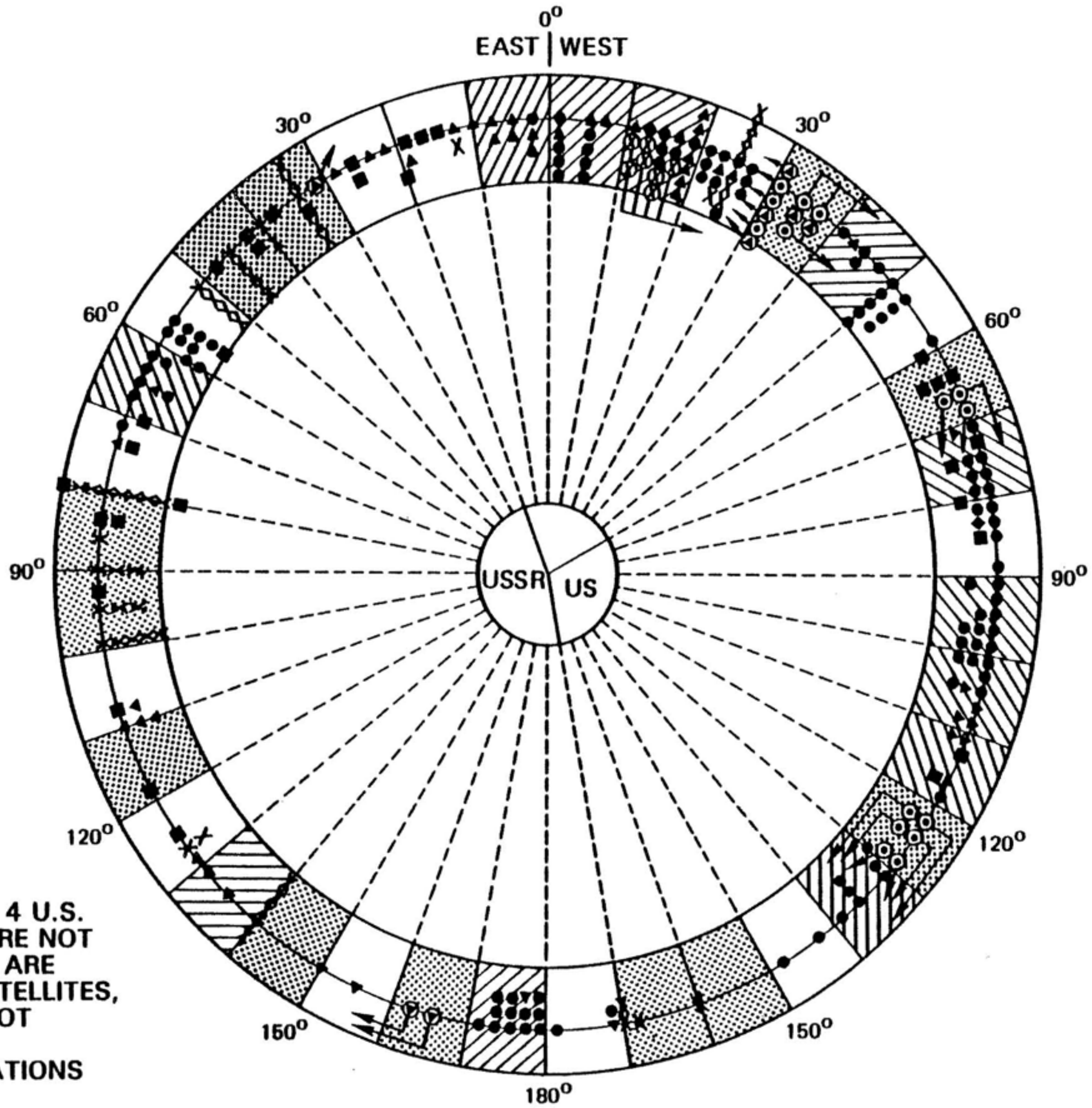
NUMBER OF SATELLITES IN OTHER SIDE'S ZONES

WESTERN ALLIANCE	23
SOVIET BLOC	7
	30

SDZ DESIGNATION

- WESTERN ALLIANCE (hatched)
- SOVIET BLOC (dotted)
- NEUTRAL (blank)

			NUMBER OF SATELLITES
WESTERN ALLIANCE	U.S.	●	123
	OTHERS	▲	56
SOVIET BLOC	USSR	X	60
	OTHERS	♦	1
REST		■	32
			272



NOTE: 3 U.S. EARLY WARNING SATELLITES AND 4 U.S. ELECTRONIC INTELLIGENCE SATELLITES ARE NOT SHOWN OR COUNTED. THEIR LOCATIONS ARE CLASSIFIED. 3 USSR EARLY WARNING SATELLITES, WHICH WILL BE CLASSIFIED, ARE ALSO NOT SHOWN OR COUNTED. NOR ARE 4 USSR METEOROLOGY SATELLITES WHOSE LOCATIONS ARE YET TO BE DETERMINED.

frequent orbital adjustments would be required to prevent these satellites from drifting into the other side's zones. Allowing up to two live satellites in the other's zones at any given time would reduce this adjustment frequency. Moreover, geostationary satellites are being kept within smaller and smaller positional fluctuation. The United States now maintains some communications satellites to within one-tenth of a degree from their designated slots. In truth, if one wishes to place one's satellites less than one-tenth of a degree away from the other side's zone, one would have to make more frequent orbital adjustments and, thus, incur a penalty in cost or operational lifetime. On the other hand, if one gave up such slots in one's zones, the other side could not use them either because they are not in its zones. Then, these slots would be "wasted." They could amount to 1.3 percent of the total available slots.* More probably, they would be considerably less. Many WA and SB zones are adjacent to their own or neutral zones, instead of the other side's zones. Then, drifting into neighboring zones would be allowed. Also, the excluded slots could be used by third countries. If the excluded area is considerably larger than $.1^{\circ}$ or, say, $1/2^{\circ}$, one can modify the SDZ agreement by making it permissible to drift satellites within $1/2^{\circ}$ into the other side's zones. Since both sides are likely to put their critical satellites near the center of their SDZs, this reduction of effective zone size by $1/2^{\circ}$ on each edge would still allow adequate keep-out distance to both sides' critical satellites. We recommend this $1/2^{\circ}$ feature because it also allows satellites currently or planned to be near the zone boundaries to remain there.

*Assume each zone has an exclusion area of $.1^{\circ}$ on each edge and there are 24 zones for WA and SB (.1 x 2 x 24/360).

SDZs have a third minor effect on available slots. It is conceivable that the number of satellites configured for certain broad or global coverage might have to be somewhat larger to compensate for the loss of some sites that fall in the other's zones but are ideal for avoiding local terrain obstruction. It is only a loss if these ideal sites are not equally ideal for use by the other side in their satellite constellation. Otherwise, the other side can take up the ideal site and nothing is wasted. To increase the number of satellites and slots needed in serving the same area or mission is equivalent to reducing the available slots. But we expect this effect to be small also.

Therefore, if the geostationary orbit ever gets too crowded, it will not have been caused by the SDZs. Also, technical advances in station-keeping, shaped beams and ground equipment, and the increased use of the higher frequency Ka band (20/30 GHZ) are expected to reduce the crowding problem.* Recently improved technology, mainly in ground stations, permits the U.S. to reduce intersatellite spacing to 2 degrees, virtually doubling the available slots for satellites using the most popular frequencies.** Moreover, most of the critical wartime missions that are performed from geostationary orbits can be performed from other orbits. After all, the Soviets still use satellites at highly elliptical 12-hour "Molniya" orbits for early warning and communications, while the United States relies almost exclusively on geostationary satellites for these missions. In truth, we would have incurred a cost penalty had we relied on Molniya orbits instead because the U.S. is at lower latitudes and can

---

* International Cooperation and Competition in Civilian Space Activities, Office of Technology Assessment, July 1985, p. 175.

**John Walsh, "Will there be Room on the Arc?," Science, 9 March 1984, p. 1044.

rely more heavily on equatorial satellites and their associated cheaper ground stations.

SDZs Do Not Restrict Third Countries' Access to Space

Developing countries' demand for space is often exaggerated. It is highly uneconomical for many nations to have their own satellites. The developed countries should assure the developing countries that the benefits of satellites are to be shared by all nations. Already, more than a dozen geostationary satellites of the International Communications Satellite Organization (INTELSAT) have been providing two-thirds of the world's transoceanic communications (TV, telephone and others) to 165 countries or territories, of which 109, including many developing countries, are members.* Without this arrangement, many countries would have no hope of enjoying the advances in space, even if slots in space were reserved for them. Similar to INTELSAT, the Soviet Union's 14-member Intersputnik has been serving the socialist countries.

Currently, the People's Republic of China, India, Indonesia, Brazil, Mexico and the Arab League have about a dozen satellites at the geosynchronous orbits. But, Iran, Colombia, Pakistan, Argentina, Papua, Nigeria and the Andean Pact have notified the IFRB of their intention to own geostationary satellites. By the early 1990s, the number of third-country geo-satellites may triple. But, SDZs do not preclude their satellites from any location. Therefore, it would not make the job of accommodating these additional satellites any more difficult.

---

*Ibid.; and Reginald Turnill, editor, Jane's Spaceflight Directory 1985, p. 223.

A Multi-national SDZ Agreement

Some might suggest that the United States should propose a bilateral, instead of a multi-national, agreement to the Soviet Union because a bilateral agreement is easier to negotiate.

The merit of any arms agreement is not that we succeed in reaching an agreement with the Soviets, but that the agreement would do us some good. While we have considered some bilateral SDZ alternatives, they do not offer nearly as much benefit to us and, in fact, are more difficult for the Soviets to accept. For example, in a bilateral agreement, the Soviets would have to allow satellites of our allies such as the UK, West Germany, France and Japan into their zones. In any case, the United States and the Soviet Union should discuss and evaluate the benefits and feasibilities of a range of both bilateral and multi-national potential agreements, if they agree on the basic principle of SDZs.

The Outer Space Treaty is an example of a multi-national or international agreement which began with bilateral negotiations between the United States and the Soviet Union, and later was approved by the General Assembly of the United Nations and opened for signature. Of course, we should involve our allies during all phases of the negotiation. In fact, preparing and negotiating the proposed agreement would offer an opportunity for the Western Alliance to identify the common purpose and means of protecting their critical satellite missions and the intrinsic troubles, particularly those in enforcement, plaguing democratic governments in standard agreements.

Why an SDZ Agreement Now?

In the last several years, U.S. sources were asserting that the Soviets have tested or even developed space-based ASAT homing vehicles or "killer satellites."* While these claims might be unsubstantiated, space-based ASAT systems, especially space mines, could be developed in the near term. But, instead of negotiating for an SDZ agreement now, can we wait until there is conclusive evidence of space mine development or deployment? We cannot. First, space mine development can be conducted in a covert manner; using other military or even civilian satellite activities as cover. Second, Soviet doctrine stresses surprise attacks. In order to maximize the element of surprise, it is possible, perhaps even likely, that when the Soviets had developed a space mine capability, they would not place mines next to our critical satellites well before they had to in order to prepare for simultaneous attacks. This is particularly so if the West insists upon taking countermeasures only after we have seen the evidence of space mines deployment. Hopefully, our contingency described in Chapter II has illustrated this point.

Number of Geostationary Satellites Needing to be Repositioned

As shown in Figure II-8, only 8 of 90 current Western operational satellites are in the Soviet Bloc's zones.** They have only two satellites

---

* Reginald Turnill, editor, Jane's Spaceflight Directory 1984, Jane's Publishing Company, p. 252. It is stated that "by 1982 U.S. sources were saying that Russia was testing a space-based anti-satellite homing vehicle which could operate from a stationary orbit."

"USSR Has Antisatellite System," reported by Pierre Simonitsch, Frankfurt/Main FRANKFURTER RUNDSCHAU in German, 30 May 1985, p. 1, appeared in Department of Defense's Current News, Special Edition--Strategic Defense Initiative, July 16, 1985, p. 1. It is stated that Colonel General Nikolay Chervov, member of the General Staff of the Soviet Armed Forces, described as "nonsense" and "fantasies" assertions by the United States that the Soviet Union has "killer satellites" that can be put into orbit and then maneuvered toward their targets.

**According to Table 1, the West currently has 97 operational satellites. But the locations of seven early warning and electronic intelligence satellites are classified and not shown in Figure II-8.

in our zones. All these satellites could be grandfathered and/or repositioned to the neighboring zones. As to the future satellites (shown in Figure III-1), only 20 additional ones would have to be repositioned. Since they constitute only 13 percent of about 150 new satellites yet to be launched, the repositioning requirement should be relatively easy to accomplish.

<u>Transition Rule has Little Effect on Satellite Operations</u>

Civilian satellite operators and users are understandably unenthusiastic about any space agreement which would restrict their operations and access to space, or would increase the cost of satellite services. Keep-out zones certainly have the potential of infringing on their interests. Even the military is justifiably concerned that it could preclude them from carrying out some necessary space operations, such as inspection of and collection of information about the other side's satellites. The proposed transition rules (see Article II.3 in Chapter II) are designed to allow normal civilian and military operations to be performed with few restrictions.

Highly elliptical (HE) orbits, as defined in Article II.1 of Chapter II, do cross orbits in the other groups and HE satellites would have to transit through the other side's shells regularly. However, they do not travel through zones at geosynchronous orbits, because their high inclinations put them high above the equatorial plane when they reach the geosynchronous altitude. For self-defense shells at other altitudes, we propose to restrict the transit time of HE satellites as specified in Article II.3. The time limit is chosen in such a manner that it would not affect a normal transit. The limit varies from a quarter to four hours, depending on the location and thickness of the shell. (See Appendix B, particularly Table B-4.) It is automatically satisifed during regular satellite operations. However, if either side intends to use transit as a cover to preposition space mines for a simultaneous attack, the proposed time limit would make the attacker's coordination much more difficult.

A time limit alone would still allow the attacker to arrange a large number of transits simultaneously (provided each transit does not exceed the time limit), and mount an attack. To frustrate this tactic, we further restrict the number of satellites that can be located near the other side's declared satellites at any given time. Again, during normal operations it is highly unlikely that the number of close encounters would exceed our proposed limit. Each side should only need to make at most one orbital adjustment per shell about every three years in order to avoid a violation. For many shells, they will only need to make one adjustment every couple of decades or longer. The details are shown in Appendix B, particularly Table B-3.

Moreover, our transition rule has allowed for at least one satellite to stay indefinitely in any one of the other side's geosynchronous sectors and in every one of the other side's shells elsewhere. Thus, close and prolonged inspection can still be carried out. However, the rule does prohibit simultaneous inspection of a number of the other side's satellites in the same shell. But, giving up simultaneous inspection entails little sacrifice because a sequential inspection can perform the same mission.

Could the Soviets still mount a devastating attack on our satellites by taking advantage of the allowed number of simultaneous transits? This depends on our satellite redundancy policy. Take GPS (global positioning system) satellites as an example. When they are fully configured by the early 1990s, there will be 18 satellites and 3 spares in orbit. If the Soviets could take advantage of the three allowable transits to destroy 3 satellites, we would continue to have a full capability. In fact, even if only twelve GPS were intact, three satellites would still generally appear above the horizon of any earth point and we would still have a two-dimensional, instead of a three-dimensional, capability for positional and speed determination. In these circumstances, a three-dimensional determination would require, for example, a very accurate clock on board and its frequent synchronization with the clocks on the GPSs.

APPENDIX A

SELF-DEFENSE ZONES IN LOW EARTH AND HIGHLY ELLIPTICAL ORBITS

Currently, there are 35 operational Western Alliance satellites and 66 (average of 62 to 69 in Table 1) Soviet satellites in the low-earth orbits. In highly-elliptical orbits, the West has 16 and the Soviets have 27 satellites. The intermixing of orbits of both sides' satellites makes it impractical to divide these orbits into shells or sectors as proposed for other orbits in the text. Instead, the SDZs would have to be attached to those satellites which either side wants to protect. How large can these zones be without making frequent orbital adjustments to avoid violations?

We have developed a computer program which uses Keplerian mechanics to calculate satellite locations over time. Since the NORAD data are based on observations of satellites at different times, the program determines satellite locations at one common time. It also calculates satellite-to-satellite distances and the number of close encounters. A close encounter is defined as a satellite within a specified distance of a particular satellite of the other side. If a satellite is simultaneously within a specified distance of two satellites of the other side, it is counted as two close encounters.

At the end of 1984, we used NORAD data as of September 18, 1984 to study low earth and highly elliptical orbits. We calculated the close encounters between 33 U.S. satellites (launched since January 1, 1980) and 99 Soviet satellites (launched since January 1, 1983). Since these numbers are very similar to the current numbers of 30 and 89-96, the earlier runs should approximate the current situation between the U.S. and the Soviet Union in these orbits. Also, since the 21 non-U.S. Western Alliance satellites are for research and need not be assigned SDZs, and there are no other Soviet Bloc satellites, these runs can apply to the determination of close encounters of SB satellites to WA satellites.

Table A-1 shows the number of close encounters within 2000 km. Only 9 of 33 U.S. satellites have no close encounters and, on average, each has almost 2 Soviet companions. Therefore, a radius of 2000 km would seem impractical for satellites in these orbits.

Table A-2 shows the numbers of close encounters at four arbitrarily chosen times. For example, at a particular instant on September 18, 1984, there was one encounter within 200-300 km, two at 300-400 km and one at 400-500 km, for a total of four. Even in as little as 4 runs, one USSR satellite got as close as 90 km to a U.S. satellite. Therefore, it is unlikely that an SDZ with radius much larger than 50 km can be implemented around a sizeable fraction of satellites in low earth and highly elliptical orbits if we allow only a few simultaneous transits. On the other hand, if a space system consisted of a large number of satellites and would degrade gracefully, we could allow a large number of simultaneous transits and a larger zone size. However, much more work is required to determine the SDZ size for any given space system with a specified degree of redundancy, and the coordination and adjustments among both sides' current and future satellites, especially those going co-orbitally and counter-orbitally with respect to the other side's satellites.

In any case, satellites from both sides would have to be ranked in one tally. When two satellites of opposite sides come within each other's

Table A-1

USSR/U.S. Satellite Encounters Within 2000 km
(At a Particular Instant on September 18, 1984)

33 U.S. Satellites (Launched between 1/1/80 and 9/18/84)
99 USSR satellites (Launched between 1/1/83 and 9/18/84)

No. of Close Encounters Per U.S. Satellite	No. of U.S. Satellites
0	9
1	10
2	6
3	1
4	3
5	3
6	0
7	1
	33

Average: 1.8
Range: 0 to 7

Table A-2

USSR/U.S. Satellite Encounters Within Various Distances
(At a Particular Instant on 9/18/84 and three arbitrarily chosen subsequent times of 10/9/84, 11/4/84 and 12/20/84)

33 U.S. Satellites (Launched between 1/1/80 and 9/18/84)
99 USSR Satellites (Launched between 1/1/83 and 9/18/84)

Distance, d, Between USSR and U.S. Satellites	Number of Close Encounters at a particular time on 9/18/84	10/9/84	11/4/84	12/10/84
$0 \leq d < 100$ km	0	0	0	1
$100 \leq d < 200$ km	0	0	0	0
$200 \leq d < 300$ km	1	0	0	0
$300 \leq d < 400$ km	2	1	0	1
$400 \leq d < 500$ km	1	0	5	0
Total	4	1	5	2
Closest Encounter Distance	261 km	328 km	447 km	90 km

SDZ, the satellite with the lower rank is considered to be in transit through the SDZ of the satellite with the higher rank.

Let us assume that the WA and SB had agreed that no more than 5 satellites can simultaneously stay within 50 km of the other side's satellites. Could we add other provisions to the agreement to further complicate the planning and execution of a surprise attack? Both sides could agree that the number of satellites simultaneously within a larger distance, say 500 km, of any one of the other side's satellites, cannot exceed a larger number, say 50. Moreover, they could agree that no more than a mutually specified number of satellites, without prior approval, be allowed to violate any one or a combination of conditions such as the following:

a) a satellite cannot stay continuously for more than 1 day within a distance of 500 km of any one of the other side's satellites. The distance is determined as if the other side's satellite continues to move along its declared orbit. Responsibility for compliance rests with the lower ranked satellite. However, an unannounced movement more than 500 km off of its declared path drops a satellite's rank to the bottom of the ranked list.

b) a satellite must make a relative movement of 36 km in an hour with respect to the other side's satellites when they are within 500 km. The distance determination and responsibility are as in a).

c) a satellite cannot make maneuvers to pursue any of the other side's declared satellites when they are within 500 km and have just made evasive maneuvers. The distance determination and responsibility are as in a).

It is apparent from the complexity of these rules that, while they could make simultaneous attacks from space mines much more difficult, they would also be much more difficult to monitor, comply with and take advantage of. Initial SDZ negotiation or even agreement should not include these orbits. But detailed studies should be conducted on the feasibilities and benefits of not only satellite-attached SDZs but also non-satellite-attached spherical shells similar to those proposed for other orbits but of thickness on the order of 100 km for future satellites.

APPENDIX B

DETERMINATION OF MAXIMUM NUMBER AND TIME OF ALLOWABLE TRANSITS

Basically, we want to know how often each side needs to maneuver a satellite in order to avoid violation of an SDZ agreement. We characterize this as the expected, elapsed time between maneuvers or orbital adjustments.

First, we need to describe the situation within an altitude shell. In each shell there are a number of satellites around each of which one side has declared a self-defense sphere (SDS). We call them "shell satellites." The other side has "loopers" which are defined as satellites whose highly elliptical orbits intersect the altitude shell in question. Therefore, the loopers can potentially transit through the SDSs. The time which a looper takes to transit an altitude shell is called shell transit time and the time to transit an SDS is called sphere transit time.

Our model takes the following parameters as input:

A_l = lower bound of shell altitudes in km

A_u = upper bound of shell altitudes in km

L_p = looper's perigee in km

L_a = looper's apogee in km

Q = angle in degrees that the looper's path makes with the earth-centered radial upon entering the shell

N_s = number of declared shell satellites

R = radius of self-defense sphere in km

N = adjustment factor for correcting correlations or setting bounds

N_l = number of loopers

R_e = earth radius = 6400 km

Then, the mean shell radius in km is*

$$M_s = (A_1 + A_u) / 2 + R_e \tag{B-1}$$

and the mean looper radius in km is

$$M_1 = (L_p + L_a) / 2 + R_e \tag{B-2}$$

The speed of shell satellites in km/sec is

$$V_s = 631.4 \, (1/M_s)^{.5} \tag{B-3}$$

and the speed of loopers in km/sec during transit through the shell is approximated by

$$V_1 = 631.4 \, (2/M_s - 1/M_1)^{.5} \tag{B-4}$$

The relative velocity between the looper and the shell satellite is

$$V_r = ((V_1 * \sin Q - V_s)^2 + (V_1 * \cos Q)^2)^{0.5} \tag{B-5}$$

The period of a looper in minutes is

$$T_1 = (2 \text{ PI} * M_1) / (60 \, V_1) \text{ where PI} = 3.1416 \tag{B-6}$$

Define

$$\text{DT} = \text{Average sphere transit time}$$

$$= \frac{(4/3) \, R}{V_r} \tag{B-7}$$

The probability of finding a shell satellite within SDS radius R from the looper in a time period DT during shell transit is**

$$q_1 = \frac{N_s * V_r * \text{PI} * R^2 \, (4/3) \, R}{(4/3) \, \text{PI} \, (R_u{}^3 - R_1{}^3) \, V_r} \tag{B-8}$$

* Except for the semi-geosynchronous WA shell where we use the radius of a typical GPS satellite directly.

**We assume that the shell satellites are randomly distributed within the shell volume. If they are randomly distributed on a surface at mean shell altitude, essentially the same final formula results. Moreover, since the satellite density in the shell is extremely low in all of our cases, we need not be concerned about the insignificant probabilities of finding more than one shell satellite within R from the looper.

where

R_u = radius of shell's upper boundary
= $A_u + R_e$

R_1 = radius of shell's lower boundary
= $A_1 + R_e$

The probability that the looper is within the shell is

$$q_2 = \frac{(R_u - R_1) / \cos Q}{V_1 * 60\ (T_1/2)} \tag{B-9}$$

Therefore, the probability of finding a shell satellite within R of a looper during any time interval DT is

$$q = q_1 * q_2 = \frac{N_s * N * R^3 * (R_u - R_1)}{(R_u{}^3 - R_1{}^3)\ 60\ (T_1/2)\ (\cos Q)\ V_1} \tag{B-10}$$

The purpose of adding an adjustment factor N will be explained later. If we could assume that what happened in one period, DT, were independent of what happened in another period, then the probability that no sphere transit occurs during DT would be

$$P(0) = (1 - q)^{N_1} \tag{B-11}$$

Similarly, the probabilities of one and two sphere transits are

$$P(1) = N_1 * (1 - q)^{(N_1 - 1)} * q \tag{B-12}$$

$$P(2) = (N_1 * (N_1 - 1) / 2) * (1 - q)^{(N_1 - 2)} * q^2 \tag{B-13}$$

The cumulative probabilities of transits exceeding 0, 1 and 2 are

$$P(>0) = 1 - P(0) \tag{B-14}$$

$$P(>1) = 1 - P(0) - P(1) \tag{B-15}$$

$$P(>2) = 1 - P(0) - P(1) - P(2) \tag{B-16}$$

The expected, elapsed time until transits exceeding 0, 1 or 2 is

$$T(>i) = \frac{(4/3)\ R}{P(>i) * V_r} (3.1709 * 10^{-8}) \qquad i = 0, 1, 2 \qquad \text{(B-17)}$$

In Table B-1, the input assumptions of runs are shown. These runs will be used to determine the maximum number of simultaneous sphere transits allowed in each altitude shell. The allowed number of transits depends on the parameters appearing in Table B-1 and can differ from shell to shell. For each shell type, we prepared two data sets. The reference one corresponds to the projected satellite distribution in the early 1990s. The bound one corresponds to more satellites and an unfavorable correlation of both sides' satellite orbits. We essentially use the latter one to set the transition rules. This selection assures conservatively that no frequent orbit adjustments will need to be made during the normal course of satellite activities.

Recall that we have assumed independent events in the derivation but included a factor N for adjustments. In fact, neighboring events are highly correlated. If a looper is found in an SDS near the end of a time period DT, it is almost certain that the same looper will still be in the same SDS at the beginning of the next time period. This occurrence of transits back to back essentially doubles the probability of finding a shell satellite, q, in equation (B-10). We simply set N to be 2 in the reference data set to capture this correlation. In the data set for setting bounds, we further double N from two to four to allow for possible unfavorable, nonuniform satellite distributions within a shell. We believe that this increase in the probability q (equation (B-10)) should be ample for setting the allowable number of transits large enough so that

Table B-1

Input Assumptions for Determination of Allowable Number of Zone Transits

Run No.	Input Data Set	Al (km)	Au (km)	Lp (km)	La (km)	R (km)	Ns	Nl	N
Intermediate Earth Orbits									
IR	Reference	19800	21100	705	39655	500	21	26	2
IU	Bound	19800	21100	705	39655	500	30	40	4
IIR	Reference	3200	4500	705	39655	500	5	25	2
IIU	Bound	3200	4500	705	39655	500	10	40	4
IIIR	Reference	16200	17500	705	39655	500	5	26	2
IIIU	Bound	16200	17500	705	39655	500	10	40	4
IVR	Reference	3000	8000	705	39655	500	5	26	2
IVU	Bound	3000	8000	705	39655	500	10	40	4
VR	Reference	8000	13000	705	39655	500	5	26	2
VU	Bound	8000	13000	705	39655	500	10	40	4
Above Geosynchronous Orbits									
VIR	Reference	55000	60000	402	113818	2000	5	6	2
VIU	Bound	55000	60000	402	113818	2000	10	20	4
VIIR	Reference	115000	120000	5366	132864	2000	5	6	2
VIIU	Bound	115000	120000	5366	132864	2000	10	20	4

the transition rule would almost always be satisfied and only very infrequent orbital adjustments would be necessary for compliance.

In runs for the intermediate earth orbits, we used Soviet loopers because the Soviets have more highly elliptical satellites (see Table 1) which transit through shells there, and would have to make more orbital adjustments. For above geosynchronous orbits, we used the West's loopers because the situation is reversed. Again, these selections allow us to set the transition rules conservatively.

In Table B-2, we show the orbital characteristics of three satellites which are chosen as standard loopers. For shells at intermediate earth orbits, the Molniya looper (#1) is used. Since it does not reach shells above geosynchronous orbits, we need two other loopers. They are selected because they have the shortest periods for which their orbits intersect the shell in question. Generally, the shorter the period, the more frequently the satellite will enter the other side's shell. Our selection assures that, in reality, fewer orbital adjustments than those estimated here would be required.

In Table B-3, the expected time interval between orbital adjustments is shown. It depends on the number of allowable, simultaneous transits. If we insist on no transit through any SDS within a shell, many adjustments would have to be made every year. That is not practical. But the time interval lengthens drastically when we allow one transit (but not two simultaneous transits) through SDSs in a shell. This means that one transit in each of two spheres or two transits in one sphere is treated as a violation.

Table B-2

Selected Orbital Characteristics of Standard Loopers

Looper #	Satellite	Perigee (km)	Apogee (km)	Period (min)	Average Speed (km/s)
1	1985-040A USSR/Molniya 3-24	705	39655	717.9	3.87
2	1984-088B FRG/IRM	402	113818	2653	2.51
3	1977-102B ESA/ISEE 2	5366	132864	3440	2.30

Table B-3

Expected Time Interval Between Orbital Adjustments
To Avoid Simultaneous Transits Exceeding an Agreed Number

Run No.	Elapsed Time in Years								
	Agreed Transit No. = 0			Agreed Transit No. = 1			Agreed Transit No. = 2		
	$Q = -45^\circ$	$Q = 0$	$Q = 45^\circ$	$Q = -45^\circ$	$Q = 0$	$Q = 45^\circ$	$Q = -45^\circ$	$Q = 0$	$Q = 45^\circ$
Intermediate Earth Orbits									
IR	.0028	.0051	.0067	5.4	14	13	>100	>100	>100
IU	.0006	.0012	.0015	.27	.72	.66	>100	>100	>100
IIR	.0020	.0036	.0046	5	13	12	>100	>100	>100
IIU	.0003	.0006	.0007	.12	.31	.28	72	>100	>100
IIIR	.0089	.017	.022	62	>100	>100	>100	>100	>100
IIIU	.0015	.0027	.0035	1.6	4.2	3.9	>100	>100	>100
IVR	.0026	.0047	.006	7.7	20	18	>100	>100	>100
IVU	.0004	.0008	.001	.20	.52	.47	>100	>100	>100
VR	.0050	.0092	.012	24	62	56	>100	>100	>100
VU	.0008	.0015	.0019	.62	1.6	1.5	>100	>100	>100
Above Geosynchronous Orbits									
VIR	.066	.12	.16	>100	>100	>100	>100	>100	>100
VIU	.0049	.0091	.012	2.8	7.3	6.7	>100	>100	>100
VIIR	.24	.43	.50	>100	>100	>100	>100	>100	>100
VIIU	.018	.032	.037	21	54	44	>100	>100	>100

For shells at above geosynchronous orbits, the time between adjustments is at least 2.8 years, if one transit is allowed. The time is over 100 years if two simultaneous transits are allowed. Since the agreement will stipulate that the transit number will be updated when needed, we can choose one allowable transit in the initial agreement and increase it to two when the need arises. We have already seen that increasing the transit number by merely one lengthens the time significantly. Thus, only a small change in transit number will be necessary.

There is a possibility that the mission of close inspection of the other side's satellites could require one satellite staying indefinitely within the other side's self-defense sphere. Thus, we recommend that the maximum allowable number of simultaneous sphere transits in any above-geosynchronous shell be two, instead of one. However, when and if orbital adjustment ever becomes necessary, an alternative to maneuvering the transitting satellite is to temporarily move the inspecting satellite outside the other side's zone.

Similarly, for shells at intermediate earth orbits, we recommend that the maximum number of simultaneous transits through any shell be three.

In addition to restricting the number of simultaneous transits through self-defense spheres in any shell, we propose to limit the transit time of any individual looper. Again, one exception is allowed for any need of indefinite close inspection. The typical transit time of a looper during routine flight through a shell is simply,

$$T_t = (A_u - A_l) \;/\; (V_l \cos Q) \tag{B-18}$$

In Table B-4, the transit times through shells of various altitudes and thicknesses are shown. While one can specify different maximum allowable

Table B-4

Typical Transit Time Through Self-Defense Shell

Related Run No.	Lower Shell Altitude (A_1 in km)	Upper Shell Altitude (A_u in km)	Looper Speed in Shell (V_1 in km/s)	Transit Time $Q = 0^{o}$	$Q = 45^{o}$	Proposed Maximum
				..........(T_t in hrs)	....	
Intermediate Earth Orbits						
IR and IU	19300*	21600*	3.9	.16	.23	.5
IIR and IIU	3200	4500	7.9	.05	.06	.25
IIIR and IIIU	16200	17500	4.4	.08	.12	.25
IVR and IVU	3000	8000	7.2	.19	.27	.75
VR and VU	8000	13000	5.7	.24	.34	.75
Above Geosynchronous Orbits						
VIR and VIU	55000	60000	2.5	.56	.79	4
VIIR and VIIU	115000	120000	1.1	1.3	1.8	4

*Transit through the semi-geosynchronous shell (19800 to 21100 km) and two adjoining 500 km shells. See Article II.3.iii.

transit times for different shells, we choose the same value for shells of the same type for the sake of simplicity. They range from a quarter of an hour for 1300 km shells in other intermediate earth orbits (Run numbers II and III) to four hours for 5000 km shells in above geosynchronous orbits (Run numbers VI and VII). Since the allowable transit time has been set to be at least twice as long as the normal transit time, this restriction, while it complicates the planning and execution of a surprise attack, has practically no effect on regular satellite operations.