Order Number 9304741

Strategic and political implications of strategic defense systems' development

Tsaganea, Doru, Ph.D.

City University of New York, 1992

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

STRATEGIC AND POLITICAL IMPLICATIONS

OF STRATEGIC DEFENSE SYSTEMS' DEVELOPMENT

by

DORU TSAGANEA

A dissertation submitted to the Graduate Faculty in Political Science in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1992

This manuscript has been read and accepted for the Graduate Faculty in Political Science in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

September 30, 1992
Date

Chair of Examining Committee

Sept 30, 1992
Date

Executive Officer

Prof. Richard Sacksteder
Prof. Abraham Bargman
Prof. Mark Sheingorn
Prof. Sumit Ganguly

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

CONTENT

INTRODUCTION

I wrote the proposal for this dissertation during the winter of 1989-1990, but I started to think these topics and to develop some mathematical models since 1985. At that time the international system was bipolar and the Soviet Union was one of the two superpowers. President Reagan's Strategic Defense Initiative, although controversial, was regarded as an important national challenge. Its supporters presented it as the means of replacing vulnerability based nuclear deterrence with non-nuclear strategic defense and assured survival. Its adversaries criticized it as a method to increase the US first strike capability or as technologically unfeasible. For its supporters the main questions were how to make it economically efficient and technologically feasible. For its adversaries, how to delay it. But as different as their opinions were, both proponents and opponents considered the program to be a major and significant one. Consequently, I intended to analyse in my dissertation SDI's political and strategic impact upon East-West relations in general, and American-Soviet relations in particular.

But at present, three years after the fall of the Berlin Wall, the international situation is completely different. Changes, rightly called of historical magnitude, took place. The

Cold War ended, the international communist system collapsed and the Soviet Union disintegrated. At the present time, the United States remains as the sole superpower in the world. But the majority of analysts considers that this situation is temporary, that we are witnessing a transition period, and that the emerging international system will be a multipolar one.

In these new conditions, a natural question arises, will strategic defense be necessary in the future international system ? An affirmative answer to this question implies the continuation of the research and development program started by President Reagan's Strategic Defense Initiative. A negative one could mean the program's cancellation. As a result the topics of this dissertation must be adapted to the new international situation. Instead of studying the impact of a well established armament program on a bipolar system, one should analyse whether strategic defense systems will be necessary in the emerging international system.

From a methodological point of view the study of this question implies four levels of analysis: political, strategic, technical-military, and scientific-technological. At the political level, one should examine which will be the main characteristics of the international system that will emerge at the end of the present transition period. At a strategic level it is necessary to study which strategic doctrine is likely to prevail in the future system, and subsequently what should be the relationship between offense and defense. The conclusions reached at the strategic level must be used at technical-military level for deciding what kinds of weapon systems are necessary and what should be their performance. Finally, at the scientific-technological level one should examine if the military requirements are technologically feasible and how they could be efficiently materialized. Taking into consideration the significance of the present political changes and my educational background, I refer in my study to the first two levels of analysis. The topics of this dissertation do not deal with technical-military or scientific-technological problems.

A second methodological remark refers to the construction of the mathematical models which I utilise to derive new arguments, or only to reinforce assertions resulting from regular non-mathematical reasoning. The models are built on the basis of sets of equally balanced, neutral assumptions. Those assumptions neither support nor reject the strategic defense. They allow the derivation of any kind of conclusions. But the mathematical reasoning which begins with those neutral models leads to conclusions which are not neutral. In other words, at the beginning the inference of any conclusions is potentially possible, but at the end one is accepted and the other, or the others, are rejected. In this manner I conclude by using a correct logical method that the strategic defense is necessary. Its necessity is not assumed in the models, it is inferred from them.

A third methodological remark refers to the interpretation and significance of theoretical concepts and mathematical models. Because they have an abstract and general character, they may and they should be used only for making predictions at a similar level of analysis. The relationship between those concepts and models, and the empirical situation is a relation from general to particular. It is not one of total equivalence. Therefore, one should rationally expect that the concrete situation would only partly correspond to the theoretical predictions.

I make references to mathematical theories and mathematical models for international relations analysis that are close to my models in the sections of this disseratations where my models are included. First, I refer to Khinchin's classical results regarding the measure of entropy in section 2.4. (pp. 117 - 118). Second, I describe how I developed my functions (curves) for analysing the utility of the first strike and the disutility of the corresponding counterstrike in section 3.1. (pp. 145 - 146). I explain how I realized that the utility theory extensively used in Economics might be applied in the study of a nuclear confrontation by attending the Correlates of War Seminar, at the University of Michigan at Ann Arbor. And third, I compare my mathematical models for analysing the relationship between strategic offensive and defensive systems with those developed by Richardson, Zinnes and Gillespie, Intriligator and Brito, Zinnes and Muncaster, and Saperstein and Mayer-Kress in section 4.1. (pp. 186 - 188).

In the first chapter, I briefly present President Reagan's conception regarding SDI, some pro and con arguments, and several evaluations of the program. Although I agree with a considerable number of ideas included in this chapter, I stress that these are not developed by myself and they do not represent the original contribution expected in a dissertation. This chapter is included in order to show how the theoretical concept of strategic defense could be embodied in a a real program. It is not an extensive historical analysis of the SDI debate. It has a relatively independent character in relationship to the other four chapters which are logically connected among them. Several reasons explain its content. The official studies, or their unclassified summaries, in which the original arguments in favor of SDI were presented are easily available. There is also a large number of excellent books in which the pro and con arguments are extensively described and evaluated against each other. And third, a number of important contending arguments are at the technical-military and scientific-technological levels of analysis, which are not the levels used in this dissertation.

I start my own analysis with the second chapter. I focus on what kind of international system will emerge at the end of the present transition period, how stable it will be, and which will be the main causes of insecurity. Based on predictions made by scientists analysing empirical information, and on Kaplan's theoretical principles regarding the disintegration of a bipolar system, I conclude that the future international system will be a balance of power system. (This conclusion does not contradict the obvious fact that at present the international system is in a large measure characterized by unipolarity. It does not refer to the present, but to what is probable to be at the end of the transition period.)

I continue my analysis by asking if the future balance of power system will be more or less stable than the former bipolar one. Using Waltz's theory I answer that it it is very probable that it will be less stable. I introduce the concept of system used in System Analysis, and I describe the main properties of a dynamic system. On this basis, I show that the differeneces between the concept of stability defined in System Analysis and that employed by Waltz. I observe that Waltz considers that "a system is stable as long as its structure endures," and I construct a mathematical model in order to examine in a more rigorous manner this assertion. I consider that system's instability and strain are similar with its entropy or its degree of complexity and disorganization. Using the mathematical concept of entropy I demonstrate that, among other properties, the stability of a multipolar balance of power system is lower than that of a bipolar one. This result is consistent with Waltz's affirmation and enforces it.

Taking into consideration the predictions made by the analysts working in the field of nuclear proliferation, it is necessary to accept that an increased number of countries will have nuclear capabilities, nuclear weapons, and adequate means of delivery in the first quarter of the next century. Linking these predictions with the results obtained by using my mathematical model, I conclude that the association between the relatively high structural strain specific to a balance of power multipolar system and the relative extended spread of mass destruction weapons and appropriate means of delivery will probably constitute the main potential danger in the emerging multipolar system.

The above assertion is made at the political level of analysis, and on its basis two main conclusions are derived. First, a reasonable military power must be maintained bacause although in the future international system the dangers will be different, and perhaps less menacing, than those of the Cold War era, they will not disappear. And second, the multipolarity of the future world questions the role of the vulnerability based deterrence in preventing a nuclear war. Consequently, a reexamination of the mutual assured destruction doctrine is necessary.

For these reasons I analyse in the third chapter what might be the role of this doctrine in a multipolar international system. I observe that the majority of politicians and independent analysts consider that since the late sixties it was the vulnerability based deterrence, embodied in the MAD doctrine, which prevented the outbreak of a nuclear war. I briefly show how this doctrine emerged and I specify its main assumptions. I build utility functions to describe the gain resulting from a first nuclear strike, and disutility functions to evaluate the damages caused by the counterstrike. I define net disutility functions by combining the two categories of functions, and I use one of these net disutility functions to make a theoretical classification of nuclear, or potentially nuclear, powers. I differentiate among (1) countries that totally reject the use of nuclear weapons, (2) countries that have a "flexible", but really highly restrictive policy like the United States, and (3) countries that are inclined with a relatively significant probability to use them. On the basis of this classification and of the requirements of vulnerability based deterrence, I show that some of the MAD doctrine's requirements will not be, or will only partly be fulfilled in the future multipolar international system. The causes will be national and international systemic.

Among the domestic causes, the most important will probably be the following, (1) the emergence of nuclear powers having systems of political, social and moral values different from those held by the superpowers during the Cold War era, (2) the high level of instability which will characterize some of the future nuclear powers, and (3) the increased possibility of technological failure and accidents caused by nuclear proliferation. The international systemic causes will be rooted in the future international system's structure. It seems that the following will be the most important. First, in a balance of power system with three or more actors, who have equal or comparable strategic nuclear forces, even though the strategic nuclear forces of each power are equal or comparable to those of any other, they can not be equal to the sum of those owned by all the others. Second, in the future international system it will be possible to forge unequal, significantly asymmetrical coalitions among nuclear powers. And, third, several of the emerging nuclear powers are continental countries, some of them with common borders. And this means that they will be more vulnerable than "insular" countries like the United States. Specifying these domestic and international systemic causes which might limit the role of MAD, it is at the same time necessary to stress their abstract, theoretical character. They refer to potentially possible situations, but this does not mean that all these possibilities will become realities. For example the emergence of nuclear powers having systems of values different from those held by the USA and the former USSR does not mean that a nuclear war would be necessarily imminent. The assertion presented before as a first international systemic cause is of course obvious, but it is not in any way sure that the strategic nuclear forces of all the future major international actors will be equal among themselves. But even if not all these causes will work, and even if the action of some of them will be limted, they must be taken into consideration.

On the basis of the mathematical models built in this chapter and on the above remarks, I conclude that in the emerging multipolar system vulnerability based deterrence will have a relatively limited role in preventing the outbreak of a nuclear war. Consequently, under the assumption of anarchic order, the development of strategic defense systems will be necessary to compensate for the potential partial failure of vulnerability based deterrence embodied in the MAD doctrine. This argument is made at the strategic level of analysis, and is the first direct one in favor of strategic defense developed in this dissertation.

In the next chapter I examine the (in)stability of a system in which the actors have only strategic offensive nuclear weapons. In the first section I stress the utility of a systemic approach in order to understand the problem of stability and the relationship between offensive and defensive systems. I build a general mathematical model in which the offensive weapons are considered to be state variables and the defense systems are regarded as control variables (the state and control variables are defined in section 2.3. p. 102) I particularize the model for the case in which the countries have only offensive nuclear weapons, and I focus on the stability problem. I consider that the system is stable if the amounts of nuclear weapons owned by each actor remain constant or decrease, and is unstable if they increase. Using this model, I show that in the case of real adversity, the opponents have a normal tendency to continuously increase their power. This objective can be attained in two ways - by increasing the number of warheads (and increasing, keeping constant or decreasing the number of delivery systems), and/or by improving the performance of warheads and/or delivery systems.

The choice of one or another method depends on the treaties and agreements in which an actual or a potential nuclear power is a partner and on its technological capabilities. This tendency toward a continuous increase of power means that an international system in which the nuclear powers have only offensive weapons is unstable. Hence, a means must be included to control the offensive nuclear arms race, in quantitative and/or qualitative versions, and to make the system stable. These means might be agreements to limit or to decrease the number of strategic offensive weapons and/or the development and deployment of strategic defensive systems. But under the assumptions of anarchic order and potential adversity, the agreements do not provide sufficient security. Some nuclear powers might refuse to participate in the agreements, others might be inclined to fulfill only a part of their obligations or to deceive. It is also normal to expect that new offensive technologies, not barred by the treaties, will emerge. Furthermore the treaties cannot protect against accidental launches or launches by rogue commanders or renegade states. **Therefore, under the before specified assumptions, a substantial improvement in the level of security requires the development and deployment of strategic defense systems in addition to strategic armament limitation agreements.** This is my second argument explaining the necessity of strategic defense.

My third and last strategic argument is included in the same chapter, and is connected with the nuclear arms race spiral. I build a dynamic mathematical model in which I link the increase of the number of offensive nuclear weapons owned by each power with the increases of those weapons owned by its potential adversary (-ies). **Under the logical assumption, that in a balance of power system, each nuclear power would like to have the same increase of the number of nuclear weapons as it adversary (-ies), the model shows that the arms race is continuously fuelled. Consequently the system is unstable, and under the above mentioned assumptions the strategic defense systems are necessary to stabilize it.**

Summarizing the conclusions of chapters 2, 3, and 4 one can assert that:

- the emerging international system will be a multipolar balance of power one, and its specific structural strain will be associated with nuclear proliferation;
- in the emerging international system, the vulnerability based deterrence embodied in the MAD doctrine wil have a partial role in preventing the outbreak of a nuclear war;
- the strategic offensive arms race, in quantitative and/or qualitative versions, can not be stopped;
- a system in which the adversaries have only offensive weapons is unstable;
- the tendency of each nuclear power to match the increase of nuclear offensive weapons of its adversary (-ies) fuels the arms race.

The first assertion is made at the political level of analysis. The last three, at the strategic level. The first conclusion constitutes an argument in favor of maintaining sufficient military power, because in the future world will continue to be many security dangers, and requires the reexamination of the MAD doctrine. The last three argue for the necessity of strategic defense. It will be needed to compensate for the potential partial failure of vulnerability based deterrence, to control the offensive nuclear arms race (in quantitative or qualitative versions) in a first stage, and to diminish the quantity of strategic offensive nuclear weapons in a second one.

In the last chapter I study the relationship between the development of strategic defense systems and strategic offensive systems. I refer again to the general principle model formulated in section 4.1. of the preceding chapter, and I develop it as an optimal control model. I include a criterion of performance defined at the system level and show how the development of strategic defense systems could influence the dynamics of strategic offensive nuclear armaments. I construct a second model in which I consider one nuclear power versus the other nuclear powers included in the system. I assume that the amount of financial funds which it could spend during a given planning period for building or modernizing strategic offensive systems, and for building new strategic defensive systems is given. I define a criterion of security optimization at the national level. It consists in minimizing the number of adverse nuclear weapons which could not be destroyed by its strategic defense in the case of a nuclear attack. Utilising optimal control mathematical methods, I derive the theoretically optimal programs for financial resources allocation and building new defensive systems, and building and/or modernizing offensive ones. The last model presented is based on a similar idea, but it includes two powers or two coalitions of nuclear powers, which have financial constraints and criteria of security optimization defined at national or coalition levels. Using the same type of mathematical methods, I derive the theoretically optimal programs for financial resource allocations, and building or modernizing weapon systems.

* * * * * * * * *

1. NOTES ON STRATEGIC DEFENSE INITIATIVE DEBATE

1.1. AN INTRODUCTORY REMARK

This chapter has a relatively independent character from the other four chapters. It is included in this dissertation in order to give information with regard to what has been accomplished in anti-ballistic missile defense in the United States until present. The presentation is limited only to the SDI program because this has been the most recent and by far the most ambitious and extensive program conceived not only on this side of the Atlantic, but also in the world. I refer to a concrete program in order to examine whether the theoretical concept of strategic defense may be practically materialized. It seems to me that in this manner the theoretical political and strategic arguments regarding the strategic defense developed in the following chapters are strengthened. This presentation is not a history of the SDI debate, which would be undoubtedly a remarkable topic, but is not the subject of this dissertation. It is and it should be regarded only as a brief illustration of what might be practically achieved.

The SDI literature is really extensive. It could be classified in several categories: official documents, studies and addresses; articles and books supporting the program; articles and books written to reject it; program evaluations; collections of articles and reprinted significant documents; and general and historical analyses. Here I would like to remark on several books which belong to the last two categories, because in the next sections I will refer to more specific works dealing with pro or con arguments, and evaluations.

The Star Wars Debate edited by Steven Anzovin includes general information and some important papers associated with the beginning of the program. Commentaries reflecting the main points of view prevalent in the mid 1980s, written by some leading analysts, or persons holding official positions, were included in The Strategic Defense Debate: Can "Star Wars" Make Us Safe edited by Craig Snyder in 1986. In the same year, Zbigniew Brzezinski, published more than thirty essays written by statesmen and scholars in Promise or Peril, the Strategic Defense Initiative. One year later, Harold Brown, the former secretary of defense, edited a collection of articles too. It was entitled The Strategic Defense Initiative: Shield or Snare ?. For relatively more recent opinions of some leading defense analysts can be usefully consulted Security Implications of SDI edited by Jeffrey Simon. An updated collection of relevant articles and documents can be found in The Search for Security in Space edited by Kenneth N. Luongo and W. Thomas Wander.

General historical information concerning the program is presented in a number of books. For example, The Technology, Strategy and Politics of SDI edited by Stephen J. Cimbala, or While Others Build: the Commonsense Approach to the Strategic Defense Initiative by Angelo Codevilla, refer to the first years of the program. For an updated history and for substantial inside information, SDI and the Alternatives by Col. Simon P. Worden is perhaps the most rewarding.

* * * * * * * * *

1.2. PRESIDENT REAGAN'S CONCEPTION ON SDI

The Strategic Defense Initiative had some of its roots in the ABM Treaty debate of the late sixties, and it has been significantly influenced by the conclusions reached by several strategic analysis groups between 1976 and 1983. (Worden, 1991, pp. 112-113) In 1976, President Ford's Foreign Intelligence Advisory Board selected a team headed by Richard Pipes to make evaluations of Soviet intentions, in parallel with those made by the CIA. The team concluded that the Soviet Union did not accept MAD as its basic strategic nuclear doctrine. The Soviets were interested in achieveing nuclear superiority, and subsequently a credible first strike capability. The Committee on the Present Danger was founded in the same year by a bipartisan group including among others Paul Nitze, Eugene W. Rostow, Richard Allen and Max Kampelman. They were against the SALT II strategic offensive arms agreements, and supported a reexamination of the utility and technological faisibility of strategic defense.

In addition to these two teams which focused especially on general strategic problems, another three groups analysed some new technological developments. The High Frontier group was founded in 1980 and it has been leaded by Lt. Gen. Daniel Graham, a former head of the Defense Intelligence Agency. Their technical studies concluded that space based kinetic energy weapons (small missiles mounted on satellites) may constitute an acceptable missile defense in the near future. A second group included several laser experts who emphasized the capabilities of space based lasers for destroying the incoming nuclear missiles or warheads. In 1979, they convinced the Carter administration to approve a program for developing a space laser prototype by the beginning of the 1990s. The third influential group included some of Edward Teller's collaborators from Lawrence Livermore National Laboratory who considered that a laser might receive the necessary energy from a nuclear explosion, and consequently could have sufficient power to destroy the attacking missiles and/or warheads out of atmosphere.

Under the influence of these ideas, and at the suggestion of some of his senior advisers, President Reagan addressed the nation on March 23, 1983. In the last part of that televised speech, which has since became famous, President Reagan referred relatively unexpectedly to the problem of strategic defense. He challenged in an energetic manner the vulnerability based deterrence from both strategic and moral points of view. He said that in the future the "offensive retaliation" should not be the only means to defend American national security. Defensive measures must be taken to counter the Soviet threat. The strategic ballistic missiles of the Soviet Union which might be fired against the United States and its allies should be intercepted and destroyed during their flight before reaching their targets.

To prevent some objections which he and his advisers obviously expected, President Reagan pointed out that he has recognized the limitations, problems, and ambiguities associated with the development of strategic defense systems. He said that he had understood that those systems could be regarded as means to promote an aggressive policy. But he expressed his conviction that they have been necessary to maintain peace. He concluded his speech with the words, "With these considerations firmly in mind I call upon the scientific community in our country, those who gave us nuclear weapons, to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete."[1]

Following the President's speech, two studies were completed between June and October 1983, The Defensive Technologies Study and The Future Security Strategy Study. The first was conducted by a group of scientists led by Dr. James C. Fletcher, a former and future administrator of NASA. The second was elaborated by a team led by Dr. Fred S. Hoffman, the director of "Pan Heuristics", a policy analysis organization from Los Angeles. In their summary published in the Spring of 1984, were presented the principles of a mainly space-based ballistic missile defense and were enumerated seven "key functions" which should be performed by such a defense. Those functions would be: (1) prompt and reliable warning of an attack and initiation of defense, (2) continuous tracking of all threatening objects from the beginning to the end of their trajectories, (3) efficient interception and destruction of the booster or post-boost vehicle, (4) efficient discrimination between enemy warheads and

---

1. President Ronald Reagan, "Address to the Nation", Washington, D.C., March 23, 1983, reprinted in The Strategic Defense Debate: Can "Star Wars" Make Us Safe, edited by Craig Snyder, pp. 203-220.

decoys, (5) low cost interception and destruction in midcourse, (6) terminal interception and destruction at the outer reaches of the atmosphere, and (7) battle management, communications and data processing.[2]

On January 6 1984, President Reagan issued National Security Directive 119, establishing the Strategic Defense Initiative Organization.[3] One year later, the Administration published a pamphlet entitled The President's Strategic Defense Initiative. Its role was to clarify some of the Administration's points of view, because since the President's speech various speculations regarding the program's missions were frequent not only in the media and academia, but also among many defense analysts. But, although the pamphlet did not make more clear the missions of SDI, it presented among others three main requirements which should be fulfilled by strategic defenses. They must be able to destroy a considerable portion of the attacking objects. They must be reasonably survivable. And, they must be cheaper to be developed and deployed than the supplementary offensive countermeasures and ballistic missiles necessary to overcome them. One month later, in an address before the World Affairs Council of Philadelphia, Paul Nitze, at that time the president's senior arms control negotiator, formulated these requirements as follows, "The technologies must produce defensive systems that are **survivable**; [my emphasis] if not, the defenses would themselves be tempting targets for a first strike

----

2. Defense Against Ballistic Missiles: An Assessment of Technologies and Policy Implications, pp. 15-16.
3. Paine and Gray, 1984, p. 821.

... [and] New defensive systems must also be cost-effective at the margin [my emphasis] - that is, they must be cheap enough to add additional defensive capability so that the other side has no incentive to add additional offensive capability to overcome the defense."[4] Since then, these requirements are usually known as the Nitze criteria in recognition of the rigorous manner in which the Ambassador had formulated them.

* * * * * * * * *

----

4. Address by Ambassador Paul Nitze before the World Affairs Council of Philadelphia, February 20, 1985, in The Strategic Defense Debate: Can "Star Wars" Make Us Safe, edited by Craig Snyder, p. 223.

1.3. MISSIONS OF STRATEGIC DEFENSE

As I have shown before, the missions of strategic defense were not officially specified in a precise manner either in the presidential address of 1983 or in the 1985 document issued by the administration. There were several probable reasons. The president's speech was delivered for some tactical political reasons, before the two main studies were completed. But even after their delivery, the assessments of available technologies remained too vague to allow substantial predictions with regard to what it would be possible to defend: strategic ballistic missile silos, large military objectives, main cities, or the whole population. At the same time, it was important to make the Soviets believe that the United States was technologically capable of implementing the most ambitious scenario in order to obtain from them concessions in disarmament negotiations (even if those talks were interrupted, for it was the the mutual perception that they will probably resume).

From a theoretical point of view, strategic defense could have several objectives of different orders of complexity. For example, in 1984, Keith B. Payne and Colin S. Gray considered that the near term role of ballistic missiles defense "would be to provide protection for the US nuclear deterrent and perhaps protection of the nation against small or accidental attacks." If the future technological developments will allow it, then a "comprehensive BMD coverage" for "urban and industrial America" will be developed on long term.[1]

In 1986, Colin Gray differentiated eight possible missions.[2] From simple to complex, they might consist in protecting: (1) strategic offensive forces; (2) National Command Authorities (NCA) and strategic command, control and communications (C3); (3) US and allied theater nuclear and general purpose forces and their logistic infrastructure; (4) US and allied cities against light coercive attacks, "strayed warheads", and careless countermilitary strikes; (5) US and allied economic and administrative assets that are essential for recovery; (6) against an accidental or unauthorized missile launch; (7) against nuclear blckmail by "cozy states"; and (8) US and allied societies against heavy attacks.

Two years later, Jerome Slater and David Goldfischer identified several similar objectives.[3] The most ambitious one would be a full-scale population defense of the United States, making vulnerability based deterrence useless. It would abolish at the same time the Soviet capability of assured destruction, making nuclear weapons obsolete. A second objective might consist in the protection of the United States retaliatory force for "enhancing deterrence rather than replacing it." And finally, a

----

1. Paine and Gray, 1984, p.826.
2. Colin Gray,Deterrence and Strategic Defense: A Positive View, in The Strategic Defense Debate: Can "Star Wars" Make Us Safe ?, edited by Craig Snyder, pp. 176-177.
3. Jerome Slater and David Goldfischer, Population Defense Through SDI: An Impossible Dream, in Defense Policy in the Reagan Administration, edited by William P. Snyder and James Brown, pp. 333-335.

third, more modest one, might be a limited protection of US cities against an "unauthorized or accidental Soviet launch" or an "attack by a small nuclear power."

In 1989, Milton, Davis and Parmentola differentiated at their turn three main approaches to strategic defense consistent with the above mentioned objectives.[4]

The first would logically consist of maintaining the same strategy of vulnerability based deterrence which has prevailed in the past. One version of this approach might be not to deploy any defense. The other would be to deploy a limited defense to improve the survivability of US land based ICBMs. Having as a result the increase of the capacity of destruction of the counterstrike, it would reinforce the deterrent character of the US nuclear offensive forces. Subsequently, the adversary would be even more reluctant to initiate a nuclear attack. The second approach would consist in developing strategic defenses to protect a significant number of military targets. This would diminish the gain which the adversary might expect by initiating a first nuclear strike, and subsequently discourage him from doing it. The third one would be the most comprehensive conceivable. It would imply an extensive deployment of strategic defense systems to protect the whole territory and population of the United States and of its allies, and finally would eliminate the nuclear threat.

Although the potential missions of strategic defense were

----
4. Milton, Davis and Parmentola, 1989, pp. 149-163.

not officially specified, and the Adminitration's intentions were not sufficiently clear, the president's initiative caused extensive debates. A brief summary of the main pro and con arguments is presented in the next section.

* * * * * * * * *

1.4. ARGUMENTS IN FAVOR OF AND AGAINST SDI

1.4.1. NATURE OF ARGUMENTS

The arguments in favor of and against SDI have been of a complex nature: strategic, military-technological, moral, and political-economic. The most extensive and substantial debates took place in the strategic and military-technological fields. The moral controversy implied ethical principles and convictions and religious beliefs. The political and economic arguments referred not only to the American-Soviet relationship, but to national priorities and resource allocation too.

At the official level, strategic pro arguments associated with military and technological ones were initially included in the afore-mentioned two studies completed in 1983, Defense Technologies Study and Future Strategy Study. Two years later, strategic and political pro arguments were presented in President's Strategic Defense Initiative, in The Strategic Defense Initiative published by the Department of State, and (besides con arguments and evalauations) in Ballistic Missile Defense Technologies: Summary published by the Office of Technology Assessment of the Congress. A substantial description of the Administration's conception was also made by Payne and Gray in their above quoted article published in 1984, "Nuclear Policy and the Defensive Transition."

As expected, the officials of Reagan Administration energetically supported the program. In interviews, addresses before political and professional associations, and articles, they emphasized the necessity and feasibility of the program. Secretary of State George P. Shultz, and Secretary of Defense Caspar W. Weinberger attended many news programs and made statements of support in various speeches. Paul Nitze, the senior arms control expert of the administration presented his opinions in **"SDI: Its Nature and its Rationale"**, in **"The Impact of SDI on US-Soviet Relations"**[1] and with the occasion of political and scientific reunions. Fred C. Ikle, Undersecretary of Defense between 1981 and 1988, supported the program within a general political and strategic framework in the article, **"Nuclear Strategy: Can There Be a Happy Ending?"** published in Foreign Affairs. At his turn Robert C. McFarlane, President's National Security Adviser betweeen 1983 and 1985 made a realistic and balanced evaluattion of SDI in his article entitled, **"Effective Strategic Policy"** published in the same journal.

The Joint Chiefs of Staff and the SDI Organization director enthusiastically backed the program. At successive points in time they made evaluations, nearly always positive, expressing their convinction in the future success of the SDI. Favorable arguments were also extensively presented in a considerable number of books published by scientists, defense analysts, or military men. In the early eighties, one of the most influential books was Lt. Gen. Daniel Graham's High Frontier: A Strategy for

----

1. in Security Implications of SDI, edited by Jeffrey Simon.

National Survival, published in 1982. Five years later, Edward Teller expressed his uncompromising views in favor of SDI in Better a Shield than a Sword, and in 1991 Col. Simon P. Worden, one of the remarkable advocate of the program, published the consistent monograph entitled SDI and the Alternatives.

Some of the most substantial arguments against SDI were included in the book published in 1985 by Sidney S. Drell, Philip J. Farley, and David Holloway, and entitled The Reagan Strategic Defense Initiative: A Technical, Political and Arms Control Assessment. Important political, strategic and military-technological objections against SDI were extensively discussed in two books published by the Union of Concerned Scientists in 1984 and 1986. They were The Fallacy of Star Wars and Empty Promise: The Growing Case Against Star Wars. Comparable opinions were expressed in several papers delivered at a Pugwash Symposium, in 1986, and included one year later in Strategic Defenses and the Future of the Arms Race: A Pugwash Symposium, edited by John Holdren and Joseph Rotblat.

The Soviet position regarding SDI was discussed from a Soviet point of view in Weaponry in Space: The Dilemma of Security, edited by Yevgeny Velikhov, Roald Sagdeev and Andrei Kokoshin. It was analysed from an American point of reference in The Soviet Perspective on the Strategic Defense Initiative by Dmitry Mikheyev and in various articles.

The feasibility of the program was also thoughtfully questioned by two former secretaries of defense. James R. Schlesinger published the article entiltled "Rhetoric and Realities in the **Star Wars Debate."** Harold Brown made known his opinions in **"Is SDI Technically Feasible?"** and **"The Strategic Defense Initiative."** Equally, or perhaps even more influential, was the article written by McGeorge Bundy, George F. Kennan, Robert C. McNamara and Gerard Smith, and entitled **"The President's Choice: Star Wars or Arms Control."**

From a technological point of view, the president's initiative was challenged by scientists who belonged to some of the most prestigious technological institutions of the nation. Kostas Tsipis and Matthew Bunn wrote the article entitled "The Uncer**tainties of a Preemptive Nuclear Attack."** Ashton Carter, at his turn, did an authoritative critique of lasers' capabilities in his study entitled **Directed Energy Missile Defense in Space.** Carl Sagan, the distinguished space scientist, contested the program too. He criticized it in an indirect manner in "Nuclear **War and Climatic Catastrophe: Some Policy Implications"** and in a cutting direct style in **"The Case Against SDI."**

As I have written above, the arguments in favor and against SDI can be classified in several classes - strategic, military technological, moral, and political-economic. I include in the class of strategic arguments those dealing with the strategic doctrine, the relation between offense and defense, and the magnitude of strategic nuclear forces. I consider - in the context of this dissertation - as military-technological, those referring to the structure of strategic defensive systems, the weapons which must be developed and the technologies which must be utilised to materialize the military requirements. The inclusion of moral and political-economic arguments in the respective classes is the usual one, and does not require a particular specification of criteria of classification. From theoretical and logical points of view, the order of arguments from abstract to concrete should be: (1) moral, (2) political-economic, (3) strategic, and (4) military-technological. In reality, the strategic and military-technological issues were far more debated than the other two because they were perceived to be the most important. Taking into consideration this fact, I will begin this brief presentation of the pro and con arguments with the strategic ones. I will continue with the military technological arguments, and I will end with the moral and political-economic ones. In the presentation, I will try in general to summarize each pro or con argument, because the same ideas are frequently included in a considerable number of books or articles. But I will quote some authors if it seems to me that the sensitivity of some arguments or the intensity of the debate require supplemetary support.

* * * * *

1.4.2. STRATEGIC ARGUMENTS

The strategic arguments in favor or against SDI may be classified in three categories: those referring to the magnitude and capability of the Soviet nuclear forces, those referring to the nuclear strategic doctrine, and those dealing with strategic defense itself and its relationship to strategic offense. Subsequently, I will present them in this order, and I will include the corresponding counterargument after each argument.

The proponents of SDI considered that the Soviets significantly increased the number of their ICBM warheads by the introduction of the SS-18 and SS-19 ICBMs.[1] Each missile has carried, respectively, ten and six warheads, and it was estimated by American analysts that the Soviets built an average of fifty missiles per year between 1975 and 1980. Because these new missiles were more accurate and the warheads more efficient, the capability of the Soviet Union to destroy with a first strike a relatively large fraction of the American silos and land-based missiles increased. This meant that, in relative terms, the American capability to deliver a nuclear counterstrike was reduced in comparison to what it had been when the SALT I Treaty was negotiated and ratified. Consequently, the relative decrease of the deterrent capability of the US nuclear offensive

----
1. Milton, Davis and Parmentola, 1989, pp. 4; McFarlane, 1988, p. p. 36.

forces required the development of strategic defense.

The opponents of SDI answered this argument by denying the accuracy of official American estimates. They considered that the accuracy of the new missiles, and the efficiency of the warheads, although superior to those of the previous ones, were not so remarkable as the Pentagon's officials had tried to portray them. At the same time, they contested the number of newly built missiles and regarded the estimates given by the Reagan Administration as exaggerated.

A second object of debate was the large radar built by the Soviets near Krasnoyarsk, in central Siberia, in a region forbidden by the ABM Treaty.[2] It was considered as being a central element of a long-range system having as its mission the tracking of incoming American nuclear warheads. By giving advanced information about their probable trajectories to medium and small-range radar systems it could significantly improve their performance. It was believed to be particularly effective in the case of the warheads carried by SLBMs because of their specific flight trajectories. Associated with some mobile anti-missile systems upgraded by the Soviets in the early 1980 (ABM-X-3, SA-10, SA-12) this long-range radar was regarded as a flagrant violation of the ABM Treaty, and as a suggestive example that the Soviet Union was working to develop an extensive system of strategic defense. Hence, the United States must develop its own strategic defense.

----
2. Worden, 1991, p. 153.

These arguments were countered in several ways. The Soviets argued that the radar was "designed to carry out observations of space objects."[3] They also argued that a new radar network deployed by the United States in Greenland and the United Kingdom violated the ABM Treaty. Other opponents[4] pointed out that the Krasnoyarsk radar was not totally completed. It was not sufficiently well known how efficient it might be, and how well it could work in association with the middle and short-range radar systems. It was also vulnerable to a US preemptive attack, in the hypothesis of a major conflict between the two countries. A third counterargument was that even upgraded, the Soviet anti-ballistic missile systems supposed to work with the radar network were too inefficient to constitute a real threat to the American ICBMs, SLBM, and/or the warheads during their independent flight. The debate remained undecided, and ended only with the Soviet decision to dismantle the radar as contravening to the improved relations with the United States at the end of the Cold War.

Another argument in favor of developing a US strategic defense was that the Soviets have had built the one ballistic missile defense system permitted by the ABM Treaty around Moscow.[5] The SDI's proponents asserted that the Soviets had solved the problems related to the Galosh System in the early 1970's and that they upgraded the system one decade later. They

----

3. Velikov, Sagdeev and Kokoshin, editors, 1986, p. 110.
4. For example, John Tirman, The Politics of Star Wars, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, p. 25.
5. Milton, Davis & Parmentola, 1989, p. 5; Worden 1991, pp. 149-152.

pointed out that the rebuilt system had 100 interceptors, which has been the maximum number permitted by the ABM Treaty.

The counterargument was that the new system was as inefficient against the American ICBMs of the 1980, as it was the old Galosh system against those of 1970.[5] The debate implied intelligence estimates which were from the beginning expected to be only partly accurate. And at their turn, this partly accurate information referred to Soviet tests which were considered by American analysts as being only partly relevant. Subsequently, the acceptance or the rejection of this argument was more a matter of believing or not open statements based on intelligence reports, than the result of a rigorous evaluation of the systems' performance. In general it was perceived that, although upgraded, the Soviet system was too primitive to present a real obstacle to the American missiles.

A fourth element of contention was the Soviet defense against strategic aircraft. The Soviets had about 9000 strategic surface to air missiles (SAM) launchers, over 1760 interceptor aircraft and the all necessary sensor and computing power.[6] The supporters of SDI argued that the upgraded anti-aircraft missile systems constituted a formidable threat against the American strategic bombers. Therefore, the deterrent role of one of the three main pillars of strategic triad considerably eroded.

The opponents answered in a differentiated manner. They contested only slightly the high class of Soviet anti-aircraft

----
5. Tirman, idem, p. 26.
6. Milton, Davis and Parmentola, 1989, p. 5.

defense (even after the young German pilot landed in the Red Square) but they pointed out that this "respond[ed] to US actions"[7] It was also argued that the use of strategic bombers for a nuclear attack against Soviet Union had a very low probability. The most probable was the massive use of ICBMs and SLBMs, and subsequently the high class of the Soviet anti-aircraft defense was not a relevant argument in favor of strategic defense.

The last argument which might be included in this group was that the Soviets emphasized civil defense for leadership and population, by developing an extensive network of deep underground shelters in and around Moscow, and in other cities of strategic importance.[8] It was estimated that the shelters for party and government leaders could accommodate 110,000 persons. It was also considered that it was possible to protect sufficiently well between 12% to 24% of the "essential work force" at important industrial instalations, and that there were also built about 1500 shelters for 10 to 20 million people in urban areas.[9] Such very large preparations to survive a counterstrike suggested that they had aggressive intentions envisaging a potential first nuclear strike against the United States and its allies. To limit the damage, the argument went, the United States must develop strategic defense.

The rejection of this pro argument was relatively simple. The SDI's opponents said that those shelters had nothing to do

----

7. Tirman, idem, p. 26.
8. Ikle, 1985, p. 814.
9. Milton, Davis and Parmentola, 1989, p. 5.

with initiating a nuclear strike. That they were only a normal precautionary measure. A measure reinforced by the secretive and centralized character of the Soviet society, and comparable to similar steps taken in the United States in the sixties.

The second class of strategic arguments dealt with strategic doctrine. They have essentially referred to the MAD doctrine and to the question of whether it had really been followed by the United States, the Soviet Union, or by both. The common characteristic of these arguments has been that they supported or rejected the SDI mainly on the basis of the assumptions and predictions of the principal strategic offensive doctrine. They have only tangentially referred to the characteristics of the potential strategic defense itself or to the relationship between strategic defense and offense.

An important number of analysts, in majority members of the US military have supported SDI by contesting that MAD was the main American strategic doctrine. They have argued that the United States prevented the outbreak of a nuclear war not on the basis of vulnerability based deterrence, but because of retaliation based deterrence. They have considered that MAD was not the basis for strategic nuclear planning for the military, even in those periods in which different American administrations have stated that it was. They supported this point of view by using statements like the following made by General David Jones, a former Chairman of the Joint Chiefs of Staff. Testifying before the Congress he said, "I do not subscribe to the idea that we ever had it [MAD] as our basic strategy [and] I have been involved with strategic forces since early 1950s."[10] This opinion, which seems to be widespread in all the echelons of the military, was expressed by Col. Simon P. Warden, a convinced supporter of SDI, as follows, "Most Americans believe MAD is the basis of US nuclear strategy ... it is not. Rather than ending all thoughts of war, nuclear weapons have been integrated into a "warfighting" strategy. In this complicated plan, nuclear weapons, along with non-nuclear weapons, prevent war beacuse we are able to fight and **prevail** [my emphasis] if the need arises."[11] Subsequently because "the United States deters war by maintaining nuclear offensive forces sufficient **to beat** [my emphasis] an aggressor, even if struck first"[12] any means which could increase the capacity to do it would increase the chances of peace. Development and deployment of strategic defense systems increases the survivability of American nuclear offensive forces and, consequently, they improve the chances of prevailing in a nuclear war. Hence they are necessary, have concluded the SDI's supporters.

These opinions were energetically rejected not only by SDI's opponents. The supporters of MAD, without regard to whether they have had an adverse or ambivalent position on SDI, argued that the vulnerability based deterrence safeguarded peace for several decades.[13] They stressed again that it was totally unrealistic to believe that a nuclear war could be won. Any

----

10. Quoted in Worden, 1991, p. 61.
11. Worden, 1991, p. 1.
12. Worden, 1991, p. 61.
13. McGeorge Bundy, George F. Kennan, Robert C. McNamara, Gerard Smith, 1984; Robert C. McNamara, 1983.

erosion in the perception of MAD as the main method to prevent war would be extremely dangerous. It could mean that the difference between nuclear and conventional weapons is only quantitative, and not qualitative. And therefore they could be actually used to fight a war, and not only to prevent it. As a result the rejection of MAD could lead to the acceptance of the first nuclear strike as a viable alternative. On the basis of these considerations, SDI's opponents rejected the program by contesting a main premise of its necessity - the retaliation based nuclear deterrence.

The second argument in this category dealt with Soviet strategic nuclear doctrine. SDI's supporters used the conclusions of those students of the Soviet nuclear strategy who have had considered that the Soviets did not ever accept MAD principles for their nuclear planning. On the basis of those conclusions they asserted that the Soviets were prepared to fight and to prevail in a nuclear war. Consequently an effective strategic defense was necessary to improve the survivability of the American strategic offensive forces in a first stage, and to protect the nation's main assets in a second one. The analysts who asserted that the USSR did not comply with the MAD principles have usually begun their analyses from a political perspective. They asserted that the Soviet Union regarded itself, in accordance with the Marxist-Leninist theory, as being surrounded by hostile forces. For this reason, the Soviets applied the so called "correlation of forces" theory to increase their military power and to improve their power position in the world. But this theory fuelled an expansionist, highly aggressive foreign policy. Consequently, the Soviets did not obey the requirements of vulnerability based deterrence. They were ready themselves to fight and to defeat the West by using nuclear weapons.[14]

This argument was contested by those who considered that the Soviets complied with the MAD principles in general, and by the SDI's opponents in particular. They usually did not deny the political analyses made by their adversaries or the correlation of forces theory. But they contested that the Soviets derived on that basis the conclusion that they could win in a nuclear war. Hence, they said, the Soviet Union developed its nuclear forces only to deter a possible American attack, and not to initiate a first strike. "Like the United States, however, the Soviet doctrine favors a posture of deterrence: nuclear war is to be avoided, and the most logical way to prevent it is to deter attack by maintaining large and capable offensive nuclear forces. These forces - predominantly land-based ICBMs - may be used preemptively or in retaliation, the former preferred if the United States appears ready to strike," wrote John Tirman.[15]

The third argument is a combination of the first two. Analysts who supported SDI affirmed that both superpowers based their strategies on retaliation based nuclear deterrence. At their turn, their adversaries asserted exactly the opposite. They said that both superpowers accepted the vulnerability based

----

14. An independent presentation of this point of view in: Donald M. Snow, National Security: Enduring Problems of US Defense Policy.
15. Tirman, idem, p. 24.

deterrence as the basis of their nuclear strategies, and the declarations made by the American and Soviet military against MAD were irrelevant. Consequently they argued, SDI must be rejected as being a useless and destabilizing element.

A couple of other arguments which might be associated with the MAD doctrine, but which did not refer only to the Soviet Union, were discussed too.

The proponents argued that some of the future enemies of the United States "may not always be so restrained" as the Soviets were because of their political, social and national characteristics, or because the national leaders "do not always have complete control of the military forces under their comand."[16] Consequently, MAD will not perform its role in deterring them. The opponents rejected the argument on cost-benefit reasons. They asserted that it was unrealistic to implement a multi-billion dollar system only to defend against a potential threat posed by some "third world dictators."

Another argument in SDI's favor has been the possibility of a launch by accident, either because the Soviet arsenal was very large, or because of nuclear proliferation. Against the first part of this argument, the Soviet scientists opposing the program argued that "the probability of an error or a failure of the battle management system, would be much higher than the probability of a random launch, especially if the nuclear arsenals of both sides were cut drastically ... and if the

----

16. Milton, Davis and Parmentola, 1989, p. 7.

reliability of the early-warning and control systems were to be steadily improved."[17]

An important topic of contention was the allies' fate. The SDI's supporters affirmed that the protection of the United States' allies in Europe, and perhaps of Japan too, required strategic defense.[18]

The opponents counterargued by asking how would it be possible to defend all those areas at thousands of miles distance, if it were not clear if even the continental territory of the United States could be defended. And second, the physicists opposing the program observed that the paths of the potential missiles attacking Western Europe would be totally different from those of the potential Soviet ICBMs directed toward the United States. As a result several key elements of the so called multiple layered defense concept (described in section 1.4.3.) were irrelevant.

The third category of strategic arguments has referred to strategic defense itself and to its relationship with strategic offense.

A first problem included in this category is that of survivability. The supporters of SDI answered in an affirmative manner to the corresponding Nitze criterion. They considered that it would be possible "to produce defensive systems that are survivable." The opponents answered in a negative way, which meant that "the defenses would themselves be tempting targets for

----

17. Velikov, Sagdeev and Kokoshin, editors, 1986, pp. 118-119.
18. Hughes, 1990.

a first strike." The debate was extensive but not conclusive. The supporters argued that it would be easier to harden a space based defensive system than a ballistic missile or a warhead. The opponents counterargued by affirming that the space based defense systems could be destroyed or incapacitated with ground based weapons, and that many other technical measures might be envisaged to improve the survavibility of ICBMs targeted by strategic defense.[19] In the 1990s, the so called brilliant-pebble, a kinetic energy interceptor, was regarded by the supporters as a substantial argument proving that the survivability requirement can be fulfilled. But, because the research has been classified, it was relatively easy for the opponents to express strong reservations. And it is, of course, probable that the debate will continue as it has always been the case with any debate refering to the survivability of a weapon system.

A second subject of controversy included in this category has perhaps been one of the most interesting raised by thwhole SDI debate: are the strategic defense systems a stabilizing or destabilizing element ? The question has implied two aspects: the impact of a fully deployed strategic defense system, and the stability during the deployment period, or the so called transition stability. Since his first speech on SDI, President Reagan ackowledged that associated with offensive weapons, the

----

19. Richard L.Garwin, **The Soviet Response: New Missiles and Countermeasures**, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 129-146; Velikhov, Sagdeev and Kokoshin, idem, pp. 98-104.

development and deployment of strategic defense systems might suggest that United States had offensive intentions. Paul Nitze stressed that this was a possible and important risk. In his above quoted speech, he pointed out that in his opinion the concept of strategic defense "is wholly consistent with deterrence" but also "that the transition period - if defense technologies prove feasible ... could be tricky." He observed that in such a context the United States must "avoid a mix of offensive and defensive systems that, in a crisis, would give one side or the other incentives to strike first."[20] A possibility which could be reinforced if the protection of ICBMs by strategic defense would be significantly improved.

The opponents of SDI made from its destabilizing character a main, and perhaps the most convincing, objection against the program. Sidney D. Drell, Philip J. Farley and David Holloway stressed that "intensified national programs in pursuit of ABM defenses can, and are likely to, prove destabilizing for the strategic balance and risky for our security, as each nation fears the purpose as well as the capability of its opponent's defenses." They considered that the research and development for strategic defensive systems deployment "is not a harmless step" because "even if a deployed system never materializes, increased instability can result as both sides build up their forces to preserve their deterrent capability as well as to match each other's anticipated ABM capability."[21] In order to prevent this

----
20. Nitze, idem, in Craig Snyder, editor, p. 225.
21. Drell, Farley and Holloway, 1985, pp. 94-95.

dangerous situation the SDI research must be closely associated with substantial arms control negotiations.

At their turn, the Soviet analysts emphasized that a result of developing strategic defense systems by one side might be the buildup of strategic nuclear forces by the other. This might imply the increase in the number of ICBMs, the increase of the number of warheads on MIRVed ballistic missiles or the development of cheap unarmed "fake ICBMs." In accordance with the Soviet point of view, "one could regard the SDI program as a manifestation of the desire to establish military superiority, to acquire first-strike capabilities with impunity and do away with any bans on offensive strategic forces."[22]

Three other arguments supporting the destabilizing character of the program were derived from technological considerations. Some adversaries of SDI emphasized that by associating strategic defense systems with anti-satellite (ASAT) weapons, it would be possible to destroy important military satellites.[23] But those satellites are vital for obtaining information regarding the behavior of the adversary and subsequently preventing a baseless nuclear (counter)attack. The perception that the satellites are increasingly vulnerable might fuel a dangerous and highly unstable arms race in space. A

----

22. Velikhov, Sagdeev and Kokoshin, editors, 1986, pp. 101-102 and p. 115.
23. John Tirman and Peter Didisheim, **Lethal Paradox: The ASAT-SDI Link**, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 107-128; Velikhov, Sagdeev and Kokoshin, editors, p. 107.

second argument referred to limited defense.[24] Assuming that the defense of population would be technologically impossible, some of SDI's critics asserted that the real goal was a limited defense. The main goal of this limited defense would be the protection of land-based ICBMs. But **this implies increasing** the **first strike capability which might considerably destabilize** the **system.** The third counterargument was mainly supported by the Soviets. They affirmed that the so called defensive space-based weapons can be also used as first strike weapons against ground and air targets.[25] And that kind of utilization could considerably multiply the danger of conflict.

Another aspect of the stability problem has been transition stability. The opponents emphasized that the defense systems could be destroyed during their deployment. And that without taking into consideration any other objections even this possibility could constitute a cause for a conflict which might degenerate into a nuclear war. They stressed that without a cooperative relation between the superpowers, this difficulty has been insurmountable. The supporters of SDI acknowledged the importance of this objection and answered by advocating a cooperative process of transition, in which each superpower would refrain from achieving advantages which might be regarded as damaging by the other.

* * * * * * * * *

----

24. Peter A. Clausen, **Limited Defense**, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 147-160; James Schlesinger, 1985.
25. Velikhov, Sagdeev and Kokoshin, editors, p. 107.

1.4.3. MILITARY-TECHNOLOGICAL ARGUMENTS

According to the aforementioned studies from the first half of the last decade, several emerging technologies and technological achievements have made feasible the development of an effective strategic defense. The most significant and promising have been the following:[1]

- development of directed energy devices, lasers and particle beams capable of more effectively discriminating between warheads and decoys, and intercepting and destroying the warheads;
- construction of new sensors, probably using infrared light, which could detect and track the incoming attacking missiles from their launch;
- important achievements in computer hardware and software allowing an effective engagement against a great number of attacking objects;
- development of very small non-nuclear interceptor missiles utilising miniaturized computers and new sensor technologies;
- the important expansion of US access to outer space, allowing the operation of the space based defensive systems in a technically and economically efficient manner.

On the basis of these estimations, the Reagan administra-

----

1. Simon P. Worden, US Strategic Defenses in 2010: A Conjecture,in Implications of SDI,edited by Jeffrey Simon, p. 35.

tion security analysts concluded that there were sufficient reasons to initiate an important program of research and development in order to build a space based strategic defense. The main concept on which it has been based has been the so called multiple layered defense. That is associated with the flight characteristics of a ballistic missile and implies the following elements.[2]

1. The typical flight of a long range ballistic missile has four phases: boost, post-boost, midcourse, and terminal. The boost phase starts with the launch and lasts until the rocket engines stop. During this phase the boosters accelerate the missile to a final velocity of 6-7 Km/s. The post-boost phase includes the flight of the vehicle carrying nuclear warheads and decoys. It starts when this vehicle detaches from the carrying missile after the boosters burned out, and it ends when the reentry vehicles (nuclear warheads and decoys) are released. The midcourse phase includes their flight on ballistic trajectories outside the earth-atmosphere. The terminal phase denotes the flight of nuclear warheads toward their targets in the atmosphere.

2. At least one layer of defense must be employed in each phase.

3. In each layer of defense must be included systems which would detect a missile attack and track the trajectories of

----

2. Defense Against Ballistic Missiles: An Assessment of Technologies and Policy Implications; Drell, Farley and Holloway, 1985; Barry W. Holman,The Future of SDI: A Framework for Decision Making, in Essays on Strategy VI edited by Thomas C. Gill; Worden, idem; Velikhov, Sagdeev and Kokoshin, editors, p. 17.

the attacking objects. They would also discriminate among attacking objects and identify their potential targets. Finally they must intercept and destroy the incoming ballistic missiles and warheads. They should be at the same time able to hand on unintercepted targets to subsequent layers and manage the battle in a reliable manner in all the phases.

4. Each layer must be effective and independent in relationship with the others.

5. The layers must work as a complex system of succcesive filters.

The multiple layered defense would require the development of three main kinds of systems: sensor, intercept, and battle management systems.

The sensor systems must include: sensors for an initial boost phase defense based on advanced infrared technologies; sensors for post-boost and midcourse phases, capable of tracking the relatively cold attacking objects, which would probably use long-wave infrared devices; sensors for late midcourse and terminal phases, including airborne carried and laser-ranging systems, and ground based terminal imaging radars.

Two main kinds of interceptors have been envisaged for the destruction of the missiles and reentry vehicles: hit-to-kill non-nuclear homing interceptors, and directed energy weapons. The hit-to-kill or kinetic energy weapons could be deployed in space or on the ground, and they could be used for destroying the attacking objects (missiles, vehicles loaded with warheads and decoys, or separate warheads) during all the phases of flight.

They would consist of small rocket-powered homing interceptors carried by satellites, ground based kinetic energy weapons for exo-atmospheric interception, ground based kinetic energy weapons for endo-atmospheric interception, and high velocity kinetic interceptors for attacking the future ballistic missiles provided with fast-burn boosters.

The directed energy weapons are based on laser and particle beam technologies. The lasers act by burning holes in the attacking objects. The particle beams would destroy those objects by deeply penetrating them and destroying or disrupting the functioning of their internal parts. They could be ground based lasers, space based lasers, space based particle beams weapons, and nuclear directed energy weapons (X-ray lasers).

The battle management systems would require not only progress in computer hardware technologies, but also writing unprecedentedly large programs. This second objective could be achieved by using methods of automating software production.

This general conception of multiple layered defense was contested from different perspectives by a number of scientists and defense analysts. For example, Greg Nelson and David Redell stressed the difficulties implied by writing extremely complex and highly reliable software.[3] They classified the functions of software in low, middle and high level categories. At the low level, the system must control sensors and weapons,

----

3. Greg Nelson and David Redell, Could We Trust the SDI Software, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 87-106.

and process a very high volume of data coming from the sensors. The middle-level functions should include: surveillance and target acquisition; track formation and decoy discrimination; kill assessment; scheduling and allocation of weapons and other resources; and dynamic reconfiguration to compensate for damaged components. The high level functions would consist of: coordination among system components, coordination with command authority, automated weapon release, and detection of attacks on the system itself.

These extremely complex functions would require computer programs of unprecedented dimensions, (on the order of 10 million lines of code) which must be able to answer in real time to multiple solicitations. They must be simultaneously very fast and highly reliable. But speed and reliability are two contradictory requirements. Hence, the SDI software might be affected not only by some regular programming errors, but far more important, by principle limitations.

The authors differentiate three types of limitations. The first are the limitations of system redundacy, that is how many systems are necessary to insure that at least one is always working. The second group includes the limitations of software-fault tolerance. And finally, the third category refers to the limitations of simulation and partial testing. Taking into consideration all these elements, the authors affirm that, "given the magnitude of this software engineering challenge, there is a significant chance that the development effort would simply fail to produce a deployable system at all." Because of the impossibility of operational testing "the reliability of the system would always be in doubt." (p. 106)

Another argument has referred to SDI command and control systems. Robert Zirkle emphasized five "general concerns."[4] A first major problem would consist in designing the appropriate structure of the command and control system by deciding the levels of coupling and centralization. A second major difficulty would be caused by the "sheer complexity" of the system. The other three would refer to the mechanisms of weapon release, reactions to false alert, and the relationship to the system of command and control of strategic offensive forces. The author asserted that "the extent of integration required to make the defense effective may prove unattainable." The necessity to react in a very short interval of time for destroying the attacking objects "may increase the likelihood of mistakingly activating the system." (p. 85) The complexity of the whole system might be so high that it would be impossible to develop a completely adequate and safe communication, command and control system. Therefore "because C3 system may prove not only unreliable, but an inadvertent catalyst for conflict, it shows again that the SDI risks a serious erosion of crisis stability." (p. 86)

Besides contesting its feasibility, another way of arguing against SDI, from a technological point of view, has been by emphasizing the probable Soviet response. For example, Richard L. Garwin, one of the most convinced opponents of the program,

4. Robert Zirkle, A Tangled Network: Command and Control for SDI, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 62-88.

stressed that the Soviets might build fast-burn boosters, shortening considerably the time in which a missile could be identified and destroyed, and making the identification itself more difficult.[5] The Soviets could also develop single-warhead missiles which would strongly increase the number of targets which should be tracked by the defense systems. Hardening missiles or modifying flight trajectories might also be taken into consideration. Although extremely expensive, the multiple layered defense would be ineffective against nonballistic nuclear threats, like strategic cruise missiles carrying nuclear warheads. And the Soviets might also develop and build new types of decoys for all the phases of the attacking objects' flight (the only exception being the last one, in the atmosphere).

Many of these conclusions regarding the multiple layered defense were consistent with those reached by Sidney D. Drell, Philip J. Farley and David Holloway in their study published in 1985. I quote their general conclusion because it has expressed in a synthetic manner the opinions of many opponents of the program. They asserted that, although "there have been major technological advances in recent years, ... we do not know how to build an effective nationwide strategic defense against ballistic missiles." And they pointed out that "this is true whether the goal is to transcend deterrence with a nearly leakproof defense or to enhance it with an effective but partial defense."[6]

* * * * *

----

5. Richard L. Garwin, **The Soviet Response: New Missiles and Countermeasures**, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 129-146.
6. Drell, Farley and Holloway, 1985, p. 63.

1.4.4. MORAL ARGUMENTS

Starting with the presidential address of March 23, 1983, the Reagan Administration tried also to support the SDI, and to make it largely accepted by the American people by emphasizing its moral character. The members of the Administration argued in its favor by stressing that the nuclear weapons are immoral because of their extraordinary destructive capability. The MAD doctrine implies putting at risk the lives of tens of millions of innocent people. By contrast, strategic defense will not be directed against people, but against weapons. And even more important, strategic defense will be essentially non-nuclear.

As they were summarized by Douglas P. Lackey, who is however skeptical of SDI moral superiority, the main ethical pro arguments might be the following.[1] The SDI program is necessary because it "would save American lives in the event of a nuclear attack." Deterrence without defense is immoral because it "involves a commitment ... to kill many innocent people ... violates the right to self-defense [and] involves threats of revenge." And finally, but perhaps equally important, "space is the new high ground and the nation that siezes [it] ... will control the destiny of future human generations."

These pro arguments were considered by the SDI supporters

----

1. Douglas P. Lackey, Four Unsound Moral Arguments for Strategic Defense, in Ethics and Strategic Defense: American Philosophers Debate Star Wars and the Future of Nuclear Deterrence, edited by Douglas P. Lackey, pp. 72-78.

not only as being consistent with main ethical principles, but also as being in full accordance with the American ethos. For example, Michael Vlahos argued that the interest in strategic defenses was caused by "an impending American cultural rejection" of MAD.[2] In his opinion, "Strategic defense offers more and less than a defended world. It is not, and probably will never become, a simple shield. There is no hope that it will end US-Soviet competition. But it offers more in that weapons in space can alter the terms of that competition **in ways that satisfy American cultural imperatives** calling for change in the nuclear world."

Some important religious organizations have been sympathetic to these points of view, while others rejected them. The qualified support given by the Catholic Bishops Conference has perhaps been typical for the positions of those who have backded president Reagan's initiative. In a pastoral letter of 1983 entitled **"The Challenge of Peace: God's Promise and Our Response"**, they expressed their opinion that the deliberate initiation of a nuclear war, even on a limited scale, can not be accepted from a moral point of view. It is necessary to answer non-nuclear attacks also by non-nuclear means. Consequently, the development of non-nuclear defensive strategies consitutes "a serious moral obligation." Three years later, nuclear based deterrence was also criticized by the United Methodist Council of Bishops which released the declaration **"In Defense of Creation: The Nuclear Crisis and a Just Peace."**

----

2. Vlahos, 1986, p. 4 and pp. 101-102.

In 1988, the Ad-hoc Committee on the Moral Evaluation of Deterrence of the National Conference of Catholic Bishops issued a declaration dealing with the SDI program specifically.[3] The bishops have considered that "some of the officially stated objectives of the SDI" have been in accordance with the principles of the previous pastoral letter. Consequently they have supported those objectives under several conditions. Among them, there have been the continuation of the arms control negotiations, the prevention of any escalation of the offensive arms race because of SDI, and the keeping of defense expenditures within morally acceptable limits. They have backed research and development, but not the systems' deployment, and have asked for compliance with the ABM Treaty. They have required assessments of each new step in the program's advancement, in order to evaluate its effects for improving international stability. And they have also emphasized that spending for the program must not adversely affect the allocation of funds for other morally significant objectives.

The ethical arguments against SDI have usually been not independent.[4] They have been based on the strategic and technological challenges to the program. The principle of strategic

---

3. Rreprinted in Ethics and Strategic Defense: American Philosophers Debate Star Wars and the Future of Nuclear Dterrence, edited by Douglas P. Lackey, p. 150.
4. For example: Steven Lee The Moral Vision of Strategic Defense, The Philosophical Forum, Volume XVIII, Number 1, Fall 1986, reprinted in Ethics and Strategic Defense: American Philosophers Debate Star Wars and the Future of Nuclear Deterrence, edited by Douglas P. Lackey, pp. 79-83; Jonathan Schonsheck, Philosophical Scrutiny of Strategic Defense Initiative, Journal of Applied Philosophy 3:2, 1986, partly reprinted in the same book, pp. 107-119.

defense in itself has not been contested, but it has been considered to be unrealistic. For example, Jonathan Schosheck wrote that "a transition from a strategy of deterrence to a strategy of defense is unthinkable unless one's defensive weapons can be expected to be incredibly successful at intercepting an adversary's weapons - this because so few nuclear weapons are sufficient to eliminate a nation as a geopolitical entity." (p. 111) The philosophers who have opposed SDI on ethical grounds have been convinced that the defense of population has been impossible because of insurmountable technological difficulties. As a result they have regarded the program as only another means to increase the protection of US ICBMs, enhancing the American first strike capability and subsequently the possibility of a nuclear conflict. Therefore, because they have strongly opposed the nuclear war as being totally immoral, they have also rejected SDI because it might increase its probability.

* * * * *

1.4.5. POLITICAL-ECONOMIC ARGUMENTS

Political-economic arguments in favor or against SDI have been frequently associated with strategic, technological, and moral arguments. But because the program has been only in an exploratory stage, and consequently the information available was limited, the arguments were advanced with relative timidity, and in a general non specific manner. The most interesting debate was caused by Paul Nitze's criterion regarding cost-effectiveness at the margin. The proponents of the program argued that it has been possible to build new defensive systems "cheap enough to add additional defensive capability so that the other side has no incentive to add additional offensive capability to overcome the defense"[1] as the criterion requires.

The opponents affirmed that this was impossible, because always the offensive missiles, implying relatively well known technologies, will be cheaper to be built than the highly sophisticated space based defensive systems. The criterion, being logically self-evident, and being formulated by one of the most respected supporters of the program was accepted by the supporters, although they were unable for a long period of time to substantiate their assertions by a concrete achievement. The adversaries emphasized the significance of Nitze's criterion, although it was formulated by an administration official, because they were convinced that it could not be fulfilled.

---

1. Nitze, idem, p. 223.

Finally, in the early nineties, the construction of the brillant-pebble seemed to be the first concrete achievement backing the SDI's supporters point of view.[2] The critics in the Congress and in the media, however, continued to be skeptical, arguing that it has not been sufficiently significant to derive general conclusions about the program's efficiency.

Other arguments, although important, were less debated because they were sufficiently known. Both supporters and adversaries considered that advancing them again could not affect in a considerable measure the public opinion or Congress. But, however not very much discussed, those issues were always present. The Administration and the conservative circles considered that the United States had a significant economic advantage in comparison to the Soviet Union, and consequently any additional military expenditures would stress far more the Soviet economy than the American one. The supplementary military expenditures would increase the economic hardship, the internal, social and political strain in Soviet Union, accelerating the collapse of communism. At the same time the American technological basis being significantly superior to the Soviet one, American industry would be in a far better position to develop an efficient strategic defense. The SDI would have an important spin-off in some key areas of basic research and technological development.

Within this general framework, Dmitry Mikheyev, for exammple, wrote that SDI should be considered as "the central element

---

2. Worden, 1991, p. 195.

of a new US global strategy." This new strategy must imply a mixture of offense and defense which could contribute in "[1] significantly reducing the expansionism of the Soviet empire by reducing its internal capacity to sustain further ventures; [2] decreasing the degree of economic and political control exercised by Moscow over nations in the socialist orbit ... [and (3)] enhancing and broadening the conditions in which pluralistic societies and free institutions can flourish."[3]

The critics of the program rejected the pro arguments by stressing the huge cost of the program, considered by them to be several times higher than that estimated by the Administration.[4] They pointed out that the technological feasibility of the program was not sufficiently well proved to risk spending such an impressive amount of money. They have also emphasized that the national security might be substantially improved without taking such economic risks, by spending less money in alternative fields - sophisticated highly accurate classical armaments, new types of strategic missiles, etc.. And there were also the critics who pointed out that the country has really not had the money necessary for funding the program. And even if eventually some funds might be available, they must be spent for improving economic infrastructure, the system of education, and medical assistance.

* * * * *

----

3. Velikov, Sagdeev and Kokoshin, editors, p. 3.
4. John Tirman, The Politics of Star Wars, in Empty Promise: The Growing Case Against Star Wars, edited by John Tirman, pp. 1-33.

1.5. ASSESSMENTS OF SDI PROGRAM

Involving important political, military and economic interests, and being highly sensitive for American national security, the SDI program has generated, as I have shown, a strong debate from its beginning. As a result, both the Administration and the think-tank groups, whether supporters or opponents, have tried to assess the feasibility and the results of the program at different points in time. Because it is impossible to quote here all these evaluations, and because some reflected partisan political interests, I will include here some which seem to me to represent mainstream points of view.

Two years after President Reagan's speech, in September 1985, the Office of Technology Assessment of the Congress published a pamphlet regarding ballistic missile defense technologies, entitled <u>Ballistic Missile Defense Technologies: Summary</u>. According to it, both proponents and opponents of SDI agreed that the United States "should adopt whatever BMD [Ballistic Missile Defense] posture will be the most likely to minimize the risk of nuclear war" (p. 44) and that "some reasearch on BMD" (p. 44) was necessary. But they disagreed with regard to the intensity of research and development programs and with the desirability of deployment. After the opinions of the majority of supporters and opponents of the program were presented in parallel, the Office formulated his own findings as follows.

The efficiency and capability of any ballistic missile defense system depend on the interaction between the defensive systems which would be developed and their potential offensive threat. It is impossible to assure the survival of US population without Soviet cooperation. But if the Soviet Union accepts "to cooperate in a transition to mutual assured survival" negotiations for reducing the number of offensive nuclear systems will be necessary. The deployment of ballistic missile defense without the common agreement of the superpowers could cause "great uncertainty." There is a sufficiently advanced technology to develop strategic defense in order to improve the protection of land based American ICBMs against a potential Soviet first strike. It is too early to evaluate the effectiveness and the cost of a ballistic missile defense system. The decision concerning how fast to go on with the program implies many elements. Subsequently, it would be prudent to follow such a policy that the Soviets would comply with the provisions of the ABM Treaty, during the period in which the US will do its research.

In 1986, in a Lamont Lecture given at Harvard University, Herbert York, the first director (1952-1958) of the Lawrence Livermore National Laboratory, compared SDI with other armament programs and derived several conclusions. He asserted that "the pursuit of strategic defense is very probably futile," and that it is very probable that it will cause a new arms race. But in his opinion, it "is not intrinsically incompatible with arms

---

1. York, 1987, pp. 20.

control.

In 1988 the Aspen Strategy Group published a book significantly entitled On the Defensive ? The Future of SDI including several articles resulting from the Group's meetings during the two preceding years. The main article entitled "The Future of SDI: An Introduction," written by William J. Perry, Brent Scowcroft, Joseph S. Nye, Jr., and James A. Scheer, gave an implicit evaluation of what had been done until that time, by focusing on the future development of SDI. The authors have considered five priorities for the program. (pp. 6-10) The first must be to conceive a "more plausible near-term agenda" for BMD research and development. The main areas of study should be: conventional BMD systems; sensing technologies for early warning, tracking, and target acquisition; and countermeasures technologies. The second priority must be those specific SDI technologies and weapon systems implying long-term research. Among them, the authors included: advanced surveillance acquisition, tracking and kill assessment (SATKA) technologies; directed energy weapons (DEW) systems and concepts; optical technologies for DEW; kinetic energy weapons (KEWs); and survivability enhancements technologies. The third objective must be to concentrate experimental work on technology development and not on engineering development and field demonstrations. Fourth, the provisions of the ABM Treaty must be respected. The traditional interpretation must be accepted. And finally it would be useful to "negotiate deep cuts in offensive arms and continued restraints on defense" with the Soviet Union as steps toward a future "comprehensive package."

In another article published in the same book, and entitled **SDI and the US Defense Posture**, Michael M.May, a former director of the Lawrence Livermore National Laboratory, formulated several remarks with regard to SDI (pp. 182-183). He considered that the program should have little effect on nuclear deterrence. It would be difficult to predict how the research and development implied by SDI would affect the ways in which the two superpowers receive attack warnings and communicate. As a result of SDI the "costs and risks" of the nuclear offensive weapons might increase. The increase would be caused by changes in the structure of offensive forces and the extension of the arms race in space. The expenditures for SDI research and development could be between 10% and 30% of the whole defense budget for research and development. The program could have significant research spin-offs in computer hardware and software, and optics. The SDI research and development program might improve the anti-aircraft and anti cruise-missile defense.

Also in 1988, in a comprehensive analysis of defense policy during the Reagan Administration, published by the National Defense University, a chapter (also quoted in section 1.3. p. 23) was dedicated to strategic defense. The two authors, Jerome Slater and David Goldfischer, have asserted that the total defense of population has been an "impossible dream." But they have considered that strategic defense could be in the near future developed "to provide at least modestly effective defense against a variety of possible limited attacks, and to serve as a base and model for a future defense-dominant world." (p. 360) In the long term, strategic defense would be necessary for several reasons. Some nations having nuclear weapons might not adhere to nuclear disarmament agreements. The end of the Cold War does not mean that "serious international conflicts" (p. 359) will be impossible in the future. The nuclear weapons technology can not be "disinvented." And there will always be the danger of "clandestinely retained nuclear weapons" too.

As I have before specified, Col. Simon P. Worden is a convinced supporter of the program, and not an independent analyst. But it seems to me that it might be useful to include here his evaluation, because it is one of the most recent available and is made by one of the best informed persons.

Assessing the program in a large perspective he stresses that the role of SDI has been "to drive the Soviets away from strategic offensive strategies in particular and away from quantitative strategic paradigms in general."[2] In his opinion this objective was achieved because the Strategic Defense Initiative proved that the advantages obtained by the Soviets by using their correlation of forces doctrine can be efficiently eliminated. The possibility of "new, unpredictible space-based offensive capabilities" also convinced the Soviets that they cannot win in a future arms race. As a result, the quantitative basis of the Soviet grand strategy disappeared. And "with the basic assumption of Soviet power gone, many other Soviet assumptions evaporated as well" observed the author more than

---

2. Worden, 1991, p. 195.

half of a year before the disintegration of the Soviet Union.

Col. Worden considers that the "brilliant pebble" has proved that strategic defensive systems could be cost effective at the margin. And because this assessment criterion, which is perhaps the most demanding, has been met, it is necessary to give the deserved attention to the future of the program. SDI must be used as a "lever to force continued reductions" of the Soviet strategic nuclear arsenal. It should also be oriented toward potential threats coming from third world countries. And the program must continue to be used as a means to develop new technologies in two main directions: general space exploration, and space based application capabilities development.

I am ending this list of evaluations with perhaps the most recent available. As The New York Times related,[3] Dr. David S. C. Chu, Assistant Secretary of Defense for program analysis and evaluation, recommended in an internal Pentagon document of May 15, 1992, that the deployment of the first antimissile system developed under the SDI program should be delayed. He referred to a plan to deploy 100 rocket-powered interceptors at a single site, (the most probable in North Dakota) in order to destroy by impact the potentially incoming nuclear warheads. The cost of the system has been estimated to be $35 billion, and the deployment was scheduled for 1997. Dr. Chu recommended a revised plan requiring "that prototype arms and other antimissile apparatus could be thoroughly tested, and

----

3. Pentagon Analyst Questions Plan for Early "Star Wars" Deployment, The New York Times, June 2, 1992; Pentagon Plans One-Year Delay of "Star Wars", The New York Times, June 6, 1992.

modified if necessary, before being put into mass production." This would be necessary to prevent any technical risks and to avoid any considerable supplementary expenditures in order to modify or repair the system after its deployment.

The Assistant Secretary suggested that the deployment could "at earliest" be achieved by 1999, but that it might be delayed until the year 2003, if important difficulties would appear during the testing. But in what seems to be a political compromise, Donald J. Atwood, the Deputy Secretary of Defense, testified to a subcommittee of the Senate Armed Services Committee, that the system will have its debut in 1998. He based his testimony on discussions with other Pentagon officials. But it seems to me that the exact year of deployment is not the main issue. What is really important, is that from the nature of recommendations and of the talks taking place in the Senate Copmmittee, a significant conclusion may be derived. There are notable achievements in the development of strategic antimissile systems. The first, relatively limited objectives of SDI, are on the way to be fulfilled. And these relatively limited objectives were the only ones realistically expected by informed persons to be fulfilled in the first phase of the program.

Less than two weeks after the publication of these two articles, a historic agreement was signed by the American and Russian presidents regarding a drastic reduction of the number of strategic offensive missiles. The United States will reduce its number of strategic warheads from 11602 in 1991, to 8592 by middle or late nineties, and to 3000-3500 in the year 2003. Simultaneously, Russia will diminish its nuclear arsenals from 10877 in 1991, to respectively 6940 at the middle of the disarmament period and to 3000-3500 at the end of the interval.[4]

Discussing the agreement, the US Secretary of State (This Week with David Brinkley, June 21, 1992) expressed his support for the SDI program, and stressed Russia's interest in cooperation. In the same day, Senator Sam Nunn of Georgia, the Chairman of the Senate Armed Services Committee, unequivocally backed the program. In his opinion it is necessary in order to prevent accidental launches or launches by rogue commanders or renegade states.

* * * * * * * * *

----

4. Thomas L. Friedman, Reducing the Russian Arms Threat, The New York Times, June 17, 1992.

1.6. CONCLUSIONS

The SDI program was conceived in a tense period of the Cold War. From a political point of view, it was the result of the general frustration caused by the erosion of American military power which brought Ronald Reagan to the presidency. The substantial increase of Soviet nuclear capabilities, the expansionist, aggressive policy promoted by the Soviet leaders in general, and the invasion of Afghanistan in particular, were perceived by important segments of the American people as changing the balance of power in the Soviet Union's favor. In those tense international conditions, in order to reestablish the equilibrium of power it was perceived as being necessary either to increase the American strategic offensive forces or to develop strategic defensive systems. At the recommendation of leading scientists and strategic analysis groups, the Reagan Administration chose the second alternative.

Like any major military program, since its very beginning the Strategic Defense Initiative has been energetically debated. But despite setbacks and a vigorous opposition, the program has continued. At present, nine years after its inception, there are notable achievements, but also remaining questions. But it is in general encouraging to remark that a realistic approach is prevailing. It became clear that the protection of the whole population cannot be achieved in the foreseeable future. A major nuclear attack by an equally powerful nuclear power cannot be neutralized. The only realistic goal for the near future consists in defending against accidental missile launchings and attacks by rogue commanders and renegade states.

The complexity of the program requires not only a large scale research and development effort but also thorough tests before and during deployment. Without those tests, the systems could hide crippling flaws implying important security risks and expensive repairs or modifications. The first stage of the program will consist in the development and deployment of land based interceptors. Their most probable mission will be the protection of ICBMs. Under the assumption of a cooperative relation with Russia, the number of nuclear warheads will be significantly reduced. The same kind of relations will be necessary in order to renegotiate the ABM Treaty for going to new stages of the program.

The concrete achievements are classified, but the testimonies in the Congress regarding the first systems' deployment toward the end of this decade, or at the beginning of the next one, suggest that they are significant. This means that the relatively limited objectives of the program, the only ones which were rationally expected for this first phase, are on the way to be fulfilled. Consequently, the SDI program as a whole can be considered as being coherent, substantial and remarkably realistic for a program of this magnitude. A magnitude which made clear from the beginning to the informed people that many elements of the initial conception will be changed, that others will be abandoned, and that undoubtedly some new ones will appear.

In conclusion, it seems to me that all that was achieved until the present constitutes a premise which allows one to assert that the antimissile defense, conceived in rational and realistic limits, is an attainable objective. Those achievements suggest that the theoretical concept of strategic defense can be practically materialized. On this basis I will study in the next three chapters whether strategic defense will, or will not, be necessary in the future multipolar system. In the last chapter I will focus on the theoretical relationship between strategic defense and offense.

* * * * * * * * *

2. STRAIN AND SECURITY IN THE EMERGING MULTIPOLAR SYSTEM

2.1. FROM BIPOLARITY TO MULTIPOLARITY

2.1.1. EMPIRICAL REMARKS

In a field of study proverbial for the diversity of opinions, it is not only surprising but also encouraging, to observe a virtual consensus in the characterization of the present historical period. The majority of scholars studying the international political arena - historians, political scientists, military analysts - aggree that the Cold War is over. The bipolar international system established in the aftermath of the World War II is disintegrating, and the world is in a period of transition toward a new international structure. The prevalent opinion is that the emerging international system will be multipolar. Several articles published during the last three years in Foreign Affairs and Foreign Policy magazines support these assertions.

Analysing the main directions of President Bush's foreign policy, Michael Mandelbaum considers it necessary to begin his study with a characterization of the end of the Cold War. He observes that the Cold War ended with West's victory. But that victory was not a military one, although the Western military might was an important factor in contesting Soviet expansionism in Europe. In his opinion the fall of communism was "a victory of Western ideas, Western political institutions and, above all, Western economic practices." (p. 15)[1] Consequently the adoption of "market forms of economic organization" is probably the most extended and significant process characterizing the present time.

Interested in the development of a new strategic concept, and writing with the authority given by a life dedicated to the study of security problems, Paul Nitze observes that for more than four decades the United States had a clearly defined central objective in foreign and defense policies. It consisted of taking "the lead in building an international world order based on liberal economic and political institutions, and to defend the world against communist attack."[2] (p. 1) But as a result of significant structural transformations on the international scene, "the political-strategic situation is now changed. We are in an **important** period of transition [my emphasis]." (p. 1) And because "A time of transition is bound to be a period of uncertainty" (p. 7) a new strategic concept must be developed.

In an article published in the fall of 1990, and entitled significantly, **"A New World Order and its Troubles"** Stanley Hoffmann analyses from a general point of view the present historical period. He writes, "We are entering a new phase of history ... it is a period in which the discrepancies between the formal organization of the world, into states and the realities of power, which do not resemble those of any past international system, will create formidable contradictions and difficulties."

----

1. Michael Mandelbaum, The Bush Foreign Policy, Foreign Affairs, Vol. 70, No. 1.
2. Paul Nitze, America: An Honnest Broker, Foreign Affairs, Vol 69, No. 4

(p. 115) The antagonisms and their roots will not be eliminated. We should expect not only conflicts similar to traditional quarrels based on ideology and religion, but also conflicts caused "by the realm of interdependence", or by the adversity between the state and the people. In Hoffmann's opinion the post Cold War international system will have specific characteristics. They will be significantly different from those of other previous international structures. He considers that "**from a structural point of view - the distribution of capabilities - it** [the international system] **will be multipolar.** [my emphasis] But the poles will have different currencies of power - military (the Soviets), economic and financial (Japan and Germany), demographic (China and India), military and economic (United States)." At the same time each type of power will have different importance and utility. For example "demographic power is more a liability than an asset, the ability of military might is reduced, only economic power is fully useful because it is the capacity to influence others by bringing them the very goods they crave." (p. 12)

A comparable topic is extensively analysed by Charles William Maynes, the editor of Foreign Policy, in two programatic articles published in 1990. The first is entitled "**America Without the** Cold War" and constitutes an evaluation of the international political scene and of the role of the United States in the present historical phase. The second, entitled "The New Decade" focuses on the main areas of political priority for the 1990s. As many other scholars, Maynes considers that "the world has arrived at one of those rare moments in history when everything seems to change. Questions not seriously discussed since the end of World War II are now being constructively considered." (p. 3)

Maynes agrees that the present phase is one of transition. But, he also emphasizes its main particularity. Comparing it with other periods of major historical transition he stresses that "unlike those earlier periods, no major new military threat is likely to replace the old one anytime soon. ... Unlike Napoleonic France or Nazi Germany, the Soviet challenge to the established order has not been crushed but contained until its revolutionary dynamism has been exhausted." (p. 4) The new international system is multipolar and **"there are five power centers in the world that, [that] at least in the near term, determine the fate of the globe - China, Japan, the Soviet Union, the United States, and Western Europe** [my emphasis]." (p. 9) Consequently, during the new decade, will be at least six "areas" which should be explored with priority for detecting potential conflicts and designing efficient policies. They are:

- the potentially adversarial relationship between the center and the periphery,
- the circulation of general information and political ideas,
- the development of multilateral, highly complex relations among various actors,
- the democratic deficit (the relatively limited responsibility and accountability of international experts and international organizations),

- the new security order,
- the new development model.

The title of an article published in 1991 by John Lewis Gadddis "Toward the Post-Cold War World" is only slightly different from those of other works dealing with the present historical period. But the author tries in addition to the description of the main characteristics of the process of political transition, to explain its causes. He writes, "another form of competition has emerged ... it is the contest between forces of integration and fragmentation in the contemporary international environment." (p. 103) The author specifies that he uses "the term "integration" in the most general sense, which is the act of bringing things together to constitute something that is whole. It involves breaking down barriers that have historically separated nations and peoples in such diverse areas as politics, economics, religion, technology and culture." (p. 103) The integration process is multilateral and complex, and it may be associated with the communication revolution, with the increase of interdependence in the world economy, and with the quest for collective security. Integration implies the spread of advanced political ideas, and "there is some reason to think" that the peace since 1945 has been its "by-product."

In opposition to the forces of integration there are the forces of fragmentation. They "are resurrecting old barriers between nations and peoples - and creating new ones - even as others are trembling." (p. 105) The main forces of fragmentation are nationalism, protectionism in the economic field, religion, the "simple drive for power", and the fragmenting internal tendencies existing in various countries.

The author considers that it is impossible to assert that as a whole one set of forces is politically, socially or morally superior to another. For this reason "the contradiction that exists between the acts of balancing and integrating power ought to make us look carefully at the post-Cold War geopolitical map." (p. 108) Some of the main problems of the post-Cold War world will be:

- long term ecological problems,
- evolution of Europe associated with the unification of Germany,
- disintegrative consequences of the "triumph of liberalism in Soviet Union",
- boundaries in the Middle East and Africa,
- the energy market,
- the "post-Marxist revolution" crisis,
- internal socio-economic and political threats.

As a result of the persistence of these problems, "The end of **the** Cold War ... **brings not an end to threats, but rather a diffusion of them:** [my emphasis] one can no longer point to a single source of danger, as one could throughout most of that conflict, but dangers there still will be". (p. 113) The future world will preserve many characteristics of the previous one, but will have, of course, some new, specific features. "No one seriously claims that, with the end of the Cold War, we can abandon the international state system or relinquish national sovereignty," remarks Gaddis. Therefore "The United States and its allies retain the interest they have always had in the balancing of power, [my emphasis] but that this time the power to be balanced is less that of states or ideologies - that are tending toward integrationist and fragmentationist extremes. Instead of balancing the forces of democracy against those of totalitarianism the new task may well be to balance the forces of integration and fragmentation against each other." (p. 114)

If Professor Gaddis regards the post-Cold War world from the point of view of a historian, William Pfaff tries to explain the international political process and structure from the point of view of a publicist interested in political science. For him, the concept of power is essential, and consequently entitles his article published in 1991 "Redefining World Power" After a consistent analysis of the role of the superpowers during the Cold War years, and of the main transformations taking place at the present time, the author stresses that "the conclusion generally drawn from these changes is that the world is moving toward a restored pluralism of power, a multipolar geopolitics [my emphasis]." (p. 39)

Pfaff considers that in the longer term the structure of the international system will be shaped by three major factors. The first consists of the results of the historical transformations taking place in the [former] Soviet Union, because "once the old system has been undermined and the powers of revolutionary change begun, it usually proves uncontrolable."

(p. 40) The second is the development of new relations in Europe, and especially the multilateral integration of Western Europe. The third factor consists in the evolution of social, economic and political situation in the United States.

As a result of complex interactions of these three major variables, "the international prospect today is not so much a world dominated by a single superpower as it is one lacking even great powers that meet the traditional definition of invulnerability. No nation is invulnerable; none is autonomous." (p. 46)

Holding a high position in the European Community and writing from a different geopolitical perspective, Jacques Delors expresses ideas which are not however very different in comparison with those developed and supported by the American analysts. In an article entitled "Europe's Ambitions", he considers that the following three processes influence the world balance of power:

- the change in East-West relations,
- the loss of influence of the non-aligned countries,
- the growing strength of Japan and of some of its neighbors.

Although the strain which was associated with the Cold War is considerably decreasing, some old threats persist, or some other new ones emerge. Among them the most menacing are:

- the persistence of regional conflicts,
- the proliferation of weapons of mass-destruction,
- the surge in what he is inclined to call "ideologies of exclusion."

As a result of these threats, and of the complexity of the new international system "the idea of security is not a solely military concept. It involves ideology, values, socioeconomic systems, and the environment." (p. 18) For these reasons any discussion about security must also refer to all these elements. In establishing their priorities and formulating their security policies, the members of the European Community must "never forget" that their most vital political, socio-economic and moral values might be "at stake and under threat."

It is well known that the economic competition between Japan, the European Community and the United States is tough. But **"Japan's Vision"** concerning the world as it is formulated by the former Prime Minister Kaifu is in concordance with the American and European ideas. In an article with this title he wrote that starting with this decade a new era is beginning. The present moment can be considered as "a turning point of the international order" from a political and economic point of view. By their impressive magnitude, the changes taking place in the whole world are really unique for the era which began after the World War II. A new world order is emerging and its main goals must be the following:

"- first, to ensure peace and security;
- second, to respect freedom and democracy;
- third, to guarantee world prosperity through open market economies;
- fourth, to preserve an environment in which all people can lead rewarding lives; [and]

- fifth, to create a stable international order founded upon dialogue and cooperation." (p. 31)

As I have affirmed at the beginning of this section, and I have tried to show with the above quotations, the majority of analysts consider that the world is in a transition period from a bipolar to a multipolar balance of power system. There are however some who although partially agree with this scenario on long term, reject it on short and medium ones. They contest either the multipolarity or the balance power structure. Hence, I will end this list of examples with quotations from two articles supporting this relatively minority points of view.

The first is entitled **"The Unipolar Moment"**, and is written in a journalistic manner different from the scholarly style of the articles usually published in the prestigious publication of the Council on Foreign Relations. The author, Charles Krauthammer, considers that "the most striking feature of the post-Cold War world is its unipolarity." (p. 24) But, although he argues in favor of this idea on several pages, he feels also constrained to finally add, "No doubt, multipolarity will come in time. In perhaps another generation or so there will be great powers coequal with the United States, and the world will, in structure, resemble the pre-World War I era." (p. 24) And it seems to me, that this remark coming from a supporter of the unipolarity idea constitutes a substantial argument in favor of the theory that the future international system will be multipolar.

The second article, published in the spring of 1992, is entitled "A New Concert of Powers" and is remarkable by the scholarly character of analysis. Its author, Richard Rosecrance differentiates three methods of regulation of the international system regarded as an anarchic one. Those are "the traditional balance of power, nuclear deterrence and rule by a central coalition." (p. 64) He rejects the first two, but prefers the third. The balance of power is "an inefficient mechanism at best", and it was a cause of the two world wars of this century. The nuclear deterrence involved very large money expenditures, which "prevented the so-called superpowers from dealing effectively with domestic social problems." (p. 64) In opposition to these two, the rule by a central coalition although has existed only sporadically was "by far the most efficient peacekeeping device." (p. 65)

The author observes that "the breakup of the Soviet Union, the liberation of Eastern Europe, the Gulf War and the rapprochement between the United States and Russia have lent the world a new concert of powers." He considers that at present **"five great bases of power again control the organization of the world order: the United States, Russia, the European Community, Japan and China"** [my emphasis] (p. 65) Rosecrance does not regard the rule by a central coalition as a method of balancing in accordance with the balance of power principle, but as something different, or even opposite to that principle. As a result he concludes that significant efforts are necessary to be made in order to preserve this new concert of powers. Othewise the rule by central coalition might be replaced - as it always was in the past - by a balance of power system. Therefore because the article has a normative character, it is possible to conclude that the author considers himself that the probability of that outcome - the reemergence of the balance of power as the main regulation method - is the highest.

If one summarizes the main ideas included in these articles and in other numerous empirical analyses, published in the last three years, it is possible to conclude that the Cold War is over and that the world is in a period of transition. This period is characterized by several political, economic, social, and military global processes. Among them, the most important are the following:

- the disintegration of the communist international system, the collapse of communism as a major political and socio-economic system, and as a viable ideology;
- the end of the Cold War;
- the integration of (Western) Europe;
- the advance of parliamentary democracy and market economy in Central and Eastern Europe;
- the transition toward a mature stage of industrialization in several countries from the third world, allowing them to maintain important military forces and to develop or buy relative sophisticated weapons system;
- the emergence or reemergence of a XIXth century type nationalism in several countries of Asia, North Africa and South America, associated with the new stage of industrialization and the corresponding expansion of

their military capabilities;

- the substitution of tribalism by incipient nationalism in sub-Saharan Africa;
- the increase of social, economic, and political differences between the most developed and the less developed geographic areas;

At the national actor level, the processes which will most influence the evolution of the future international system's structure are the following:

- the disintegration of the former Soviet Union and the formation of the Commonwealth of the Independent States, associated with a high level of political, social, economic, ethnic, and military instability;
- the relatively slow increase of productivity in the United States;
- the development of a unitary socio-economic structure and of a homogenous political culture in Germany;
- the probable rebirth of a pro-democracy movement in China as a consequence of the improvement of the level of education and culture of the people;
- the increase in the use of its economic power for attaining political objectives by Japan.

In accordance with the opinions expressed by the majority of analysts, the international political system which will emerge as a result of the cross-cutting influences of these global and national processes will be multipolar. It will include five major centers of power: United States, Russia (single or in association with other successor states of the former Soviet Union), Western Europe, China, and Japan. The United States and Russia (after a first period characterized by major structural changes, and a second one of consolidation and stabilization) will continue to be complex military, political and economic powers. Western Europe and Japan will be economic superpowers, but, at least in the foreseeable future, will be relatively reluctant to develop independent military capabilities comparable with their economic might. China will try to follow the first two superpowers, but from a considerable distance. India, will become the first in a second group of powers, powers which will have weapons of mass destruction and advanced means of delivery but which will not possess an adequate economic infrastructure. In this second group will be also included other countries, far smaller, but which will be able to have a significant role in the international arena thanks to their nuclear capabilities. Among those countries will probably be: Israel (which already is a nuclear power), Pakistan, and South Africa. The international balance of power will be also affected in a very important measure by the future decisions regarding the nuclear arsenals which will be made by Ukraine, Belarus and Kazakhstan. If they decide in favor of maintaining nuclear forces they will be in a class surpassed only by the United States and Russia.

In conclusion, on the basis of various factual observations and analyses, it is possible to make the following assertions:

- the bipolar international system is disintegrating as a result of the deep structural changes taking place in Eastern Europe and the former Soviet Union and of the end of the Cold War;
- the present period is one of transition;
- the emerging international system will be multipolar, it will have a highly complex structure;
- although interdependence will increase, and the supranational actors will become more important, the nation-states will survive as main actors on the international scene.

For connecting these assertions in a logical manner, and for being able to make predictions with regard to the properties of the future international system, a rigorous theoretical framework is necessary. Consequently, the next section will include a theoretical analysis. It will be based on some of Morton Kaplan's abstract concepts and principles developed in his classical book System and Process in International Politics.

* * * * * * * * *

2.1.2. A THEORETICAL APPROACH

Morton Kaplan wrote System and Process in International Politics during some of the most tense years of the Cold War. But it is not an empirical study of those dramatic times. It is essentially a theoretical treatise on the international political system and its functioning. The book is remarkable by its abstract character, and by the logical consistency of arguments. Dealing with general theoretical problems, it has preserved its actuality and scientific utility. Similar to a mathematical theorem or to a general scientific theory, Kaplan's concepts and theoretical models may be applied for formally describing and analysing various empirical situations. Hence, in this section, I will use his classification of international political systems for explaining from a theoretical point of view the transition from bipolarity to multipolarity.

Kaplan differentiates six distinct types of international systems:

- the balance of power system
- the loose bipolar system
- the tight bipolar system
- the universal system
- the hierarchical system in its directive and non-direc-
- tive forms
- the unit veto system.

The main properties of the international system during the Cold War era (with the exception of the first two or three years) identified it as as a loose bipolar one. According to Kaplan, such a system has been characterized "by the presence of two major bloc actors, a leading national actor within each bloc, nonmember national actors, and universal actors, all of whom perform unique and distinctive role functions within the system." (p. 39)

A set of twelve rules explains the properties and the functioning of this type of international system. Rules 1 to 6, and 8 refer to blocs and bloc members. Rules 7, and 9 to 12, refer to non-bloc members and universal actors. One considers that NATO has been "relatively non-hierarchical" and the former communist bloc was "mixed hierarchical."

The rules with regard to the blocs and bloc members are the following:

"1. All blocs subscribing to directive hierarchical or mixed hierarchical integrating principles for the international system are to eliminate the rival bloc.

2. All blocs subscribing to directive hierarchical or mixed hierarchical principles for the international system act to negotiate rather than to fight, to fight minor wars rather than major wars, and to fight major wars - under given risk and cost factors - rather than to fail to eliminate the rival bloc.

3. All bloc actors are to increase their capabilities in relation to those of the opposing bloc.

4. All bloc actors subscribing to non-hierarchical or

non-directive hierarchical organizational principles for the international system are to negotiate rather than to fight to increase capabilities, to fight minor wars rather than to fail to increase capabilities, but to refrain from initiating major wars for this purpose.

5. All bloc actors are to engage in major wars rather than to permit the rival bloc to attain a position of preponderant strength.
6. All bloc members are to subordinate objectives of universal actors to the objectives of their bloc but to subordinate the objectives of the rival bloc to those of the universal actor."

.....

8. Bloc actors are to attempt to extend the membership of their bloc but to tolerate the non-member position of a given national actor if non-tolerance would force that national actor to support the objectives of the rival bloc or to join the rival bloc." (p. 38)

The loose bipolar system is stable if a set of specific conditions "serve as relatively constant bounds for the system." (p. 39) If one or several of these necessary conditions are no longer fulfilled, the bipolar system becomes unstable and has the tendency to transform into one of the other five general types of systems. The way of transformation and the nature of the system replacing it depend on the causes of instability and disintegration.

Consequently, it is possible to formulate a first theoretical question having also significant practical implications:

> **What kind of international system will emerge as a result of the disintegration of the loose bipolar system of the Cold War era ?**

For obtaining the theoretical answer, it is necessary to observe which was the main cause of instability, and to check the rules defining the systems which might potentially replace the disintegrating system.

It is accepted by virtually all analysts that the collapse of the communist bloc has been caused by the strong internal strain which existed in all the Eastern European countries and by the "stagnation" and general internal erosion of former Soviet Union itself. And this general collapse is an even stronger cause for structural change than the systemic instability considered by Kaplan as the condition of transformation.

He wrote, "Internal political conditions within the non-leading national actors of a bloc must permit them to contribute to the proper functioning of the bloc. Otherwise, the bloc will become unstable. The instability of one bloc, while the other bloc remains stable, will constitute a factor tending to produce a hierarchical international system if the stable bloc is hierarchical or mixed hierarchical. **If the stable bloc is non-hierarchical, the international system will tend toward a "balance of power" system,** [my emphasis] or possibly toward a universal or mixed form of international organization."

(pp. 41-42)

The communist bloc was hierarchical and unstable. The Western bloc has been non-hierarchical and stable. Hence the international system might evolve toward a "balance of power" system or toward a universal system. To examine if the alternative of a universal system might be viable, it is necessary to specify how such a system is defined and whether the conditions allowing its development exist, or will exist.

According to Kaplan, a universal system is characterized by the following rules:

"1. All national actors are to attempt to increase their rewards and access to facilities.
2. All national actors are to attempt to increase the resources and productive base of the international system.
3. When rules one and two give rise to conflicting prescriptions, rule one is to be subordinated to rule two. Likewise, if the operation of rule one threatens the minimal standards of any national actor, it is to be subordinated to considerations involving the ascriptive base of the total society.
4. All actors are to use peaceful methods to obtain their objectives. They are not to resort to force or the threat of force.
5. Human beings who have role functions within the organs of the international system are to make decisions in these roles according to the requirement of the international

system. They are not to modify their decisions according to particularistic or ascriptive criteria having reference to national actors in which they also happen to hold memebership." (p.48)

On the basis of the studies made by virtually all students of the international scene, it is possible to assert that the political, economic, social, and military conditions allowing the development and the functioning of a system defined by the above rules do not exist at present, and will not exist in the forseeable future. The organization of such a system would also be practically impossible even if the United States would like and/or would be interested in doing it. Although it remains the sole superpower after the disintegration of the Soviet Union, it has not the capability to dramatically change the behavior of all the other major actors. As it is known, there are important doubts, in this country and abroad, even with regard to President Bush's "new international order," which would however imply less radical changes. President's conception is closer to Kaplan's concept of non-directive hierarchical system and not to that of universal system. But the organization of a non-directive hierarchical system requires only the existence of an actor assuming a strong leadership, which is less difficult than changing the behavior of all the other major actors. Consequently, the disintegrating bipolar system can not evolve into a universal system. It can be transformed only into a "balance of power" system.

This argumentation is logically sufficient within

Kaplan's theoretical framework and it is not necessary to examine in detail other ways of transformation of the disintegrating bi-polar system. It is obvious that because the bloc which collapsed was the communist bloc, the future international system cannot be a tight bipolar one or a directive hierarchical one. Neither can it be a unit-veto system because the conditions required for the existence of such a system will not exist. There will probably be a tendency toward a non-directive hierarchical system at the beginning of the transition period. But it will not last for a long period of time, because the main cause of this tendency is the sudden collapse of the communist bloc, and not the powerful economic, social, demographical and political forces which are really shaping the future international system.

In conclusion, on the basis of all these theoretical considerations, it is possible to give the following answer to the question previously formulated:

> **It is probable that the emerging international system will be a "balance of power" system.**

For this reason, in the next section, I will briefly present three of the most authoritative conceptions concerning this type of system, and I will formulate in a general manner a question concerning its stability.

* * * * * * * * *

2.2. THE STABILITY PROBLEM IN A BALANCE OF POWER SYSTEM

Under the assumption that the future multipolar world will constitute a balance of power system, it is necessary to specify from the beginning what one understands by this.

The concept of balance of power is one of the most studied concepts in the field of international relations, and there is an impressive number of more or less diverging opinions regarding it. But for the logical chain of argumentation of this dissertation, it is not necessary to do an extensive comparative analysis of those different points of view. It is sufficient to include only a few relevant conceptions to derive an operational understanding of the concept.

In Politics Among Nations, Hans J. Morgenthau and Kenneth W. Thompson have employed the term "balance of power" with four meanings "(1) as a policy aimed at a certain state of affairs, (2) as an actual state of affairs, (3) as an approximately equal distribution of power, [and] (4) as any distribution of power." (p. 187) In the authors' opinion, "the balance of power and policies aiming at its preservation are not only inevitable but are an essential stabilizing factor in a society of sovereign nations; and ... the instability of the balance of power is due not to the faultiness of the principle but to the particular conditions under which the principle must operate in a society of sovereign nations." (p. 187) The authors consider the balance of power principle as a major element of the realist theory, and focus on its patterns, methods, structure and manner of evaluation. There are two main patterns, direct opposition and competition, and several methods of balancing. Those are the "divide and rule" method, the principle of compensations (mainly of a territorial nature), the armaments usually associated with arms race, and the conclusion of alliances. The balance of power has a complex character. Morgenthau and Thompson refer to dominant and dependent systems and analyse their structural changes. Because of its complexity, it is necessary to evaluate the utility of balance of power as a means "for the preservation of peace and security." One should assess not only its stabilizing effect, but also its uncertainties and limitations.

Morton Kaplan thoughtfully studied the balance of power from a systemic point of view in the book mentioned in the previous section. In his opinion the following rules describe the individual behavior of national actors who belong to such an international system:

They

"1. Act to increase capabilities but negotiate rather than fight.
2. Fight rather than pass up an opportunity to increase capabilities.
3. Stop fighting rather than eliminate an essential national actor.
4. Act to oppose any coalition or single actor which tends to assume a position of predominance with respect to the rest of the system.
5. Act to constrain actors who subscribe to supranational

organizing principles.

6. Permit defeated or constrained essential national actors to re-enter the system as acceptable role partners or act to bring some previously inessential actor within the essential actor classification. Treat all essential actors as acceptable role partners."[1]

Writing in the late seventies, from a neo-realist point of view, Kenneth Waltz analyses the balance of power within a sophisticated conceptual framework.[2] He defines the structure of the international system "by the arrangement of the system's parts and by the principle of that arrangement". (p. 80) The system is characterized by an anarchic order, and therefore international politics is a selfhelp one. This means that "the ruler's and later the state's interests provide the spring of action; the necessities of policy arise from the unregulated competition of states; calculations based on these necessities can discover the policies that will best serve the state's interests; success is the ultimate test of policy, and success is defined as preserving and strengthening the state." (p. 117) Consequently "A balance-of-power theory, properly stated, begins with assumptions about states: they are unitary actors, who at minimum, seek their own preservation and, at maximum, drive for universal domination." (p. 118)

The balance of power is "a theory about the results produced by the uncoordinated actions of states. The theory makes assumptions about the interests and motives of states, rather

----
1. Kaplan, 1975 <1957>, p. 23.
2. Waltz, 1979.

than explaining them. What it does explain are the constraints that confine all states." (p. 121) The politics associated with this theory "prevails wherever two, and only two requirements are met: that the order be anarchic and that it be populated by units wishing to survive." (p. 121) He emphasizes that "balancing ... is the behavior induced by the system" and that "the first concern of states is ... to maintain their position in the system." (p. 126)

Studying attentively Waltz's conception with regard to the balance of power, one observes that it is the normal conclusion of a logical chain of assertions:

- the international political system is composed of an international political structure and of interacting units, the nation-states;
- the international political structure is an abstract concept which refers to the mutual position or arrangement (with a very general and abstract meaning) of states;
- the international political structure is anarchic;
- the nation-states struggle to maintain their position in the system, their central objective is survival;
- struggling for autonomy and security at the same time, the nation-states preserve the anarchic character of the international political structure;
- the international political system is a self-help system;
- as a result a complex relationship of balance of power emerges.

It is, of course, impossible to predict exactly which will be the specific characteristics of the emerging balance of power system. But it is possible to assert that many of them will be close or similar to those specified by the above mentioned scholars. And this is sufficient for formulating the central question of this section:

Will the emerging balance of power system be more or less stable than the disintegrating bipolar system of the Cold War era ?

A general answer to this question can be given immediately, by using Waltz's theory. But a more elaborate answer will involve the construction of a mathematical model, a discussion of the concept of stability and a corresponding reformulation of the above question. Hence, I will end this section with the general answer based on Waltz's theory, and I will reserve the next section for discussing the relationship among stability, strain, and entropy in the international system.

Waltz defines the concept of stability in the following manner, "a system is stable as long as its structure endures. [and] In self-help systems, a structure endures as long as there is no consequential change in the number of principal units." (p. 135) Within this conceptual framework, Waltz considers not only that "Smaller is More Beautiful than Small," (p. 134) but also that "Smaller is better than small". (p. 136) And concludes that "Smaller systems are more stable, and their members are better able to manage affairs for their mutual benefit." (p. 136) By "small" he obviously understands that the number of system's units is small, and not that the nation-states included in the system are small. Observing that a bipolar system is "smaller" than a multipolar one, it is possible to answer to the previous question that:

> **It is probable that the emerging multipolar system will be less stable than the bipolar system of the Cold War period.**

* * * * * * * * *

2.3. STABILITY, STRAIN AND ENTROPY IN THE EMERGING MULTIPOLAR INTERNATIONAL SYSTEM

The word stability is used very frequently by a large variety of people - analysts of the international arena, political scientists focusing on internal problems of various countries, political leaders, journalists, etc. And although only a few try to explain or to clarify it, virtually all seem to consider that stability is something which is unquestionably desirable. Or that stability is better than instability. In some cases, its utilization is completely inappropriate, but because it is associated with the ideas of good and prosperity is included in political speeches, party platforms, or propaganda articles. It was for example bizarre to observe how many statesmen and analysts holding significant positions expressed their support for stability in Europe before 1989. Did they understand by stability the preservation of European division and of the dictatorial regimes of Eastern Europe. Or they were thinking to something else, and were only using a wrong term to express their ideas ? When some of our politicians express their desire and hope for stability in Asia, do they understand by this the preservation of the present Beijing regime ?

In consequence, taking into consideration the ambiguity of this term, it is necessary to analyse and to specify it with more rigor. Without such a clarification it is impossible to derive consistent knowledge about the theoretical properties of the emerging multipolar system. For understanding the concept of stability, it is first necessary to describe the concept of system.

In Webster's Dictionary, a system is defined as "a collection of objects united by some form of interaction and interdependence."

In a classical book concerning System Theory, L. A. Zadeh and Ch. A. Desoer wrote: "An abstract system, or simply, a system, $\mathcal{S}$, is a partially interconnected set $\mathcal{A}$ of abstract objects α_1, α_2, α_3, ... termed the components of $\mathcal{S}$. The components of $\mathcal{S}$ may be oriented or non oriented; they may be finite or infinite in number; and each of them may be associated with a finite or infinite number of variables."[1]

In an important book published in 1969, R. E. Kalman, P. L. Farb and M. A. Arbib "regard a system as a structure into which something (matter, energy or information) may be put at certain times and which itself puts out something at certain times," and they give a consistent axiomatic definition of the mathematical concept of dynamic system.[2]

In general, in System Analysis, one considers that a system is constituted from a set of elements and a set of connections among those elements. It exists in a given environment and it is delimited by a set of elements called frontier or boundary. The flows directed from the environment toward the system are named inputs, and the flows directed from the system toward the environment are called outputs. (Fig. 2.3.-1)

----
1. Zadeh and Desoer, 1963, p. 65.
2. Kalman, Falb and Arbib, 1969, pp. 4-5.

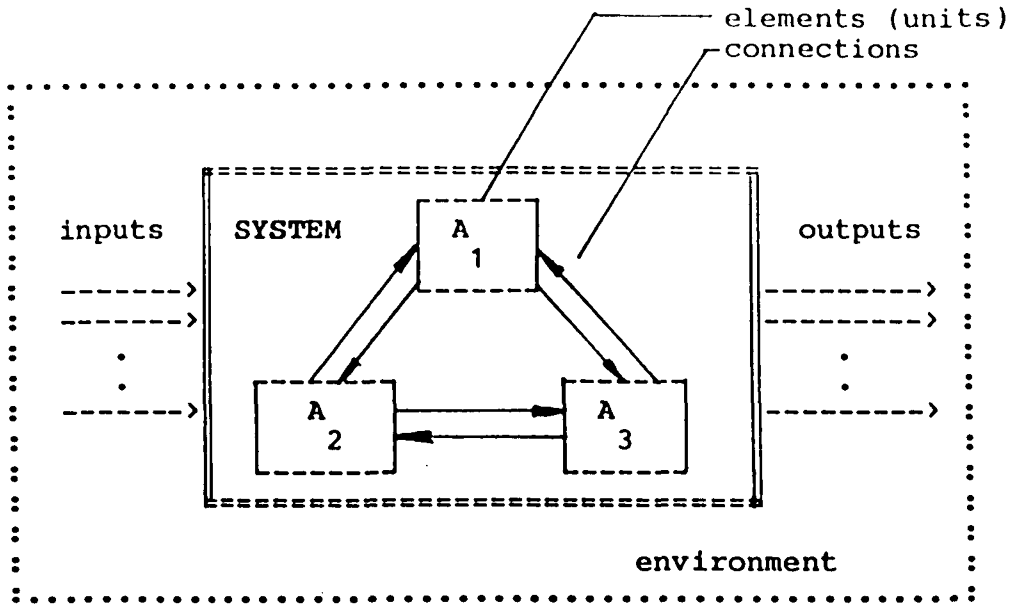


Fig. 2.3.-1.

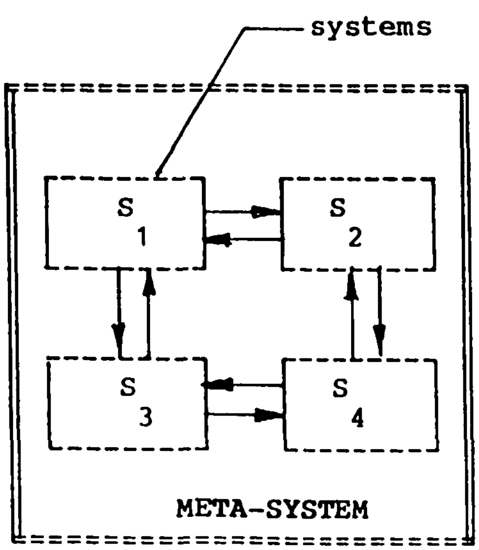


Fig. 2.3.-2.

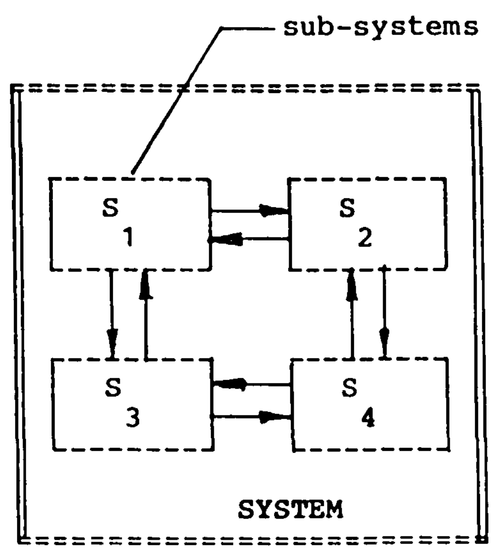


Fig. 2.3.-3

If several systems are connected among them by input-output connections, they result in a **meta-system.** (Fig. 2.3.-2) In other words, the components of a meta-system are themselves systems.

The elements of a system may be themselves very complex, and consequently may be considered as being **sub-systems.** (Fig. 2.3.-3) Depending on the level of analysis, and on the level of generalization, it is possible to consider a given complex system as a meta-system having various systems as its units, or as a system having different sub-systems as its elements.

If all the elements, connections, or numerical variables characterizing a system do not change in time, the system is called static. If at least one of them is changing, the system is called dynamic.

A dynamic system is characterized by three sets of variables: input variables, state variables, and output variables. The input variables describe the flows directed from the environment toward the system. The state variables are associated with the internal properties of the system. The output variables characterize the flows directed from within the system toward the environment. The input variables are of three kinds: proper input variables, control variables, and perturbations. The paths of state variables depend on the internal properties of the system, on the initial conditions in which the system has been at the beginning of its motion in time, and on the input variables. The paths of the output variables depend on the internal structure of the system, on the paths of state variables and on the trajectories of input variables (directly or through the state variables).

The concept of stability used in System Analysis is only associated with dynamic systems. The system is assumed not to be under external influences and therefore the input variables are considered equal to zero. The property of stability is an internal property of the system. The concept of stability refers to the state variables, and not to the system's element. It is defined for a continuous and smooth motion in time (evolution, decline, etc.). It is not defined for discontinuities of the paths of the state variables.

One considers that:

- a system is stable if the paths of all its state variables tend to zero (or to a finite number) when the time increases; (Fig. 2.3.-5)
- a system is unstable if the paths of some of its state variables tend to increase to positive infinity or to decrease to negative infinity when the time increases; (Fig. 2.3.-6)
- a system is bounded if the paths of its state variables successively increase and decrease between finite limits when the time increases. (Fig. 2.3.-7)

It is also said that a state variable depends stably on the variation of initial conditions, if the distance between its trajectories corresponding to the first and second initial conditions remains finite when the time increases. (Fig. 2.3.-4)

If one compares this concept of stability with that utilised in the question formulated in the previous section

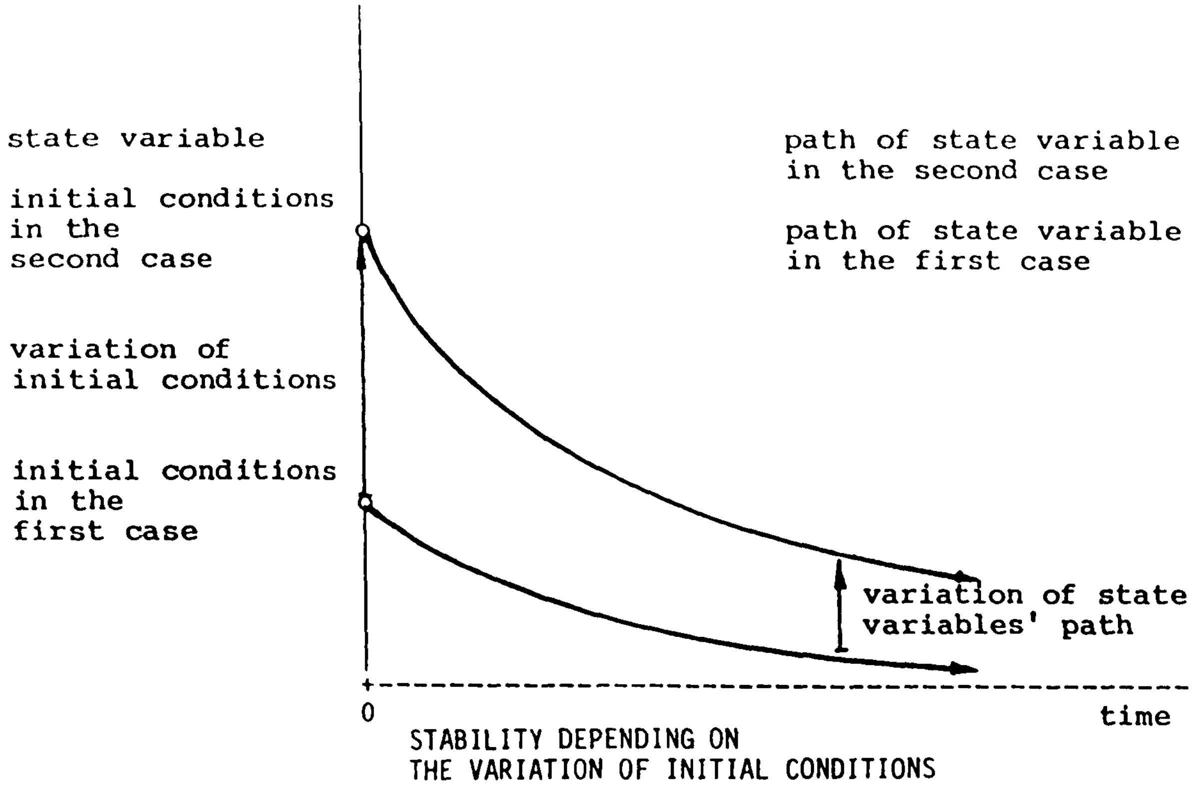


Fig. 2.3.-4.

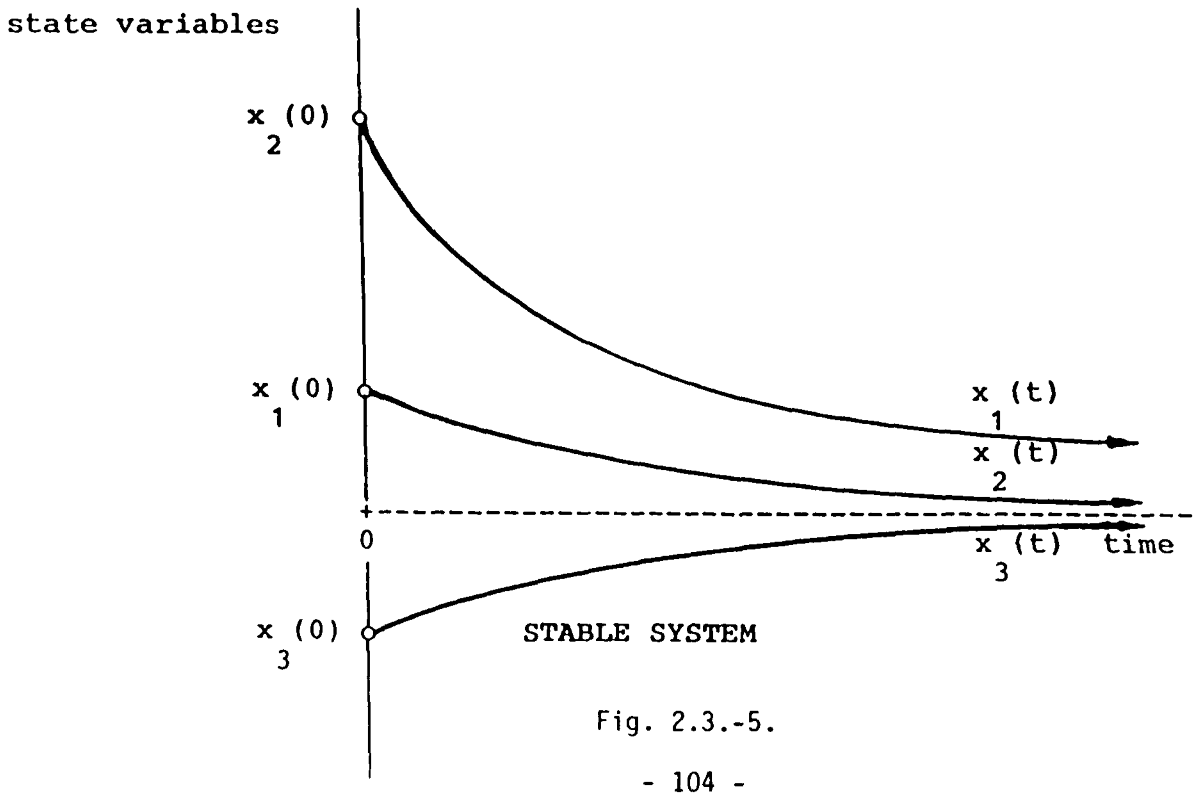
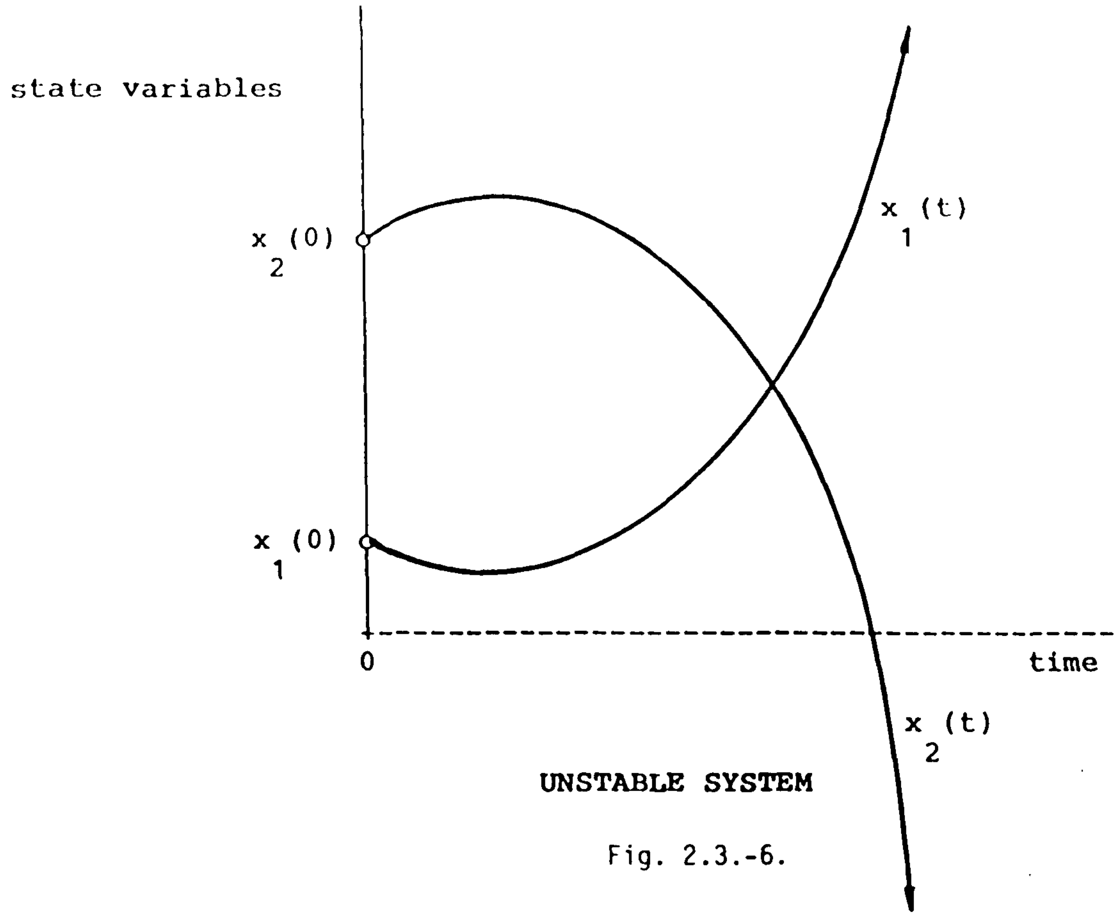
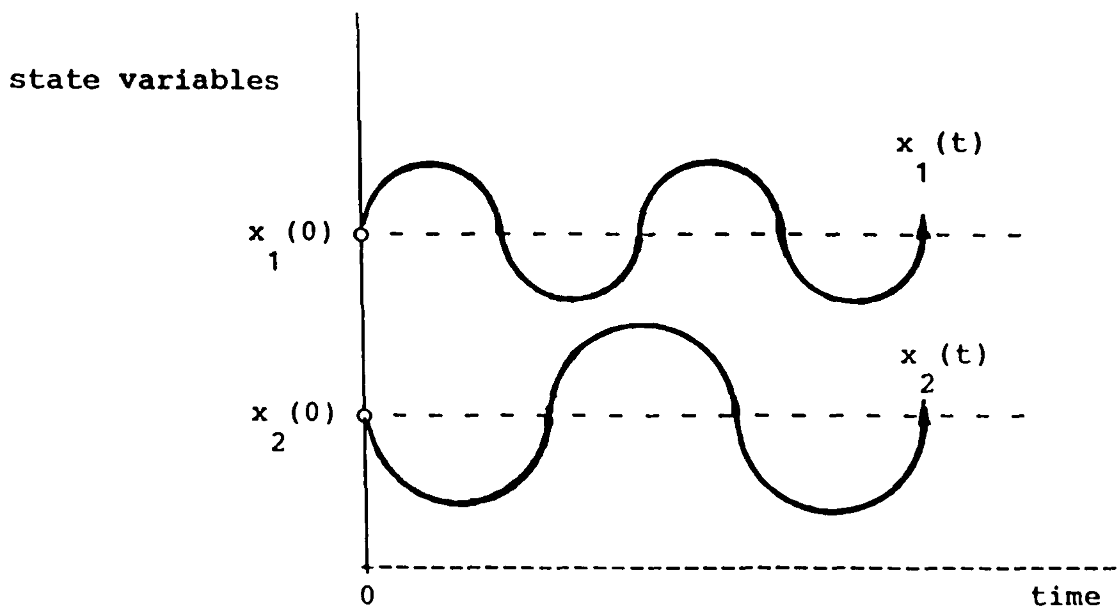


Fig. 2.3.-5.



UNSTABLE SYSTEM

Fig. 2.3.-6.



OSCILLATORY SYSTEM

Fig. 2.3.-7.

and in the Waltz's theory used for answering that question, one observes significant differences. For understanding these differences it is first necessary to compare the concepts of sub-system, system, and meta-system defined in System Analysis, with the concept of international system utilised by Waltz and others. One observes without difficulty that:

- the international political system may be considered a system or a meta-system from the point of view of System Theory;
- the units of the international political system - the nation-states - may be regarded as component sub-systems of a system, or as component systems of a meta-system;
- the international political structure is defined by the relationship ("arrangement" and "principle of that arrangement" in Waltz's terms) among sub-systems if the international system is considered a system, and by the relationship among systems if the international system is regarded as a meta-system;
- each nation-state is characterized by a domestic political structure (leaving the field of international politics and Waltz's theory, and stepping into that of national politics, this structure might be associated with a set of political variables which may be considered as state-variables within the framework of System Theory).

In this chapter, I consider that the international political system is a system, and that its units, the nation-states are sub-systems. (Fig. 2.3.-8, Table 2.3.-1)

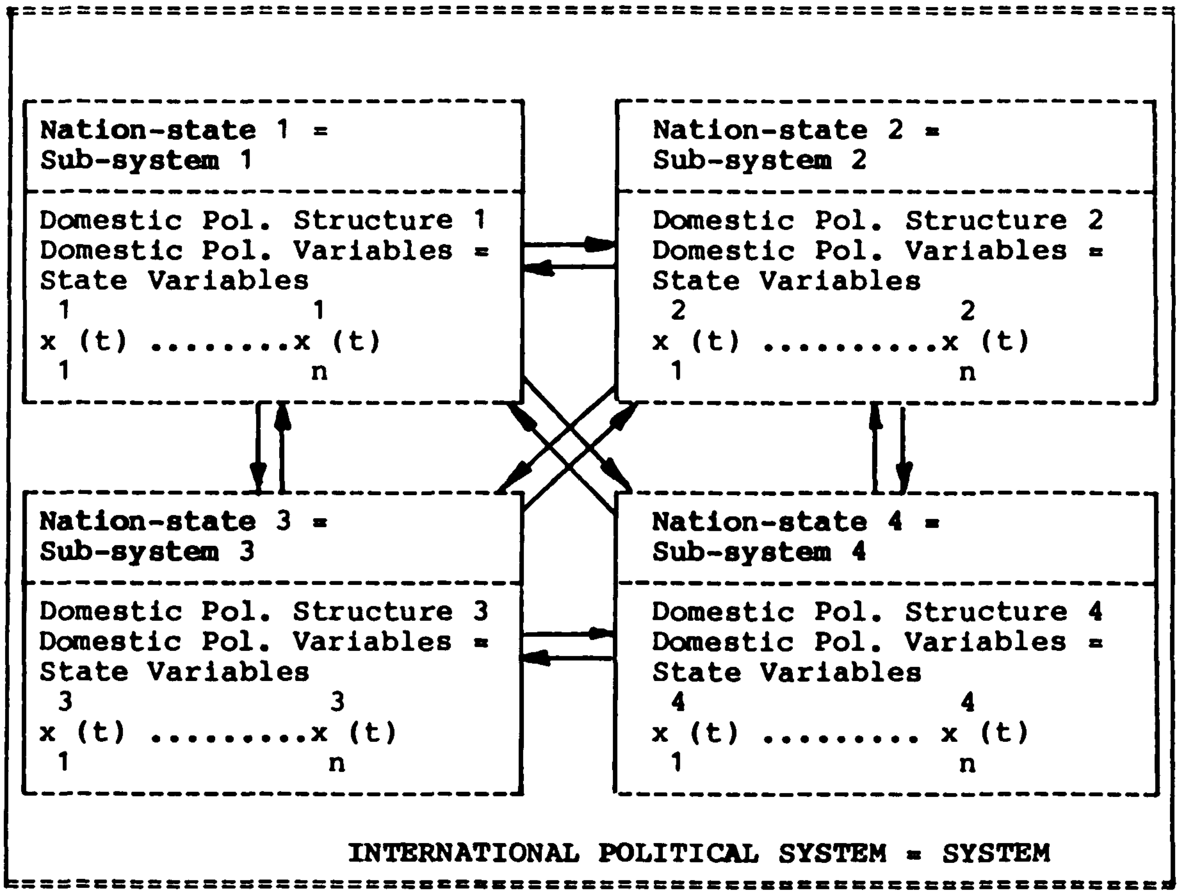


Fig. 2.3.-8

International Politics Theory		System Theory
International Political System	=	System
System Level Analysis	=	System Level Analysis
Unit / Nation State	=	Sub-system
Unit Level Analysis	=	Sub-system Level Analysis
Domestic Political Structure	=	Sub-system Structure
Domestic Political Variables	=	State Variables

Table 2.3.-1 Concepts Equivalence

Within this systemic framework, one remarks that the stability of the international political system as a whole depends on the stability of its components - the nation-states - and on the stability of the arrangement or position of the nation-states inside the system. Consequently, one may differentiate three meanings of the concept of stability:

1. **internal stability** of nation-states;
2. **structural stability** of international political structure;
3. **global stability** of the international political system as a whole;

On this basis, it is possible to consider that:

1. A nation-state (unit or sub-system) is internally stable if the main domestic political variables which characterize that nation-state do not surpass some superior or inferior boundaries. It is also internally stable if any sudden modification of the relationship among those variables is diminishing during the system's evolution in time.

2. An international political system is structurally stable to the extent that its structure - the arrangement or the position of nation-states - tends to be preserved.

3. An international political system is globally stable if its units are internally stable and if its structure is stable. This means that global stability implies simultaneously internal stability and structural stability.

On this theoretical basis it is possible to assert that the concept of stability used in the question formulated in the previous chapter or in the Waltz's theory refers to what is called in this section structural stability. In this case, the internal features of the actors and their continuous transformation in time are not implied, and the comparison is made between structures.

At its turn, the concept of structural stability allows comparisons between:

- two systems which have the same number of actors, but have different distributions of capabilities; or
- two systems which have a different number of actors, but in which the actors have similar or comparable capabilities.

Taking into condideration the concept of structural stability, Waltz's assertion that "Smaller systems are more stable" can be reformulated in a more explicit manner: **a balance of power international system with a smaller number of actors tends to survive for a longer period of time than a balance of power international system with a larger number of actors.**

The above remark suggests that there are monotonic relations between complexity, level of disorganization, structural (in)stability and strain. All increase when the number of actors increases and decrease when that number decreases.

One observes that a concept utilized in physics (thermodynamics), management (organizational theory), economics, and Mathematical Theory of Information has some properties which might allow one to associate it with the strain and instability of the international system. This concept is the entropy. It is defined as "a measure of the disorder of a closed thermodynamic system," or as "a measure of the amount of information in a message." (Webster's Dictionary)

The resemblance of those concepts suggests:

- to reformulate the question regarding the stability of the emerging multipolar system in a manner adequate to the topics of this dissertation;
- to define a measure for structural stability and structural strain;
- to test from a logical point of view the assertion that the structural instability and subsequently the structurral strain are higher in a multipolar system than in a bipolar one.

I will dedicate the following sections to the study of the last two problems, and I will end this one by giving two new formulations of the question asked in section 2.2.. They are:

Will the structural strain/structural (in)stability of the emerging multipolar system be higher or lower than that of the disintegrating bipolar system?

and

Will the entropy of the emerging multipolar system be larger or smaller than the entropy of the disintegrating bipolar system?

The answers to these questions will be given in section

2.5. on the basis of the model which I will construct in the next section.

* * * * * * * * *

2.4. A MATHEMATICAL MODEL TO INTERPRET STRUCTURAL STRAIN AND STRUCTURAL INSTABILITY

As I have indicated in the previous section, the mathematical concept of entropy may be considered resemblant to the concepts of structural instability and structural strain. For this reason it can be utilised for measuring the potential strain existing in different types of systems: bipolar, tripolar or multipolar. And the quantitative evaluation of strain, at its turn, can be used for comparing these types of systems among themselves.

To demonstrate these assertions I will build a mathematical model, in which I will consider that:

1. An international political system S, is a set of n nation-states, from a given geographical area (possibly the whole world): $S = (s_1, s_2, \ldots s_k, \ldots s_n)$, during a given historical period. The historical period is defined as the interval of time between two successive major structural changes. By major structural change one understands a significant change of the number of actors and/or a considerable modification of the distribution of capabilities across the system. One assumes that the system is closed and the external influences are negligible.

2. The nation-state s_k has a capability c_k, so that the distribution of capabilities across the system is $C = (c_1, c_2, \ldots c_k, \ldots c_n)$.

3. The system S is associated with a system A of elementary events: $A = (a_1, a_2, \dots a_k, \dots a_n)$ so that for each nation-state s_k there is an elementary event a_k. The event a_k is interpreted as a structural change induced by the s_k nation-state acting in its own interest.

4. A probability p_k is associated with each elementary event a_k. The p_k probability is estimated by the relative capability of the s_k nation-state, that is the ratio between its c_k capability and the sum of the capabilities of the all nation-states included in the system:

$$p_k = \frac{c_k}{\sum_{j=1}^{n} c_j} \qquad k = 1, 2, \dots n$$

$$0 \leq p_k \leq 1 \tag{2.4.-1}$$

$$\sum_{k=1}^{n} p_k = 1$$

Therefore, the distribution of capabilities across the system $C = (c_1, c_2, \dots c_k, \dots c_n)$ determines the distribution of probabilities $P^n = (p_1, p_2, \dots p_k, \dots p_n)$. This notation is summarized in the following table:

S	= (international system)	$s_1 \quad s_2 \ \dots \ s_k \ \dots \ s_n$
C	= (distribution of capabilities across the system)	$c_1 \quad c_2 \ \dots \ c_k \ \dots \ c_n$
A	= (complete system of elementary events)	$a_1 \quad a_2 \ \dots \ a_k \ \dots \ a_n$
P	= (distribution of probabilities)	$p_1 \quad p_2 \ \dots \ p_k \ \dots \ p_n$

(2.4.-2)

The above distribution table can be utilised to evaluate the structural strain or structural instability which may cause a major structural change of the system. To derive a measurement formula, one assumes that the structural strain (and/or structural instability) is a function of $p_1, p_2, \dots p_n$:

$$H(A) = H(p_1, p_2, \dots p_k, \dots p_n) \qquad (2.4.-3)$$

There are several ways in which the function H(A) can be deduced. For example, it is possible to begin with the following three properties which must be satisfied by it.

1. The structural strain and instability specific to a balance of power international system should be higher than those associated with any other type of system having the same number of nation-states. This means that the function $H(p_1, p_2, \dots p_n)$ must take its largest value for $p_k = 1/n$, $(k = 1,2, \dots n)$,

$$H(1/n, 1/n, \dots 1/n) \geq H(p_1, p_2, \dots p_k, \dots p_n) \qquad (2.4.-4)$$

2. The structural strain and instability H(A', A") of an international system including two sub-systems (regional systems) S' and S", interacting among them, should be equal to the sum

of the amounts of structural strain of the two sub-systems.

One considers that the structural strain and/or structural instability of the whole international system $H(A'A'')$ is defined for all the bilateral actions which might change the international structure $a'_k a''_l$, $k = 1, \ldots m$, $l = 1, \ldots p$. They are performed by the nation-states included in both sub-systems. Those actions are associated with a distribution of probabilities $p'_k p''_{kl}$, $k = 1, \ldots m$, $l = 1, \ldots p$, that is given by the following table:

$$
\begin{array}{c c|c c c c c c c}
 & & & & A'' & & & & \\
\hline
 & & a''_1 & a''_2 & \ldots & a''_l & \ldots & a''_p & \\
\hline\hline
 & a'_1 & p'_1 p''_{11} & p'_1 p''_{12} & \ldots & p'_1 p''_{1l} & \ldots & p'_1 p''_{1p} & \\
 & a'_2 & p'_2 p''_{21} & p'_2 p''_{22} & \ldots & p'_2 p''_{2l} & \ldots & p'_2 p''_{2p} & \\
A' & & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\
 & a'_k & p'_k p''_{k1} & p'_k p''_{k2} & \ldots & p'_k p''_{kl} & \ldots & p'_k p''_{kp} & \\
 & & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \\
 & a'_m & p'_m p''_{m1} & p'_m p''_{m2} & \ldots & p'_m p''_{ml} & \ldots & p'_m p''_{mp} & \\
\end{array}
\qquad (2.4.-5)
$$

The probabilities p'_k, $k = 1, 2, \ldots m$, refer to structural changes induced by bilateral actions initiated by the nation-states included in the sub-system S'. The probabilities p''_{kl}, $k = 1, \ldots m$, $l = 1, \ldots p$, refer to structural changes induced by bilateral actions initiated by the countries from the sub-system S'' under the general presumption that the distribution of capabilities in the sub-system S'' is affected by the distribution of capabilities in the sub-system S'.

On the basis of the (2.4.-3) assumption, the structural strain of the sub-system S' should be:

$$H(A') = H(p'_1, p'_2, \dots p'_n) \qquad (2.4.-6)$$

In accordance with the same assumption, in the general case in which the distribution of capabilities of the sub-system S" is affected by the distribution of capabilities of the sub-system S', the structural strain of the sub-system S" should be:

$$H_{A'}(A'') = \sum_{k=1}^{m} p'_k H_k(A'') \qquad (2.4.-7)$$

Therefore, in a general case, the structural strain of the whole international system H(A'A"), and the amounts of strain specific to both sub-systems, H(A') and $H_{A'}(A'')$, should satisfy the relation,

$$H(A'A'') = H(A') + H_{A'}(A'') \qquad (2.4.-8)$$

In the particular case of independent distributions of capabilities, $H_{A'}(A'')$ is equal to H(A") and subsequently the relation that should be satisfied reduces to:

$$H(A'A'') = H(A') + H(A'') \qquad (2.4.-9)$$

3. If a nation-state having a capability equal to zero is included in, or adheres to an S international system, its structural strain and instability should remain the same, that is

$$H(p_1, p_2, \dots p_n, 0) = H(p_1, p_2, \dots p_n) \qquad (2.4.-10)$$

Using similar mathematical assumptions, but giving to them an informational interpretation, Khinchin has proved the existence of a unique formula to measure the entropy in a classical article published in 1953 and entitled **The Entropy Concept in Probability Theory.**[1] That is:

$$H(p_1, p_2, \ldots p_n) = - \lambda \sum_{k=1}^{n} p_k \log_2 p_k \qquad (2.4.-11)$$

where λ is a positive constant, and the logarithms can be taken on an arbitrary but fixed base. (pp. 9-13)

The sign (-) is included in order to obtain a positive number as measure, taking into account that $p_k \leq 1$ implies $\log_2 p_k \leq 0$. λ is usually considered equal to one. The base of logarithms is chosen equal to 2 for obtaining H = 1 for n = 2 and $p_1 = p_2 = 1/2$, the unit of measure of entropy being by definition the entropy of a system with two equally probable events.

This measurement formula has a general character, and it can be particularized from case to case. For example, by applying it in the before discussed case of an international system including two sub-systems, one observes that the H(A'A") structural strain of the whole international system is given by the following formula:

$$H(A'A") = - \sum_{k=1}^{m} \sum_{l=1}^{p} p'_k p"_{kl} \log_2 p'_k p"_{kl} \qquad (2.4.-12)$$

At its turn, the structural strain of the S" sub-system, under the assumption that its distribution of capabilities is affected by the S' sub-system is given by the formulas:

----

1. Reprinted in Khinchin, 1957.

$$H_k(A'') = - \sum_{l=1}^{p} p''_{kl} \log_2 p''_{kl} \qquad k = 1,2, \ldots n$$

$$H_{A'}(A'') = \sum_{k=1}^{m} p'_k H_k(A'') \qquad (2.4.-13)$$

The simplest mathematical properties of entropy are the following, and they may be proved without any difficulty,[2]

1. the entropy is non-negative (it is positive or zero):

$$H(p_1, p_2, \ldots p_k, \ldots p_n) \geq 0 \qquad (2.4.-14)$$

2. the entropy is zero if one elementary event is completely certain (its probability is 1):

$$H(p_1, p_2, \ldots 1, \ldots p_n) = 0 \qquad (2.4.-15)$$

3. the entropy is maximized if the elementary events are equally probable:

$$H(p_1, p_2, \ldots p_k, \ldots p_n) \leq H(1/n, 1/n, \ldots 1/n, \ldots 1/n) \qquad (2.4.-16)$$

4. the entropy of the (A'A") system of events is:

$$H(A'A'') = H(A') + H_{A'}(A'') \qquad (2.4.-17)$$

5. the entropy is the same if a new elementary event with probability equal to zero is included:

$$H(p_1, p_2, \ldots p_k, \ldots p_n, 0) = H(p_1, p_2, \ldots p_k, \ldots p_n) \qquad (2.4.-18)$$

The first property is a normal requirement for any measure. The second one has a simple, but interesting, inter-

---

2. Khinchin, 1957, pp. 2-9.

pretation. In the case of an absolute hegemon the instability is zero and the stability is tending to infinity. (But this infinite stability and total peace seem to be those prevailing in a penitentiary colony, and not in a community of free nations!) The last three properties are the conditions utilised to derive the entropy formula, and at their turn they can be proved starting with that formula.

These properties show that the structural strain and structural instability of an international system may be considered resemblant to its entropy, and consequently they can be evaluated by using the formula of entropy. The level of structural stability of the international political system might be measured by the inverse of its degree of structural strain or structural instability $S = 1/H$.

Summarizing the concepts which are utilised in the model, one obtains the following table (Table 2.4.-1):

Table 2.4.-1. Elements of Mathematical Model

(International Politics) Concepts	Mathematical Model
nation-state	element of system: s_k (sub-system)
international political system	system: $S = (s_1, s_2, \ldots s_k, \ldots s_n)$

capability of s_k nation-state	c_k
distribution of capabilities across the system	$C = (c_1, c_2, \dots c_k, \dots c_n)$
structural change in the interest of the s_k nation-state	elementary event: a_k
major structural change at system level	complete system of events: $A = (a_1, a_2, \dots a_k, \dots a_n)$
probability of a change in the interest of the s_k nation-state	$p_k = \frac{c_k}{\sum_{k=1}^{n} c_k}$
probabilities associated with a major structural change	distribution of probabilities: $P = (p_1, p_2, \dots p_k, \dots p_n)$
structural strain or structural instability	entropy $H = - \sum_{k=1}^{n} p_k \log_2 p_k$
structural stability	inverse of entropy $S = 1/H$

One observes that in this model I associate the concept of international political system with the concept of system, and the concept of nation-state with the concept of system's element (sub-system). I do not use the associations: international political system = metasystem, and nation-state = system, because the model implies only one level of analysis. It does not imply the analysis of internal stability of each nation-state. Consequently I have considered that it is more convenient to use the vertical relation system => elements (sub-systems), instead of the vertical relation meta-system => system.

* * * * * * * * *

2.5. FORMAL PROPERTIES OF STRUCTURAL STRAIN AND STRUCTURAL STABILITY

Using the model built in the preceding section of this chapter, I will illustrate in this section several properties of structural strain and structural stability. These properties have an independent character, however the first two may be also considered as mathematical demonstrations of two of Waltz's assertions.

Property 1. **The structural stability of a S international political system is minimal if the capabilities of the nation-states included in that system are equal,**

$$S(1/n, 1/n, \dots 1/n, \dots 1/n) \leq S(p_1, p_2, \dots p_k, \dots p_n) \quad (2.5.-1)$$

In other words, this means that a balance of power international system is the least stable system among all the types of systems which include the same number of nation-states.

To prove this proposition, one uses the relations:

$$S(1/n, \dots 1/n, \dots 1/n) = 1/H(1/n, \dots 1/n, \dots 1/n)$$

$$S(p_1, p_2, \dots p_k, \dots p_n) = 1/H(p_1, p_2, \dots p_k, \dots p_n)$$

and one observes that on the basis of the property #3 of entropy:

$$H(p_1, p_2, \dots p_k, \dots p_n) \leq H(1/n, 1/n. \dots 1/n. \dots 1/n)$$

Consequently:

$$S(1/n, 1/n, \dots 1/n, \dots 1/n) \leq S(p_1, p_2, \dots p_k, \dots p_n)$$

One remarks that this proposition is consistent with the following assertion made by Waltz: "Carried to its logical conclusion, this argument must mean that tranquility would prevail in a world of many states, all of them are approximate equals in power. I reach a different conclusion. The inequality of states, though it provides no guarantee, at least makes peace and stability possible." (p. 132)

Property 2. **The structural stability of a balance of power international political system S^n with n nation-states is higher than the structural stability of a balance of power international political system S^m with m nation-states if n is smaller than m,**

$$S(1/n, \ldots 1/n) > S(1/m, \ldots 1/m), \quad n < m \qquad (2.5.-2)$$

To prove this proposition in a general case, one must consider that the capabilities of the nation-states, or coalitions of nation-states are relatively equal. And, this assumption may be accepted, because it is implied by the predictions of the balance of power principle.

If $P^n = (1/n, \ldots 1/n, \ldots 1/n)$ and $P^m = (1/m, \ldots 1/m, \ldots 1/m)$, than the structural instabilities for S^n and S^m are:

$$H(1/n, 1/n, \ldots 1/n, \ldots 1/n) = -(n/n)*\log_2 1/n = \log_2 n$$

$$H(1/m, 1/m, \ldots 1/m, \ldots 1/m) = -(m/m)*\log_2 1/m = \log_2 m$$

The assumption: $n < m$ implies $\log_2 n < \log_2 m$, and consequently the structural instability of S^n is smaller than the structural instability of S^m,

$$H(1/n, \ldots 1/n, \ldots 1/n) < H(1/m, \ldots 1/m, \ldots 1/m).$$

Observing that $S=1/H$, one finally obtains:

$$S(1/n, \ldots 1/n, \ldots 1/n) > S(1/m, \ldots 1/m, \ldots 1/m)$$

For balance of power international systems it is possible to draw stability and instability curves depending on the number of nation-states included in the system. They are shown in Fig. 2.5.-1 and Fig. 2.5.-2.

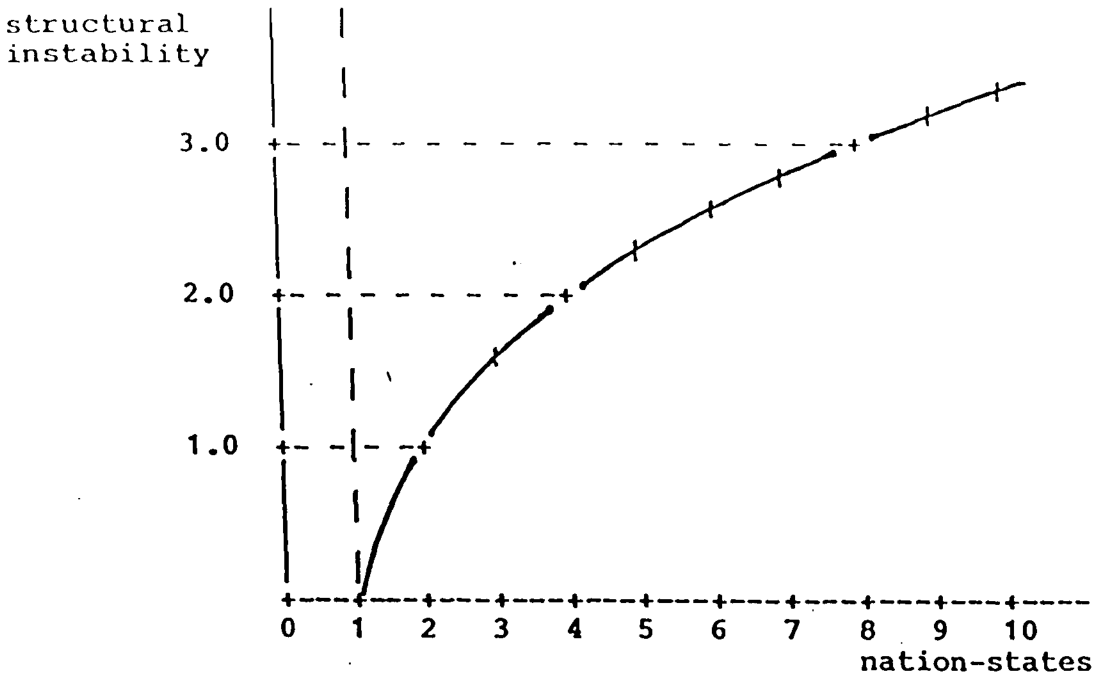
This property is also in accordance with Waltz's assertion that "Smaller systems are more stable and their members are better able to manage affairs for their mutual benefit", (p. 136) under the assumption that he refers in this statement to balance of power international systems. And this assumption may be made, because of the context of the corresponding chapter of Theory of International Politics.

Property 3. **The structural instability and structural strain H of an international political system S is maximal if the capabilities of states included in that system are equal,**

$$H(1/n, 1/n, \ldots 1/n, \ldots 1/n) \geq H(p_1, p_2, \ldots p_k, \ldots p_n) \quad (2.5.-3)$$

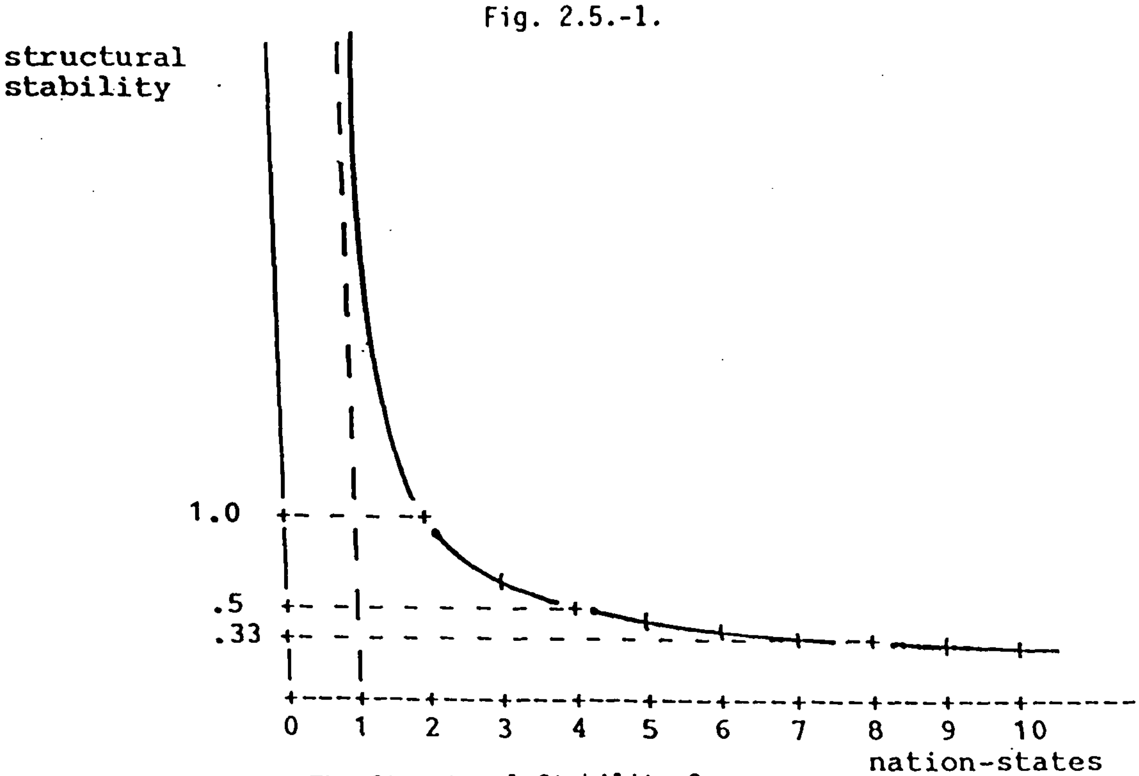
This is the reverse of Property 1. and it is equivalent to it. Its proof is immediate, this proposition being from a mathematical point of view identical with the property #3 of entropy (p. 118).

Property 4. **The structural instability and structural**



The Structural Instability Curve

Fig. 2.5.-1.



The Structural Stability Curve

Fig. 2.5.-2.

strain of an international political system with one nation-state (the global empire!) is zero,

$$H(1) = 0 \qquad (2.5.-4)$$

The proof is immediate, $H(1) = - 1\log_2 1 = 0$

Property 5. The structural instability and structural strain of an international political system including an absolute hegemon is zero,

$$H(0,\ 0,\ \ldots\ 1,\ \ldots\ 0) = 0 \qquad (2.5.-5)$$

The proof is also immediate, this being the property #2 of entropy. (p. 118)

Property 6. **Alliances increase the structural stability and diminish the structural instability and structural strain.**

If one considers an international political system S' composed of n nation-states, in which there is the following distribution of capabilities: $C' = (c_1, c_2, \ldots c_i, \ldots\ c_j, \ldots c_n)$ its structural instability is:

$$H' = H(p_1, p_2, \ldots p_i, \ldots p_j, \ldots p_n) \qquad (2.5.-6)$$

If two countries i and j conclude an alliance, than the new distribution of capabilities is: $C'' = (c_1, c_2, \ldots c_i + c_j, \ldots c_n)$ and the structural instability is:

$$H'' = H(p_1, \ldots p_{i-1}, p_{i+1}, \ldots p_{j-1}, p_{j+1}, \ldots p_n, p_i + p_j) \qquad (2.5.-7)$$

For proving this property, it is necessary to show that

$S'' > S'$, or equivalently that $H'' < H'$.

One observes that it is possible to write:

$$H' = H(p_1, p_2, \ldots p_{i-1}) + H(p_{i+1}, \ldots p_{j-1}) +$$

$$H(p_{j+1}, \ldots p_n) + (H(p_i) + H(p_j)) \qquad (2.5.-8)$$

and

$$H'' = H(p_1, p_2, \ldots p_{i-1}) + H(p_{i+1}, \ldots p_{j-1}) +$$

$$H(p_{j+1}, \ldots p_n) + H(p_i + p_j) \qquad (2.5.-9)$$

One remarks that for proving that $H'' < H'$, it is sufficient to show that:

$$H(p_i, p_j) > H(p_i + p_j) \qquad (2.5.-10)$$

To prove this inequality, one observes that the relation,

$$-p_i \log_2 p_i - p_j \log_2 p_j > -(p_i + p_j)\log_2 (p_i + p_j) \qquad (2.5.-11)$$

may be written as it follows,

$$-p_i (\log_2 p_i - \log_2 (p_i + p_j)) - p_j (\log_2 p_j - \log_2 (p_i + p_j)) > 0 \qquad (2.5.-12)$$

And this last relation is true for p_i and p_j having the properties specified in section 2.4. Consequently, $H'' < H'$, and $S'' > S'$.

* * * * * * * * *

2.6. STRUCTURAL STRAIN AND INTERNATIONAL SECURITY

On the basis of the theoretical properties proved in the preceding section, it is possible to make the following general predictions, answering in this manner the two questions formulated at the end of section 2.3.. In comparison with the bipolar international system of the Cold War era, the emerging multipolar system will probably be characterized by:

- a more complex international structure,
- a lower level of structural stability,
- a higher level of structural strain,
- the possibility of concluding asymmetrical, unequal coalitions.

On the basis of the empirical remarks included in section 2.1.1., and of other similar considerations, one can assume with a relative high level of probability, that the emerging system will include five centers of power. As I specified in section 2.1.1. United States and Russia (single or in alliance with other successor states of the former Soviet Union) will continue to be complex political, economic, and military powers. Western Europe (under the assumption that the Treaty of Maastricht will be ratified and implemented) and Japan will become economic superpowers, but will be probably reluctant, at least during the foreseeable future to develop independent military forces comparable with their economic might. They will be far more interested to use their economic power for political objectives. China however will have all types of power, but will be at a considerable distance behind the first two.

It is probable that from the point of view of strategic armaments, the system will be characterized by the following elements, during the transition period:

- three countries - United States, Russia, and China will have major arsenals of nuclear weapons and advanced means of intercontinental delivery (with, of course, significant differences from one country to another);
- at present it is impossible to predict if Ukraine, Belarus, and Kazakhstan will keep the strategic nuclear weapons which exist on their territories because of the high volatility of the situation; but if they will decide to maintain them they would be important nuclear powers;
- Western Europe, however will continue to remain for a couple of years under the American nuclear umbrella, will develop a more independent military structure; the strategic offensive nuclear capabilities of Britain and France will be probably compensated by the development of complementary (perhaps defensive) systems by others (probably Germany);
- Japan will use more and more her economic power for political objectives, will have a medium size, but extraordinarily efficient military capability, and will probably be very reluctant to develop nuclear weapons;
- India will try to develop military capabilities relatively closed to the first five, but her important scientific potential will be only partly utilised

for military purposes because important funds will be allocated for improving its economic infrastructure;

- a group of regional powers: Israel, South Africa, etc. will have nuclear weapons or advanced technological capacities to manufacture them, and the corresponding systems of regional delivery;
- some countries will maintain and other will develop limited quantities of chemical and biological weapons;
- as a result of technological improvements, the preeminent future powers (USA, Russia, Western Europe, China and Japan) will be able to develop highly sophisticated conventional weapons capable of destruction comparable to those which at present might be caused by tactical nuclear weapons.

The **relatively high level of structural strain specific to a multipolar balance of power system associated with the relatively extended spread of nuclear and other mass destruction or highly efficient conventional weapons, will constitute the main challenge to international peace and security in the future international system.** In consequence, adequate means for preventing the outbreak of regional or global nuclear conflicts must be conceived, designed, and implemented. They will be of two types: politico-miltary arrangements (alliances, accords, agreements, etc.) and new weapons systems.

* * * * * * * * *

2.7. CONCLUSIONS

The content of this chapter may be summarized in the following chain of assertions logically connected among them:

- the communist bloc has collapsed as a result of its own internal tensions;
- the bipolar international system of the Cold War era is disintegrating;
- the world is in a period of transition (these first three remarks are based on political observations and analyses);
- according to Kaplan's theoretical models the future international system will be a multipolar balance of power system;
- the (structural) stability of a multipolar balance of power system is lower than that of a bipolar system in accordance to Waltz's theory;
- the preceding conclusion is reinforced by a mathematical model which considers that:
  - = the structural instability and structural strain are resemblant to the international system's entropy,
  - = the structural instability and structural strain are evaluated by using the mathematical formula of entropy;
- the entropy of a balance of power system with a larger number of actors is higher that that of a system with a smaller number of actors (result obtained by using the

mathematical model);

- the potential structural strain of a multipolar balance of power system is greater than the structural strain of a bipolar system;
- in the emerging multipolar balance of power system there will probably be five major centers of power (according to political predictions);
- in the same future system, there will be several regional powers having nuclear weapons, nuclear capabilities, or other kinds of mass destruction weapons; they will also have appropriate means of regional delivery (also according to predictions based on empirical information);
- **the association between the relatively high structural strain specific to a balance of power multipolar system and the relatively extended spread of mass destruction weapons and appropriate means of delivery will probably constitute the main potential danger in the emerging international system;**

This last assertion implies that a reasonable military power must be maintained by the United States and its allies (perhaps only "frieds" in the future !) because in the future multipolar international system the dangers will be different, and probably less menacing that those which existed during the Cold War, but they will not disappear. The prevention of nuclear war and preservation of peace will require the development of adequate political-military structures and new strategic systems. Those strategic systems might be offensive or defensive ones.

With regard to the strategic offensive systems it is possible to conceive three possibilities: to maintain them at the present level, to increase their number, or to decrease it. Regarding strategic defensive systems, there are two main alternatives: to develop them on a limited basis or not. The extended development cannot be realistically taken into consideration in the foreseeable future. By combining these versions one obtains six scenarios (Table 2.7.-1). They are considerably different concerning the cost and the degree of security which they could provide. In order to assess them it is necessary to

		Defensive Systems	
		Do not develop	Develop
Offensive Systems	Decrease the number	(1)	(4)
	Maintain at the same level	(2)	(5)
	Increase the number	(3)	(6)

Table 2.7.-1.

examine, among other elements, the basic strategic nuclear doctrine, the (in-)stability of the strategic offensive nuclear arms race, and the relationship between strategic defense and offense. Therefore, I will dedicate the next three chapters to the study of these problems, and I will finally suggest which scenario should be rationally preferred.

* * * * * * * * *

3. LIMITATIONS OF VULNERABILITY BASED DETERRENCE (MUTUAL ASSURED DESTRUCTION) TO PREVENT A NUCLEAR CONFLICT IN A MULTIPOLAR INTERNATIONAL SYSTEM

3.1. ASSUMPTIONS OF MUTUAL ASSURED DESTRUCTION DOCTRINE

The Mutual Assured Destruction doctrine, as a theoretical embodiment of vulnerability based deterrence, emerged as a main nuclear strategy during the late sixties and early seventies. It was the consequence of the development of strategic nuclear weapons and of advanced means of delivery by the United States and Soviet Union. Its persuasive power, and scientific and political prestige have been caused not only by its logical coherence but also by the fact that many analysts and statesmen have considered that because of it, the peace between the superpowers was maintained during the second half of the Cold War era.

During the years of the Cold War, the American doctrine regarding the use of nuclear weapons changed several times as a result of the technological progress and the evolving Soviet threat. As Hartmann and Wendzel remark, during the period of American nuclear monopoly, the atomic bomb was regarded as "the great equalizer"[1] of the huge Soviet conventional forces. After the detonation of the first atomic device by the Soviets and the intensification of the Cold War, the American strategic policy was formulated in two programatic documents: NSC-68 (submitted to

1. Hartmann and Wendzel, 1988, p. 226.

the President on April 1950) and NSC 162/2 (approved on October 1953).

Starting from an analysis of the "present world crisis", American-Soviet conflict, and Soviet "fundamental design", the authors of NSC-68 emphasized the strongly aggressive character of Soviet Union's foreign policy. The apparent reservation in the Soviet behavior was not the result of their moderation. It was caused by a lack of certitude that they could win a war with the West. But this attitude might change as their capabilities improve. Consequently, the United States must make a large-scale and immediate effort to considerably strengthen its military forces. It should be prepared for both total and limited war contigencies. (idem, p. 228)

NSC 162/2 reflected President Eisenhower's strategy, known under the name of New Look. It included as a main element the doctrine that in the case of a war, the United States would "consider nuclear weapons to be as available for use as other munitions."[2] But in the middle fifties, it became clear for many that that doctrine implying massive nuclear retaliation in response to a Soviet attack was not credible because of its "all-or-nothing" characteristics. (idem, pp. 231-232) Consequently it was replaced by the Flexible Response doctrine. Finally, in the late sixties, the Soviets achieved the nuclear parity with the United States, and the Mutual Assured Destruction doctrine emerged.

As Hartmann and Wendzel observe, by 1967, as a conse-

---

2. Quoted in Hartmann and Wendzel, 1988, p. 230.

quence of the implementation of President Kennedy's strategic plans by the Johnson Administration, the United States had a strategic arsenal including 1000 Minutemen and 54 Titan silo-based ICBMs, 656 SLBMs on 41 Polaris submarines, and about 600 long-range bombers. (idem, p. 234) That triad had been conceived to ensure that the United States "would have enough strategic forces left after a Soviet attack to be able to retaliate," (idem, p. 234) according to the prescriptions of the Flexible Response doctrine. But, as the two authors remark, "Flexible response implies not just a variety of forces and a range of options, but the ability to choose effectively among them in some controlled fashion." (idem, p. 234) And this was only partly possible with the technology of that time. In addition to this fact, several other reasons contributed to a gradual shift from Flexible Response to Mutual Assured Destruction. They were (idem, p. 235):

- the denial by the Soviets of "any possibility of a controlled nuclear war;"
- the objection made by United States' allies regarding a partial decoupling (the possibility that the United States might choose not to retaliate against the Soviet Union in the case of a nuclear attack directed by that country against the US allies);
- the instability caused by the fact that a first strike is more useful and effective than the counterstrike, because it allows the destruction of adversary's ICBMs and strategic nuclear aircraft before the opponents might use

them;

- Secretary of Defense McNamara's conviction that it became impossible to destroy a "substantial portion" of the Soviet arsenal as a result of the measures taken by the Soviets to considerably improve their survivability;
- Secretary of Defense McNamara's opinion that the budget for procurement of nuclear weapons must be kept in reasonable limits.

Like other famous theories or doctrines, the Mutual Assured Destruction has a simple, elementary elegance: "... the essential postulate was that the United States, after absorbing a Soviet attack, should be assured of having sufficient retaliatory capacity to destroy an unacceptably large portion of Russia's population and industrial capacity (originally stipulated to be one-third and two thirds respectively)."[3] And later, in 1960, estimated to be 20% to 25% of the Soviet population and 50% of Soviet industry.[4]

In general terms, this means that one assumes that there are two opponents and that each of them has nuclear weapons and adequate means of delivery. One also assumes, with a high level of probability, that some nuclear weapons could survive a first nuclear strike. As a result, those surviving weapons could and would be used for a counterstrike against the main assets of the power which initiated the first strike. Both

---

3. Hartmann and Wendzel, 1988, p. 235.
4. Alain C. Enthoven and K. Wayne Smith, How Much Is Enough: Shaping the Defense Program, 1961-1969, pp. 175 and 207, quoted by Milton, Davis and Parmentola, 1989 p. 145.

adversaries use the same reasoning, and consequently they do not begin a nuclear war, being fully convinced that as an effect of the counterstrike a large part of their population would be killed.

One observes that the MAD doctrine works under the following assumptions:

- the adversaries behave in a strictly rational manner;
- there are two adversaries, or two opposite alliances (although this assumption is not explicitly emphasized, it is usually implied in analysis);
- the two adversaries have comparable (essentially equivalent) nuclear arsenals concerning the number of warheads, the number of systems of delivery and their technological and strategic performance;
- a considerable portion of each adversary's nuclear arsenals will certainly survive a first strike;
- the two opponents share a basic ethical principle, although their political, social, and economic principles are very different or strongly opposed: they would not accept the certain death of a large fraction of their populations as the price of victory;
- the distribution of population on the two territories is comparable, both countries having a considerable number of large cities;
- the mass killing of population by nuclear explosion is considered to be in accordance with the law of war.

As I have shown in section 1.4.2. when I presented pro and con arguments regarding SDI, there have been various opinions concerning the MAD doctrine. There have been politicians and strategic analysts, perhaps in a majority, who have considered that the United States's policy complied with its principles. But there have been others, especially among the military men, who have argued that America has based its defense on retaliation based deterrence. They emphasized that MAD has never been taken into consideration in nuclear planning and that the American forces have been always ready to prevail even in a nuclear war thanks to a "warfighting strategy."[5]

With regard to the posture of the former Soviet Union, there have been several points of view too. The official Soviet position was that the "communist camp" was surrounded by aggressive "imperialist forces" aiming at the destruction of the "communist camp" in general and of the Soviet Union in particular. The Soviets emphatically stated that the only objective of the Soviet foreign policy was "to safeguard peace" and that they would utilise the nuclear weapons to defend the "peace loving state of the working class" against the "Western aggression." But, despite the rhetoric, the political leadership followed a relatively cautious approach. Until the years in which President Reagan formulated his Strategic Defense Initiative, and Mikhail Gorbachev became the general secretary of the Communist Party, the Soviet leadership preferred not to make very clear in public statements its position on MAD although the 1992 ABM Treaty implied that both superpowers accepted it (the MAD

----

5. Worden, 1991, pp. 1 and 61.

doctrine). The causes of that position were mainly idelogical. A total rejection of the doctrine could have been in contradiction with the officially stated "peace loving" policy of Soviet Union. But its total acceptance might have been perceived by the hard line communists as a compromise with the enemy. Or equally "anti-Leninist," that one could assume that the "imperialist opponents" could think and behave in a rational and moral manner. But this ambiguous position gradually changed after President Reagan's speech on SDI. The Soviet leadership began to be aware of what the United States might achieve, and it was subsequently suggested that the Soviet Union was fully complying with the vulnerability based deterrence's principles. This point of view was even more emphasized by Gorbachev's policy aiming at considerably improved relations with the West. However, regardless of the political leaders' statements, the position of the Soviet military men was a kind of mirror image of that of their American counterpart. They proudly emphasized that they were always ready to defend the motherland and to defeat the enemy by using all the weapons at their disposal, including the nuclear ones.

Among the American students of Soviet strategy there have been two opposite schools of thinking. According to one, the Soviets complied with the MAD principles, despite their rhetoric. According to the other, they did not, and their unique objective was to achieve nuclear superiority and to enhance their first strike capability. The first has prevailed among politicians and in the academya, and has included well known personalities like

Robert C. McNamara, McGeorge Bundy, or Henry Kissinger. The second school has been prevalent among the military men and in the conservative circles. Among the analysts who supported this second point of view were Richard Pipes, Fred C. Ikle, Eugene V. Rostow, and Pentagon officials.

In order to illustrate these diverging opinions I present here several examples in addition to those given in section 1.4.2. (pp. 38-39). Making a rigorous and extensive analysis of Soviet strategic power, Robbin F. Laird and Dale R. Herspring wrote, "**We maintained that Soviet leaders, both civilian and military, recognize the objective reality of assured destruction in an all-out nuclear war.** [my emphasis]" And they affirmed as early as in 1984 that "Soviet military writers have shifted the focus of their attention away from preparing to fight an all-out nuclear war against the West as the key military option."[6]

This opinion has been consistent with one expressed two years earlier by Raymond L. Garthoff. He had considered that the Soviet political and military leadership recognized that "**under contemporary conditions there is a strategic balance between two superpowers which provides mutual deterrence;** [my emphasis] that the nuclear strategic balance is basically stable, but requires continuing military efforts to assure its stability and continuation."[7]

Writing in the same revue, Richard Pipes, at his turn,

----

6. Laird and Herspring, 1984, pp. 5-6.
7. Raymond L. Grathoff, Mutual Deterrence and Strategic Arms Limitation in Soviet Policy, <u>Strategic Revue</u>, Fall 1982, p. 37, quoted in Laird and Herspring, 1984.

started his analysis with a similar premise, but derived a completely different conclusion. He asserted that "Soviet strategists regard "mutual deterrence" to be a reality of the balance of nuclear forces as presently constituted, **but they mean to alter this balance in their favor and in this manner secure a monopoly on deterrence** [my emphasis]".[8]

In a paper written in 1986 and revised for publication a couple of years later, Eugene V. Rostow stressed that "the Soviet nuclear policy is to build a force capable of deterring any American response - conventional or nuclear - to Soviet aggression against American security interests."[9] In his opinion the Soviet and American approaches to deterrence were totally opposed because if "**the American goal is to deter Soviet aggression against our interests; the Soviet [is] to deter any American defense against Soviet aggression** [my emphasis]."

Taking into consideration these opposite points of view, two natural questions arise:

Which will the prevailing strategic doctrine be in the future multipolar international system ?

and

Will that doctrine require strategic defense or not?

Several answers could be given to these questions depending on the initial premises. The most simple would be the conservative one. MAD has never been the basic strategic nuclear

----

8. Richard Pipes, Soviet Strategic Doctrine: Another View, Strategic Review, Fall 1982, p. 56, quoted in Laird and Herspring, 1984.
9. Eugene V. Rostow, Will We Be More Secure in 2010, in Security Implications of SDI, edited by Jeffrey Simon, pp. 225-226.

doctrine. It was never followed either by the United States or by the former Soviet Union. It has been only an elegant logical construction of some sophisticated "liberals." Therefore, the future situation will be comparable to the past one. The basis of nuclear planning should be retaliation based deterrence reinforced by a vigorous strategic defense as real policy. Mainly non-nuclear strategic defense for protecting the population, as declaratory policy.

The second answer would come from the MAD doctrine's supporters. Nuclear war was prevented during the Cold War only because of vulnerability based deterrence. The nuclear weapons are completely different from the classical ones. The quantitative difference is so great that it becomes essentially qualitative. Their only reason is to prevent a war, not to be used in a war. The idea of gaining in a nuclear conflict is worse than a terrible nonsense. It is suicidal. Exactly as it was in the past, in the future the peace will be the result of the equilibrium of terror too. Any element which could affect that equilibrium would be destabilizing and might ignite a nuclear conflict. The development and deployment of strategic defensive systems would be therefore not only useless, but also extremely dangerous. The SDI research and development must be drastically scaled down. Deployment must be not even taken into consideration.

In this dissertation, I give a third answer. I assume, as the MAD supporters do, that vulnerability based deterrence prevented the outbreak of a nuclear war during the Cold War. But

I remark based on the analysis made in the preceding chapter that it is rational to expect that in the future international system some of the assumptions required by MAD (p. 138) will cease to be fulfilled. The international conditions will be different from those prevailing in the former bipolar system. Instead of two superpowers, will be several major powers. A group of medium or small countries will develop nuclear capabilities, and will probably build nuclear weapons and/or other weapons of mass destruction. They will also have adequate means of regional delivery. The systems of moral values of the actors included in the first group, and especially of those of the second, will be very different from those held by the United States and the former USSR during the Cold War era. Although Mutual Assured Destruction will remain a main nuclear strategic doctrine, there will gradually emerge conflictual situations in which it might fail to prevent a nuclear attack. These reasons make necessary a reexamination of the assumptions on which the doctrine has been based and of the doctrine itself. For this purpose, in the following two sections I will use utility and disutility functions (curves) for analysing the initial strike and the corresponding counterstrike. I will base my analysis on a very simple remark; within the framework of European and American civilizations, while the utility of the most important gain is bounded, the disutility of death is unlimited. The use of curves and graphs will probably make the reading relatively more difficult. But they will allow a more clear and rigorous presentation of the final results.

I started to develop these utility and disutility functions during the summer of 1988. At that time I was a visiting scholar in the ICPSR Summer Program in Quantitative Methods at the University of Michigan, at Ann Arbor. At Professor J. David Singer's invitation I was attending the weekly seminars of the Correlates of War Project. At one of those seminars, Professor Singer remarked that during the nuclear era none of the confrontations involving major nuclear powers had resulted in a nuclear war. Although those powers have frequently declared their intentions to use nuclear weapons under some more or less specified conditions they have always been reluctant really to do it. Thinking to this remark, I realized that the utility and disutility functions largely applied in mathematical-economic modeling might be employed for evaluating the advantage of a first nuclear strike and the disadvantage of the corresponding counterstrike.

During the 1988-1989 academic year, while attending classes at my university in New York, I continued to study this problem for my own scientific interest. I wrote a paper in which I constructed various utility and disutility functions (curves) and a dynamic model for analyzing the dynamics of a nuclear crisis. During the next summer I went again to the University of Michigan with two purposes. One was to do research in the library regarding the problems of strategic defense, because the sources in New York City were very limited. The second one was to continue to attend the Correlates of War Seminar and to develop my paper. I described to Professor Singer some of my mathematical models and I asked him whether he wrote some papers regarding the dynamics of a nuclear crisis. He gave me a short paper which he included in a research proposal submitted to the World Society Foundation from Zurich, Switzerland. In that paper he described among other problems the probable phases of a confrontation involving nuclear powers. Studying those phases, I observed that his conclusions derived from empirical considerations were in accordance with my conclusions derived by using theoretical mathematical models. My utility and disutility curves matched unexpectedly well the phases described by Prof. Singer. The fact that two persons, thinking completely independent and using totally different methods, have reached unexpectedly close answers to the same research problem made me to believe that my mathematical models were relevant. Encouraged by this fact, I extended my paper and I presented it to the Correlates of War Seminar under the title **A Remark on the Propensity to Use Nuclear Weapons During a Crisis.**

During the next two years I focused on the MAD doctrine and I applied some of the utility and disutility functions (curves) to explain it. I presented my results at the Conference of the International Security Studies of the International Studies Association, held in Columbus, Ohio, in November 1990. The title of my paper was **The Mutual Assured Destruction Doctrine in a Multipolar International System.** The content of the next sections (3.2. and 3.3.) is based on that paper and represents a geometrical (improved, I hope) version of my initial algebraic models.

* * * * * * * * *

3.2. UTILITY AND DISUTILITY FUNCTIONS (CURVES) FOR ANALYSING THE MUTUAL ASSURED DESTRUCTION DOCTRINE

3.2.1. THE UTILITY OF THE INITIAL STRIKE

I seems to me that the utility of the initial strike may be regarded as a function of the gain, which a nuclear power, henceforth referred as to the first power could obtain by threatening to use, or really using nuclear weapons in a conflict with a second power. This function should have a value of zero for no gain and a maximal value for the total and unconditional surrender of the adversary. This would usually imply the occupation, rule, and probably exploitation of the second country by the first one. **Under these assumptions, one obseves that although the gain resulting from the complete defeat of the adversary could be very important, it is always finite. At the same time, the utility of that maximal, but limited gain, is finite too.** In other words, the utility of the most decisive victory over an opponent is always bounded.

This gain-utility function, and the corresponding curve, should have the three properties required in macro-economics for a utility function. It should have a value of zero in the origin, it should be increasing, and it should be concave from below. The first requirement is self-evident because it is impossible to derive any amount of utility if its object does not exist. The second property is obvious too. The satisfaction given by a larger quantity of goods should be higher. The third condition is associated with the decreasing marginal utility of goods.

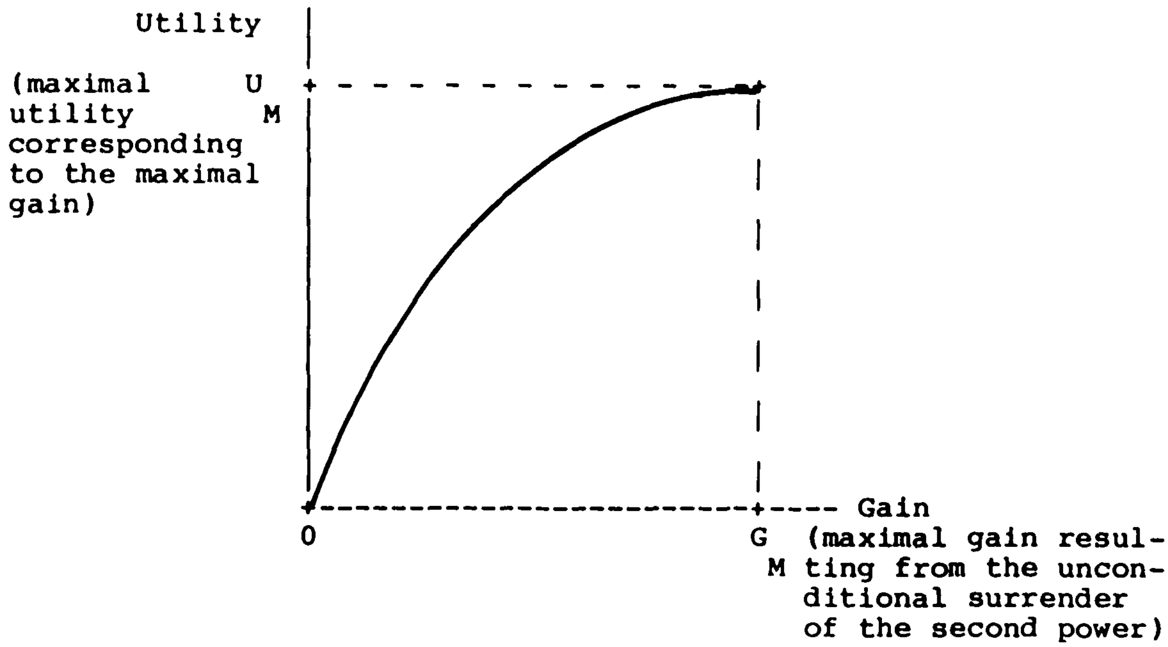
According to the theory virtually unanimously accepted by economists, the utility added by any supplementary unit of a good is smaller than the utility added by the preceding unit.

The gain might be evaluated in monetary units, or might be normalized by dividing the gain amounts by the maximal gain which could be obtained by the first power as a result of the second country's surrender. As it is known from economics, although the concept of utility is widely utilised, there is not a unitary point of view regarding the manner in which the utility should be evaluated, or even if it is in principle possible to measure it. Therefore, I would suggest taking into consideration two alternative approaches. First, that it is estimated in (quasi-)monetary units. Second, that the utility is a concept having only a vague, quasi-quantitative connotation comparable to a considerable number of other concepts used in psychology, sociology and political science. Consequently, one might assert that the utility could be bigger or smaller, but one cannot specify the unit of measure without artificial speculations. The first approach has the advantege of being more precise and allowing a relatively more rigorous analysis. But it considerably limits the meaning of the concept of utility itself. The second approach saves the concept's connotations, but it makes practically impossible a concrete measurement.

Having in my mind all these limitations, however I consider that the use of the concept of utility is rewarding for the study of nuclear powers' behavior during a potential nuclear conflict. Therefore, on the basis of the above assumptions, I present two possible versions of the gain-utility curve in Fig. 3.2.1.-1 and Fig. 3.2.1.-2. In the first case, the gain is evaluated in monetary units. In the second case, the gain is normalized and the utility is estimated by the monetary value of the gains.

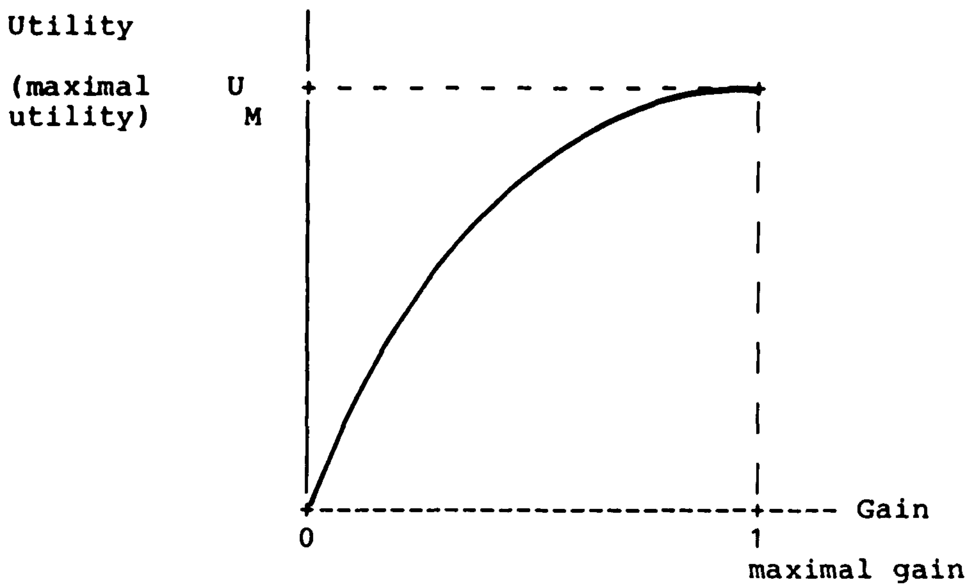
I consider that the gain, at its turn, can be associated with the first power's propensity, will, or readiness to use nuclear weapons against the second power as a consequence of a powerful escalation of a conventional conflict. One assumes that the gain could be measured, as in the case of the gain-utility curve in monetary units, or that it could be normalized. On the other side, it seems to me that the propensity could be estimated by using a scale going from zero to one. Zero means the lack of any threats regarding the use of nuclear weapons. One means the launch of the first country's nuclear ICBMs. A possible scale, assuming that the first country would be the United States, might be the following:

0.0 - no threats regarding the use of nuclear weapons;
.1 - "well balanced" articles simultaneously published in leading American nespapers supporting the utility of a nuclear strike against the second power;
.2 - testimony by the Undersecretary of State, that the US take actively under consideration the use of nuclear weapons against the second country;
.3 - the President meets the Secretaries of State and Defense, the Director of the CIA, the National Security Adviser, and the Chairman of the Joint Chiefs of Staff. The NSC is in in extended session; sober media coverage;
.4 - the Under-Secretary of Defense for policy analysis states that the nuclear weapons will not be immediately used;
.5 - the last US nuclear submarine scheduled to be in patrol in the case of a major conflict leaves its base; the event is extensively covered by the media;
.6 - all US forces around the world are put in the highest level of nuclear alert; the order is classified;
.7 - a powerful explosion, believed to be that of a small



The Gain-Utility Curve

Fig. 3.2.1.-1



The Gain-Utility Curve for Normalized Gain

Fig. 3.2.1.-2

nuclear device, is recorded by the US allies in a remote, deserted area of the second country; no comment from Washington or from the capital of the second country;

.8 - the White House makes public that all the US forces have been put in the highest level of nuclear alert;

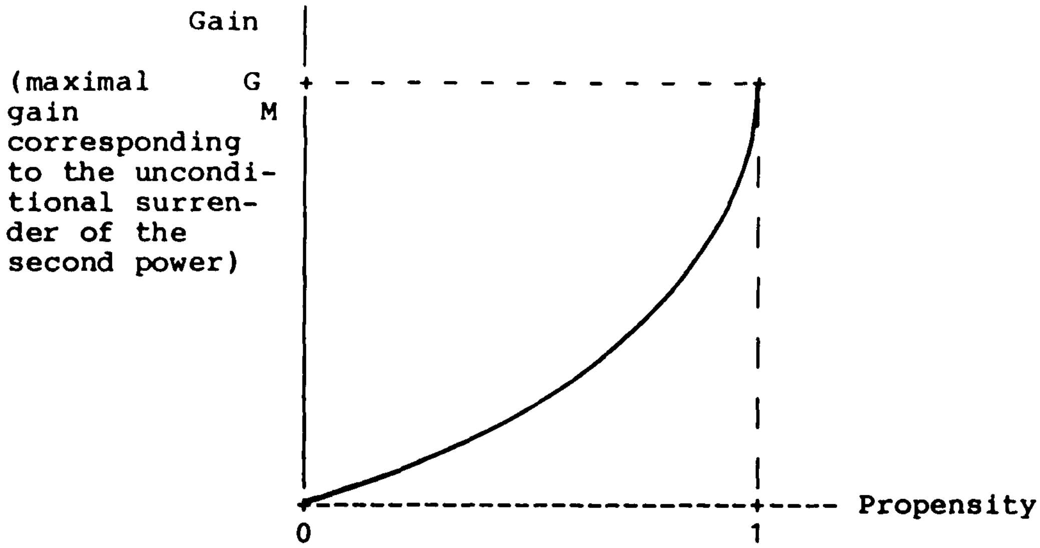
.9 - US strategic aircraft carrying nuclear weapons take off from bases surrounding the second country; the President addresses the nation;

.95 - the strategic aircraft cross the borders of the second power;

1.0 - US nuclear ICBMs are launched.

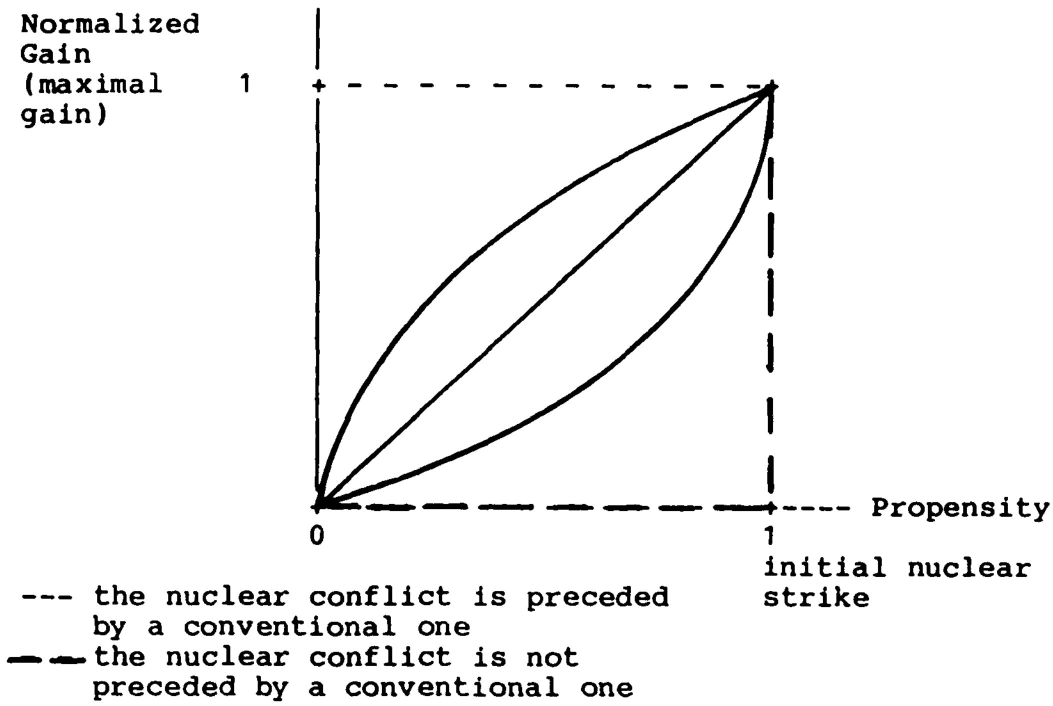
It is also natural to consider that a nuclear conflict would probably be the result of the powerful escalation of a conflict in which conventional weapons are used. Consequently, the above scale should be put in parallel with another one measuring the intensity of the conventional conflict. Associating the information obtained by using the two scales, it might be possible to derive a sufficiently accurate evaluation of the propensity to use nuclear weapons.

As in the preceding case, the gain can be measured in monetary units, or can be normalized. From an abstract point of view, the propensity-gain curve may have various shapes. It might be convex, concave, or a straight line. The most natural shape would be one that is convex from below. The least probable would be a curve that is concave from below. In the particular case of an "instantaneous" nuclear conflict, which is not preceded by a conventional one (hypothetical example: a nuclear conflict between the USA and USSR caused by the Cuban Missile Crisis) the propensity-gain curve is step-shaped, because the gain might be obtained only because of the initial nuclear strike. Several possible types of the gain-propensity curve are shown in Fig. 3.2.1.-3 and Fig. 3.2.1.-4.



The Propensity-Gain Curve

Fig. 3.2.1.-3

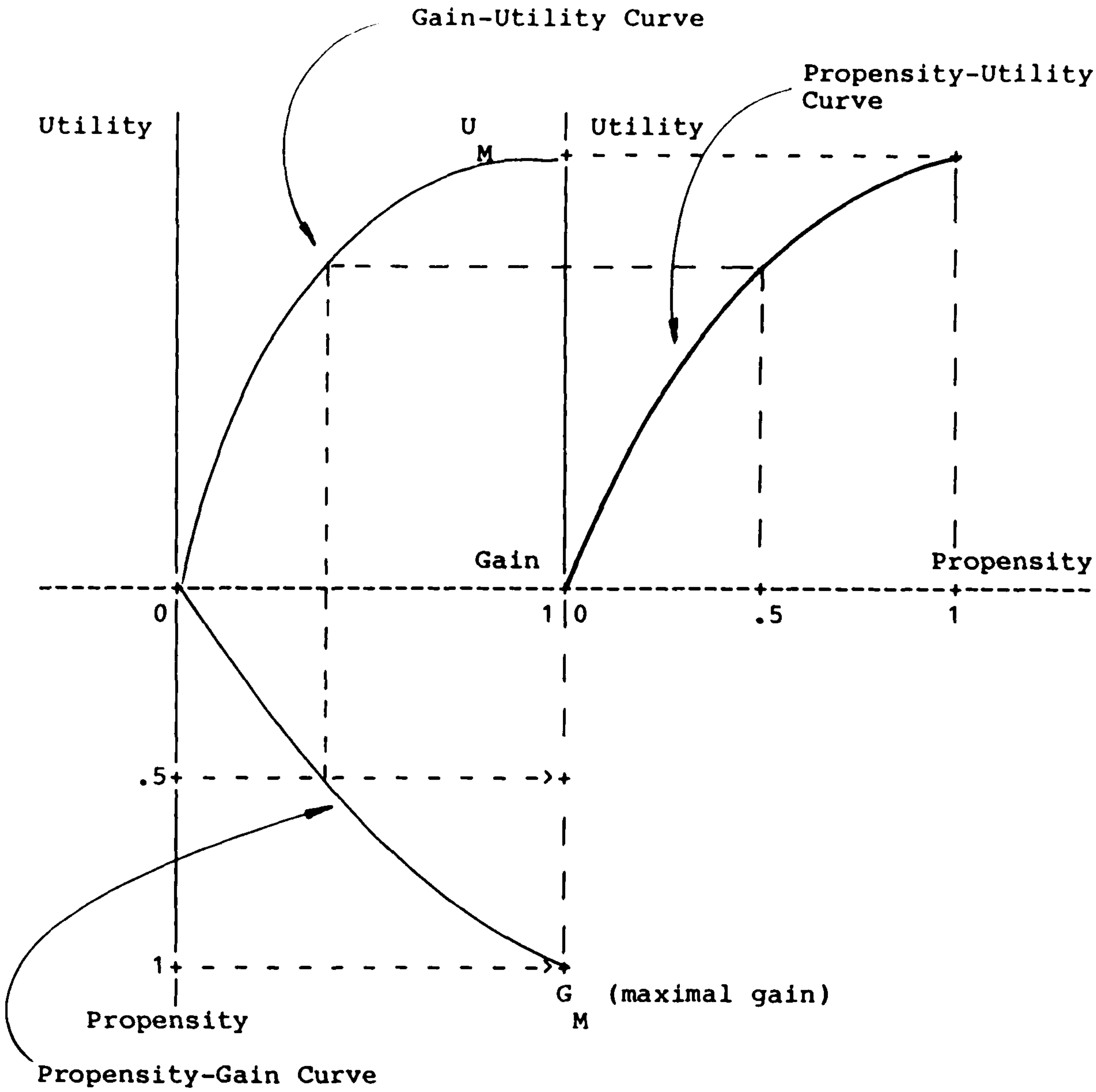


The Propensity-Gain Curve for Normalized Gain

Fig. 3.2.1.-4

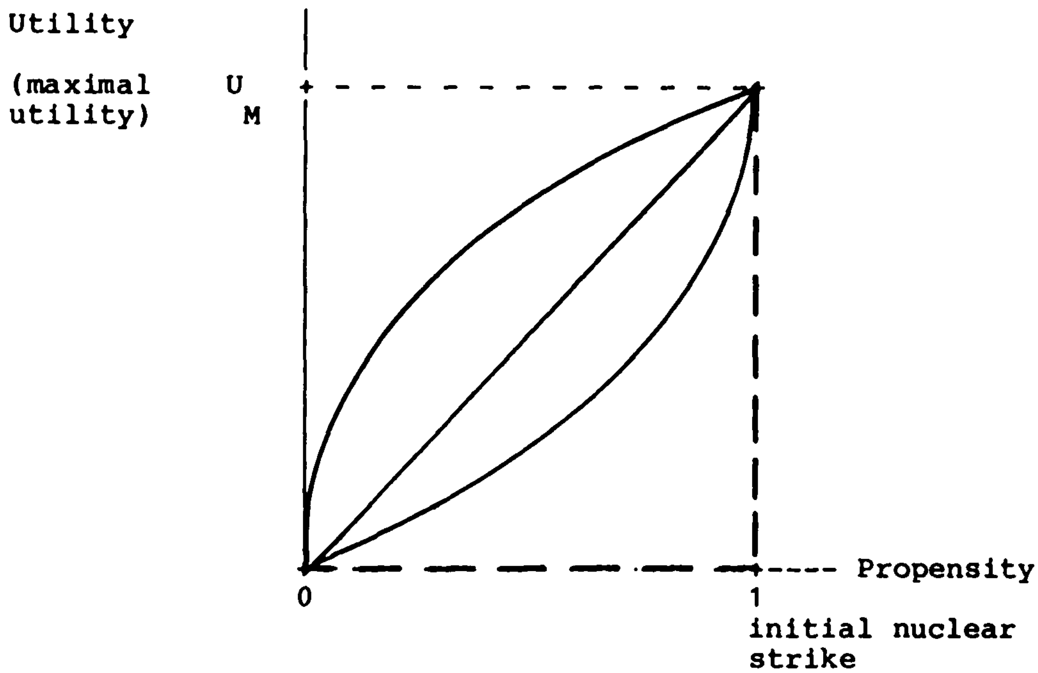
If one associates the propensity-gain curve with the gain-utility curve one obtains the propensity-utility curve. An example of geometrical construction of this last curve, for normalized gain is presented in Fig. 3.2.1.-5. One assumes that a conventional conflict precedes the nuclear one, that the propensity-gain curve is convex from below, and that its convexity is less marked than the concavity of the gain-utility curve. One observes that because it is possible to build four kinds of propensity-gain curves (including the case in which the nuclear conflict is not preceded by a conventional one), and one type of gain-utility curve, one can obtain four kinds of propensity-utility curves: convex, concave, a straight line, and a step-shaped curve. If the propensity-gain curve is concave from below, or it is a straight line, the propensity-utility curve is concave with respect to the origin. If the propensity-gain curve and the gain-utility curve are symmetrical with respect to the horizontal axis (the gain axis in Fig. 3.2.1.-5), then the security-utility curve is a straight line. If the concavity of the gain-utility curve is more marked than the convexity of the propensity-gain curve, then the propensity-utility curve is concave. In the opposite case, the propensity-utility curve is convex. But regardless of its shape, the propensity-utility curve is superiorly bounded for the propensity having values between zero and one. Its essential property is that all its values are finite. The four types of propensity-utility curves which might be hypothetically derived are presented in Fig. 3.2.1.-6.

* * * * *



Construction of the
Propensity-Utility Curve

Fig. 3.2.1.-5



--- the nuclear conflict is preceded by a conventional one
- - the nuclear conflict is not preceded by a conventional one

Types of Propensity-Utility Curves

Fig. 3.2.1.-6

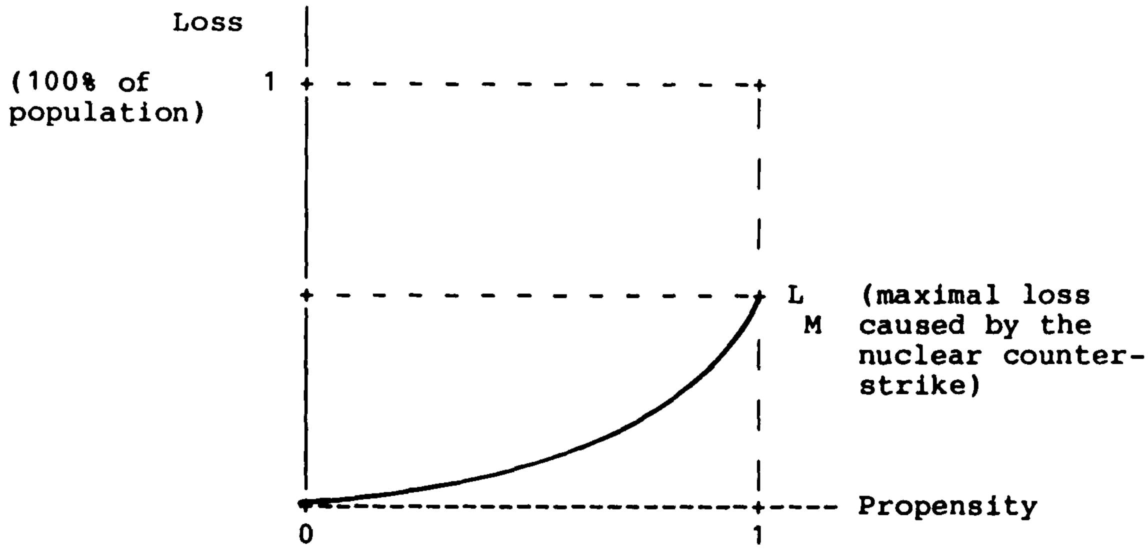
3.2.2. THE DISUTILITY OF THE COUNTERSTRIKE

If the target of a nuclear attack is also a nuclear power, it is normal for the power which envisages an initial strike - call it again the first nuclear power - to expect a nuclear riposte from its adversary. As a result, it evaluates not only the utility of its own first strike, but also the disutility of the opponent's nuclear retaliation. Consequently, in this chapter I will focus on the disutility function associated with the nuclear riposte.

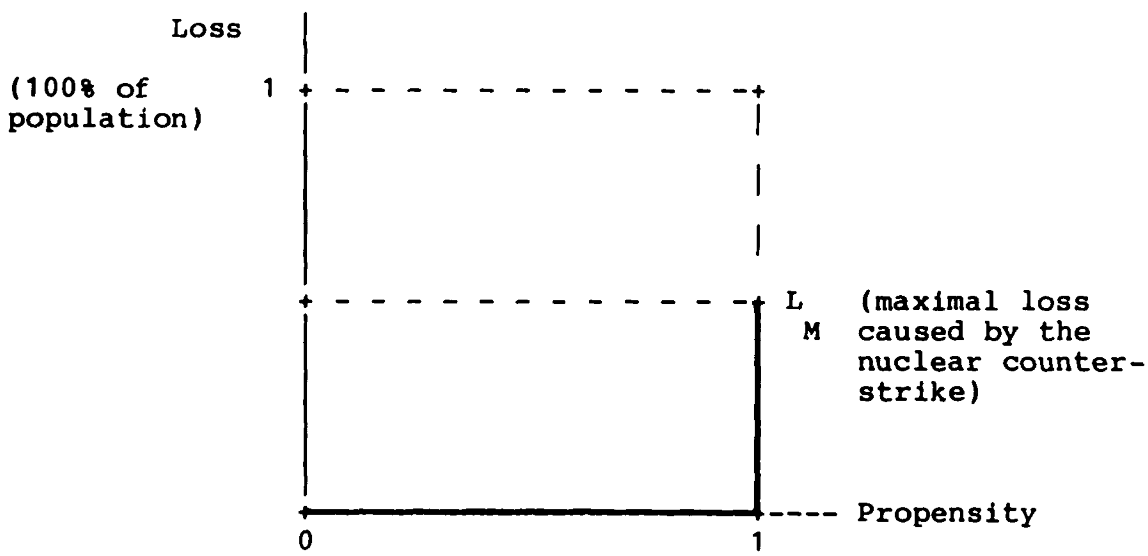
The curve describing the relationship between the propensity to use nuclear weapons and the disutility of the counterstrike results from associating two curves in a manner comparable to that used in the preceding section. The first curve describes the relation between the first power's propensity to use nuclear weapons, and its loss caused by the counterstrike with which the second power would respond. This loss may be evaluated by the percentage of the population which would be killed during the escalation of the conventional conflict which could lead to the use of nuclear weapons and during the nuclear confrontation itself. It is rational to consider that the loss would increase as the conventional conflict escalates, and that the maximal loss will be caused by the nuclear counterstrike. Consequently, such a curve should have a value of zero for no threat to utilize nuclear weapons, should increase when the propensity increases, and should be convex from the origin. The last property is required by the loss caused by the escalation of the conventional conflict and by the terrible destruction which would be caused by the counterstrike itself. The graph of this curve is shown in Fig. 3.2.2.-1 (a). The graph of the same curve under the assumption that a conventional conflict has not preceded the nuclear one is shown in Fig 3.2.2.-1 (b).

The curve describing the disutility of the loss should have a special shape. Because in Western civilization the disutility of death is infinite, the loss-disutility curve should tend to infinity, when the number of deaths approaches a percentage considered to be inadmissible within that civilization's system of values. This percentage, having an order of magnitude between 20% to 35% (see section 3.1., pp. 130) might be regarded as a kind of "inadmissibility threshold." Consequently, this curve should have a value of zero in the origin, should be convex from below, and must asymptotically increase to positive infinity for a loss of population approaching that "inadmissibility threshold." The graph of this curve is shown in Fig. 3.2.2.-2 (a). This particular curve describes the behavior of nuclear powers like the United States or the former Soviet Union. But it also suggests that there could be powers having their loss-disutility curves at its left or at its right.

The powers having a behavior described by loss-disutility curves positioned on the left side (Fig. 3.2.2.-2 (b)), are very sensitive to the losses caused by the counterstrike. Therefore they will not use nuclear weapons if they have them, or they



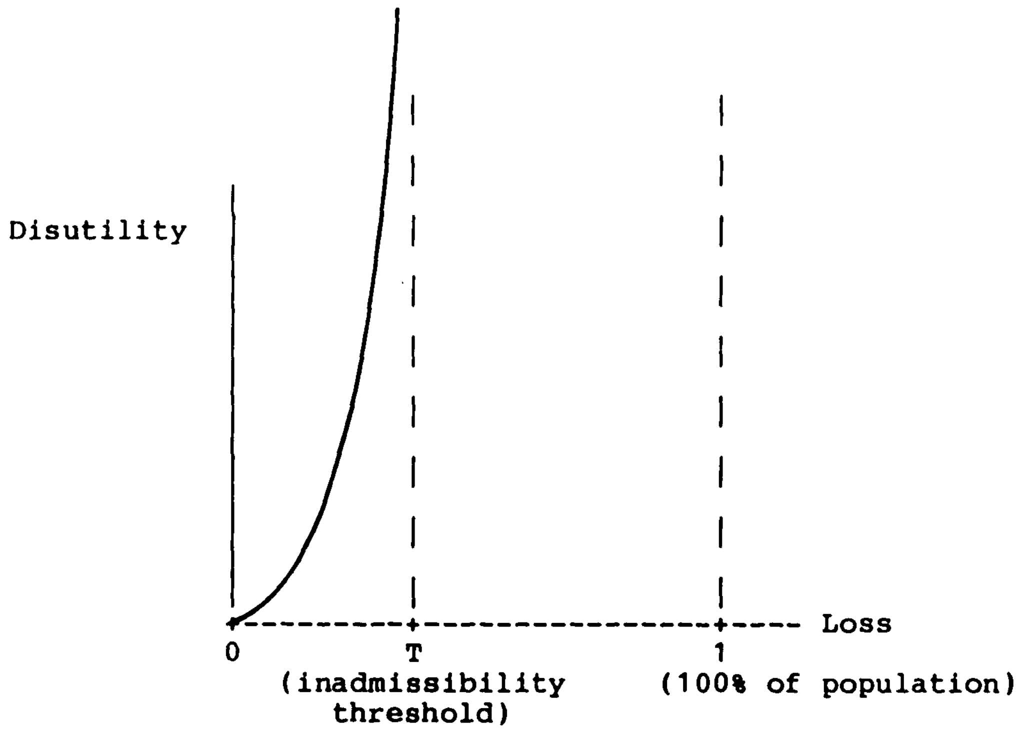
(a) a conventional conflict preceds the nuclear one



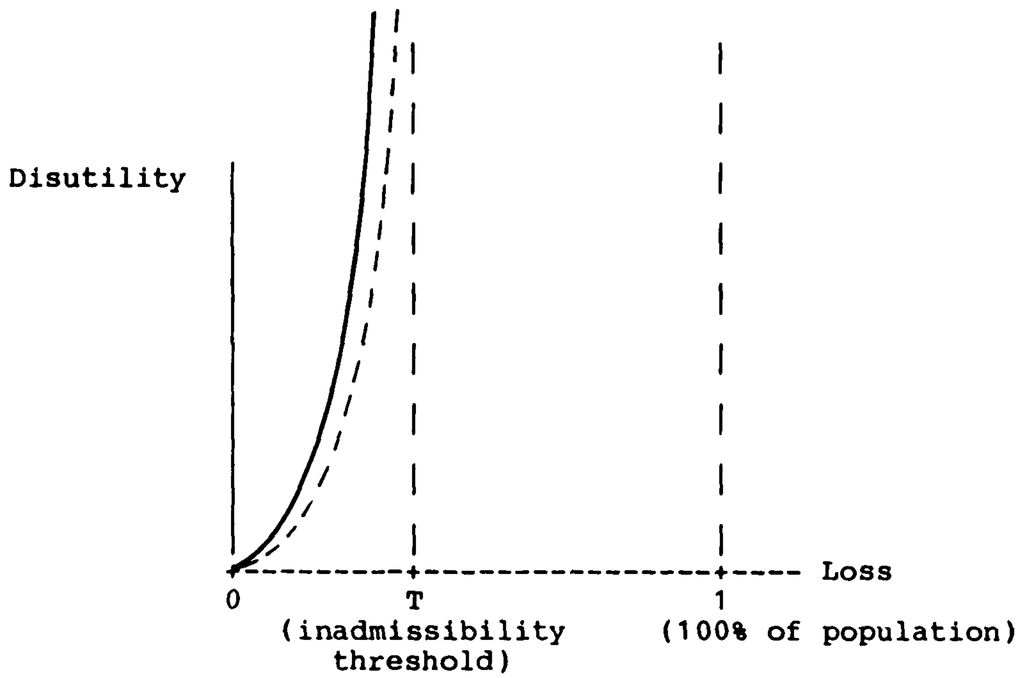
(b) the nuclear conflict is not preceded by a conventional one

The Propensity-Loss Curve

Fig. 3.2.2.-1



(a) Power having a regular behavior
(like the US or the former USSR)



(b) Country having a sensitive behavior

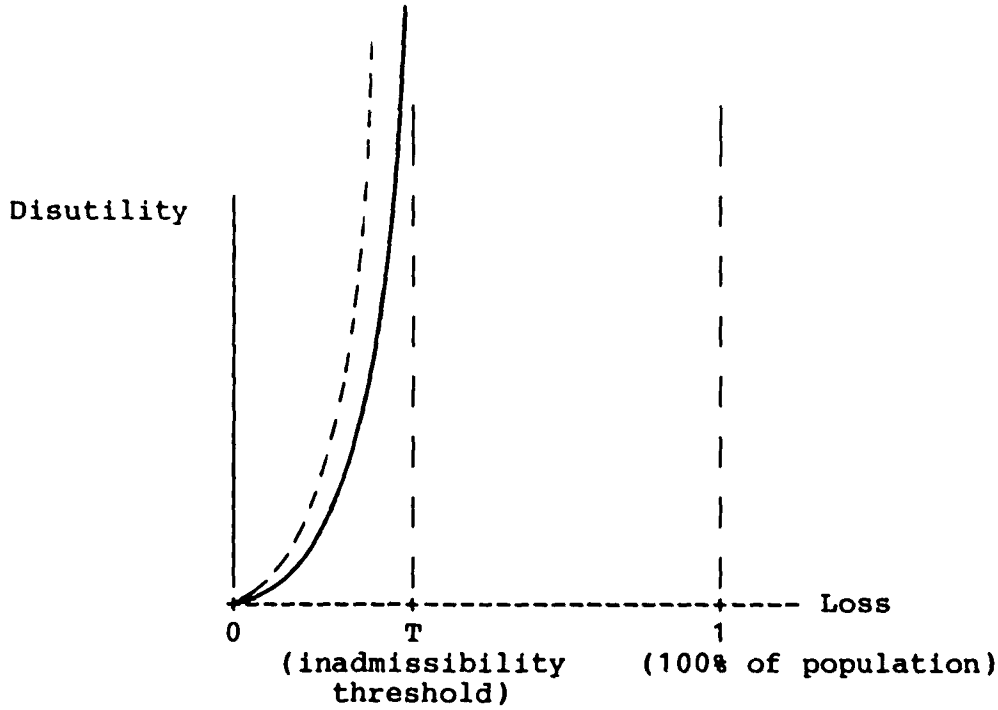
The Loss-Disutility Curve

Fig. 3.2.2.-2

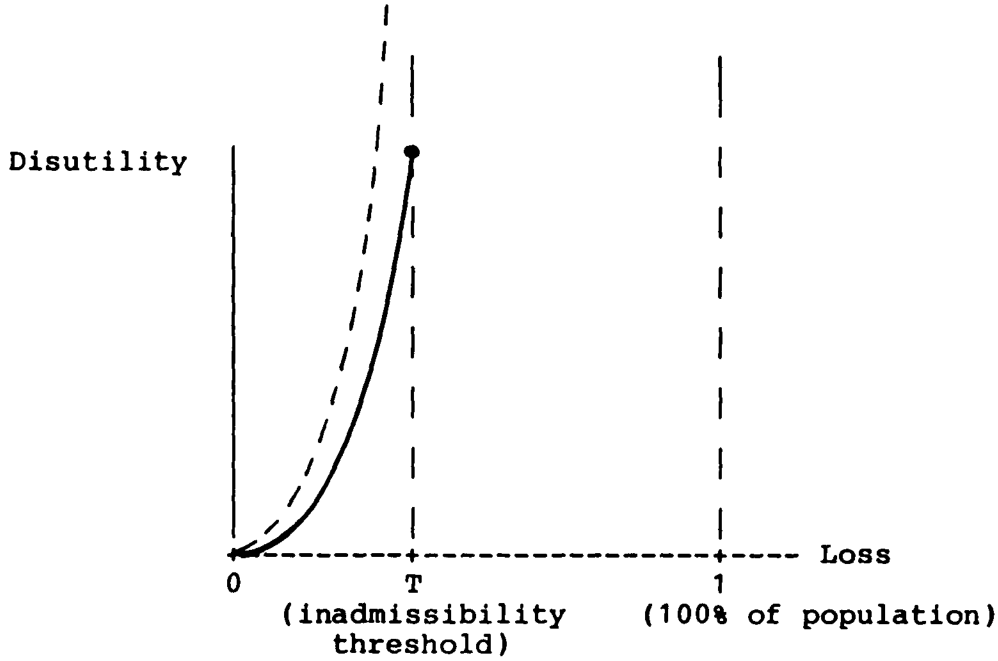
will not accept their development even should they have the technological capability to do it.

The countries which have loss-disutility curves positioned to the right are less sensitive to the loss caused by a counterstrike than the United States or the former Soviet Union might have been. If those curves tend to positive infinity, the difference between the powers whose behavior is described by them and the "regular" powers is only one of degree of sensitivity, as is shown in Fig. 3.2.2.-3 (a). But if those curves, although strongly increasing, intersect the threshold, as it is presented in Fig. 3.2.2.-3 (b) the difference is qualitative and essential. This means that the powers which have a behavior described by these curves consider that the disutility of the nuclear counterstrike, although it could be very high, is finite. Therefore, such countries might accept to initiate a first nuclear strike. Summarizing, I would differentiate three kinds of loss-disutility curves: (1) those corresponding to countries which do not accept the loss which might be caused by the nuclear counterstrike, (2) those referring to powers which have a theoretically flexible, but practically highly restrictive attitude, and (3) those which describe the behavior of countries which attach a finite disutility to the loss.

If the propensity-loss curve is associated with the loss-disutility curves, one results the propensity-disutility curves. They are convex from below. In the case of "normal" or highly sensitive powers they tend asymptotically to positive infinity for a propensity approaching one. But in the case of



(a) Country having arelatively less sensitive behavior than a regular country

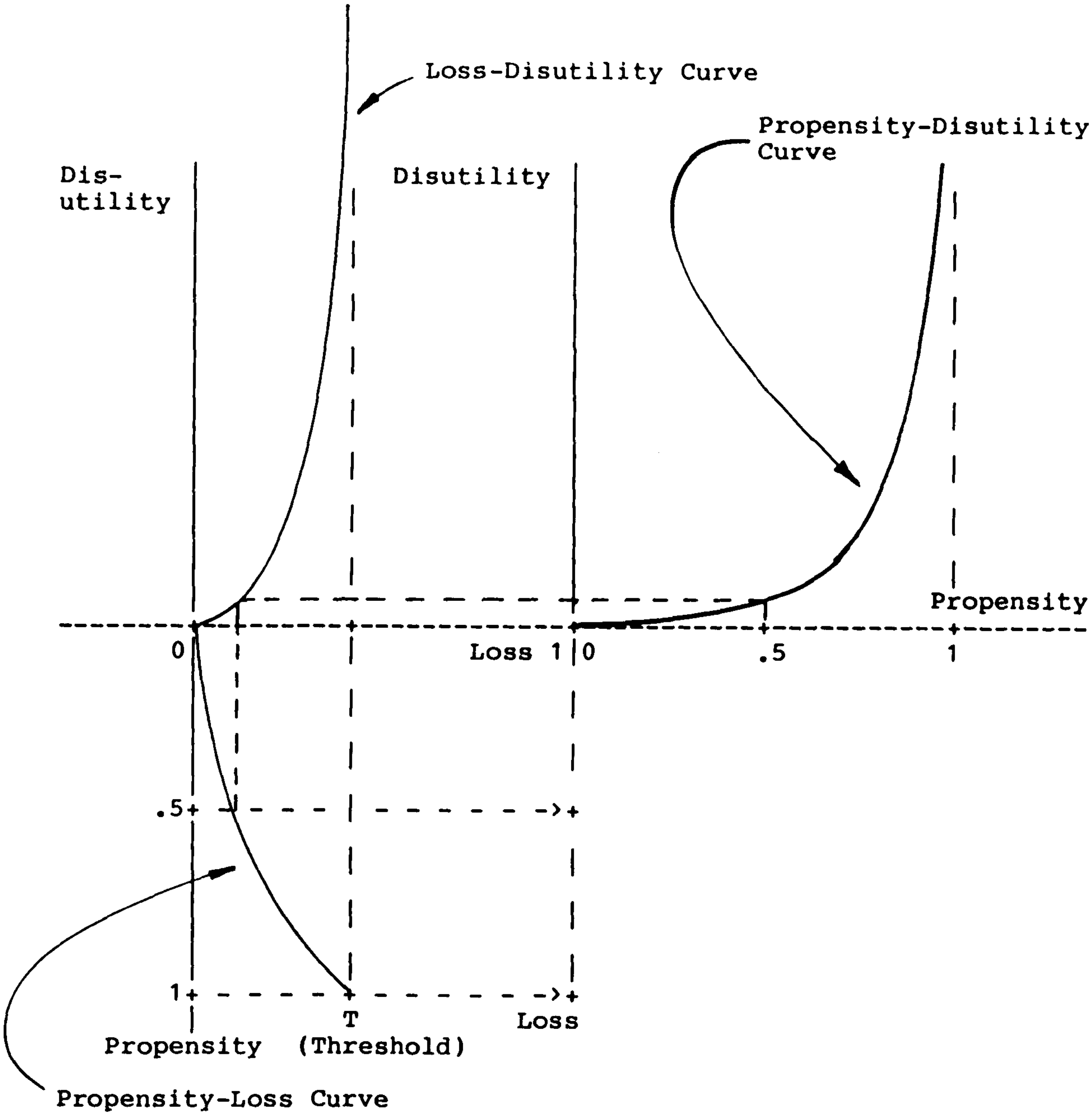


(b) Country associating a finite disutility to the loss

The Loss-Disutility Curve

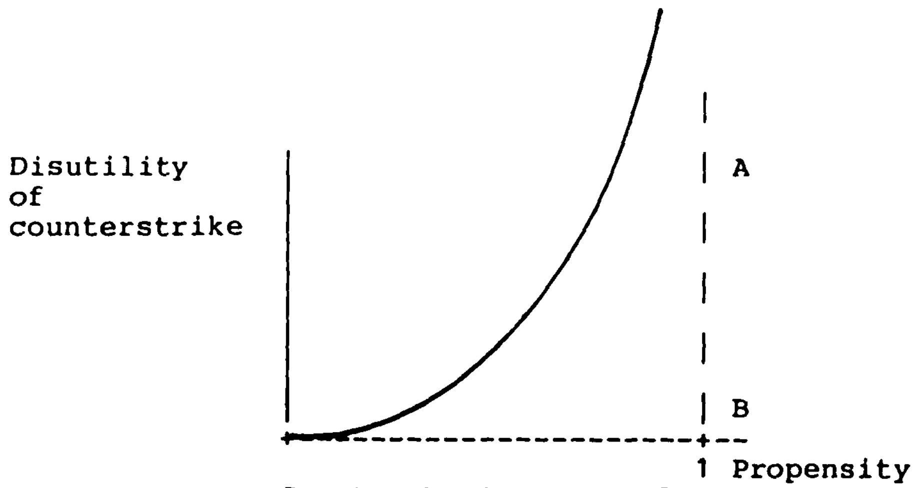
Fig. 3.2.2.-3

countries associating a finite disutility to the loss caused by the nuclear counterstrike they are limited, for propensity approaching one. The construction of the propensity-disutility curve for the regular case under the assumption that the nuclear conflict is preceded by a conventional one is presented in Fig. 3.2.2.-4. Various possible types of propensity-disutility curves are shown in Fig. 3.2.2.-5.

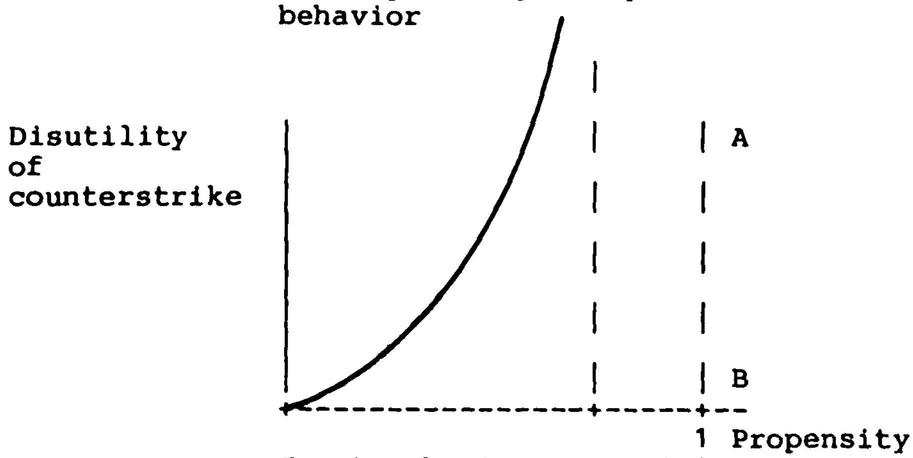


Construction of the
Propensity-Disutility Curve

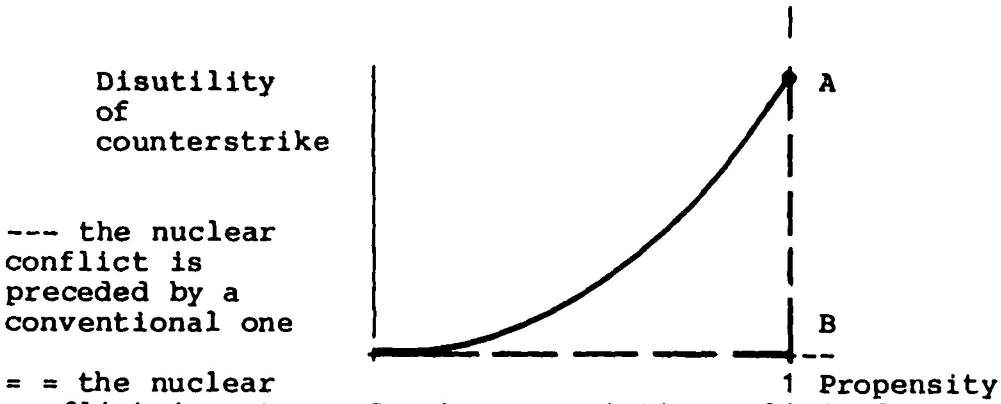
Fig. 3.2.2.-4



Country having a regular
behavior



Country having a sensitive
attitude



Country associating a limited
disutility to the loss caused by
the counterstrike

Types of Propensity-Disutility Curves

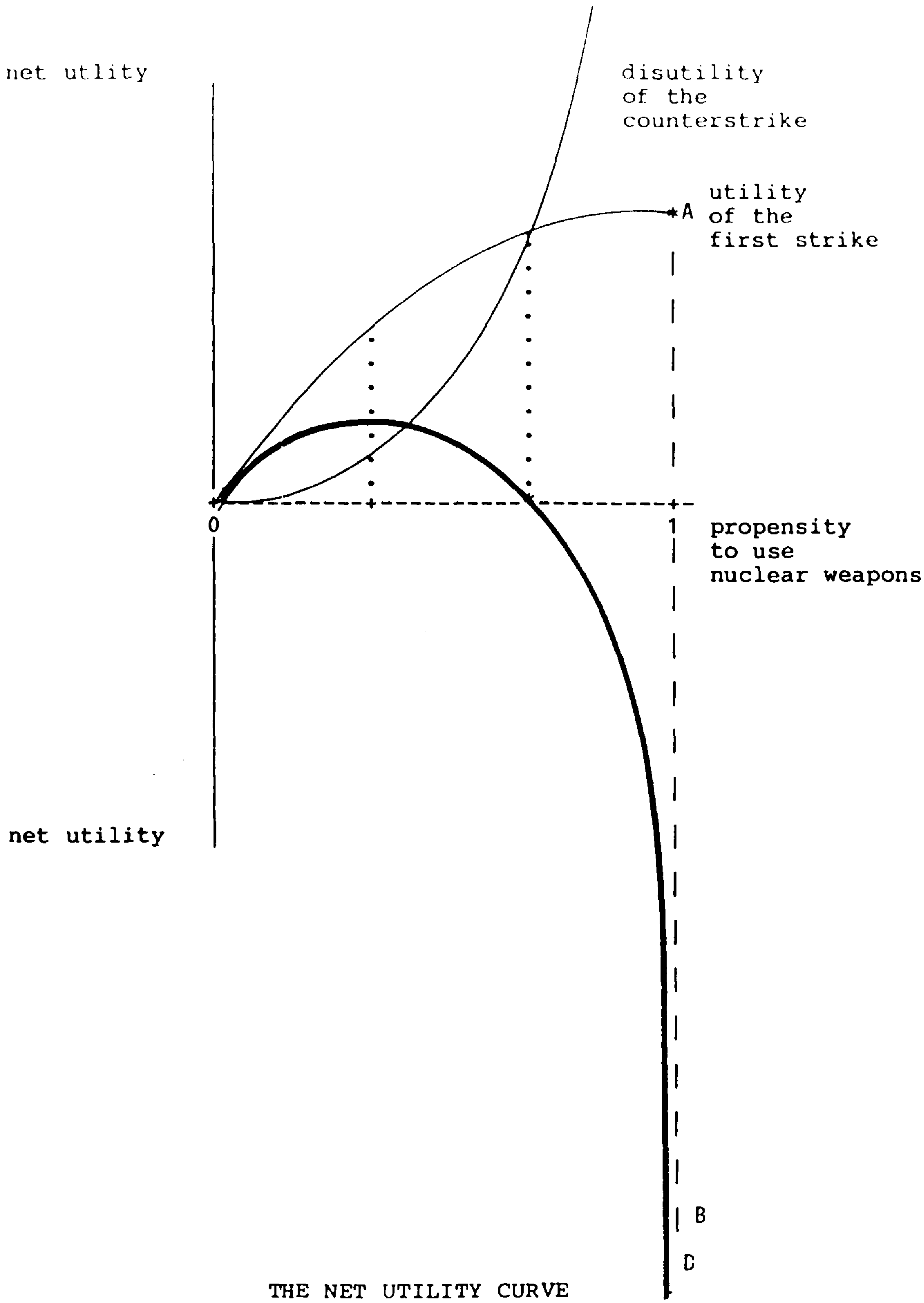
Fig. 3.2.2.-5

3.3. THE COST-BENEFIT (NET DISUTILITY) FUNCTION (CURVE)

3.3.1. THE CONSTRUCTION OF THE COST-BENEFIT (NET DISUTILITY) (FUNCTION) CURVE

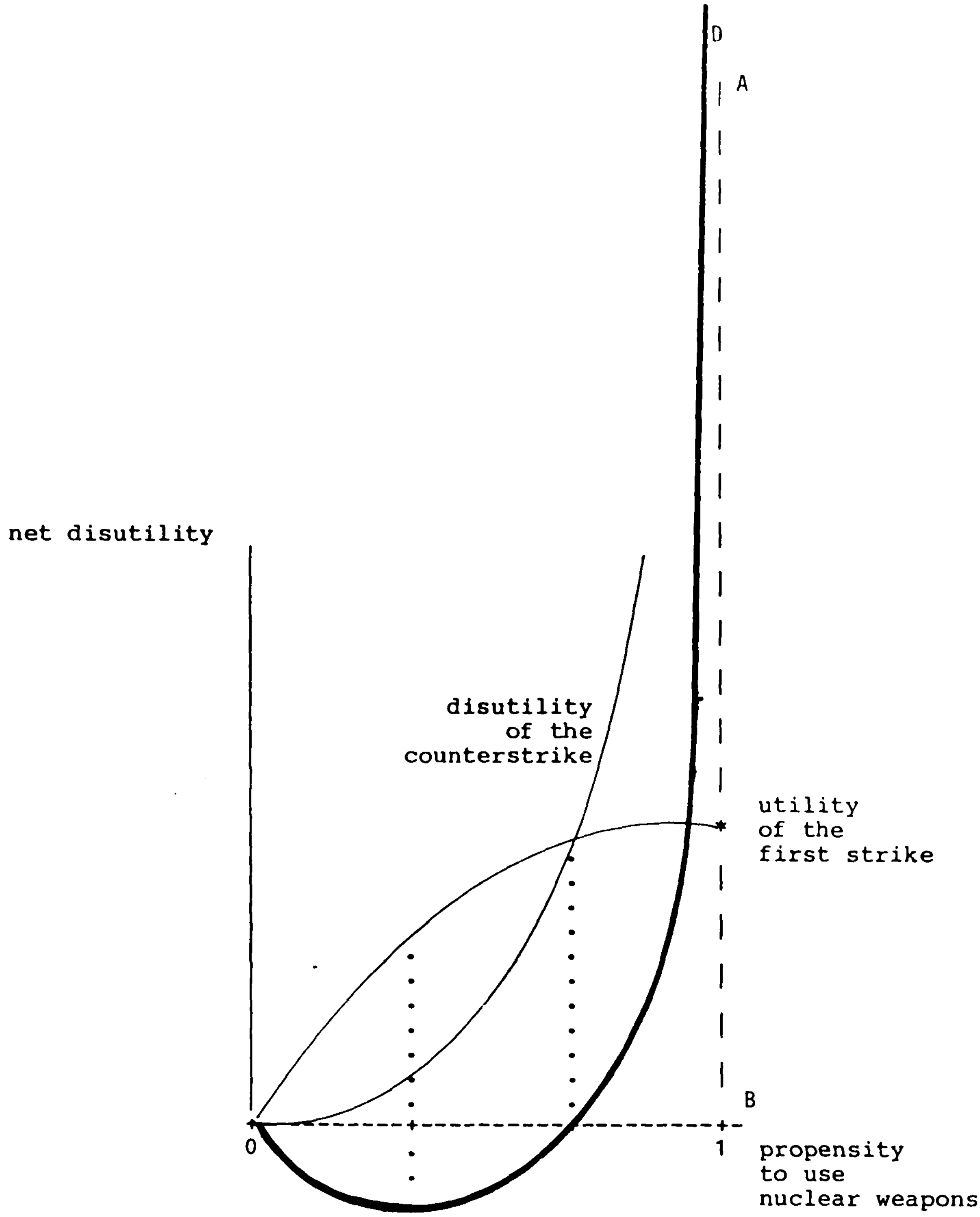
When a nuclear power envisages the use of its nuclear weapons, it does not separately take into consideration the utility of the first strike or the disutility of the nuclear riposte. It considers both simultaneously. Consequently, it is necessary to build a function/curve - call it the cost-benefit or net disutility function/curve - which will associate the utility and disutility functions/curves.

The most simple - but probably also the most intuitively convincing - way to build the cost-benefit curve would be to compute the difference between the utility of the first strike and the disutility of the riposte. It is also possible to consider the difference between the disutility of the riposte and the utility of the first strike, the cost-benefit function, or the net disutility curve, being exactly the same as in the first case but having the opposite sign. One observes that both curves could be built for all the utility and disutility functions described in the sections 3.2.1. and 3.2.2.. In Fig, 3.3.1.-1 is shown a net utility curve built under the assumption that the propensity-utility curve is concave (from below), and that the propensity-disutility curve tends to positive infinity. Its symmetrical net-disutility curve is presented in Fig. 3.3.1.-2. In both cases it is also assumed that a conventional conflict precedes the nuclear one.



THE NET UTILITY CURVE

Fig. 3.3.1.-1.



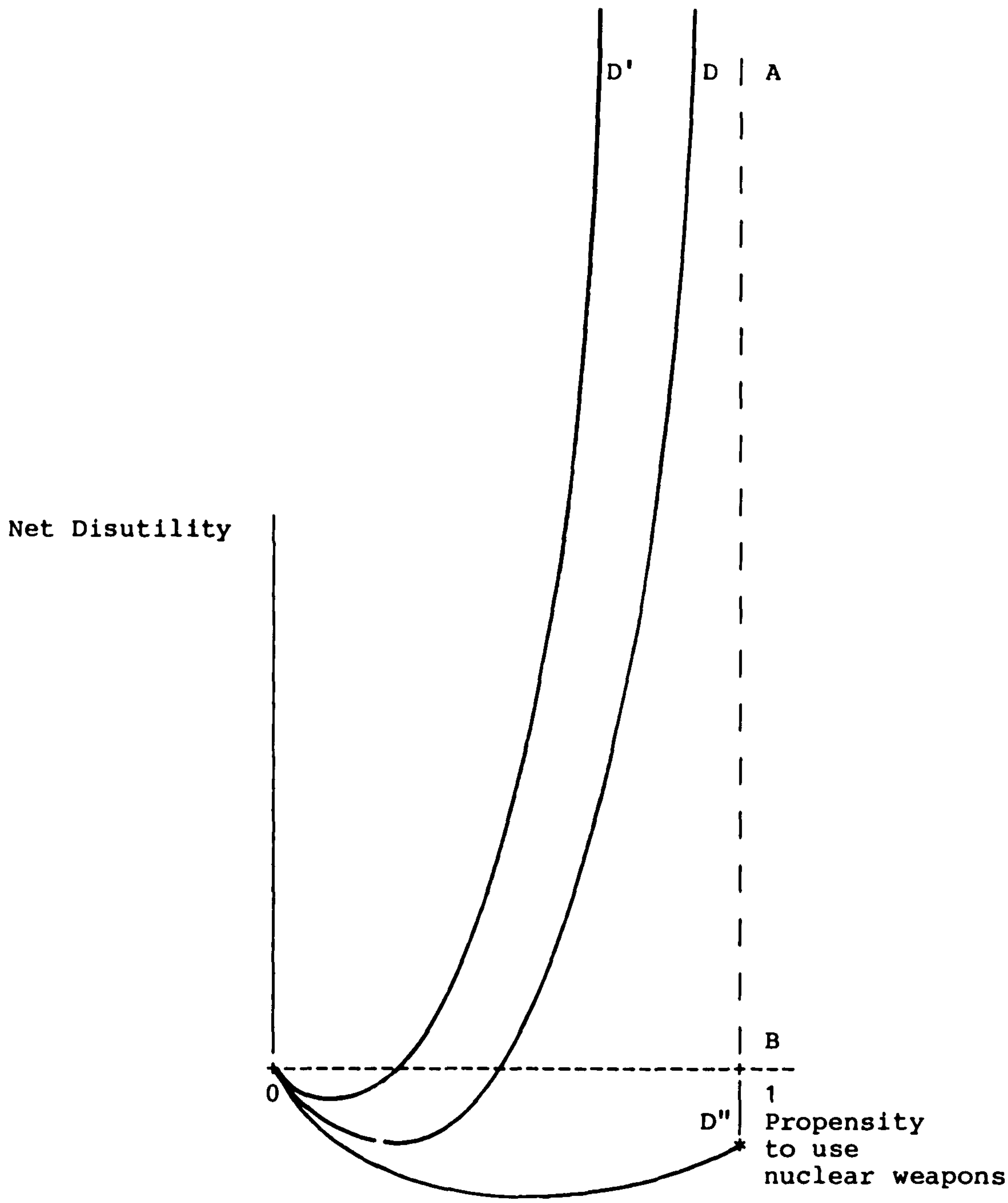
THE NET DISUTILITY CURVE

Fig. 3.3.1.-2

3.3.2. A CLASSIFICATION OF POTENTIAL NUCLEAR CONFLICTS USING THE NET DISUTILITY CURVE

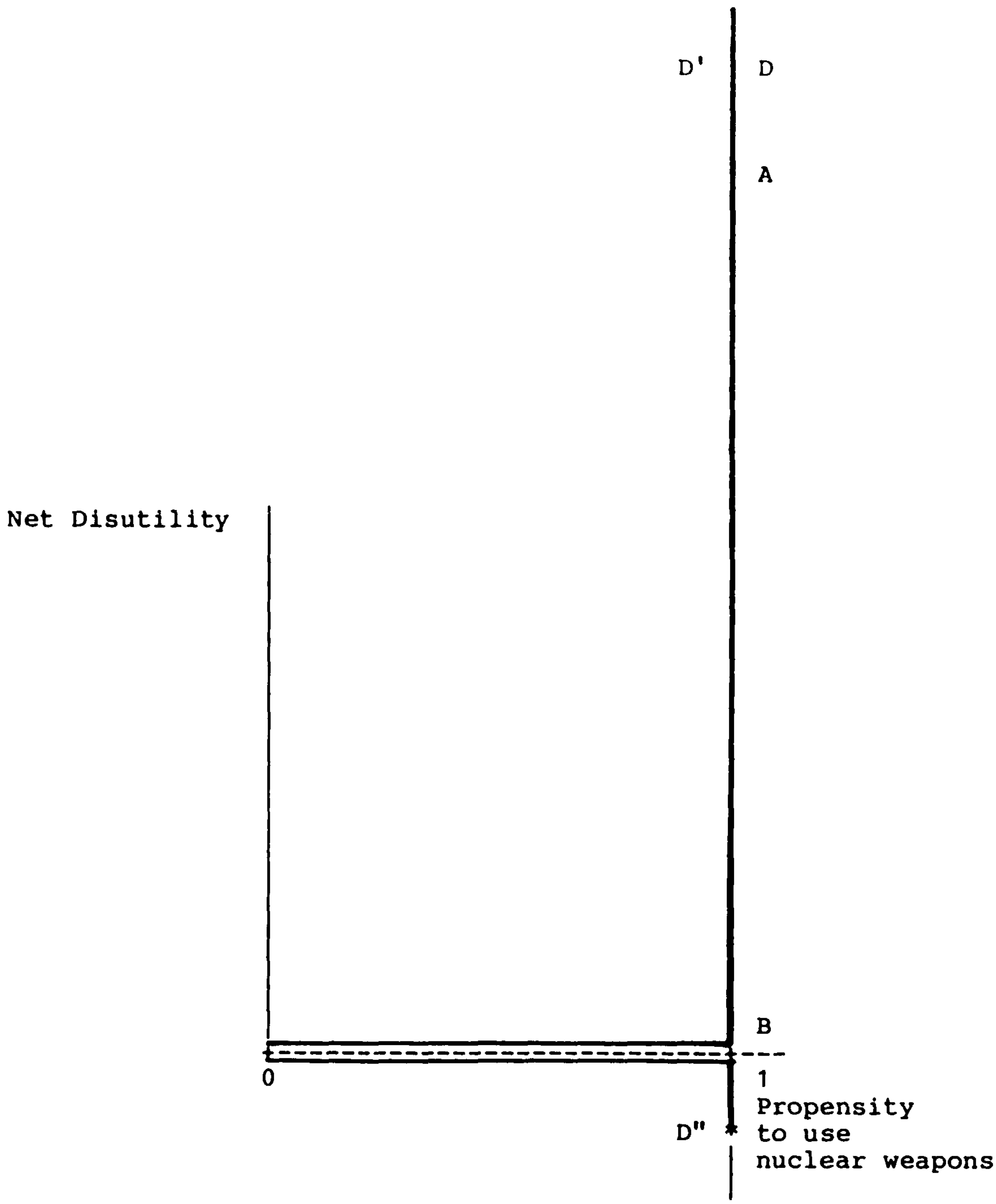
If one associates the propensity-utility curves shown in Fig. 3.2.1.-6 with the propensity-disutility curves presented in Fig. 3.2.2.-5., it is possible finally to draw the graphs included in Fig. 3.3.2.-1 and Fig. 3.3.2.-2. The first refers to the case in which a conventional conflict precedes the nuclear one. The second graph refers to a nuclear conflict which is not preceded by a conventional one. On the basis of these graphs, one may differentiate three kinds of powers (countries or coalitions):

- powers which do not accept initiating a nuclear conflict in any conditions: either because they do not have nuclear capabilities, or because the losses caused by the counterstrike are incompatible with their system of moral, political, and social values (their OD' net disutility curves are at the left of the OD curve in Fig. 3.3.2.-1);
- powers which have a theoretically flexible attitude concerning the first strike, but which are extremely reluctant to really use the nuclear weapons (their behavior is described by the OD curve);
- powers which might accept initiating a nuclear conflict but are fully aware of the consequences of the counterstrike (their OD" net disutility curves intersect the AB



Classification of Nuclear Powers (Countries or Coalitions) by Using the Net Disutility Curve (The nuclear conflict is preceded by a conventional one)

Fig. 3.3.2.-1



Classification of Nuclear Powers (Countries or Coalitions) by Using the Net Disutility Curve (The nuclear conflict is not preceded by a conventional one)

Fig. 3.3.2.-2

vertical line).

If one assumes for convenience, that each of these powers (countries or coalitions) might be either large or small, then it is possible to build the matrix shown in Table 3.3.2.-1. Reading on the row, we have the three kinds of countries or

		ATTACKED					
		N		F		Y	
		S	L	S	L	S	L
ATTACKER N	S						
	L						
F	S	*	*				
	L	*	*	*		*	
Y	S	*	*	*	*	*	
	L	*	*	*	*	*	*

N = powers which do not accept initiating a nuclear conflict
F = powers which have a theoretically flexible attitude
Y = powers which might accept initiating a nuclear conflict
S = small country
L = large country

Table 3.3.2.-1

coalitions in the role of initiators of the first nuclear strike. Reading on the column, we have their behavior in the role of attacked powers. One observes that in nearly half (17) of the total number of potential conflicts (36) the nuclear attack might be possible.

The matrix shows that the nuclear attack was avoided during the Cold War period because that was a conflict in which both adversaries were large powers with theoretically flexible, but practically extremely reluctant behavior in using nuclear weapons. The model of that conflict is the case 4.4. in the matrix: F.L. against F.L.. The British and the French nuclear forces were always regarded by the Soviets in connection with the American forces. And it was always obvious that a nuclear attack on Britain or France would imply a nuclear war with the United States. Consequently, thanks to the existence of N.A.T.O., the situation 4.3. from the matrix: F.L. against F.S., did not emerge during the cold war era.

* * * * *

3.4. LIMITS OF APPLICABILITY OF MUTUAL ASSURED DESTRUCTION DOCTRINE IN A MULTIPOLAR SYSTEM

3.4.1. LIMITATIONS CAUSED BY DOMESTIC FACTORS

At least three kinds of domestic limitations regarding the applicability of MAD in the future international system can be envisaged. They would be caused by:

- the appearance of nuclear powers having systems of political and moral values different or very different from those held by the US and USSR during the Cold War era;
- a high level of political and ethnic instability which would characterize some of the future nuclear powers, making the control of nuclear weapons uncertain;
- an increased possibility of technological failures and accidents as a result of the proliferation of nuclear weapons.

In the future international system (which will probably be multipolar), some actors which might have nuclear weapons will have different or very different systems of political and moral values from those held by the superpowers during the Cold War era. Consequently, the assumptions of rationality and comparable ethical behavior concerning a nuclear conflict might become irrelevant.

Focusing again on the matrix shown in Fig. 3.3.2.-1, and assuming that the propensity to initiate a nuclear attack may be - for convenience - evaluated by using the following values:

LEVEL OF PROPENSITY	
(blank)	zero
*	low
**	moderate
***	high

one might build the matrix shown in Table 3.4.1.-1 (I am, of course, convinced that various diverging opinions might be expressed with regard to this matrix. Therefore I would like to emphasize that I consider it only as a basis for discussions and not a definitive result.)

			ATTACKED					
			N		F		Y	
			S	L	S	L	S	L
ATTACKER	N	S						
		L						
	F	S	***	***				
		L	***	***	**		*	
	Y	S	***	***	**	*	*	
		L	***	***	***	**	**	*

Table 3.4.1.-1

Some of the potential future conflicts will probably be of the kind shown below the main diagonal of this matrix, toward the lower left corner. Consequently, the probability of a nuclear conflict might be higher in a multipolar balance of power system than it was in the bipolar one. The vulnerability based deterrence will remain an important means to prevent the outbreak of a nuclear war. But its area of action will have limits.

A second limitation will be caused by the political instability that will undoubtedly exist inside some of the future nuclear powers. Because of that instability, one or another group of people opposing the government, or having only "divergent opinions" could gain partial or total control of the nuclear weapons. As a result they could initiate a first strike, without the agreement of the government recognized by the international community. At the same time, the potential victim of the strike does not know sufficiently well against whom to direct the counterstrike. And this might be regarded as a kind of safeguard by the people from the first country who would like to initiate the first strike. The hope that the counterstrike might be not so devastating or that it might be directed against another population group or area of the country diminishes the deterrent character of the counterstrike.

The third limit caused by internal factors consists in the fact that the probability of an accidental unauthorized attack, caused by technical failure or human error will be higher in some less industrialized countries, than it has been in the highly industrialized countries which have owned nuclear weapons until present.

* * * * * * *

3.4.2. LIMITATIONS CAUSED BY STRUCTURAL SYSTEMIC FACTORS

In addition to the domestic factors that would probably limit the role of vulnerability based deterrence there will be structural factors embedded in the configuration of the international system.

After 1970, during the second half of the Cold War era, when MAD emerged as a determinant strategic nuclear doctrine, the two superpowers had relatively equal strategic nuclear arsenals and means of delivery. But, in the future multipolar world, there will be several major actors having advanced strategic nuclear weapons and corresponding means of delivery, even without taking into consideration the medium and small nuclear powers. Moreover, this will imply more than a numerical difference. The new configuration will be qualitatively different from the former bipolar structure.

The structural causes which would probably limit the deterrent action of MAD can be explained in the following manner. In a bipolar system, each actor may be equal to the other. But in a balance of power system with three or more actors (that own equal or comparable strategic nuclear forces) even though the strategic nuclear forces of each power are equal or comparable to those of any other, they can not be equal to the sum of strategic nuclear forces owned by all the others. In a bipolar system the others and the other are the same. In a balance of power multipolar system they are not. One observes that in making this remark, I consider that in the nuclear era, the theoretical concept of balance of power system implies that the main actors have equal or comparable strategic nuclear forces (as it also was the case of the bipolar system). In reality, in the emerging international system it will be of course possible to have significant differences from one actor to another. But, if this should be the case, then the system's character must be questioned. It should be analysed to what extent it would be a balance of power system, and to what extent not.

Nevertheless, even if the assumption of equality or comparability is accepted, one could formulate objections against the rationale of this first structural limitation to the role of vulnerability based deterrence . For this reason, it is necessary to make a brief comment regarding the relationship between the nuclear armaments and the conventional ones, and that between the quantities of nuclear weapons themselves.

It is obvious that because of their overwhelming destructive capability, nuclear weapons cannot be balanced by other offensive weapons. At the same time, the number of warheads, the number of means of delivery, and their technological performance must be regarded as significant too. At the present technological level, and even more at the future level, the differences in number and performance are and will be important. In the nuclear era, one cannot consider that a balance of power exists among independent (non-allied) actors that have significantly different nuclear arsenals.

Nuclear weapons' characteristics make the situation different from that which existed during the European Concert's period. At that time, Britain had the mightiest navy in the world, but a relatively small army. France and Germany had large armies, but relatively weak navies. The Russian army was perhaps larger than any other, but it was regarded as less efficient than the French and especially the German one. For these reasons, each actor perceived the others as having a power equal or comparable to its own, and was "playing" in the "concert." But when Germany decided to develop a high seas fleet comparable to the British one, the strain gradually increased, and the European Concert was replaced by the two opposite alliances. The addition of a powerful navy to the most efficient European army destroyed the balance.

In the era of conventional aramaments, compensating with one kind of military power for the lack of another, or adding one type of military power to another, was completely rational. But, in the nuclear age, the addition of even the most powerful conventional weapons to the nuclear ones would only be partly relevant. It would be like adding a finite quantity to infinity. The infinity would not be significantly affected. Nevertheless, it would be erroneous to infer from this correct assertion another one that is not. The fact that adding conventional weapons to strategic nuclear weapons, does not significantly affect the strategic capability of a country does not mean than adding new strategic nuclear weapons to the existing strategic nuclear weapons is irrelevant. The power of one hundred nuclear warheads could be regarded as extraordinary (perhaps even infinite !) if it is compared to the power of the classical armaments owned by a medium country during the World War II period. But it would be an error to consider it equivalent to the power of ten thousand nuclear warheads. (the infinity is a tricky concept - the number of points of a circle is infinite, but the circle could be larger or smaller !)

Taking into consideration these specifications, it seems to me that it is reasonable to condider that the potential insecurity, strain and structural instability might be higher in a multipolar balance of power system. Although MAD can deter a first strike in a bilateral conflict, it can only partly discourage a multilateral first strike against one actor in a multilateral conflict. To feel more secure, the actors might improve the technical performance of the nuclear weapons and systems of delivery which might fuel a new multilateral arms race. They might in parallel conclude alliances in a tendency toward a bipolar structure. Such a structure being less strainful because "the other is equal to the others," and because the entropy is smaller.

A second limitation might be caused by the fact that **in a multipolar system, it is possible to develop unequal asymmetrical alliances (three against two, four against one) among actors who all have nuclear weapons.** And this means that the equality, or at least comparability, assumption, will be significantly eroded. But this assumption is essential, because in the case of a conflict between a very powerful actor (superpower, coalition of significant nuclear powers) and a small nuclear power having relatively primitive means of delivery and being located at a relatively long distance, the first one can use nuclear weapons and win. Because the number of first actor's expected deaths would be significantly lower than the 20% - 25% admissible threshold, a first nuclear strike might be a reasonable and efficient option. Hence, the role of vulnerability based deterrence in a multipolar balance of power system would probably be relatively more limited that in a bipolar one.

The third structural limitation will be caused by the fact that **the majority of the emerging nuclear powers are continental powers, many with common borders. Therefore, they are more vulnerable to attacks than the United States which is an "insular" country.** This geographical configuration might constitute an incentive for the continental powers to develop strategic defensive systems. And, as a result, the United States would react by developing its own defensive system in order to diminish the potential imbalance.

* * * * * * * * *

3.5. CONCLUSIONS

In accordance with the conclusions derived at the end of the second chapter, the emerging international system will be a balance of power multipolar one. In that system the major actors (with the probable exception of Japan) will have nuclear weapons and advanced means of intercontinental delivery. Some of the intermediary and small powers will also own nuclear weapons and means of regional delivery.

The Mutual Assured Destruction doctrine has been developed in the conditions of a bipolar system, in which the two main opponents had equal or at least comparable nuclear arsenals and means of delivery. However, they had very different, even opposed, political, social and economic systems, they had a common ethical conception regarding the destruction of very large portions of their population.

In the future multipolar system, in which probably an increased number of actors will have nuclear weapons and appropriate means of delivery, the conditions in which the MAD doctrine was developed will cease to exist, and consequently its assumptions will be only partly met. Therefore several limitations regarding its applicability will appear. The most probable internal causes of these limitations will be:

1. the behavior of those countries and governments having political and moral systems allowing them to accept mas-

sive losses of their own population for destroying their adversary, especially if that is considerably less powerful;

2. the weakening of central control over nuclear weapons, as a result of political instability existing in some countries having nuclear arsenals;

3. the relatively lower level of technological safeguards in some of the future nuclear powers, having as effect an increased probability of an accidental launching of a nuclear missile.

The structural systemic properties of the future international system which would be partly incompatible with the MAD doctrine's assumptions are the following:

1. in a balance of power international system having three or more actors, which own equal or comparable strategic offensive nuclear forces, although the nuclear forces of an actor might be equal to those of any other actor, they cannot be equal to the combined forces of all the other actors included in the system;

2. in a balance of power international system including several nuclear powers it is possible to build unequal, asymmetrical coalitions among nuclear powers;

3. some of the emerging nuclear powers will be continental ones, being more vulnerable to attacks than the "insular" ones.

As a consequence of the joint action of the domestic and structural systemic limitations, reliance on vulnerability based deterrence alone could become dangerous. It could cause a multilateral strategic nuclear arms race. In order to prevent it, and the dangerous instability which might be caused by it, it might become necessary to create new political and military structures and to continue the research and development of strategic defensive systems. As I have shown in chapter 1, important strategic questions and major technical challenges have been associated with the development of these systems, but there have also been encouraging elements. All that has been achieved until the present indicates that a strategic defense, conceived on a realistic scale, can be practically achieved. Therefore it is possible to give the following answers to the two questions formulated in section 3.1. (p. 142):

1. **in the future multipolar balance of power international system, the vulnerability based deterrence, embodied in the MAD doctrine will continue to have a significant role in preventing a nuclear conflict, but it will be limited by domestic and structural systemic factors. Therefore, a complex mixed strategy should be developed.**
2. **This complex mixed strategy must associate strategic defense with strategic offense in order to prevent the potential dangers which might be caused by a partial failure of vulnerability based deterrence to prevent a nuclear conflict.**

Hence, on the basis of these remarks, I dedicate the next two chapters of this dissertation to the study of the impact of strategic defensive systems on strategic offensive arms race (in)stability, and to their relationship with strategic offensive systems in general.

I use the Dynamic System Theory as a general framework of analysis, and I develop several mathematical models and corresponding computer programs for simulating various defense policies. In the last section of the next chapter I employ a model and the adequate software for showing how the strategic offensive arms race's spiral occurs. In the fifth chapter I include three optimal control models for analysing the relationship between the development of strategic offensive systems and the development of strategic defensive ones. I also simulate various possible policies by using my computer programs.

* * * * * * * * *

4. STRATEGIC DEFENSE: A MEANS TO STABILIZE THE STRATEGIC OFFENSIVE ARMS RACE

4.1. UTILITY OF AN APPROACH BASED ON SYSTEM ANALYSIS

In the preceding chapter I have shown that in a multipolar balance of power international system, the vulnerability based deterrence might have a relatively limited role in preventing a nuclear conflict. In the first chapter, on the other side, I have briefly presented the controversy regarding the (de)stabilizing effect of SDI. For a better understanding of the relationship between strategic defense and offense I develop several mathematical models based on Dynamic System Analysis. I focus in this chapter on the instability of a strategic offensive arms race, and on the possibility to control its dynamics by developing strategic defensive systems. Furthermore, I study the optimal relationship between the development of defensive and offensive systems in the next (and last) chapter of this dissertation. It seems to me that a mathematical modeling approach based on Dynamic System Analysis allows a clearer definition of concepts like stability, security, and level of analysis. At the same time, this kind of analysis provides a more consistent formulation of some processes like the influence of strategic defense systems development on the evolution of strategic offensive weapons, optimal allocation of financial resources, and security optimization. In this chapter, and in the next one I am using Dynamic System Analysis as a mathematical framework of analysis for two reasons. The problems to be studied have a significant degree of complexity, and they have elements evolving in time which cannot be studied by using static methods.

The models that I include in this dissertation are improved versions of a set of original models (USCO Reg. Number: TXU 239-905, May 1986) which I started to develop and to test since 1985. In that year I became interested in studying the political and strategic impact of President Reagan's Strategic Defense Initiative and I realized that three main ideas could be applied for describing the dynamic relationship between the strategic offensive weapons and strategic defensive systems. The first consisted in employing a system of non-homogeneous differential equations as a basic model. The second was to consider the strategic nuclear weapons (strategic nuclear warheads) as state variables, and the strategic defensive systems as the control variables. The third one was to use optimal control methods (the Euler-Lagrange Algorithm, the Pontryagin Principle) for deriving potentially optimal policies of developing strategic defensive systems. Since then I have continued to work (to improve, I hope) on those models, and I delivered several papers at national and international scientific conventions and conferences. A list of my papers is included at the end of the bibliography.

The use of systems of differential equations for modelling an arms race, has a long tradition initiated by Richardson's seminal book, Arms and Insecurity, published in

1960. This modelling technique was employed by several distinguished analysts of international security problems (Zinnes, Gillespie and Rubinson 1976; Baugh, 1976; Brito and Intriligator, 1984; Zinnes and Muncaster, 1984; etc.), and is considered at present a classical modelling method. The second basic principle, that of regarding the strategic defensive systems as control variables, was applied (to the best of my knowledge) only by Saperstein and Mayer-Kress in their simulation model for analysing the impact of SDI on the arms race, published in 1988 (two years after I developed my initial system of models).

The analysis of the strategic offensive arms race's stability made in section 4.2.2. of this chapter is comparable to that done by Zinnes, Gillespie and Rubinson in their 1976 article. But the two models included in section 4.2.3. for describing the arms race's spiral are (to the best of my knowledge) completely new.

The models presented in chapter 5. resemble other optimal control models because optimal control methods are used for deriving optimal trajectories for the state and control variables. But they are different, because of the manner in which the control variables and the criterion of optimum are defined.

From the point of view of the relationship that is described, my models resemble the Saperstein and Mayer-Kress's model too. Like them I consider the strategic defensive systems as control variables in order to study their influence on the strategic offensive arms race. But while they develop a discrete nonlinear simulation model without a criterion of optimization, I include in my models criteria of optimum. I develop them as optimal control models and I solve them using analytical methods. In comparison to my models, that of Saperstein and Mayer-Kress has the advantage of giving a better description of the relationship between strategic offensive and defensive systems. At the same time it has the disadvantage of not allowing the derivation and the subsequent study of optimal policies. These advantages and disadvantages are caused by the fact that the two authors do not have to solve an optimal control problem (as I do), but only to compute the solutions of a system of equations with differences under various sets of assumptions (different scenarios). Therefore my models and their model may be regarded as complementary. The characteristics of the optimal control methods require a kind of trade-off. It is possible to make a remarkably accurate description of the relationship between the two types of strategic systems (as the two authors do), but not to derive optimal trajectories. Or it is possible to compute the optimal paths, but to take into consideration only a relatively general and abstract description of the relationship (as I do).

With these specifications, I can continue my analysis of the relationship between the dynamics of strategic offensive weapons and that of strategic defensive systems by using concepts and methods of Dynamic Systems Analysis. I consider that:

- the international system includes n actors who have nuclear weapons or nuclear capabilities:

$$S = (S_1, S_2, \ldots S_n)$$

- the strategic offensive nuclear weapons owned by the actors at a t point in time are described by the state vector:

  $o(t) = (o_1(t), o_2(t), \dots o_n(t))$

  $o(t) \in O$

  $t \in T$

  where O is the set of state variables and T is the set of time points;

- the strategic defensive systems owned by the actors at a t point in time, are described by the control vector:

  $d(t) = (d_1(t), d_2(t), \dots d_n(t))$

  $d(t) \in D$

  $t \in T$

  where D is the set of control variables and T is also the set of time points.

In order to evaluate the components $o_i(t)$, $i = 1, \dots n$, one can employ standard (conventional) units, in a manner similar with that extensively used in macro-economics and economic statistics. Therefore, one considers that a standard unit of strategic offensive nuclear weapons represents the simplest and least efficient weapon owned by the nuclear powers at the t_o initial point in time of analysis. Each more efficient and more advanced system is evaluated as a multiple of the standard units. If a strategic offensive nuclear system is three times more efficient than the standard unit it will be counted as three systems, although it is only one item. In a similar manner, the components $d_i(t)$ are evaluated in standard units of strategic defensive systems representing the less efficient systems initially developed.

One assumes that the increase or decrease of strategic offensive weapons owned by each actor depends on its own quantity of this kind of weapons, on that owned by the other actors included in the system, and on the strategic defensive systems developed by itself and by the other actors. Consequently, it is possible to build the following differential system:

$$\dot{o}_1(t) = f_1(o_1(t), \ldots o_n(t), d_1(t), \ldots d_n(t), t)$$
$$\dot{o}_2(t) = f_2(o_1(t), \ldots o_n(t), d_1(t), \ldots d_n(t), t)$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\dot{o}_n(t) = f_n(o_1(t), \ldots o_n(t), d_1(t), \ldots d_n(t), t) \qquad (4.1.-1)$$

which can be also written in the following matrix expression:

$$\dot{o}(t) = F(o(t), d(t), t) \qquad (4.1.-2)$$

where F is a column vector $F = (f_1(t), \ldots f_n(t))$. One considers that in the general case each function f_i, $i = 1, 2, \ldots n$, depends not only on o(t) and d(t), but also on t. This means that the coefficients might be variable in time. Consequently, the model can describe the modification in time of the relationship among $\dot{o}(t)$, o(t), and d(t), and not only a constant in time relationship among them.

This system constitutes the basic model which will be specified in the next sections of this chapter for studying the following three problems:

- the (in)stability of a strategic arms race under the assumption that the actors own only strategic offensive nuclear weapons;
- the impact of the development of strategic defensive systems on the development of strategic offensive systems; and
- the optimal allocation of financial resources for building strategic defensive systems, and building, modernizing or dismantling strategic offensive systems.

* * * * * * * * *

4.2. THE (IN)STABILITY PROBLEM IN THE CASE OF STRATEGIC OFFENSIVE ARMS RACE

4.2.1. CHARACTERISTICS OF STRATEGIC OFFENSIVE ARMS RACE

The empirical data show that from the beginning of the nuclear era until the conclusion of the SALT I Treaty, the two superpowers were continously increasing the number of strategic nuclear warheads and means of delivery. After 1972, although the number of means of delivery was maintained within the limits prescribed by the treaty, the strategic offensive nuclear arms race did not stop. Two main courses have been followed. One was the development of MIRVs which allowed a considerable increase in the number of nuclear warheads carried by a missile. The other was a consistent improvement of missiles' accuracy. The first process slowed down during the early eighties when its main objectives and limits were attained. But the second process has continued. It became a part of a vigorous effort to improve general technological performances of strategic systems. As a result, the strategic offensive arms race did not stop. Only its main objective shifted from quantity to quality. Instead of a race for a greater number of weapons, it became a quest for superior quality.

The disintegration of the Soviet Union at the end of 1991 the dramatic changes taking place in that part of the world, and the new agreement regarding the drastic reduction of strategic nuclear forces until the year 2000/2003 by the United States and Russia make practically impossible any rigorous predictions. Without access to classified information one cannot affirm anything substantial with regard to the Russians' program of research and development to improve the quality of their strategic offensive weapons. It is also important to observe that a drastic reduction of the number of ICBMs is not necessary contradictory to the improvement of the remaining ones' performance. In this way, it is useful to remember that the development of MIRVed ICBMs was the response to the SALT I Treaty which limited the number of ICBMs.

The adversarial relationship between the United States and the former Soviet Union disappeared, but a relative level of suspicion remains between this country and the successor states which have nuclear weapons. Russia is not America's adversary, but is not - at least until now - its ally either. The simple fact that each country has the capability to totally destroy the other in a very short interval of time cannot be discounted by any person holding a high political or military position in Washington or Moscow. At the same time, the increase of efficiency of strategic armaments owned by the other nuclear powers, and the development of nuclear capabilities by developing countries give new dimensions to the strategic offensive arms race. And these new dimensions must be taken into consideration even under the most favorable assumptions concerning American-Russian relations. And, even if the real arms race between the two former adversaries is closed, we should always be aware of a potential one. Even if its probability is low, or very low, we must be prepared to start "running" again at any moment at which a future potential adversary or coalition of adversaries would initiate a new arms race.

Without taking into consideration the impact of the strategic defensive systems' development, a potential strategic offensive arms race in a multipolar balance of power international system would have the following characteristics:

- it would be multipolar;
- it would be fuelled by the structural strain associated with a balance of power multipolar system;
- although it might be more extended, it would be less acute than the race between the superpowers during the Cold War era, because although in a balance of power multipolar system the total strain is higher than in a bipolar one, the strain between actors might frequently be smaller;
- the race among the major nuclear powers would essentially be for superior quality;
- the race among intermediate and small nuclear power would give priority to quantity.

This potential strategic offensive arms race might be more complex than that which existed between the superpowers and it is therefore useful to analyse it by using a mathematical model.

* * * * * * *

4.2.2. A MODEL FOR THE STUDY OF A POTENTIAL STRATEGIC OFFENSIVE ARMS RACE

In Dynamic System Analysis, the concept of stability is associated with the trajectories of state variables under the assumption that the input variables are equal to zero for the period of time which is analysed. This means that when one analyses whether a system is stable or not, one considers that there are no connections between the environment and the system. The system is assumed to be free of external influences. Stability is considered as a characteristic internal property of the system.

On the basis of these remarks, one observes that the general model developed in section 4.1. can be used for studying the stability of a strategic arms race, supposing that strategic defensive systems are not developed. If the arms race is regarded as a regular quantitative one, increases in the values of $(o_1(t), o_2(t), \ldots o_n(t))$ represent increases in the quantities of strategic offensive weapons (nuclear warheads). If the arms race is regarded as a qualitative one the increases must be regarded as improvements in performance (which from the measurement point of view means a higher number of standard units for the same physical unit). If one does not consider strategic defensive systems, the (4.1.-1) differential system can be specified as it follows:

$$\begin{aligned} \dot{o}_1(t) &= f_1(o_1(t), \ldots o_n(t), t) \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \dot{o}_n(t) &= f_n(o_1(t), \ldots o_n(t), t) \end{aligned} \qquad (4.2.2.-1)$$

On the basis of the concept of stability described in section 2.3. (p. 103), it is possible to consider that a S system of n countries which own strategic offensive weapons is stable if the quantity of strategic offensive weapons owned by each country has the tendency to stabilize at a constant level after a specific interval of time regardless of the initial quantity.

For analysing the conditions in which the system is stable I will consider a particular case of the (4.2.2.-1) system, which simplifies the problem considerably from a mathematical point of view. I will suppose that the system is linear and homogeneous, that is:

- the effects or influences of all the stocks of strategic offensive weapons owned by the actors on the variation of the amount of strategic offensive weapons owned by one country are additive;
- the coefficients are constant in time.

In this particular case, the system is:

$$\begin{aligned} \dot{o}_1(t) &= a_{11} o_1(t) + a_{12} o_2(t) + \dots + a_{1n} o_n(t) \\ &\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \dot{o}_n(t) &= a_{n1} o_1(t) + a_{n2} o_2(t) + \dots + a_{nn} o_n(t) \end{aligned} \qquad (4.2.2.-2)$$

or written in a matrix expression

$$\dot{o}(t) = Ao(t) \qquad (4.2.2.-3)$$

where A is the following n x n matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n1} & \dots & a_{nn} \end{bmatrix} \qquad (4.2.2.-4)$$

If the $\lambda_1, \lambda_2, \dots \lambda_n$ roots of the characteristic equation of the (4.2.2.-2) differential system:

$$|A - \lambda E| = 0 \qquad (4.2.2.-5)$$

are real and different, the general solution of the (4.2.2.-2) system is:

$$\begin{aligned} o_1(t) &= C_{11} e^{\lambda_1 t} + C_{12} e^{\lambda_2 t} + \dots + C_{1n} e^{\lambda_n t} \\ &\dots\dots\dots\dots\dots\dots \\ o_n(t) &= C_{n1} e^{\lambda_1 t} + C_{n2} e^{\lambda_2 t} + \dots + C_{nn} e^{\lambda_n t} \end{aligned} \qquad (4.2.2.-6)$$

where $C_{11}, C_{12}, \dots C_{nn}$ are n x n constants. Among these constants, the n constants from the first row $C_{11}, C_{12}, \dots C_{1n}$, are independent and they may be calculated utilizing the initial conditions $o^o = o(t^o)$. The other n(n-1) constants are dependent on the n independent constants and they may be computed by using them.

If a real root λ_i of the (4.2.2.-5) characteristic equation is a multiple root and the order of multiplicity is j, then the (4.2.2.-10) solution will be modified as it follows:

$$o_1(t) = C_{11} e^{\lambda_1 t} + \dots + C_{1i} e^{\lambda_i t} + C_{1,i+1} t e^{\lambda_i t} + \dots +$$

$$C_{1,i+j-1} t^{j-1} e^{\lambda_i t} + \dots + C_{1n} e^{\lambda_n t}$$

....

$$o_n(t) = C_{n1} e^{\lambda_1 t} + \dots + C_{ni} e^{\lambda_i t} + C_{n,i+1} t e^{\lambda_i t} + \dots +$$

$$C_{n,i+j-1} t^{j-1} e^{\lambda_i t} + \dots + C_{nn} e^{\lambda_n t} \qquad (4.2.2.-7)$$

If the (4.2.2.-5) characteristic equation has a pair of conjugate complex roots:

$$\lambda_i = \alpha + i\beta$$

$$\lambda_{i+1} = \alpha - i\beta$$

then the general solution of the (4.2.2.-2) system will be:

$$o_1(t) = C_{11} e^{\lambda_1 t} + \dots + e^{\alpha t}(C_{1i} \cos\beta t + C_{1,i+1} \sin\beta t) + \dots +$$

$$C_{1n} e^{\lambda_n t}$$

....

$$o_n(t) = C_{n1} e^{\lambda_1 t} + \dots + e^{\alpha t}(C_{ni} \cos\beta t + C_{n,i+1} \sin\beta t) + \dots +$$

$$C_{nn} e^{\lambda_n t} \qquad (4.2.2.-8)$$

If the characteristic equation has real and different, real and multiple, and conjugate complex roots, then the general solution is a combination of the (4.2.2.-7) and (4.2.2.-8) solutions.

The necessary and sufficient condition that all the solutions of the (4.2.2.-6) dynamic system are asymptotically stable is:

$$\mathrm{Re}\lambda_i < 0 \text{ for all } i = (1,2, \ldots n)$$

In a general case this property may be studied by using numerical methods. In the particular case of a bipolar system, it is possible to obtain immediately the roots of the characteristic equation, and to subsequently discuss the system's stability.

One considers the (4.2.2.-2) system for n=2,

$$\begin{aligned} \dot{o}_1(t) &= a_{11} o_1(t) + a_{12} o_2(t) \\ \dot{o}_2(t) &= a_{21} o_1(t) + a_{22} o_2(t) \end{aligned} \qquad (4.2.2.\text{-}9)$$

and one supposes that

$$\begin{aligned} o_1(t_o) &= o_1^o \\ o_2(t_o) &= o_2^o \end{aligned} \qquad (4.2.2.\text{-}10)$$

where o_1^o and o_2^o are the stocks of strategic offensive weapons owned by the two potential opponents at the beginning of the time interval of analysis.

The a_{12} and a_{21} coefficients associate the variation of the amount of strategic offensive weapons owned by one opponent with the stock owned by the other. The a_{11} and a_{22} coefficients reflect the general policies of developing strategic offensive weapons pursued by each of the two potential opponents depending on their general interests and on the international system as a whole.

The characteristic equation of the (4.2.2.-9) system is:

$$\begin{vmatrix} a_{11}-\lambda & a_{12} \\ a_{21} & a_{22}-\lambda \end{vmatrix} = 0 \qquad (4.2.2.-11)$$

or

$$\lambda^2 - (a_{11} + a_{22})\lambda + (a_{11}a_{22} - a_{12}a_{21}) = 0 \qquad (4.2.2.-12)$$

and it has the following solutions:

$$\lambda_{1,2} = \frac{[a_{11} + a_{22}] \pm \sqrt{(a_{11} - a_{22})^2 + 4a_{12}a_{21}}}{2} \qquad (4.2.2.-13)$$

If one supposes that λ_1 and λ_2 are real and $\lambda_1 \neq \lambda_2$ the general solution of the (4.2.2.-9) system is:

$$o_1(t) = C_{11}e^{\lambda_1 t} + C_{12}e^{\lambda_2 t}$$

$$o_2(t) = C_{21}e^{\lambda_1 t} + C_{22}e^{\lambda_2 t} \qquad (4.2.2.-14)$$

where the constants C_{11} and C_{12} are independent and can be computed by using the (4.2.2.-10) initial conditions.

If the λ_1 and λ_2 roots are real and equal,

$$\lambda_1 = \lambda_2 = \lambda_o$$

the solutions of the (4.2.2.-9) system are:

$$o_1(t) = C_{11} e^{\lambda_o t} + C_{12} te^{\lambda_o t}$$
$$o_2(t) = C_{21} e^{\lambda_o t} + C_{22} te^{\lambda_o t} \qquad (4.2.2.-15)$$

and the constants $C_{11}, \ldots C_{22}$ have the same properties.

If the λ_1 and λ_2 roots are conjugate complex,

$$\lambda_{1,2} = \alpha \pm i\beta$$

the solutions are:

$$o_1(t) = e^{\alpha t}(C_{11} \cos\beta t + C_{12} \sin\beta t)$$
$$o_2(t) = e^{\alpha t}(C_{21} \cos\beta t + C_{22} \sin\beta t) \qquad (4.2.2.-16)$$

and the $C_{11}, \ldots C_{22}$ constants will have the same properties as in the first case. This last case has an interesting interpretation. The roots λ_1 and λ_2 can be conjugate complex only if one of the coefficients a_{12} or a_{21} is negative while the other is positive. But this would imply that one opponent would disarm because the other arms. This is contradictory to an adversarial relationship between two powers. It really corresponds to an alliance, in which one partner bases its security on the other's armament effort. The American nuclear umbrella covering Western Europe during the Cold War era is a good illustration of this case.

This system is asymptotically stable only if Re $\lambda_1 < 0$ and Re $\lambda_2 < 0$. If this condition is met, and the roots are real and different or real and multiple (in this case would be one root, having the order of multiplicity equal to 2), the stocks of strategic offensive weapons owned by the two powers tend to decrease regardless of their initial amounts of such weapons. If the roots are conjugate complex and the condition is met, the oscillations of the stocks of weapons are damped in time.

If Re $\lambda_1 = 0$ and Re $\lambda_2 = 0$ the system is oscillating and the amplitude of oscillations is constant.

If the roots are conjugate complex, and Reλ is positive, the oscillations of the stocks of nuclear offensive weapons are amplified.

If at least one real characteristic root is positive, the system is not stable from a mathematical point of view. It is obvious that from the model's point of view, negative trajectories are meaningless, although from a general mathematical point of view they are completely rational. Consequently, if the system is not stable, and the state trajectory(-ies) decreases to negative infinity one should take into consideration only the positive segments of the paths. And, they have such segments because the initial conditions are always positive. As a result this case can be considered as a kind of quasi-stability from the point of view of the model, although it is a case of instability from a mathematical point of view.

On the basis of the characteristic equation one observes that:

$$\lambda_1 + \lambda_2 = a_{11} + a_{22}$$
$$\lambda_1 * \lambda_2 = a_{11} a_{22} - a_{12} a_{21} \qquad (4.2.2.-17)$$

Therefore, it is possible to have stable trajectories of of $o_1(t)$ and $o_2(t)$ only in two cases:

1. $a_{11} + a_{22} < 0$ and $a_{11} a_{22} - a_{12} a_{21} = 0$

and (4.2.2.-18)

2. $a_{11} + a_{22} < 0$ and $a_{11} a_{22} - a_{12} a_{21} > 0$

(4.2.2.-19)

In the first case they tend asymptotically toward constant values different from zero when the time is increasing for any given initial conditions. In the second case they tend asymptotically to zero under the same assumptions.

For analysing these two cases, one assumes that the two powers are real adversaries, and consequently the a_{12} and a_{21} coefficients are positive.

In both cases, this assumption implies that $a_{11} a_{22}$ must be also positive, and consequently it is necessary to have

$$\text{sign } a_{11} = \text{sign } a_{22} \qquad (4.2.2.-20)$$

This condition, and the condition $a_{11} + a_{22} < 0$ imply $a_{11} < 0$ and $a_{22} < 0$. Thus, in the first case it is necessary to have simultaneously:

$$a_{11} < 0$$

$$a_{22} < 0 \qquad (4.2.2.-21)$$
$$a_{11} a_{22} = a_{12} a_{21}$$

This means that the two stocks of strategic offensive weapons could decrease asymptotically to two constant levels only if:

(1) the two countries have a tendency to arm because of their mutual mistrust and adversity ($a_{12} > 0$, $a_{21} > 0$), but a tendency to disarm in relationship to the other countries ($a_{11} < 0$, $a_{22} < 0$);

and

(2) their tendency to disarm ($a_{11} a_{22}$) compensate for (is equal to) their mutual tendency to arm ($a_{12} a_{21}$).

Likewise to the first case, in the second one, it is necessary to simultaneously have:

$$\text{sign } a_{11} = \text{sign } a_{22}$$

and (4.2.2.-22)

$$a_{11} + a_{22} < 0$$

And this is possible only if:

$$a_{11} < 0$$
$$a_{22} < 0 \qquad (4.2.2.-23)$$
$$a_{11} a_{22} > a_{12} a_{21}$$

This means that the two stocks of strategic offensive weapons might asymptotically decrease to zero only if:

(1) the two countries have a tendency to arm because of their mutual mistrust and adversity ($a_{12} > 0$, $a_{21} > 0$), but a tendency to disarm in relationship to the other

countries ($a_{11} < 0$, $a_{22} < 0$);

and

(2) their tendency to disarm ($a_{11} a_{22}$) is stronger than their mutual tendency to arm ($a_{12} a_{21}$).

* * * * * * * * *

4.2.3. A MATHEMATICAL MODEL TO EXPLAIN THE CAUSE OF STRATEGIC OFFENSIVE ARMS RACE'S SPIRAL

The models included in the preceding section are useful for understanding the dynamics of a strategic offensive arms race in quantitative and/or qualitative versions. But they do not explain its causes. To attain this purpose it is necessary to analyse in more detail the behavior of nuclear powers. It is useful to observe that they not only increase their capabilities in respect to their opponents' capabilities, but also in reaction to the **increase** of opponents' capabilities. The consequence of this tendency is the **strategic offensive arms race's spiral.** The arms race's spiral can be regarded from two different perspectives: quantitative and qualitative. If the number of nuclear weapons increases there is a quantity spiral. If their performance improves, one can refer to a quality spiral. In reality, the two processes are frequently combined, the arms race acquiring a very dangerous character, as it was for long periods during the Cold War era. It is also necessary to consider that there is an arms race spiral if the increase in performance overcompensates for the decrease in the number.

For a better understanding of the causes of strategic offensive arms race's spiral, in either quantitative or qualitative versions, I will consider the bipolar and the tripolar cases. It is possible to obtain a simple and intuitive analytical solution to the bipolar case, but tripolarity would require many computations which are not justified to be included here. As a result I will discuss the latter only partly in order to suggest the difficulties as well as the utility of a generalization.

One considers that $o_1(t)$ and $o_2(t)$ have the same significance as in the sections 4.1. and 4.2.2. and one writes the following system:

$$\begin{aligned} \dot{o}_1(t) &= a_{11}\, o_1(t) + \bar{a}_{12}\, \dot{o}_2(t) \\ \dot{o}_2(t) &= \bar{a}_{21}\, \dot{o}_1(t) + a_{22}\, o_2(t) \end{aligned} \qquad (4.2.3.\text{-}1)$$

The a_{11} and a_{22} coefficients describe, as in the model presented in section 4.2.2.(p. 199), the armament policy of each power regardless of its main opponent's policy. But the $\bar{a}_{12}$ and $\bar{a}_{21}$ coefficients reflect the increase or decrease of the stocks of strategic offensive weapons of each country as a reaction to the increase or decrease of strategic offensive weapons owned by its main opponent. They are in absolute value higher than the a_{12} and a_{21} coefficients for a given bipolar system.

The (4.2.3.-1) system can be written in the following standard form:

$$\begin{aligned} \dot{o}_1(t) &= \frac{a_{11}}{(1 - \bar{a}_{12}\,\bar{a}_{21})}\, o_1(t) + \frac{\bar{a}_{12}\, a_{22}}{(1 - \bar{a}_{12}\,\bar{a}_{21})}\, o_2(t) \\ \dot{o}_1(t) &= \frac{a_{11}\,\bar{a}_{21}}{(1 - \bar{a}_{12}\,\bar{a}_{21})}\, o_1(t) + \frac{a_{22}}{(1 - \bar{a}_{12}\,\bar{a}_{21})}\, o_2(t) \end{aligned} \qquad (4.2.3.\text{-}2)$$

and its characteristic equation is the following

$$\lambda^2 - \frac{a_{11} + a_{22}}{1 - \bar{a}_{12}\bar{a}_{21}}\lambda + \frac{a_{11}a_{22} - a_{11}a_{22}\bar{a}_{12}\bar{a}_{21}}{(1 - \bar{a}_{12}\bar{a}_{21})^2} = 0 \qquad (4.2.3.-3)$$

The roots of this characteristic equation are:

$$\lambda_{1,2} = \frac{1}{2(1 - \bar{a}_{12}\bar{a}_{21})}\left[(a_{11} + a_{22}) \pm \sqrt{(a_{11} - a_{22})^2 + 4a_{11}a_{22}\bar{a}_{12}\bar{a}_{21}}\right] \qquad (4.2.3.-4)$$

and in order to understand the characteristics of the corresponding state trajectories one must analyze the value of the $(1 - \bar{a}_{12}\bar{a}_{21})$ expression for various values of the $\bar{a}_{12}$ and $\bar{a}_{21}$ coefficients.

One observes that the increase in the strategic offensive weapons envisaged by the first power includes two components: the first is given by the $a_{11}o_1(t)$ product, and the second by the $\bar{a}_{12}\dot{o}_2(t)$ product. The first component reflects the armament policy of the first power regarding its main national interests and the general dangers existing in the international system. The second component characterizes its response to its main adversary's strategic armament policy. For example, a value of .6 for the $\bar{a}_{12}$ coefficient means that the second component of the first power's increase would be 60% of the second powers's increase of its number of strategic offensive weapons. A value of one, means that the second components of the first power's increase should be equal to the second power's total increase in strategic offensive weapons. A similar remark can be made with regard to the second power's armament policy in answer to its main national interests, general international dangers, and the first power's strategic armament policy.

If one supposes a regular adversarial relationship generating a strategic arms race, the coefficients of the (4.2.3.-1) system are positive:

$$a_{11} > 0, \ \bar{a}_{12} > 0, \ \bar{a}_{21} > 0, \ a_{22} > 0 \qquad (4.2.3.-5)$$

If one also considers that each nuclear power would like to have an increase in its stocks of nuclear weapons comparable or very close to the increase in the other one's stocks, the a_{12} and a_{21} coefficients would tend to increase to 1. But this means that:

$$\lim (1 - \bar{a}_{12}\bar{a}_{21}) = 0, \ \text{as } \bar{a}_{12} \text{ and } \bar{a}_{21} \to 1, \qquad (4.2.3.-6)$$

$$0 < \bar{a}_{12} < 1, \ 0 < \bar{a}_{21} < 1$$

Consequently, the root λ_1 of the (4.2.3.-4) characteristic equation tends to positive infinity,

$$\lim \lambda_1 = +\infty \ , \text{as } \bar{a}_{12} \text{ and } \bar{a}_{21} \to 1 \qquad (4.2.3.-7)$$

$$0 < \bar{a}_{12} < 1, \ 0 < \bar{a}_{21} < 1$$

while the root λ_2 tends to positive or negative infinity. This property, at its turn, allows the derivation of another one which could be proved without difficulty:

For a t_1 fixed final point in time, and for given initial stocks of strategic offensive weapons:

$$t_1 = \bar{t}_1 = \text{fixed}$$

$$o_1(t_o) = o_1^o > 0 \qquad (4.2.3.-8)$$

$$o_2(t_o) = o_2^o > 0$$

the stocks of strategic offensive weapons: $o_1(\bar{t}_1)$ and $o_2(\bar{t}_1)$ tend to positive infinity as $\bar{a}_{12}$ and $\bar{a}_{21}$ increase to 1, $0 < \bar{a}_{12} < 1$, $0 < \bar{a}_{21} < 1$.

In parallel, the (4.2.3-6) and (4.2.3.-7) relations shows that the arms race accelerates when the coefficients $\bar{a}_{12}$, and/or $\bar{a}_{12}$ tend to 1 ($0 < \bar{a}_{12} < 1$, $0 < \bar{a}_{21} < 1$).

In reality, of course, the two stocks do not become infinite, and the interval of time in which the weapons are built does not become infinitesimal, but these mathematical properties stress an essential feature of a strategic offensive arms race. If each adversary tries to increase its stock of weapons with an amount equal to the other's increase in its stock, the arms race escalates. If the escalation consists of an increase in the quantities of weapons, there is a situation similar to that described by the strategic analysts as the arms race's spiral. If the intensification consists in the shortening of the interval of time in which the planned stocks of strategic offensive weapons are built, there is an acceleration of the arms race.

The following scenario (pp. 212-216) and the corresponding graphs illustrate the spiral. One observes that regardless of the initial stock of weapons , the tendency to match the opponent's increase causes a race in which both opponents increase their quantities of weapons.

During the Cold War era, the tendency to match the opponent's increase in nuclear capability was translated in an increase in the number and performance of warheads. Under the assumption of a treaty drastically reducing the number of strategic warheads and of means of delivery, the tendency to increase the number will stop in the future. But there is a risk that the research for technological improvement might continue. Without developing strategic defense systems, the strategic offensive arms race spiral cannot be controled. There is always the danger of shifting from a quantitative race to a qualitative one.

In the case of a tripolar system, the (4.2.3.-1) equations system becomes:

$$\begin{aligned} \dot{o}_1(t) &= a_{11} o_1(t) + \bar{a}_{12} \dot{o}_2(t) + \bar{a}_{13} \dot{o}_3(t) \\ \dot{o}_2(t) &= \bar{a}_{21} \dot{o}_1(t) + a_{22} o_2(t) + \bar{a}_{23} \dot{o}_3(t) \\ \dot{o}_3(t) &= \bar{a}_{31} \dot{o}_1(t) + \bar{a}_{32} \dot{o}_2(t) + a_{33} o_3(t) \end{aligned} \qquad (4.2.3.-9)$$

This system can be written in the following manner:

$$\begin{aligned} \dot{o}_1(t) &= a'_{11} o_1(t) + a'_{12} o_2(t) + a'_{13} o_3(t) \\ \dot{o}_2(t) &= a'_{21} o_1(t) + a'_{22} o_2(t) + a'_{23} o_3(t) \\ \dot{o}_3(t) &= a'_{31} o_1(t) + a'_{32} o_2(t) + a'_{33} o_3(t) \end{aligned} \qquad (4.2.3.-10)$$

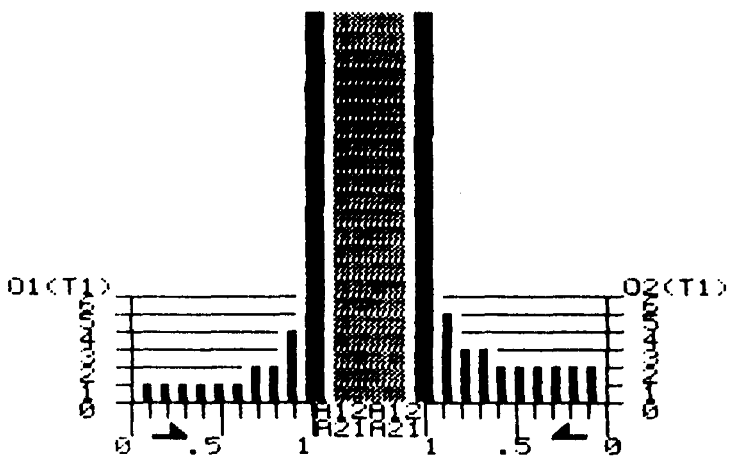
SCENARIO 1
THE INITIAL STOCK OF THE SECOND OPPONENT IS TWO TIMES HIGHER.
BOTH OPPONENTS HAVE THE SAME TYPE OF ARMAMENT POLICIES.

A11= .01
A22= .01
O1(0)= 1
O2(0)= 2
T1= 10

T1 = FINAL YEAR
O1(T1) = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE FIRST OPPONENT AT THE T1 FINAL YEAR
O2(T1) = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE SECOND OPPONENT AT THE T1 FINAL YEAR

STRATEGIC OFFENSIVE ARMS RACE'S
ESCALATION - THE SPIRAL

A12=A21= .1	O1(T1)= 1.12869388
	O2(T1)= 2.22386332
A12=A21= .2	O1(T1)= 1.15627065
	O2(T1)= 2.24317471
A12=A21= .3	O1(T1)= 1.19036799
	O2(T1)= 2.27032699
A12=A21= .4	O1(T1)= 1.2350199
	O2(T1)= 2.30906134
A12=A21= .5	O1(T1)= 1.29763459
	O2(T1)= 2.36657369
A12=A21= .6	O1(T1)= 1.3937909
	O2(T1)= 2.45828535
A12=A21= .7	O1(T1)= 1.56312461
	O2(T1)= 2.62371267
A12=A21= .8	O1(T1)= 1.94451803
	O2(T1)= 3.00164578
A12=A21= .9	O1(T1)= 3.55040212
	O2(T1)= 4.60444337

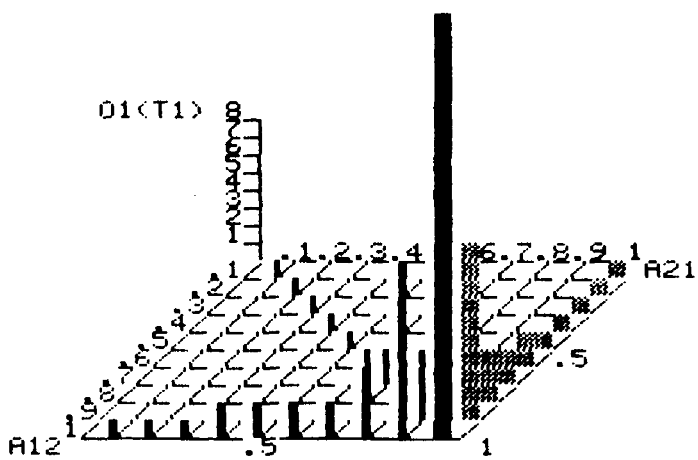


IF THE COEFFICIENTS A12 AND A21
TEND TO INCREASE TO 1 THEN THE STOCKS
OF STRATEGIC NUCLEAR WARHEADS TEND TO
INCREASE TO INFINITY

THE SPIRAL IN THE CASE OF THE FIRST OPPONENT

A12=.1->.9 A21=.1->.9	A12=1 A21=.1->.9	A12=.1->.9 A21=1
O1<T1>=		
1.12869388	1.36659764	1.14304783
1.15627065	1.41835414	1.1916064
1.19036799	1.48702454	1.25607604
1.2350199	1.58244605	1.34573618
1.29763459	1.72382843	1.47873279
1.3937909	1.95420904	1.69579592
1.56312461	2.39275505	2.11000022
1.94451803	3.5205905	3.17974433
3.55040212	10.3255889	9.69663479

O1<T1> = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE FIRST OPPONENT AT THE T1 FINAL YEAR

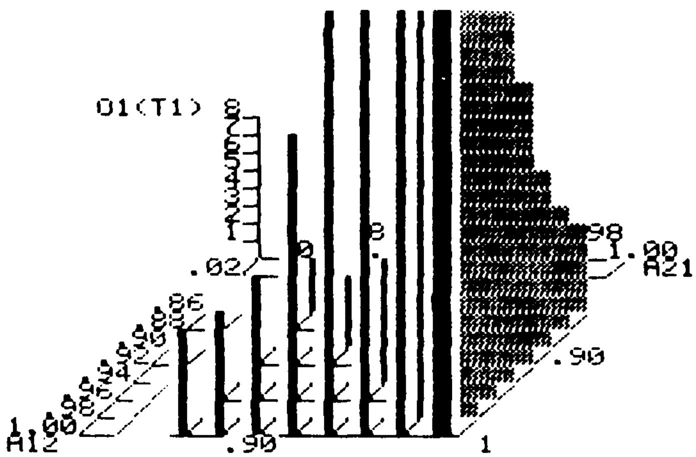


IF THE A12 AND A21 COEFFICIENTS OR ONLY ONE OF THEM TEND TO INCREASE TO 1 THEN THE NUMBER OF STRATEGIC NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE FIRST OPPONENT AT THE T1 FINAL YEAR WILL TEND TO INCREASE TO INFINITY

THE SPIRAL IN THE CASE OF THE FIRST OPPONENT

A12=.80->.98 A21=.80->.98	A12=1.00 A21=.80->.98	A12=.80->.98 A21=1.00
O1(T1)=		
1.94451803	3.5205905	3.17974433
2.08612222	3.98744521	3.62397267
2.27444304	4.64835968	4.25393867
2.53647313	5.64382136	5.20473697
2.92414805	7.27826169	6.76974157
3.55040212	10.3255889	9.69663479
4.70878268	17.286256	16.4085012
7.4152861	40.2439236	38.6601675
17.7475687	214.016472	208.298908
222.093837	31632.526	31209.3553

O1(T1) = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE FIRST OPPONENT AT THE T1 FINAL YEAR

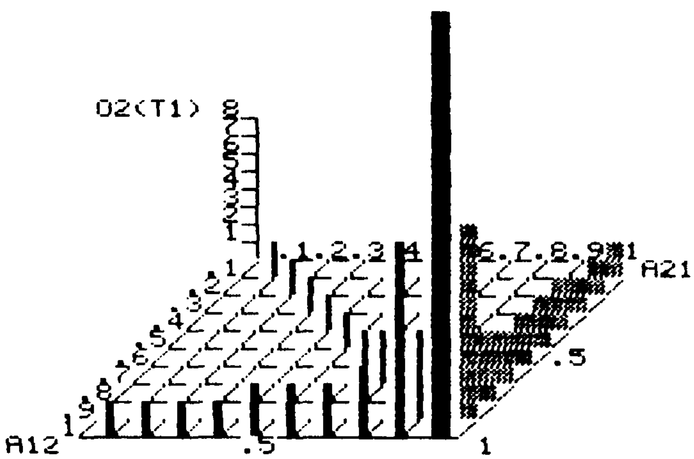


THIS GRAPH REPRESENTS A DETAIL SECTION OF THE PRECEDING GRAPH FOR THE A12 AND A21 COEFFICIENTS VARYING BETWEEN .86 AND 1.00

THE SPIRAL IN THE CASE OF THE SECOND
OPPONENT

A12=.1->.9 A21=.1->.9	A12=1 A21=.1->.9	A12=.1->.9 A21=1
O2(T1)=		
2.22386332	2.24883737	2.36061227
2.24317471	2.29818239	2.41155626
2.27032699	2.3636852	2.47915945
2.30906134	2.4547625	2.57311743
2.36657369	2.58982213	2.71236995
2.45828535	2.81016229	2.93936886
2.62371267	3.2303585	3.37173592
3.00164578	4.31441164	4.48483473
4.60444337	10.9023888	11.2168659

O2(T1) = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED
BY THE SECOND OPPONENT AT THE T1 FINAL YEAR

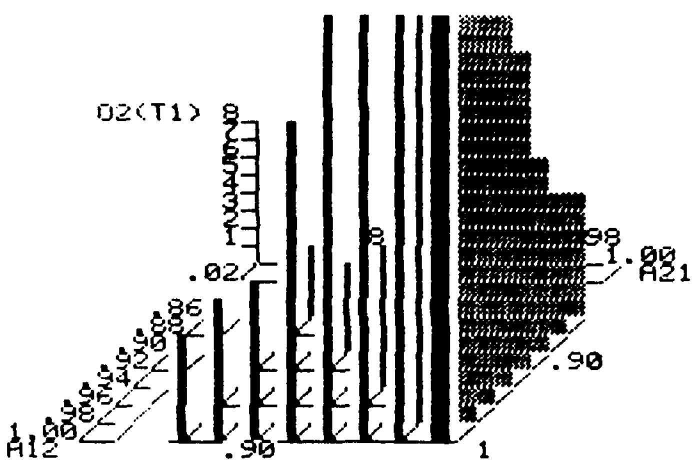


IF BOTH A12 AND A21 COEFFICIENTS OR ONLY ONE OF THEM
TEND TO INCREASE TO 1 THEN THE NUMBER OF STRATEGIC
NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE SECOND
OPPONENT AT THE T1 FINAL YEAR WILL TEND TO INCREASE
TO INFINITY

THE SPIRAL IN THE CASE OF THE SECOND OPPONENT

A12=.80->.98 A21=.80->.98	A12=1.00 A21=.80->.98	A12=.80->.98 A21=1.00
O2(T1)=		
3.00164578	4.31441164	4.48483473
3.14260478	4.7642163	4.94595256
3.33029483	5.4018119	5.5990224
3.59170808	6.363625	6.5831672
3.97877963	7.94576183	8.20002189
4.60444337	10.9023888	11.2168659
5.76224621	17.6757335	18.1146109
8.46818413	40.1020668	40.8939448
18.7999131	210.76552	213.624301
223.145639	31315.6652	31527.2505

O2(T1) = NUMBER OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE SECOND OPPONENT AT THE T1 FINAL YEAR



THIS GRAPH REPRESENTS A DETAIL SECTION OF THE PRECEDING GRAPH FOR THE A12 AND A21 COEFFICIENTS VARYING BETWEEN .86 AND 1.00

where the coefficients a'_{11}, a'_{12}, ... a'_{nn} are:

$$a'_{11} = \frac{a_{11}(1-\bar{a}_{23}\bar{a}_{32})}{(1-\bar{a}_{13}\bar{a}_{31})(1-\bar{a}_{23}\bar{a}_{32}) - (\bar{a}_{12}+\bar{a}_{13}\bar{a}_{32})(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})}$$

$$a'_{12} = \frac{a_{22}(\bar{a}_{12}+\bar{a}_{13}\bar{a}_{32})}{(1-\bar{a}_{13}\bar{a}_{31})(1-\bar{a}_{23}\bar{a}_{32}) - (\bar{a}_{12}+\bar{a}_{13}\bar{a}_{32})(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})}$$

$$a'_{13} = \frac{\bar{a}_{23}a_{33}(\bar{a}_{12}+\bar{a}_{13}\bar{a}_{32}) + \bar{a}_{13}a_{33}(1-\bar{a}_{23}\bar{a}_{32})}{(1-\bar{a}_{13}\bar{a}_{31})(1-\bar{a}_{23}\bar{a}_{32}) - (\bar{a}_{12}+\bar{a}_{13}\bar{a}_{32})(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})}$$

$$a'_{21} = \frac{(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})a'_{11}}{(1-\bar{a}_{23}\bar{a}_{32})}$$

$$a'_{22} = \frac{(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})a'_{12} + a_{22}}{(1-\bar{a}_{23}\bar{a}_{32})}$$

$$a'_{23} = \frac{(\bar{a}_{21}+\bar{a}_{23}\bar{a}_{31})a'_{13} + \bar{a}_{23}a_{33}}{(1-\bar{a}_{23}\bar{a}_{32})} \qquad (4.2.3.-11)$$

$$a'_{31} = \bar{a}_{31} a'_{11} + \bar{a}_{32} a'_{21}$$

$$a'_{32} = \bar{a}_{31} a'_{12} + \bar{a}_{32} a'_{22}$$

$$a'_{33} = \bar{a}_{31} a'_{13} + \bar{a}_{32} a'_{23} + a_{33}$$

One observes that under the assumptions:

$$0 < \bar{a}_{ij} < .5 \qquad i = 1, 2, 3$$
$$\bar{a}_{ij} \rightarrow .5 \qquad j = 1, 2, 3 \qquad (4.2.3.-12)$$

the a'_{11}, a'_{12}, ... a'_{33} coefficients of the (4.2.3-10) differential system tend to positive infinity. This means - that on the basis of a reasoning similar with that made in the bipolar case - each nuclear power would be pushed to increase to infinity its nuclear capabilities if it would like to achieve an increase equal to the average increase of its opponents' amounts of nuclear weapons.

* * * * * * * * *

4.3. CONCLUSIONS: STRATEGIC OFFENSIVE ARMS RACE CONTROL BY THE DEVELOPMENT OF STRATEGIC DEFENSE

The mathematical models included in the previous two sections reinforce the argument that an offensive strategic arms race among real or potential adversaries is unstable. Even if the number of means of delivery, the number of warheads, or both, are limited by treaties, the race for technological improvement does not stop. The continuous fear of the adversary's offensive weapons stimulates each actor's efforts to increase the technological performance of its own offensive weapons. The perception of an overwhelming mutual danger prevents the outbreak of nuclear war in accordance with the principles of the MAD doctrine. But, at the same time, it constitutes the source of the strategic offensive arms race - in its quantitative and/or qualitative versions. Even if the peace is preserved, the risks are not eliminated. And even if the number of weapons and/or delivery systems is limited in accordance with the provisions of bilateral or multilateral treaties (for example the SALT I Treaty limited the number of missiles, but not that of warheads), the race for technological improvement might continue. Because MAD and the strategic offensive arms race are the necessary effects of the same set of strategic causes, it is impossible to preserve mutual assured destruction, and at the same time to eliminate the strategic arms race, either in its quantitative version or in the qualitative-technological one. Therefore, in order to prevent a nuclear war without running a (quantitative and/or qualitative) strategic offensive arms race it is necessary to change the very basis on which both are rooted. This could be done in three manners: by concluding disarmament treaties, by developing strategic defense, or by a combination of both. The first approach implies two necessary presumptions. One should assume that the opposite part - which might be a former or potential future adversary(-ies) - will honestly fulfill its obligations deriving from the disarmament agreement, and/or that the inspectors would be able to detect any deceiving attempt. And, second, one should consider that the internal political situation in the opposite country(-ies) will be reasonably stable for having the agreement's provisions also respected by future governments. This approach is economically advantageous, and usually politically and morally popular. But it is risky, because the probability of the two assumptions is not always very high. Consequently, in order to avoid a potential risk, it is necessary to adopt approaches including the development of strategic defense. They constitute a guarantee against the possible dishonest behaviour of the government which has signed a disarmament agreement or against the unpredictible behavior of a future hostile government. And the probability of a hard line government replacing a moderate one might be significant in unstable, or very unstable, domestic political conditions.

The models included in 4.2.2. and 4.2.3. sections do not have control variables. One assumes that the opponents possess only strategic offensive weapons and consequently base their security on them. From a mathematical point of view this means that if the initial stocks of strategic offensive weapons are given, it is possible to change the characteristics of the arms race only by modifying the F functions vector of the 4.2.2.-2 system in a general case or the A matrix of the 4.2.2.-7 system in the particular case of a linear autonomous system. But this may be achieved only by structural changes in the general strategic policies and/or in the manner of perception of main opponent's armament policies. This usually implies the conclusions of arms limitation or disarmament treaties. But such treaties imply very long and laborious negotiations, and significant internal changes in the case of the actor or actors who have been promoting an expansionist policy. And these internal social and political changes are not always revolutionary. Usually they are evolutionary, which means that they take long intervals of time to be achieved.

For these reasons, it is necessary to have a flexible means to control the strategic arms race and to prevent the destruction that might be caused by a nuclear attack. And the strategic defensive systems constitute such a means in a significant measure. They may allow not only the destruction of the incoming missiles and warheads but also the reduction of the number of strategic offensive weapons. If the opponents become convinced that strategic defense systems might achieve a relatively high degree of protection if the number of offensive weapons is lower, this can also constitute a strong incentive to conclude disarmament agreements in the field of strategic offensive systems.

If one considers that $d_i(t)$ are the strategic defensive systems, measured in standard units (see section 4.1., pp. 184-185), built by the i actor in the t year, than it is possible to specify the (4.1.-1) system in the following manner:

$$\dot{o}_1(t) = a_{11}(t)o_1(t) + \ldots + a_{1n}(t)o_n(t) + $$
$$+ b_{11}(t)d_1(t) + \ldots + b_{1n}(t)d_n(t)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\dot{o}_n(t) = a_{n1}(t)o_1(t) + \ldots + a_{nn}(t)o_n(t) + $$
$$+ b_{n1}(t)d_1(t) + \ldots + b_{nn}(t)d_n(t)$$

(4.3.-1)

This system can be also written in the following matrix expression

$$\dot{o}(t) = A(t)o(t) + B(t)d(t) \qquad (4.3.-2)$$

where A(t) and B(t) are the n x n matrices of state and control coefficients.

The coefficients a_{ij}, i = 1, 2, ... n, j = 1, 2, ... n have the same significance as in the previous sections. The coefficients b_{ii}, i = 1, 2, ... n describe the linkage between the quantity of strategic defensive systems, built annually, by each actor and the increase/decrease of the stock of its strategic offensive weapons. The coefficients b_{ij}, $i \neq j$, i = 1, 2, ... n, j = 1, 2, ... n, describe the connection between the quantity of annually built strategic defensive systems by the j nuclear power and the increase/decrease of the amount of strategic offensive weapons owned by the i nuclear power.

The (4.3.-1) or (4.3.-2) systems may be used for studying the impact of various policies regarding the development of strategic defensive systems on the dynamics of the stocks of strategic offensive weapons. From a mathematical point of view this means to determine the solutions of these systems when the $d(t)$ control vector, and the o^{o} initial conditions, are given.

The same systems may be also used for determining various kinds of policies concerning the development of strategic defensive systems in relationship to the development of strategic offensive ones. If the initial and final conditions are given there usually exists an infinity of admissible trajectories of the control variables - corresponding to various policies of developing defensive systems - which allow actors to attain the final objective. Consequently, it is useful to select from this infinite set of admissible policies those which might be optimal according to one or another criterion of performance. It is also useful to study the cases in which the financial resources for building new strategic systems are given, which means from a mathematical point of view, that the control vector is under constraints. These ideas are utilised to develop three optimal control models, in the next chapter.

* * * * * * *

5. OPTIMAL CONTROL MODELS TO STUDY THE RELATIONSHIP BETWEEN STRATEGIC DEFENSIVE AND OFFENSIVE SYSTEMS

5.1. A MODEL WITH A CRITERION OF OPTIMUM DEFINED AT THE SYSTEM LEVEL

The first model which I construct in this chapter is a relatively simple one. One considers an international system including n nuclear powers which have different degrees of interest in developing strategic defensive systems. The problem consists in determining which should be their programs of building and deploying strategic defensive systems (and/or their corresponding R&D programs) so that their priorities are respected, and the quantities of their strategic defense systems are minimized. One considers that a smaller number would be preferred because it would imply a smaller financial effort. One also considers that the strategic defense systems which might be built and deployed (or the corresponding R&D programs which might be implemented) refer to all the actors taken into consideration and to their relative interest in doing it. It does not refer to only one of them. Therefore the criterion of optimum is defined at the system level. This kind of criterion constitutes one of the elements which differentiates this model from that which is included in the next section, and which has a criterion defined at the national actor's level.

For building this model I consider the system described in the last section of the preceding chapter,

$$\dot{o}_1(t) = a_{11}(t)o_1(t) + \ldots + a_{1n}(t)o_n(t) +$$

$$+ b_{11}(t)d_1(t) + \ldots + b_{1n}(t)d_n(t)$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\dot{o}_n(t) = a_{n1}(t)o_1(t) + \ldots + a_{nn}(t)o_n(t)$$

$$+ b_{n1}(t)d_1(t) + \ldots + b_{nn}(t)d_n(t) \qquad (5.1.-1)$$

One considers that the stocks of strategic nuclear weapons are evaluated by the number of strategic nuclear warheads and that the stocks existing at the t_o initial point in time are known. One also supposes that the quantities of warheads planned to be owned by each of the n countries at the t_1 final point in time are given, as a result of national decisions made in advance, or bilateral and/or multilateral agreements (the recent American-Russian agreement is a relevant example). These two assumptions imply that the initial and final conditions are given and that they are fixed:

$$o_1(t_o) = o_1^o$$
$$\ldots\ldots\ldots\ldots \qquad (5.1.-2)$$
$$o_n(t_o) = o_n^o$$

$$o_1(t_1) = o_1^1$$
$$\ldots\ldots\ldots\ldots \qquad (5.1.-3)$$
$$o_n(t_1) = o_n^1$$

If the model is used to study a program of building and deploying strategic defense systems, the control variable $d_i(t)$, ($i = 1, 2, \ldots n$), represents the number of systems which will be built and deployed by the i country in the t year. But if the model is applied for analysing a research and development program, the approach is different. Rather than computing the number of systems, one must calculate the annual R&D funds corresponding to the R&D period of time. These funds will be used for designing and testing the prototypes which will allow the building and deployment of a planned number, $\bar{d}_i$, ($i = 1, 2, \ldots n$), of strategic defense systems, during the next period of time (the building and deployment period). This number results from national predictions, or from multilateral or bilateral agreements (for example 100 systems for each country according to the ABM Treaty). Consequently the $d_i(t)$ ($i = 1,2, \ldots n$) control variables represents the financial resources which should be allocated for research and development by the i country in the t year. By dividing $d_i(t)$ ($i = 1,2, \ldots n$) to the number of systems planned to be built in the next period one obtains the annual R&D expenditures per defensive system in the case of the i country: $d''_i(t) = d_i(t)/\bar{d}_i$, $i = 1, 2, \ldots n$. In accordance with the specific significance of the control variable, the b coefficients have a different interpretation in this second case. They show how the R&D expenditures for strategic defense systems influence the variations of the stocks of strategic offensive weapons (strategic nuclear warheads).

It is natural to suppose that the actors are interested in achieving their strategic objectives with minimal efforts concerning the strategic defensive systems' construction and deployment, and/or the R&D program. Their relative priorities in promoting strategic defense are evaluated at the system level by the $p_1(t)$, ... $p_n(t)$ coefficients. A relatively big value of a $p_i(t_k)$ coefficient indicates that the i actor is relatively reluctant to develop and build strategic defensive systems at the t_k point in time. A relatively small value denotes that the i actor is interested in doing it. Consequently, the following simple criterion of optimum may be constructed,

$$[\min]\ J = \int_{t_o}^{t_1} [p_1(t)d_1^2(t) + \ldots + p_n(t)d_n^2(t)]dt \quad (5.1.-4)$$

The optimal control problem consists of determining the optimal control vector $d^*(t) = (d_1^*(t), \ldots d_n^*(t))$ which leads the (5.1.-1) dynamic system from the initial conditions to the final conditions so that the (5.1.-4) criterion of optimum is minimized. The solution of this problem entails the determination of an optimal program of developing and building strategic defensive systems, which allows a country to attain with a minimal effort, in a given interval of time, a planned amount of strategic offensive weapons starting from a given quantity of such weapons. It is of course required that all the elements of the $o^*(t)$ and $d^*(t)$ vectors should be non-negative, because negative values make no sense in the model,

$$o_i^*(t) \geq 0, \quad d_i^*(t) \geq 0, \quad \text{for } i = 1,2, \ldots n$$

Although the problem is simple, it can be solved only by using numerical methods if $n > 3$ and/or the a_{ij}, b_{ij}, and p_i, coefficients, $i = 1, 2, \ldots n$, are variable. For this reason, I will present here only the particular case in which n=2 and the coefficients are constant, that is:

$$\dot{o}_1(t) = a_{11}o_1(t) + a_{12}o_2(t) + b_{11}d_1(t) + b_{12}d_2(t)$$
$$\dot{o}_2(t) = a_{21}o_1(t) + a_{22}o_2(t) + b_{21}d_1(t) + b_{22}d_1(t) \qquad (5.1.-5)$$

$$o_1^o = o_1(t_o) \qquad o_1^1 = o_1(t_1)$$
$$o_2^o = o_2(t_o) \qquad o_2^1 = o_2(t_1) \qquad (5.1.-6)$$

$$[\min]\ J = \int_{t_o}^{t_1} [p_1 d_1^2(t) + p_2 d_2^2(t)]dt\ . \qquad (5.1.-7)$$

For computing the $d_1^*(t)$ and $d_2^*(t)$ optimal control trajectories, and the corresponding $o_1^*(t)$ and $o_2^*(t)$ optimal state trajectories one utilizes the Euler-Lagrange variational method. One constructs at first the Lagrange function:

$$L = p_1 d_1^2(t) + p_2 d_2^2(t) + \qquad (5.1.-8)$$
$$\lambda_1(t)(a_{11}o_1(t) + a_{12}o_2(t) + b_{11}d_1(t) + b_{12}d_2(t)) +$$
$$\lambda_2(t)(a_{21}o_1(t) + a_{22}o_2(t) + b_{21}d_1(t) + b_{22}d_2(t))$$

where $\lambda_1(t)$ and $\lambda_2(t)$ are two Lagrange multipliers.

The adjunct system is the following:

$$\dot{\lambda}_1(t) = -\frac{\partial L}{\partial o_1} = -a_{11}\lambda_1(t) - a_{21}\lambda_2(t)$$

$$\dot{\lambda}_2(t) = -\frac{\partial L}{\partial o_2} = -a_{12}\lambda_1(t) - a_{22}\lambda_2(t) \qquad (5.1.-9)$$

The optimal control vector can be derived by utilising the relations:

$$\frac{\partial L}{\partial d_1} = 2p_1 d_1(t) + b_{11}\lambda_1(t) + b_{21}\lambda_2(t) = 0$$

$$\frac{\partial L}{\partial d_2} = 2p_2 d_2(t) + b_{12}\lambda_1(t) + b_{22}\lambda_2(t) = 0 \qquad (5.1.-10)$$

This vector depends on two Lagrange multipliers, and it is:

$$d^*_1(t) = \frac{-b_{11}\lambda_1(t) - b_{21}\lambda_2(t)}{2p_1}$$

$$d^*_2(t) = \frac{-b_{12}\lambda_1(t) - b_{22}\lambda_2(t)}{2p_2} \qquad (5.1.-11)$$

If one substitutes the (5.1.-11) optimal control vector in the (5.1.-5) system, and if one writes together this system and the (5.1.-9) adjunct system, one finally obtains a system of four differential equations depending on $o_1(t)$, $o_2(t)$, $\lambda_1(t)$

and $\lambda_2(t)$:

$$\dot{o}_1(t) = a_{11} o_1(t) + a_{12} o_2(t) - \left(\frac{b_{11}^2}{2p_1} + \frac{b_{12}^2}{2p_2}\right)\lambda_1(t) +$$

$$+ \left(\frac{b_{11} b_{21}}{2p_1} + \frac{b_{12} b_{22}}{2p_2}\right)\lambda_2(t)$$

$$\dot{o}_2(t) = a_{21} o_1(t) + a_{22} o_2(t) - \left(\frac{b_{11} b_{21}}{2p_1} + \frac{b_{12} b_{22}}{2p_2}\right)\lambda_1(t) +$$

$$- \left(\frac{b_{21}^2}{2p_1} + \frac{b_{22}^2}{2p_2}\right)\lambda_2(t) \qquad (5.1.-12)$$

$$\dot{\lambda}_1(t) = -a_{11}\lambda_1(t) - a_{21}\lambda_2(t)$$

$$\dot{\lambda}_2(t) = -a_{12}\lambda_1(t) - a_{22}\lambda_2(t)$$

This particular system of four differential equations with constant coefficients may be solved without difficulties and the four integration constants on each its solutions depend, can be obtained by using the (5.1.-6) initial and final conditions.

If one considers the (5.1.-9) adjunct system, or the last two equations of the (5.1.-12) system, one can build the following characteristic equation,

$$r^2 + (a_{11} + a_{22})r + (a_{11} a_{22} - a_{12} a_{21}) = 0 \qquad (5.1.-13)$$

The roots of this equation are:

$$r_{1,2} = \frac{-(a_{11} + a_{22}) \pm \sqrt{(a_{11} - a_{22})^2 + 4a_{12}a_{21}}}{2} \qquad (5.1.-14)$$

and in the case of a regular arms race they are real and different because $a_{12} > 0$ and $a_{21} > 0$. Therefore, the optimal solutions, $\lambda_1*(t)$ and $\lambda_2*(t)$, depending on two constants of integration, C_3 and C_4, are:

$$\lambda_1*(t) = C_3 e^{r_3 t} + C_4 e^{r_4 t}$$

$$\lambda_2*(t) = \frac{r_3 + a_{11}}{-a_{21}} C_3 e^{r_3 t} + \frac{r_4 + a_{11}}{-a_{21}} C_4 e^{r_4 t} \qquad (5.1.-15)$$

If one substitutes $\lambda_1*(t)$ and $\lambda_2*(t)$ in the first two equations of the (5.1.-12) system, one obtains the following nonhomogeneous system of two differential equations,

$$\dot{o}_1(t) = a_{11} o_1(t) + a_{12} o_2(t) + c_{11} C_3 e^{r_3 t} + c_{12} C_4 e^{r_4 t}$$

$$\dot{o}_2(t) = a_{21} o_1(t) + a_{22} o_2(t) + c_{21} C_3 e^{r_3 t} + c_{22} C_4 e^{r_4 t}$$

(5.1.-16)

where,

$$c_{11} = -(\frac{b_{11}^2}{2p_1} + \frac{b_{12}^2}{2p_2}) - (\frac{b_{11} b_{21}}{2p_1} + \frac{b_{12} b_{22}}{2p_2}) \frac{r_3 + a_{11}}{-a_{21}}$$

$$c_{12} = -\left(\frac{b_{11}^2}{2p_1} + \frac{b_{12}^2}{2p_2}\right) - \left(\frac{b_{11}b_{21}}{2p_1} + \frac{b_{12}b_{22}}{2p_2}\right)\frac{r_4 + a_{11}}{-a_{21}}$$

$$c_{21} = -\left(\frac{b_{11}b_{21}}{2p_1} + \frac{b_{12}b_{22}}{2p_2}\right) - \left(\frac{b_{21}^2}{2p_1} + \frac{b_{22}^2}{2p_2}\right)\frac{r_3 + a_{11}}{-a_{21}} \qquad (5.1.\text{-}17)$$

$$c_{22} = -\left(\frac{b_{11}b_{21}}{2p_1} + \frac{b_{12}b_{22}}{2p_2}\right) - \left(\frac{b_{21}^2}{2p_1} + \frac{b_{22}^2}{2p_2}\right)\frac{r_4 + a_{11}}{-a_{21}}$$

The characteristic equation of the (5.1.-16) system is:

$$r^2 - (a_{11} + a_{22})r + (a_{11}a_{22} - a_{12}a_{21}) = 0$$

and its roots are the following:

$$r_{1,2} = \frac{(a_{11} + a_{22}) \pm \sqrt{(a_{11} - a_{22})^2 + 4a_{12}a_{21}}}{2}$$

Because under the assumption of an adversarial relationship, the a_{12} and a_{21} coefficients are positive, the roots are real and different. Consequently, the particular solutions of the (5.1.-16) system (the solutions of the homogeneous system) are:

$$o'_1(t) = C_1 e^{r_1 t} + C_2 e^{r_2 t}$$

$$o'_2(t) = \frac{r_1 - a_{11}}{a_{12}} C_1 e^{r_1 t} + \frac{r_2 - a_{11}}{a_{12}} C_2 e^{r_2 t} \qquad (5.1.\text{-}18)$$

The structure of the (5.1.-16) nonhomogeneous system suggests that its general solution may have the following expression,

$$
\begin{aligned}
o_1(t) &= o'_1(t) + \mathscr{A} C_3 e^{r_3 t} + \mathscr{B} C_4 e^{r_4 t} \\
o_2(t) &= o'_2(t) + \mathscr{C} C_3 e^{r_3 t} + \mathscr{D} C_4 e^{r_4 t}
\end{aligned}
\qquad (5.1.-19)
$$

where $\mathscr{A}$, $\mathscr{B}$, $\mathscr{C}$, and $\mathscr{D}$ are four constants which may be determined by using the (5.1.-16) equations. For this purpose one substitutes the particular solutions of the nonhomogeneous system,

$$
\begin{aligned}
o''_1(t) &= \mathscr{A} C_3 e^{r_3 t} + \mathscr{B} C_4 e^{r_4 t} \\
o''_2(t) &= \mathscr{C} C_3 e^{r_3 t} + \mathscr{D} C_4 e^{r_4 t}
\end{aligned}
\qquad (5.1.-20)
$$

in the (5.1.-16) relations, and one finally obtains the following algebraic system:

$$
\begin{aligned}
&(1 - \frac{a_{11}}{r_3})\mathscr{A} - \frac{a_{12}}{r_3}\mathscr{C} = \frac{c_{11}}{r_3} \\
&(1 - \frac{a_{11}}{r_4})\mathscr{B} - \frac{a_{12}}{r_4}\mathscr{D} = \frac{c_{12}}{r_4} \\
&- \frac{a_{21}}{r_3}\mathscr{A} + (1 - \frac{a_{22}}{r_3})\mathscr{C} = \frac{c_{21}}{r_4}
\end{aligned}
\qquad (5.1.-21)
$$

$$-\frac{a_{21}}{r_4}\mathcal{B} + \left(1 - \frac{a_{22}}{r_4}\right)\mathcal{D} = \frac{c_{22}}{r_4}$$

If one supposes that the solutions of this algebraic system are: $\mathcal{A}^*$, $\mathcal{B}^*$, $\mathcal{C}^*$, and $\mathcal{D}^*$, then the general optimal trajectories of the stocks of strategic offensive weapons (strategic nuclear warheads) forecast to be owned by the two opponents are:

$$o^*_1(t) = C^*_1 e^{r_1 t} + C^*_2 e^{r_2 t} + \mathcal{A}^* C^*_3 e^{r_3 t} + \mathcal{B}^* C^*_4 e^{r_4 t}$$

$$o^*_2(t) = \frac{r_1 - a_{11}}{a_{12}} C^*_1 e^{r_1 t} + \frac{r_2 - a_{11}}{a_{12}} C^*_2 e^{r_2 t} + \mathcal{C}^* C^*_3 e^{r_3 t} + \mathcal{D}^* C^*_4 e^{r_4 t} \qquad (5.1.\text{-}22)$$

The C^*_1, C^*_2, C^*_3, C^*_4 constants are the solutions of the following algebraic system obtained by using the (5.1.-4) initial and final conditions:

$$C_1 + C_2 + \mathcal{A}^* C_3 + \mathcal{B}^* C_4 = o^o_1$$

$$\frac{r_1 - a_{11}}{a_{12}} C_1 + \frac{r_2 - a_{11}}{a_{12}} C_2 + \mathcal{C}^* C_3 + \mathcal{D}^* C_4 = o_2 \qquad (5.1.\text{-}23)$$

$$e^{r_1 t_1} C_1 + e^{r_2 t_1} C_2 + \mathcal{A}^* e^{r_3 t_1} C_3 + \mathcal{B}^* e^{r_4 t_1} C_4 = o^1_1$$

$$\frac{r_1 - a_{11}}{a_{12}} e^{r_1 t_1} C_1 + \frac{r_2 - a_{11}}{a_{12}} e^{r_2 t_1} C_2 + \gamma^* e^{r_3 t_1} C_3 +$$

$$+ \gamma^* e^{r_4 t_1} C_4 = o_2^1$$

The corresponding optimal trajectories of Lagrange multipliers are:

$$\lambda_1^*(t) = C_3^* e^{r_3 t} + C_4^* e^{r_4 t}$$

$$\lambda_2^*(t) = \frac{r_1 + a_{11}}{-a_{21}} C_3^* e^{r_3 t} + \frac{r_2 + a_{11}}{-a_{21}} C_4^* e^{r_4 t} \qquad (5.1.-24)$$

and thus the optimal program of building and deploying, or doing research and development for strategic defensive systems is:

$$d_1^*(t) = \frac{-b_{11}\lambda_1^*(t) - b_{21}\lambda_2^*(t)}{2p_1}$$

$$d_2^*(t) = \frac{-b_{12}\lambda_1^*(t) - b_{22}\lambda_2^*(t)}{2p_2} \qquad (5.1.-25)$$

The Legendre condition may be also verified. The following derivative,

$$\frac{\partial^2 L^o}{\partial d} = \begin{pmatrix} \frac{\partial^2 L^o}{\partial d_1^2} & \frac{\partial^2 L^o}{\partial d_1 \partial d_2} \\ \frac{\partial^2 L^o}{\partial d_1 \partial d_2} & \frac{\partial^2 L^o}{\partial d_2^2} \end{pmatrix} = \begin{pmatrix} 2p_1 & 0 \\ 0 & 2p_2 \end{pmatrix} \qquad (5.1.-26)$$

is a positive semidefinite symmetric matrix. Therefore, the (5.1.-22) and (5.1.-25) trajectories are the only optimal ones.

In order to illustrate this model I include two scenarios in the following pages (228 - 238). In both scenarios, one considers that:

- the first power is the United States,
- the second power is Russia (Soviet Union for 1991),
- the initial year is 1991,
- the final year is 2003,
- in the initial year United States and Soviet Union owned respectively 11602 and 10877 strategic nuclear warheads (US Disarmament Agency, quoted by Thomas L. Friedman, in Reducing the Arms Threat, The New York Times, June 17, 1992),
- in the year 2003 United States and Russia will have 3500 strategic nuclear warheads (according to the recently signed agreement between the United States and Russia)

The model is employed in order to study the research and development program for strategic defensive systems. Therefore

$d_1(t)$ and $d_2(t)$ represent R&D expenditures forecast to be made by each country for finally deployment (or in the case of Russia for modernization and perhaps replacement) of 100 interceptor systems allowed by the ABM Treaty.

One considers that the relationship between the United States and Russia is cooperative regarding the strategic disarmament program, and consequently the a_{12} and a_{21} coefficients are negative. This property of the two coefficients allows one to compute the optimal analytical solutions of the model in the same manner as it was shown before. Because both a_{12} and a_{21} are negative, the roots of the (5.1.-14) characteristic equation are real and different.

In the first scenario one assumes that the United States is more interested than Russia in developing strategic defense systems ($p_1 = 1$, $p_2 = 2$). In the second, one assumes that both are eequally interested ($p_1 = 1$, $p_2 = 1$) in order to see how the research and development programs would be affected.

* * * * * * *

A MODEL WITH A CRITERION OF OPTIMUM
DEFINED AT THE SYSTEM LEVEL

SCENARIO NO. 1

A11= 3E-03
A12=-.04
A21=-.06
A22= .01
B11=-100
B12= 1E-03
B21= 1E-03
B22=-95
P1= 1
P2= 2
T0= 1991
T1= 2003
O1(0)= 11602
O2(0)= 10877
O1(T1)= 3500
O2(T1)= 3500

P1, P2 = COEFFICIENTS OF PREFERENCE

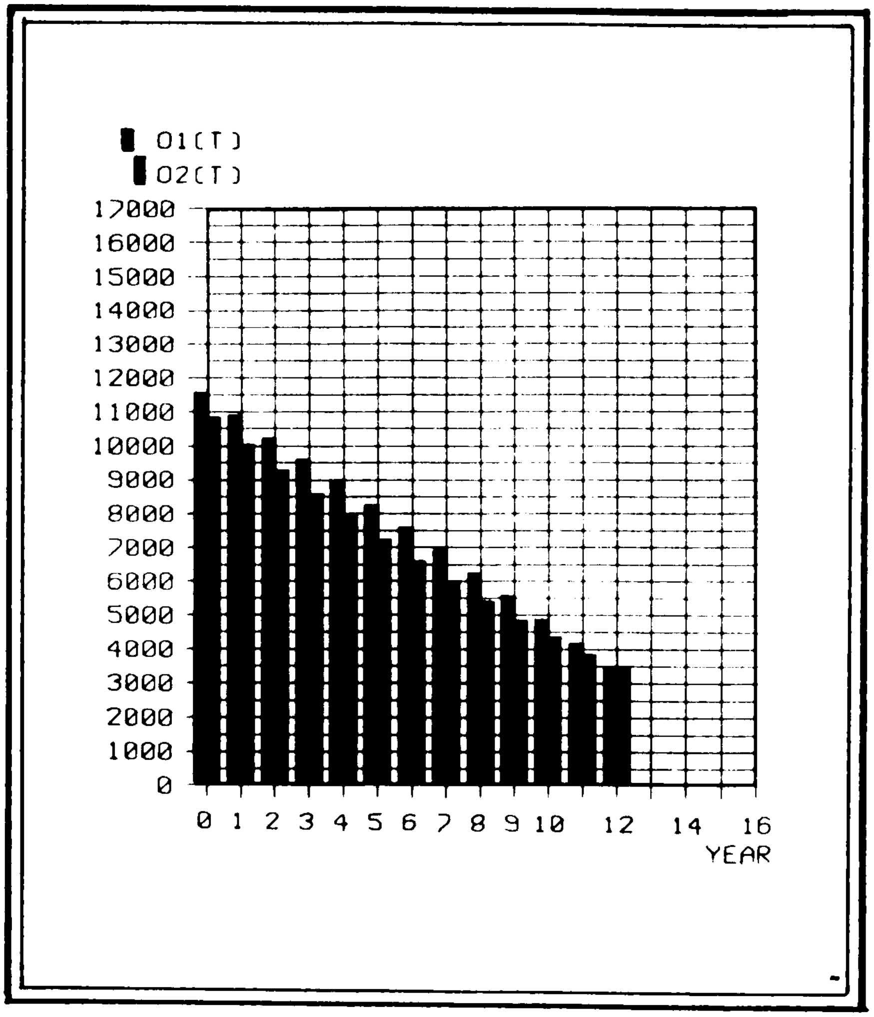
T0 = INITIAL YEAR
T1 = FINAL YEAR

O1(0), O2(0) = STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE OPPONENTS IN THE INITIAL YEAR
O1(T1), O2(T1) = STOCKS OF STRATEGIC NUCLEAR WAR-HEADS EXPECTED TO BE OWNED BY THE OPPONENTS IN THE FINAL YEAR
NOTE: ONE CONSIDERS THAT THE FIRST POWER (UNITED STATES) IS MORE INTERESTED IN DEVELOPING STRATEGIC DEFENSE SYSTEMS.

TABLE 1 STOCKS OF STRATEGIC NUCLEAR WARHEADS

T= 1991	O1= 11602	O2= 10877
T= 1992	O1= 10944.0495	O2= 10105.152
T= 1993	O1= 10288.4383	O2= 9362.00026
T= 1994	O1= 9633.66186	O2= 8647.29616
T= 1995	O1= 8978.162	O2= 7960.87808
T= 1996	O1= 8320.32285	O2= 7302.6747
T= 1997	O1= 7658.46665	O2= 6672.70851
T= 1998	O1= 6990.84907	O2= 6071.09959
T= 1999	O1= 6315.65455	O2= 5498.06979
T= 2000	O1= 5630.99099	O2= 4953.94715
T= 2001	O1= 4934.88432	O2= 4439.17076
T= 2002	O1= 4225.27263	O2= 3954.29598
T= 2003	O1= 3500	O2= 3500.00002

O1(T) = NUMBER OF STRATEGIC NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE FIRST OPPONENT AT THE BEGINNING OF THE T YEAR
O2(T) = NUMBER OF STRATEGIC NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE SECOND OPPONENT AT THE BEGINNING OF THE T YEAR



O1(T)
O2(T)
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 2: ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSIVE SYSTEMS

T= 1991	D1= 2.59336981	D2= 2.09424057
T= 1992	D1= 2.8516258	D2= 2.12487082
T= 1993	D1= 3.11326213	D2= 2.1601098
T= 1994	D1= 3.37885133	D2= 2.19998096
T= 1995	D1= 3.64896784	D2= 2.24451839
T= 1996	D1= 3.92418933	D2= 2.2937667
T= 1997	D1= 4.20509807	D2= 2.34778104
T= 1998	D1= 4.49228217	D2= 2.40662706
T= 1999	D1= 4.78633692	D2= 2.47038095
T= 2000	D1= 5.08786614	D2= 2.53912946
T= 2001	D1= 5.39748342	D2= 2.61296999
T= 2002	D1= 5.71581348	D2= 2.69201069
T= 2003	D1= 6.04349349	D2= 2.77637053

D1(T) = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT (AT THE BEGINNING OF THE T YEAR)
D2(T) = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT (AT THE BEGINNING OF THE T YEAR)

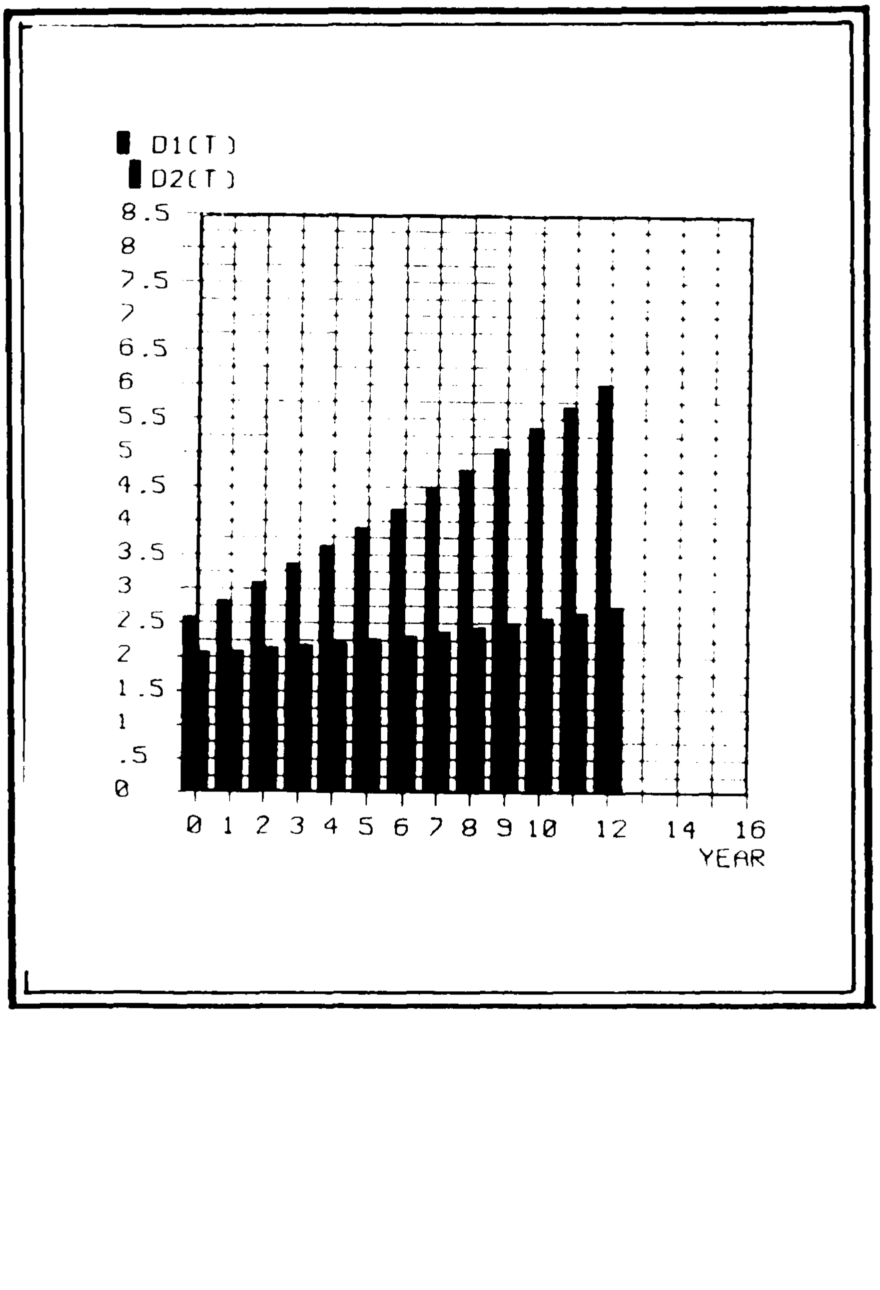

D1(T)
D2(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 3: FORECASTED VARIATIONS OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AND ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT

T=	O1'=	D1'=
1991.5	-657.950463	2.72224252
1992.5	-655.611222	2.98214149
1993.5	-654.776459	3.24570696
1994.5	-655.499863	3.51351231
1995.5	-657.839142	3.78613348
1996.5	-661.856209	4.06415035
1997.5	-667.617573	4.34814797
1998.5	-675.194519	4.63871795
1999.5	-684.663563	4.93645974
2000.5	-696.106671	5.24198192
2001.5	-709.611685	5.55590356
2002.5	-725.272636	5.87885548

O1' = ANNUAL VARIATION OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE FIRST OPPONENT (COMPUTED AS THE DIFFERENCE BETWEEN THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AT THE BEGINNING OF TWO SUCCESSIVE YEARS)
D1' = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT (COMPUTED PER (CALENDAR YEAR AS AN ARITHMETICAL MEAN BY USING THE FOLLOWING FORMULA:
D1'(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+... +2*D1(T+.9)+D1(T+1))/20)

TABLE 4 FORECASTED VARIATIONS OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AND ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT

T=	O2'=	D2'=
1991.5	-771.848042	2.10917616
1992.5	-743.151718	2.14210928
1993.5	-714.704098	2.17966198
1994.5	-686.418076	2.22186303
1995.5	-658.203381	2.26875179
1996.5	-629.966196	2.32037813
1997.5	-601.608916	2.37680246
1998.5	-573.029801	2.43809569
1999.5	-544.122641	2.50433929
2000.5	-514.776392	2.57562534
2001.5	-484.87478	2.65205658
2002.5	-454.295958	2.73374659

O2' = ANNUAL VARIATION OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE SECOND OPPONENT (COMPUTED AS THE DIFFERENCE BETWEEN THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AT THE BEGINNING OF TWO SUCCESSIVE YEARS)
D1' = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT (COMPUTED PER CALENDAR YEAR AS AN ARITHMETICAL MEAN BY USING THE FOLLOWING FORMULA:
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+...
+2*D2(T+.9)+D2(T+1))/20)

A MODEL WITH A CRITERION OF OPTIMUM
DEFINED AT THE SYSTEM LEVEL

SCENARIO NO. 2

A11= 3E-03
A12=-.04
A21=-.06
A22= .01
B11=-100
B12= 1E-03
B21= 1E-03
B22=-95
P1= 1
P2= 1
T0= 1991
T1= 2003
O1(0)= 11602
O2(0)= 10877
O1(T1)= 3500
O2(T1)= 3500

P1, P2 = COEFFICIENTS OF PREFERENCE

T0 = INITIAL YEAR
T1 = FINAL YEAR

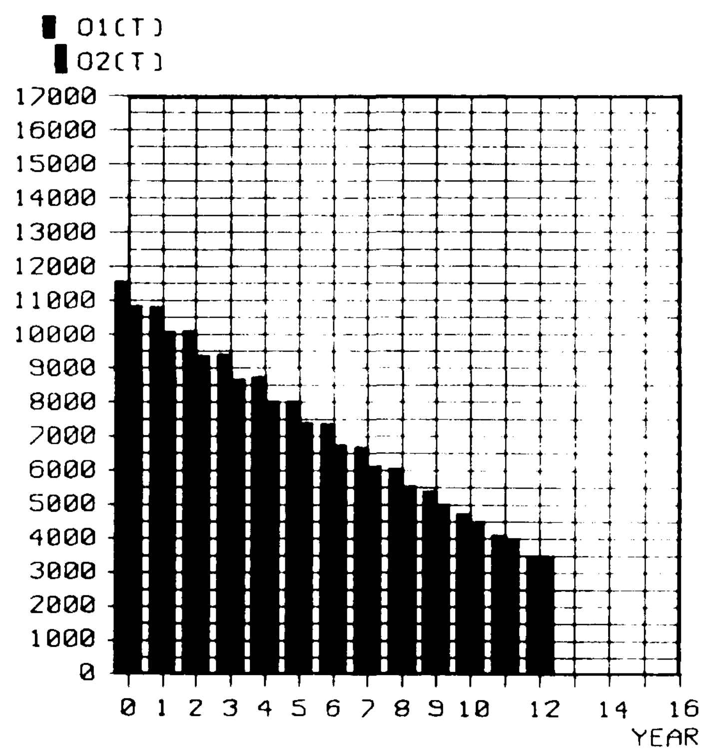
O1(0), O2(0) = STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE OPPONENTS IN THE INITIAL YEAR
O1(T1), O2(T1) = STOCKS OF STRATEGIC NUCLEAR WARHEADS EXPECTED TO BE OWNED BY THE OPPONENTS IN THE FINAL YEAR
NOTE: ONE CONSIDERS THAT BOTH COUNTRIES ARE EQUALLY INTERESTED IN DEVELOPING STRATEGIC DEFENSE SYSTEMS.

TABLE 1: STOCKS OF STRATEGIC NUCLEAR WARHEADS

T= 1991	O1= 11602	O2= 10877
T= 1992	O1= 10867.4095	O2= 10137.9149
T= 1993	O1= 10149.0782	O2= 9424.14695
T= 1994	O1= 9445.35136	O2= 8734.734
T= 1995	O1= 8754.58917	O2= 8068.78062
T= 1996	O1= 8075.16228	O2= 7425.4575
T= 1997	O1= 7405.44783	O2= 6804.00106
T= 1998	O1= 6743.82525	O2= 6203.7134
T= 1999	O1= 6088.67215	O2= 5623.9623
T= 2000	O1= 5438.35994	O2= 5064.18152
T= 2001	O1= 4791.24963	O2= 4523.8713
T= 2002	O1= 4145.68737	O2= 4002.59899
T= 2003	O1= 3500	O2= 3500

O1(T) = NUMBER OF STRATEGIC NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE FIRST OPPONENT AT THE BEGINNING OF THE T YEAR

O2(T) = NUMBER OF STRATEGIC NUCLEAR WARHEADS WHICH WILL BE OWNED BY THE SECOND OPPONENT AT THE BEGINNING OF THE T YEAR



O1(T)
O2(T)
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 2: ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSIVE SYSTEMS

T= 1991	D1= 3.43003778	D2= 1.73404773
T= 1992	D1= 3.53271196	D2= 1.84840744
T= 1993	D1= 3.64238001	D2= 1.96564333
T= 1994	D1= 3.75920987	D2= 2.08599436
T= 1995	D1= 3.88338418	D2= 2.20970373
T= 1996	D1= 4.01510054	D2= 2.33701942
T= 1997	D1= 4.15457173	D2= 2.46819469
T= 1998	D1= 4.30202608	D2= 2.60348864
T= 1999	D1= 4.45770774	D2= 2.74316669
T= 2000	D1= 4.62187711	D2= 2.88750118
T= 2001	D1= 4.79481119	D2= 3.0367719
T= 2002	D1= 4.97680406	D2= 3.19126664
T= 2003	D1= 5.16816735	D2= 3.35128179

D1(T) = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT (AT THE BEGINNING OF THE T YEAR)
D2(T) = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT (AT THE BEGINNING OF THE T YEAR)

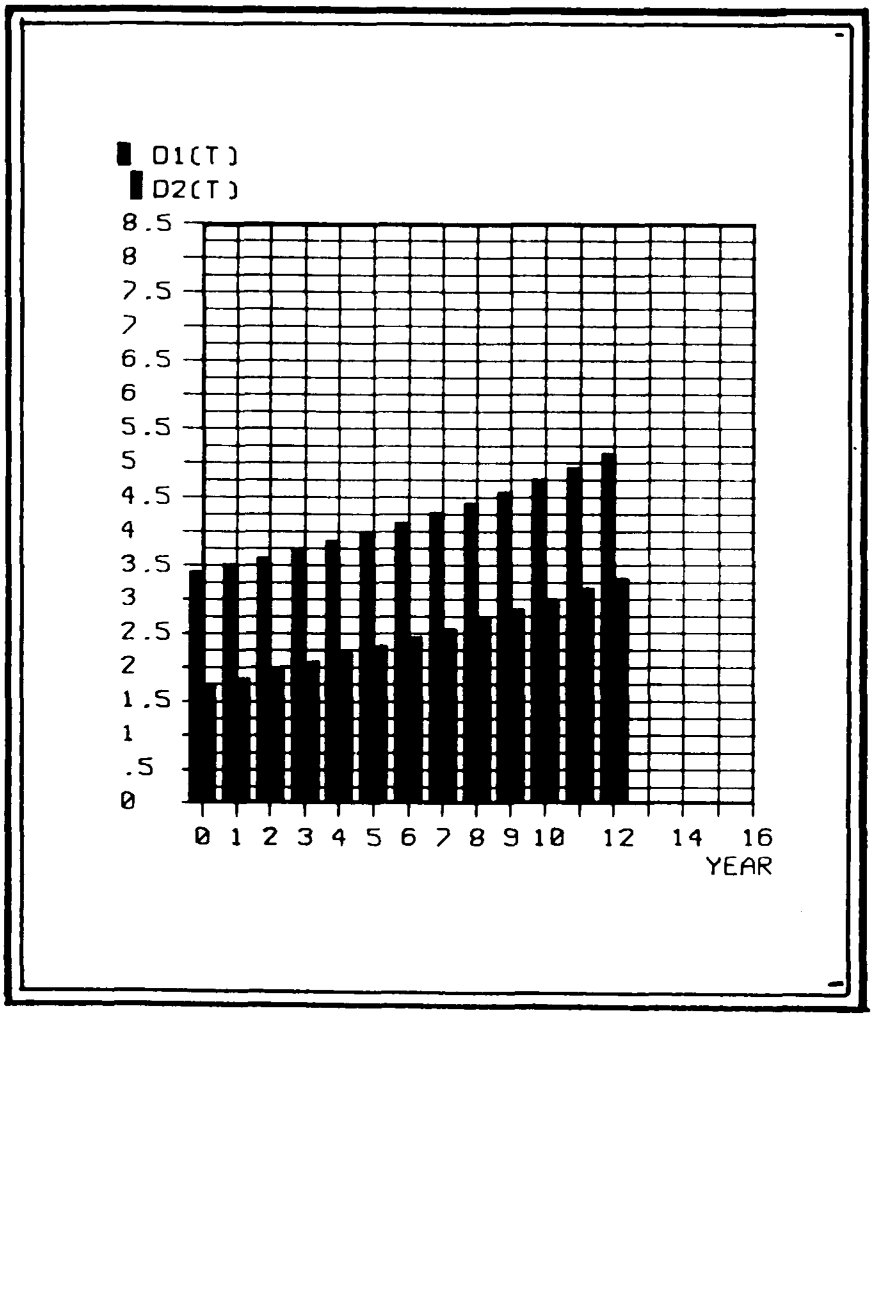

D1(T)
D2(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 3   FORECASTED VARIATIONS OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AND ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT

T=	O1´=	D1´=
1991.5	-734.59047	3.48080443
1992.5	-718.331349	3.58696229
1993.5	-703.726818	3.70019678
1994.5	-690.762192	3.82068318
1995.5	-679.426897	3.9486116
1996.5	-669.714453	4.08418718
1997.5	-661.62257	4.22763047
1998.5	-655.153107	4.37917766
1999.5	-650.312208	4.53908102
2000.5	-647.110313	4.70760919
2001.5	-645.562256	4.88504769
2002.5	-645.687365	5.07169933

O1´ = ANNUAL VARIATION OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE FIRST OPPONENT (COMPUTED AS THE DIFFERENCE BETWEEN THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AT THE BEGINNING OF TWO SUCCESSIVE YEARS)

D1´ = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE FIRST OPPONENT (COMPUTED PER (CALENDAR YEAR AS AN ARITHMETICAL MEAN BY USING THE FOLLOWING FORMULA:

D1´(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+...
+2*D1(T+.9)+D1(T+1))/20)

TABLE 4 FORECASTED VARIATIONS OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AND ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT

T=	D2' =	D2' =
1991.5	-739.085072	1.79100005
1992.5	-713.767987	1.9067783
1993.5	-689.412949	2.02555188
1994.5	-665.953375	2.14756183
1995.5	-643.323122	2.27305369
1996.5	-621.45644	2.40227805
1997.5	-600.287665	2.53549103
1998.5	-579.751099	2.67295485
1999.5	-559.780775	2.81493835
2000.5	-540.310227	2.96171755
2001.5	-521.272309	3.1135762
2002.5	-502.598984	3.27080632

D2' = ANNUAL VARIATION OF THE STOCKS OF STRATEGIC NUCLEAR WARHEADS OWNED BY THE SECOND OPPONENT (COMPUTED AS THE DIFFERENCE BETWEEN THE STOCKS OF STRATEGIC NUCLEAR WARHEADS AT THE BEGINNING OF TWO SUCCESSIVE YEARS)
D1' = ANNUAL R&D EXPENDITURES FOR STRATEGIC DEFENSE IN THE CASE OF THE SECOND OPPONENT (COMPUTED PER CALENDAR YEAR AS AN ARITHMETICAL MEAN BY USING THE FOLLOWING FORMULA:
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+...
+2*D2(T+.9)+D2(T+1))/20)

5.2. A MODEL FOR THE STUDY OF ONE NUCLEAR POWER'S BEHAVIOR IN A MULTIPOLAR SYSTEM

If the theoretical model presented at the beginning of the previous section has referred to the whole system, the model which I am developing here focuses on one country. One considers that the A nuclear power can spend the M amount of money during a specific planning period for building and/or modernizing strategic offensive weapons and for developing and building new strategic defensive systems. The quantity of strategic offensive weapons expected to be built during the first year is known. The quantity of the same weapons that should be built during the final year of the planning period is also given. One considers that it can be estimated by using long term predictions and plans. During the period of time taken into consideration, the A country may chose policies consisting in modernizing (building) strategic offensive weapons or mixed policies. The mixed policies associate modernization (building) of strategic offensive weapons with building and deployment of strategic defensive systems (or with the corresponding R&D program in a first phase). One assumes that the A nuclear power cannot influence in a significant manner the distribution of strategic capabilities in the international system. Its strategic relation with the international system is comparable to the economic relation to the market of a firm which does not have a monopolistic position. As a result, the A nuclear power considers that the future dynamics of the offensive strategic forces of its main potential adversaries are exogeneously determined. Under these assumptions, the problem for this actor consists in deriving the optimal program of developing, building or modernizing strategic offensive and defensive systems. Such an optimal program would imply the minimization of the number of adversaries' strategic nuclear weapons that cannot be neutralized (could not be destroyed in the eventuality of a nuclear attack against the A country), and the minimization of the economic effort for bulding and deploying (or developing) strategic defensive systems. The funds saved by this minimization effort will be employed for modernizing its offensive weapons.

I use the following notation:

$o(t)$ - the number of strategic offensive weapons annually modernized or built by the A nuclear power measured in standard units;

$d(t)$ - the number of strategic defensive systems annually built by the A nuclear power measured in standard units;

p_1 - the price of one standard unit of strategic offensive weapons built or modernized by the A nuclear power;

p_2 - the price of one standard unit of strategic defensive weapons built by the A nuclear power;

M - the planned amount of money which may be spent by the A nuclear power for building and modernizing defensive and ofensive systems during the $[t_o, t_1]$ interval of time;

o_1 - the amount of strategic offensive weapons owned by the main potential opponents of the A nuclear power at the t_o initial moment;

o_2 - the rate of increase/decrease of the stock of strategic offensive weapons owned by the main opponent(s) of the A nuclear power;

q - coefficient of neutralization

One considers that the dynamics of the stock of strategic offensive weapons of the A nuclear power may be described by a non-homogeneous differential equation:

$$\dot{o}(t) = ao(t) + bd(t) \qquad (5.2.-1)$$

The initial and the final conditions are given, and they are:

$$o(t_o) = o^o \qquad (5.2.-2)$$
$$o(t_1) = o^1$$

The state and control variables must obviously be non-negative:

$$o(t) \geq 0 \qquad (5.2.-3)$$
$$d(t) \geq 0$$

The financial constraint may be also formulated in a natural manner as it follows:

$$\int_{t_o}^{t_1} (p_1 o(t) + p_2 d(t))dt = M \qquad (5.2.-4)$$

The criterion of optimum is defined so that the security of the A nuclear power is maximized and its effort for bulding new strategic defensive weapons is minimized:

$$\min I = \int_{t_o}^{t_1} ((o_1 e^{o_2 t} - qd(t))^2 dt \qquad (5.2.-5)$$

Under these assumptions one can formulate the following optimal control problem: Let determine A nuclear power's optimal programs of building/modernizing strategic offensive and defense systems, o*(t) and d*(t), such as its security to be maximized during the $[t_o, t_1]$ interval of time, its effort for building new strategic defensive systems to be minimized and the cumulative expenditures for building these new systems to be equal to the planned amount of money. The effort minimization is included in order to build and deploy (or to develop) a number of strategic defensive systems that would have a neutralization capability no larger than the necessary one. The funds saved in this manner would be used for modernizing (building) strategic offensive systems.

If the model is applied for the study of an R&D program, the significance of some notations is different. These differences are comparable to those indicated in the case of the preceding model (p. 216). The control variable d(t) represents the annual R&D expenditures for strategic defense systems. The b coefficient characterizes the influence of strategic defense R&D expenditures on the increase/decrease in the number of strategic offensive systems (strategic nuclear warheads). The p_2 coefficient has a value of one (the price of a given amount of money is that amount itself). The q coefficient indicates the R&D expenditures' efficiency. It is evaluated by the ratio between the potential capability to destroy incoming attacking objects (measured in number of standard warheads) and the R&D funds spent in order to achieve it. A high value of this coefficient indicates that the developing systems are successful in testing. A low value means failures caused by design errors (for example the successful brilliant pebble increases q, but the aborted X-ray laser decreases it). By dividing q by the number of strategic defensive systems planned to be built during the construction and deployment period (for example 100 interceptors at the end of the present R&D period of SDI) one obtains the efficiency of the annual R&D expenditures for one strategic defensive system.

It is also possible to add to the model, as an exogeneous variable, the total stock of strategic offensive weapons owned by the adversaries. It does not affect the optimization problem, but allows a useful comparison between this variable, the optimal stock of modernized strategic weapons, and the optimal stock of newly built strategic defensive systems (or corresponding R&D funds).

This is an optimal control problem with functional constraints, and in order to solve it I will use the Pontryaguine Principle.

At the beginning one builds the Hamilton function:

$$H = -o_1 e^{2o_2 t} - q^2 d^2(t) + 2o_1 q e^{o_2 t} d(t) + a\psi(t)o(t) + b\psi(t)d(t) - \lambda_1 p_1 o(t) - \lambda_1 p_2 d(t) \qquad (5.2.-6)$$

and the adjunct equation,

$$\dot{\psi}(t) = -a\psi(t) + \lambda_1 p_1 \qquad (5.2.-7)$$

Using the condition,

$$\frac{\partial H}{\partial d} = -2q^2 d(t) + 2o_1 q e^{o_2 t} + b\psi(t) - \lambda_1 p_2 = 0 \qquad (5.2.-8)$$

one computes the optimal control trajectory depending on $\psi(t)$ and λ_1:

$$d^*(t) = \frac{1}{2q^2} \left(b\psi(t) + 2o_1 q e^{o_2 t} - p_2 \lambda_1\right) \qquad (5.2.-9)$$

If one substitutes the d* optimal control variable in the (5.2.-1) differential equation and if one conveniently groups, one finally obtains:

$$\dot{o}(t) = ao(t) + \frac{b^2}{2q^2}\psi(t) + \frac{bo_1}{q} e^{o_2 t} - \frac{bp_2}{2q^2}\lambda_1 \qquad (5.2.-10)$$

The general solution of the (5.2.-7) adjunct equation can be easy determined. It is:

$$\psi^*(t) = Ce^{-at} + \frac{\lambda_1 p_1}{a} \qquad (5.2.-11)$$

where C is a constant of integration. Subsequently, the (5.2.-10) equation can be written depending only on λ_1 as it follows:

$$\dot{o}(t) = ao(t) + \frac{b^2}{2q^2} Ce^{-at} + \frac{b^2 p_1 \lambda_1}{2q^2 a} + \frac{bo_1}{q} e^{o_2 t} - \frac{bp_2}{2q^2}\lambda_1 \qquad (5.2.-12)$$

One notes:

$$h_1 = \frac{b^2}{2q^2}$$

$$h_2 = \frac{b^2 p_1}{2aq^2} - \frac{bp_2}{2q^2} \qquad (5.2.-13)$$

$$h_3 = \frac{bo_1}{q}$$

and one write again the (5.2.-12) equation as it follows:

$$\dot{o}(t) = ao(t) + h_1 C e^{-at} + h_3 e^{o_2 t} + h_2 \lambda_1 \qquad (5.2.-14)$$

One remarks that this equation is a non-homogeneous one, and therefore its general solution is:

$$o^*(t) = Ke^{at} - \frac{h_1}{2a} Ce^{-at} + \frac{h_3}{o_2 - a} e^{o_2 t} - \frac{h_2}{a} \lambda_1 \qquad (5.2.-15)$$

where K is a constant of integration.

If one uses the notation,

$$h_4 = \frac{p_1}{a} \qquad (5.2.-16)$$

the (5.2.-11) solution of the adjunct equation may be written as it follows,

$$\psi^*(t) = Ce^{-at} + h_4\lambda_1 \qquad (5.2.-17)$$

and consequently, the optimal control variable becomes:

$$d^*(t) = \frac{1}{2q^2}(bCe^{-at} + bh_4\lambda_1 + 2o_1qe^{o_2t} - p_2\lambda_1) \qquad (5.2.-18)$$

If one notes:

$$h_5 = \frac{b}{2q^2}$$

$$h_6 = \frac{o_1}{q} \qquad (5.2.-19)$$

$$h_7 = \frac{1}{2q^2}(bh_4 - p_2)$$

the expression of the (5.2.-18) optimal control variable may be written again as it follows:

$$d^*(t) = h_5Ce^{-at} + h_6e^{o_2t} + h_7\lambda_1 \qquad (5.2.-20)$$

One observes that the optimal paths, o*(t) and d*(t), depend on the C and K constants of integration and on the λ_1 Lagrange multiplier. These three constants can be calculated by using the (5.2.-4) financial constraint and the (5.2.-2) initial and final conditions. If one substitutes o*(t) and d*(t) in the (5.2.-4) relation,

$$\int_{t_o}^{t_1} \Big(p_1 K e^{at} - \frac{p_1 h_1}{2a} C e^{-at} + \frac{p_1 h_3}{o - a} e^{o_2 t} - \frac{p_1 h_2}{a} \lambda_1 + p_2 h_5 C e^{-at} +$$

$$+ p_2 h_6 e^{o_2 t} + p_2 h_7 \lambda_1 \Big) dt = M \qquad (5.2.-21)$$

and if one calculates this integral, one obtains:

$$\frac{p_1 K}{a} e^{at} \Big|_{t_o}^{t_1} + \frac{p_1 h_1}{2a^2} C e^{-at} \Big|_{t_o}^{t_1} + \frac{p_1 h_3}{o_2 (o_2 - a)} e^{o_2 t} \Big|_{t_o}^{t_1} - \frac{p_1 h_2 \lambda_1}{a} t \Big|_{t_o}^{t_1} -$$

$$- \frac{p_2 h_5 C}{a} e^{-at} \Big|_{t_o}^{t_1} + \frac{p_2 h_6}{o_2} e^{o_2 t} \Big|_{t_o}^{t_1} + p_2 h_7 \lambda_1 t \Big|_{t_o}^{t_1} = M \qquad (5.2.-22)$$

The initial and final conditions written for the optimal trajectory of the state variable are:

$$o^o = o(t_o) = K e^{a t_o} - \frac{h_1}{2a} C e^{-a t_o} + \frac{h_3}{o_2 - a} e^{o_2 t_o} - \frac{h_2}{a} \lambda_1 \qquad (5.2.-23)$$

$$o^1 = o(t_1) = K e^{a t_1} - \frac{h_1}{2a} C e^{-a t_1} + \frac{h_3}{o_2 - a} e^{o_2 t_1} - \frac{h_2}{a} \lambda_1 \qquad (5.2.-24)$$

For $t_o = 0$ and for a given t_1 final point in time the (5.2.-22), (5.2.-23) and (5.2.-24) conditions generate a system of three algebraic equations in which the unknown variables are K, C, and λ_1.

$$K - \frac{h_1}{2a} C - \frac{h_2}{a_1} \lambda = o^{o} - \frac{h_3}{o_2 - a}$$

$$e^{a_1 t} K - \frac{h_1}{2a} e^{-a_1 t} C - \frac{h_2}{a_1} \lambda = o^{1} - \frac{h_3}{o_2 - a} e^{o_2 t_1} \qquad (5.2.-25)$$

$$\left(\frac{p_1 e^{a_1 t}}{a} - \frac{p_1}{a}\right) K + \left(\frac{p_1 h_1}{2a^2} e^{-a_1 t} - \frac{p_1 h_1}{2a^2} - \frac{p_2 h_5}{a} e^{-a_1 t} + \frac{p_2 h_5}{a}\right) C +$$

$$+ p_2 h_7 t_1 \lambda = M - \frac{p_1 h_3}{(o_2 - a) o_2} e^{o_2 t_1} + \frac{p_1 h_3}{(o_2 - a) o_2} -$$

$$- \frac{p_2 h_6 e^{o_2 t_1}}{o_2} + \frac{p_2 h_6}{o_2}$$

The solutions of this system may be calculated without difficulty. If one supposes that they are K*, C* and λ^*, then the o*(t) and d*(t) optimal trajectories are completely determined.

One observes that the optimal trajectories, o*(t) and d*(t), were derived by taking into consideration only the (5.2.-4) financial constraint. The (5.2.-3) non-negativity restriction was not used. The version of the Pontryaguine principle applied for solving the model does not allow optimization with respect to both types of constraints. Therefore, some optimal solutions might be not admissible. As it is known, in the general case of an optimal control problem, it is not always possible to attain a final given target if constraints similar to those included in this model must be satisfied. For this reason, I wrote a computer program for computing the optimal solutions and I made more than fifty tests by using various hypothetical data (I do not have access to classified real data). In these conditions, I obtained optimal **admissible** solutions from the first attempt in only approximately 15%-20% of the cases.

Three illustrative scenarios are included in the following pages. The data are hypothetical, although some of them, like the total number of strategic nuclear warheads owned by the potential opponents of the A nuclear power or its expenditures, might be close to the real ones, under the assumption that the A nuclear power is the United States.

In the first scenario one considers that:

- the A nuclear power has a tendency to increase the number of nuclear warheads and/or corresponding delivery systems that it annually modernizes because of the persisting international strain: a = [A] = .03 (in brackets is the notation used in the outprints);
- at the same time it has a tendency to decrease that number, because it has a strategic defense R&D program: b = [B] = -8;
- the cost of modernizing one strategic nuclear warhead and the

supporting and delivery systems is $7.5 million: p_1 = [P1] =.0075;

- p_2 is equal to 1, because the model is applied for studying an R&D program: p_2 = [P2] = 1;
- the A nuclear power intends to spend $50 billion for modernizing strategic offensive weapons and for developing strategic defensive systems: M = [ME] = 50;
- the number of strategic nuclear warheads modernized by the A nuclear power's opponents during the first year is 350: o_1 = [O1] = 350;
- the above number decreases: o_2 = [O2] = -.02
- the A nuclear power's opponents have 14000 nuclear warheads in the first year taken into consideration: [OOO1] = 14000;
- the above number exponentially decreases at an annual rate of -.1: [OOO2] = -.1
- the R&D efficiency coefficient is 30: q = [Q] = 30;
- the first year of the planning period is 1992 and the last one is 2002: t_o = [T0] = 1992, t_1 = [T1] = 2002;
- the A nuclear power intends to modernizes 325 nuclear warheads and corresponding support and delivery systems in the year 1992 and 200 in the year 2002: o^o = [O(T0)] = 325, o^1 = [O(T1)] = = 200;
- the A nuclear power intends to deploy 100 strategic defensive systems after the R&D period: [DD(T1+)] = 100;

In the second scenario, one makes the same assumptions with the exception of the q coefficient. One considers that the results of the R&D programs would be extremely unsatisfactory, and therefore the efficiency of the funds spent for this purpose would be very small: q = [Q] = 1. (This means that only one nuclear warhead might be potentially neutralized for each billion dollars spent for strategic defense research and development!)

In the third scenario I make the opposite hypothesis. I consider that the R&D program would be very efficient, and consequently the q coefficient has a high value: q = [Q] = 180. One observes that in the second scenario the efficiency is considered thirty times smaller than in the first one, while in the third example it is considered six times larger.

It is of course obvious that without using classified real data, it is impossible to make any substantial estimations regarding the price of modernizing an offensive system or the efficiency of strategic defense R&D. Therefore, I would like to stress again that these scenarios should be regarded only as illustrative ones.

* * * * * * * * *

MODEL FOR THE STUDY OF ONE NUCLEAR POWER'S BEHAVIOR
IN A MULTIPOLAR INTERNATIONAL SYSTEM

SCENARIO NR. 1
A= .04
B=-8
P1= 7.5E-03
P2= 1
ME= 50
O1= 350
O2=-.02
OOO1= 14000
OOO2=-.1
Q= 30
T0= 1992
T1= 2002
O(T0)= 325
O(T1)= 200
OO(T1+)= 100

TABLE 1: OPTIMAL ALLOCATION OF TOTAL FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	ME(T)=	ME'(T)=
1992.5	4.73662592	4.73563527
1993.5	4.8525937	4.85163428
1994.5	4.94598331	4.9450531
1995.5	5.01748234	5.0165794
1996.5	5.06773265	5.06685511
1997.5	5.09733174	5.09647774
1998.5	5.10683375	5.1060015
1999.5	5.09675065	5.09593841
2000.5	5.06755325	5.06675931
2001.5	5.0196721	5.01889478

TOTAL ME(T) = 50.0085594
TOTAL ME'(T) = 49.9998289

ME(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME'(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:

$$ME'(T+.5) = (ME(T)+2*ME(T+.1)+2*ME(T+.2)+... +2*ME(T+.9)+ME(T+1))/20$$

TABLE 2: OPTIMAL ALLOCATION OF FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	P1*O(T)=	P1*O'(T)=
1992.5	2.41778118	2.41727577
1993.5	2.36944971	2.36895268
1994.5	2.30942155	2.30893187
1995.5	2.23786971	2.23738637
1996.5	2.15494344	2.15446544
1997.5	2.06076855	2.06029491
1998.5	1.95544775	1.9549775
1999.5	1.83906088	1.83859307
2000.5	1.71166517	1.71119884
2001.5	1.57329539	1.57282959

T=	P2*D(T)=	P2*D'(T)=
1992.5	2.31884473	2.3183595
1993.5	2.48314399	2.4826816
1994.5	2.63656176	2.63612124
1995.5	2.77961262	2.77919303
1996.5	2.91278922	2.91238967
1997.5	3.03656319	3.03618283
1998.5	3.151386	3.151024
1999.5	3.25768977	3.25734534
2000.5	3.35588808	3.35556047
2001.5	3.44637671	3.44606519

P1*O(T), P1*O'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC OFFENSIVE WEAPONS
P2*D(T), P2*D'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC DEFENSIVE WEAPONS
O'(T+.5) = (O(T)+2*O(T+.1)+2*O(T+.2)+...+2*O(T+.9)+
+O(T+1))/20
D'(T+.5) = (D(T)+2*D(T+.1)+2*D(T+.2)+...+2*D(T+.9)+
+D(T+1))/20

TABLE 3. A NUCLEAR POWER'S OPTIMAL POLICY OF MODERNIZING ITS STRATEGIC OFFENSIVE WEAPONS AND DEVELOPING STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	O(T)=	O'(T)=
1992.5	322.370824	322.303436
1993.5	315.926628	315.860357
1994.5	307.922873	307.857582
1995.5	298.382628	298.318183
1996.5	287.325791	287.262059
1997.5	274.769139	274.705989
1998.5	260.726366	260.663667
1999.5	245.208117	245.145743
2000.5	228.222022	228.159845
2001.5	209.772719	209.710612

T=	D(T)=	D'(T)=
1992.5	23.1884473	23.183595
1993.5	24.8314399	24.826816
1994.5	26.3656176	26.3612123
1995.5	27.7961262	27.7919303
1996.5	29.1278922	29.1238967
1997.5	30.3656319	30.3618283
1998.5	31.51386	31.51024
1999.5	32.5768977	32.5734534
2000.5	33.5588808	33.5556047
2001.5	34.4637671	34.4606519

O(T), O'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D(T), D'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM (IN $ MILLIONS)

TABLE 4: STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE ADVERSARIES OF THE A NUCLEAR POWER AND THE A POWER'S POTENTIAL CAPABILITY TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO(T)	OO(T)	Q*DD(T)
1992	14000	350	0
1993	12667.7239	696.517442	69.565342
1994	11462.2305	1036.17338	144.059662
1995	10371.4551	1369.10368	223.156515
1996	9384.48065	1695.44151	306.544893
1997	8491.42924	2015.31743	393.92857
1998	7683.36291	2328.85938	485.025466
1999	6952.19425	2636.19278	579.567045
2000	6290.6055	2937.44057	677.297739
2001	5691.97524	3232.72326	777.974382
2002	5150.31218	3522.15895	881.365683

T=	OOO(T)	OO(T)	Q*DD'(T)
1992	14000	350	0
1993	12667.7239	696.517442	69.5507851
1994	11462.2305	1036.17338	144.031233
1995	10371.4551	1369.10368	223.11487
1996	9384.48065	1695.44151	306.490661
1997	8491.42924	2015.31743	393.862351
1998	7683.36291	2328.85938	484.947836
1999	6952.19425	2636.19278	579.478556
2000	6290.6055	2937.44057	677.198916
2001	5691.97524	3232.72326	777.86573
2002	5150.31218	3522.15895	881.247686

OOO(T) = TOTAL STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
OO(T) = STOCKS OF MODERNIZED AND NEWLY BUILT STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
Q*DD'(T) = A NUCLEAR POWER'S POTENTIAL CAPABILITY TO NEUTRALIZE ADVERSARIES' STRATEGIC OFFENSIVE WEAPONS BY DEVELOPING STRATEGIC DEFENSIVE SYSTEMS

MODEL FOR THE STUDY OF ONE NUCLEAR POWER S BEHAVIOR
IN A MULTIPOLAR INTERNATIONAL SYSTEM

SCENARIO 2
A= .04
B=-8
P1= 7.5E-03
P2= 1
ME= 50
O1= 350
O2=-.02
OOO1= 14000
OOO2=-.1
Q= 1
T0= 1992
T1= 2002
O(T0)= 325
O(T1)= 200
OO(T1+)= 100

TABLE 1   OPTIMAL ALLOCATION OF TOTAL FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	ME(T)=	ME'(T)=
1992.5	4.04358485	4.03442773
1993.5	4.70980399	4.70139218
1994.5	5.17805154	5.17035752
1995.5	5.4652207	5.45821863
1996.5	5.58759548	5.58126099
1997.5	5.56088331	5.555193
1998.5	5.40024505	5.39517714
1999.5	5.12032705	5.11586078
2000.5	4.73528894	4.73140496
2001.5	4.25883322	4.25551334

TOTAL ME(T) = 50.0598341
TOTAL ME'(T) = 49.9988063

ME(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME'(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:

ME'(T+.5) = (ME(T)+2*ME(T+.1)+2*ME(T+.2)+...
+2*ME(T+.9)+ME(T+1))/20

TABLE 2 OPTIMAL ALLOCATION OF FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	P1*O(T)=	P1*O'(T)=
1992.5	2.44434328	2.44238481
1993.5	2.4245002	2.42289042
1994.5	2.36676287	2.36549216
1995.5	2.27911091	2.27817039
1996.5	2.16931618	2.16869785
1997.5	2.04495884	2.04465502
1998.5	1.91344168	1.91344557
1999.5	1.78200594	1.78231125
2000.5	1.65774513	1.65834619
2001.5	1.54761955	1.54851147

T=	P2*D(T)=	P2*D'(T)=
1992.5	1.59924157	1.59204291
1993.5	2.28530379	2.27850176
1994.5	2.81128867	2.80486536
1995.5	3.1861098	3.18004824
1996.5	3.41827931	3.41256315
1997.5	3.51592447	3.51053798
1998.5	3.48680337	3.48173156
1999.5	3.3383211	3.33354953
2000.5	3.07754381	3.07305877
2001.5	2.71121366	2.70700187

P1*O(T), P1*O'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC OFFENSIVE WEAPONS
P2*D(T), P2*D'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC DEFENSIVE WEAPONS
O'(T+.5) = (O(T)+2*O(T+.1)+2*O(T+.2)+...+2*O(T+.9)+ +O(T+1))/20
D'(T+.5) = (D(T)+2*D(T+.1)+2*D(T+.2)+...+2*D(T+.9)+ +D(T+1))/20

TABLE 3: A NUCLEAR POWER'S OPTIMAL POLICY OF MODERNIZING ITS STRATEGIC OFFENSIVE WEAPONS AND DEVELOPING STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	O(T)=	O'(T)=
1992.5	325.912438	325.651308
1993.5	323.266693	323.052056
1994.5	315.568382	315.398955
1995.5	303.881455	303.756052
1996.5	289.242157	289.159713
1997.5	272.661179	272.62067
1998.5	255.125557	255.126077
1999.5	237.600792	237.6415
2000.5	221.032684	221.112825
2001.5	206.349274	206.468196

T=	D(T)=	D'(T)=
1992.5	15.9924157	15.9204291
1993.5	22.8530379	22.7850176
1994.5	28.1128867	28.0486536
1995.5	31.861098	31.8004824
1996.5	34.1827931	34.1256314
1997.5	35.1592447	35.1053798
1998.5	34.8680337	34.8173156
1999.5	33.383211	33.3354953
2000.5	30.7754381	30.7305877
2001.5	27.1121366	27.0700187

O(T), O'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D(T), D'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM (IN $ MILLIONS)

TABLE 4 STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE ADVERSARIES OF THE A NUCLEAR POWER AND THE A POWER'S POTENTIAL CAPABILITY TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO(T)	OO(T)	Q*DD(T)
1992	14000	350	0
1993	12667.7239	696.517442	1.59924157
1994	11462.2305	1036.17338	3.88454536
1995	10371.4551	1369.10368	6.69583403
1996	9384.48065	1695.44151	9.88194382
1997	8491.42924	2015.31743	13.3002231
1998	7683.36291	2328.85938	16.8161476
1999	6952.19425	2636.19278	20.302951
2000	6290.6055	2937.44057	23.6412721
2001	5691.97524	3232.72326	26.7188159
2002	5150.31218	3522.15895	29.4300296

T=	OOO(T)	OO(T)	Q*DD'(T)
1992	14000	350	0
1993	12667.7239	696.517442	1.59204291
1994	11462.2305	1036.17338	3.87054468
1995	10371.4551	1369.10368	6.67541005
1996	9384.48065	1695.44151	9.85545828
1997	8491.42924	2015.31743	13.2680214
1998	7683.36291	2328.85938	16.7785594
1999	6952.19425	2636.19278	20.260291
2000	6290.6055	2937.44057	23.5938405
2001	5691.97524	3232.72326	26.6668993
2002	5150.31218	3522.15895	29.3739011

OOO(T) = TOTAL STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
OO(T) = STOCKS OF MODERNIZED AND NEWLY BUILT STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
Q*DD'(T) = A NUCLEAR POWER'S POTENTIAL CAPABILITY TO NEUTRALIZE ADVERSARIES' STRATEGIC OFFENSIVE WEAPONS BY DEVELOPING STRATEGIC DEFENSIVE SYSTEMS

MODEL FOR THE STUDY OF ONE NUCLEAR POWER'S BEHAVIOR
IN A MULTIPOLAR INTERNATIONAL SYSTEM

```
SCENARIO 3
A= .04
B=-8
P1= 7.5E-03
P2= 1
ME= 50
O1= 350
O2=-.02
OOO1= 14000
OOO2=-.1
Q= 180
T0= 1992
T1= 2002
O(T0)= 325
O(T1)= 200
OO(T1+)= 100
```

TABLE 1: OPTIMAL ALLOCATION OF TOTAL FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	ME(T)=	ME'(T)=
1992.5	4.75654093	4.75578495
1993.5	4.85669688	4.8559516
1994.5	4.9393147	4.93857885
1995.5	5.0046163	5.00388862
1996.5	5.05279407	5.05207333
1997.5	5.08401128	5.08329626
1998.5	5.09840237	5.09769184
1999.5	5.09607314	5.09536591
2000.5	5.07710104	5.0763959
2001.5	5.04153525	5.04083099

TOTAL ME(T) = 50.007086
TOTAL ME'(T) = 49.9998583

ME(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME'(T) = NUMERICAL VALUE OF ME AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:

ME'(T+.5) = (ME(T)+2*ME(T+.1)+2*ME(T+.2)+...
+2*ME(T+.9)+ME(T+1))/20

TABLE 2: OPTIMAL ALLOCATION OF FUNDS EXPECTED TO BE SPENT BY THE A NUCLEAR POWER IN ORDER TO MODERNIZE ITS STRATEGIC OFFENSIVE WEAPONS AND TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	P1*O(T)=	P1*O'(T)=
1992.5	2.4170179	2.41655424
1993.5	2.36786779	2.36740274
1994.5	2.3077738	2.30730656
1995.5	2.23668461	2.2362144
1996.5	2.15453041	2.15405645
1997.5	2.06122284	2.06074432
1998.5	1.9566548	1.95617094
1999.5	1.84070038	1.84021035
2000.5	1.71321458	1.71271758
2001.5	1.57403319	1.57352838

T=	P2*D(T)=	P2*D'(T)=
1992.5	2.33952303	2.33923071
1993.5	2.48882909	2.48854887
1994.5	2.6315409	2.63127229
1995.5	2.76793169	2.76767422
1996.5	2.89826365	2.89801688
1997.5	3.02278844	3.02255193
1998.5	3.14174756	3.1415209
1999.5	3.25537277	3.25515556
2000.5	3.36388646	3.36367832
2001.5	3.46750206	3.46730261

P1*O(T), P1*O'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC OFFENSIVE WEAPONS
P2*D(T), P2*D'(T) = EXPENDITURES FOR MODERNIZING STRATEGIC DEFENSIVE WEAPONS
O'(T+.5) = (O(T)+2*O(T+.1)+2*O(T+.2)+...+2*O(T+.9)+ +O(T+1))/20
D'(T+.5) = (D(T)+2*D(T+.1)+2*D(T+.2)+...+2*D(T+.9)+ +D(T+1))/20

TABLE 3: A NUCLEAR POWER'S OPTIMAL POLICY OF MODERNIZING ITS STRATEGIC OFFENSIVE WEAPONS AND DEVELOPING STRATEGIC DEFENSIVE SYSTEMS DURING THE (T0-T1) INTERVAL OF TIME

T=	O(T)=	O'(T)=
1992.5	322.269053	322.207232
1993.5	315.715706	315.653698
1994.5	307.703174	307.640875
1995.5	298.224615	298.16192
1996.5	287.270722	287.207527
1997.5	274.829712	274.76591
1998.5	260.887307	260.822792
1999.5	245.426717	245.36138
2000.5	228.428611	228.362344
2001.5	209.871092	209.803784

T=	D(T)=	D'(T)=
1992.5	23.3952303	23.3923071
1993.5	24.8882909	24.8854887
1994.5	26.315409	26.3127229
1995.5	27.6793169	27.6767422
1996.5	28.9826365	28.9801688
1997.5	30.2278844	30.2255193
1998.5	31.4174756	31.415209
1999.5	32.5537277	32.5515556
2000.5	33.6388646	33.6367832
2001.5	34.6750206	34.6730261

O(T), O'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D(T), D'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM (IN $ MILLIONS)

TABLE 4 STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE ADVERSARIES OF THE A NUCLEAR POWER AND THE A POWER'S POTENTIAL CAPABILITY TO DEVELOP STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO(T)	OO(T)	Q*DD(T)
1992	14000	350	0
1993	12667.7239	696.517442	421.114145
1994	11462.2305	1036.17338	869.103381
1995	10371.4551	1369.10368	1342.78074
1996	9384.48065	1695.44151	1841.00845
1997	8491.42924	2015.31743	2362.6959
1998	7683.36291	2328.85938	2906.79783
1999	6952.19425	2636.19278	3472.31239
2000	6290.6055	2937.44057	4058.27949
2001	5691.97524	3232.72326	4663.77905
2002	5150.31218	3522.15895	5287.92942

T=	OOO(T)	OO(T)	Q*DD'(T)
1992	14000	350	0
1993	12667.7239	696.517442	421.061528
1994	11462.2305	1036.17338	869.000324
1995	10371.4551	1369.10368	1342.62934
1996	9384.48065	1695.44151	1840.8107
1997	8491.42924	2015.31743	2362.45373
1998	7683.36291	2328.85938	2906.51308
1999	6952.19425	2636.19278	3471.98685
2000	6290.6055	2937.44057	4057.91484
2001	5691.97524	3232.72326	4663.37694
2002	5150.31218	3522.15895	5287.49141

OOO(T) = TOTAL STOCKS OF STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
OO(T) = STOCKS OF MODERNIZED AND NEWLY BUILT STRATEGIC OFFENSIVE WEAPONS EXPECTED TO BE OWNED BY THE A POWER'S ADVERSARIES
Q*DD'(T) = A NUCLEAR POWER'S POTENTIAL CAPABILITY TO NEUTRALIZE ADVERSARIES' STRATEGIC OFFENSIVE WEAPONS BY DEVELOPING STRATEGIC DEFENSIVE SYSTEMS

5.3. A MODEL FOR THE STUDY OF TWO POWERS/COALITIONS' BEHAVIOR

The general model described at the beginning of the 5.1. section has contained a criterion of security optimization defined at the system level. The model included in the 5.2. section has included a comparable criterion defined at the nation-state level. In the first case the optimum has referred to the international system as a whole, all the nuclear actors being assumed to be in a more or less potentially adversarial relationship consistent with the characteristics of a balance of power system. In the second case, one actor has been regarded as being in a potentially adversarial relationship with the system. If the first case can be described as "all versus all," then the second may described as "one versus all" or "all versus one."

In this section I develop a model in which one assumes that there are two adversaries. They might be:

- two superpowers
- two coalitions of nuclear powers
- a (super)power and a coalition
- two regular nuclear powers having sufficient technological and economic resources to develop strategic defensive systems.

For convenience I call them the first and the second opponent, for not always repeating the above remarks.

The following notations are utilised:

$o_1(t)$ - the quantity of strategic offensive weapons which will be modernized or built by the first opponent during every year of the $[t_o, t_1]$ interval of time measured in standard units (standard strategic nuclear warheads);

$o_2(t)$ - the quantity of strategic offensive weapons which will be modernized or built by the second opponent during every year of the $[t_o, t_1]$ interval of time measured in standard units standard strategic nuclear warheads);

$d_1(t)$ - the number of strategic defensive systems which will be built by the first opponent during every year of the $[t_o, t_1]$ interval of time measured in standard units.

$d_2(t)$ - the number of strategic defensive systems which will be built by the second opponent during every year of the $[t_o, t_1]$ interval of time measured in standard units.

$p_{11}(t)$ - the price of one standard unit of strategic offensive weapons (nuclear warhead & corresponding share from the cost of the delivery system & maintenance expenditures) which will be modernized or built by the first opponent;

$p_{12}(t)$ - the price of one standard strategic defensive system built by the first opponent;

$p_{21}(t)$ - the price of one standard unit of strategic offensive weapons (nuclear warhead & corresponding share from the cost of the delivery system & maintenance expenditures) which will be modernized or built by the second opponent;

$p_{22}(t)$ - the price of one standard strategic defensive system built by the second opponent;

M_1 - total funds planned to be spent by the first opponent for modernizing its strategic offensive weapons and for buiding strategic defense systems during the whole $[t_o, t_1]$ interval of time;

M_2 - total funds planned to be spent by the second opponent for modernizing its strategic offensive weapons and for buiding strategic defense systems during the whole $[t_o, t_1]$ interval of time;

$O''_1(t)$ - the total stock of strategic offensive weapons (strategic nuclear warheads) owned by the first opponent in the t year;

$O''_2(t)$ - the total stock of strategic offensive weapons (strategic nuclear warheads) owned by the second opponent in the t year;

$w_1(t)$ - part of $O''_1(t^o)$ which should be annually neutralized by the strategic defensive systems of the second opponent;

$w_2(t)$ - part of $O''_2(t^o)$ which should be annually neutralized by the strategic defensive systems of the first opponent;

$\bar{o}_1(t)$ - the number of old and modernized strategic offensive weapons owned by the first opponent expected to be every year neutralized by the strategic defensive systems of the second opponent;

$\bar{o}_2(t)$ - the number of old and modernized strategic offensive weapons owned by the second opponent expected to be every year neutralized by the strategic defensive systems of the first opponent;

q_1, q_2 - coefficients of neutralization.

Utilizing these notations one describes the relationship between the two opponents by a non-homogeneous differential equations system. The stocks of modernized or newly built strategic offensive weapons (strategic nuclear warheads) are the state variables, and the number of annually built strategic defensive systems are the control variables. The system is the following:

$$\dot{o}_1(t) = a_{11} o_1(t) + a_{12} o_2(t) + b_{11} d_1(t) + b_{12} d_2(t)$$
$$\dot{o}_2(t) = a_{21} o_1(t) + a_{22} o_2(t) + b_{21} d_1(t) + b_{22} d_2(t)$$

(5.3.-1)

The initial and final conditions are given and they are fixed,

$$o_1(t_o) = o_1^o$$
$$o_2(t_o) = o_2^o$$

(5.3.-2)

$$o_1(t_1) = o_1^1$$
$$o_2(t_1) = o_2^1$$

The financial constraints for the two opponents are given by the following two relations:

$$\int_{t_o}^{t_1} (p_{11} o_1(t) + p_{12} d_1(t))dt = M_1 \qquad (5.3.\text{-}3)$$

$$\int_{t_o}^{t_1} (p_{21} o_2(t) + p_{22} d_2(t))dt = M_2 \qquad (5.3.-3)$$

The criterion of optimum reflects each opponent's interest in minimizing its vulnerability and the effort to build new strategic defensive systems:

$$[\min]J = \int_{t_o}^{t_1} ((\bar{o}_2(t) - q_1 d_1(t))^2 + (\bar{o}_1(t) - q_2 d_2(t))^2)dt \qquad (5.3.-4)$$

where,

$$\bar{o}_1(t) = o_1(t) + w_1(t)$$
$$\bar{o}_2(t) = o_2(t) + w_2(t) \qquad (5.3.-5)$$

One can suppose that the quotas of the total stocks of strategic offensive weapons which should be neutralized during the $[t_o, t_1]$ interval of time are equal to zero,

$$w_1(t) = 0$$
$$w_2(t) = 0 \qquad (5.3.-6)$$

or that they are different. For example they are given by the z''_1 and z''_2 percentages of the initial total stocks of strategic offensive warheads, so that:

$$w_1(t) = z''_1 o''^{o}_1$$
$$w_2(t) = z''_2 o''^{o}_2 \qquad (5.3.-7)$$

Taking into consideration the significance of the state and control variables, it is of course necessary to have:

$$o_1(t) \geq 0,\ o_2(t) \geq 0 \quad \text{for} \quad t \in [t_o, t_1]$$
$$d_1(t) \geq 0,\ d_2(t) \geq 0 \quad \text{for} \quad t \in [t_o, t_1] \qquad (5.3.-8)$$

On the basis of these relations, one remarks that it is possible to formulate the following optimal control problem: "let determine the optimal paths of the quantities of strategic offensive weapons which will be modernized (or built) by each of the two opponents and of the strategeic defensive systems which will be built and deployed by them, so as to attain the planned final stocks of modernized strategic offensive weapons at the final point in time, to minimize both opponents' vulnerability on the whole interval of time, and to minimize the effort for building new strategic defensive systems with respect to the financial constraints."

If the model is used to evaluate an R&D program, representing the current situation, there are the following modifications comparable to those indicated in the case of the preceding model:

- $d_1(t)$ and $d_2(t)$ represent the funds expected to be spent annually by the two opponents for doing research and developing prototypes of strategic defense systems;
- b_{ij}, i,j = 1,2, characterize the influence of the annual R&D expenditures for strategic defense systems on the increase/decrease of the number of strategic offensive systems (strategic nuclear warheads);
- the p_{12} and p_{22} coefficients are equal to 1;

- the q_1 and q_2 coefficients indicate the efficiency of strategic defense R&D expenditures.

It is also possible to take into consideration the total stocks of strategic offensive nuclear weapons owned by the two opponents. They are exogeneously given, and they are not included in the optimization problem. They are used for comparison.

This problem can be solved by using the Pontryagin Principle for problems with functional constraints.

One first builds the Hamilton function:

$$H = -(o_2(t) + w_2 - q_1 d_1(t))^2 - (o_1(t) + w_1 - q_2 d_2(t))^2 +$$
$$+ \psi_1(t) a_{11} o_1(t) + \psi_1(t) a_{12} o_2(t) + \psi_1(t) b_{11} d_1(t) + \psi_1(t) b_{12} d_2(t)$$
$$+ \psi_2(t) a_{21} o_1(t) + \psi_2(t) a_{22} o_2(t) + \psi_2(t) b_{21} d_1(t) + \psi_2(t) b_{22} d_2(t)$$
$$- \lambda_1 p_{11} o_1(t) - \lambda_1 p_{12} d_1(t) \qquad (5.3.-9)$$
$$- \lambda_2 p_{21} o_2(t) - \lambda_2 p_{22} d_2(t)$$

and one makes the computations indicated by the parentheses, such as one results the following expression:

$$H = - o_2^2(t) - w_2^2 - q_1^2 d_1^2(t) - 2o_2(t)w_2 + 2o_2(t)q_1 d_1(t) + 2w_2 q_1 d_1(t) -$$

$$- o_1^2(t) - w_1^2 - q_2^2 d_2^2(t) - 2o_1(t)w_1 + 2o_1(t)q_2 d_2(t) + 2w_1 q_2 d_2(t) +$$

$$+\psi_1(t)a_{11}o_1(t) + \psi_1(t)a_{12}o_2(t) + \psi_1(t)b_{11}d_1(t) + \psi_1(t)b_{12}d_2(t)$$

$$+\psi_2(t)a_{21}o_1(t) + \psi_2(t)a_{22}o_2(t) + \psi_2(t)b_{21}d_1(t) + \psi_2(t)b_{22}d_2(t)$$

$$-\lambda_1 p_{11} o_1(t) - \lambda_1 p_{12} d_1(t) \qquad (5.3.-10)$$

$$-\lambda_2 p_{21} o_2(t) - \lambda_2 p_{22} d_2(t)$$

The adjunct system can be constructed without difficulty and it is:

$$\dot{\psi}_1(t) = -\frac{\partial H}{\partial o_1} =$$

$$= 2o_1(t) + 2w_1 - 2q_2 d_2(t) - a_{11}\psi_1(t) - a_{21}\psi_2(t) + \lambda_1 p_{11}$$

$$\dot{\psi}_2(t) = -\frac{\partial H}{\partial o_2} = \qquad (5.3.-11)$$

$$= 2o_2(t) + 2w_2 - 2q_1 d_1(t) - a_{12}\psi_1(t) - a_{22}\psi_2(t) + \lambda_2 p_{21}$$

The $d_1^*(t)$ and $d_2^*(t)$ optimal control variables depend on $\psi_1(t)$, $\psi_2(t)$, λ_1, and λ_2, and they can be obtained by using the relations:

$$\frac{\partial H}{\partial d_1} = 0 \qquad \frac{\partial H}{\partial d_2} = 0 \qquad (5.3.-12)$$

They are:

$$d_1^*(t) = \frac{1}{2q_1^2}\left(2q_1 o_2(t) + b_{11}\psi_1(t) + b_{21}\psi_2(t) - p_{12}\lambda_1 + 2q_1 w_2\right)$$

$$d_2^*(t) = \frac{1}{2q_2^2}\left(2q_2 o_1(t) + b_{12}\psi_1(t) + b_{22}\psi_2(t) - p_{22}\lambda_2 + 2q_2 w_1\right)$$

(5.3.-13)

If one substitutes $d_1^*(t)$ and $d_2^*(t)$ in the (5.3.-1) differential system and in the (5.3.-1) adjunct system, and one conveniently groups, one finally obtains the following system of four differential equations:

$$\dot{o}_1(t) = c_{11} o_1(t) + c_{12} o_2(t) + c_{13}\psi_1(t) + c_{14}\psi_2(t) + c_{15}\lambda_1 + c_{16}\lambda_2 + c_{17}$$

$$\dot{o}_2(t) = c_{21} o_1(t) + c_{22} o_2(t) + c_{23}\psi_1(t) + c_{24}\psi_2(t) + c_{25}\lambda_1 + c_{26}\lambda_2 + c_{27}$$

(5.3.-14)

$$\dot{\psi}_1(t) = c_{33}\psi_1(t) + c_{34}\psi_2(t) + c_{35}\lambda_1 + c_{36}\lambda_2$$

$$\dot{\psi}_2(t) = c_{43}\psi_1(t) + c_{44}\psi_2(t) + c_{45}\lambda_1 + c_{46}\lambda_2$$

where,

$$c_{11} = a_{11} + \frac{b_{12}}{q_2}$$

$$c_{12} = a_{12} + \frac{b_{11}}{q_1}$$

$$c_{13} = \frac{b_{11}^2}{2q_1^2} + \frac{b_{12}^2}{2q_2^2}$$

$$c_{14} = \frac{b_{11}b_{21}}{2q_1^2} + \frac{b_{12}b_{22}}{2q_2^2} \qquad (5.3.-15)$$

$$c_{15} = - \frac{b_{11}p_{12}}{2q_1^2}$$

$$c_{16} = - \frac{b_{12}p_{22}}{2q_2^2}$$

$$c_{17} = \frac{b_{11}w_2}{q_1} + \frac{b_{12}w_1}{q_2}$$

$$c_{21} = a_{21} + \frac{b_{22}}{q_2}$$

$$c_{22} = a_{22} + \frac{b_{21}}{q_1}$$

$$c_{23} = \frac{b_{21}^2}{2q_1^2} + \frac{b_{22}^2}{2q_2^2}$$

$$c_{24} = \frac{b_{11} b_{21}}{2q_1^2} + \frac{b_{12} b_{22}}{2q_2^2} \qquad (5.3.-15)$$

$$c_{25} = - \frac{b_{21} p_{12}}{2q_1^2}$$

$$c_{16} = - \frac{b_{22} p_{22}}{2q_2^2}$$

$$c_{27} = \frac{b_{21} w_2}{q_1} + \frac{b_{22} w_1}{q_2}$$

$$c_{33} = -a_{11} - \frac{b_{12}}{q_2}$$

$$c_{34} = -a_{21} - \frac{b_{22}}{q_2}$$

$$c_{35} = p_{11}$$

$$c_{36} = \frac{p_{22}}{q_2}$$

$$c_{43} = -a_{12} - \frac{b_{11}}{q_1}$$

$$c_{44} = -a_{22} - \frac{b_{21}}{q_1}$$

$$c_{45} = \frac{p_{12}}{q_1}$$

$$c_{46} = p_{21}$$

Remarking on the particular structure of the (5.3.-14) differential system, one considers the last two equations which constitute a non-homogeneous differential system of $\psi_1(t)$ and $\psi_2(t)$. The solutions of this system may be derived without difficulties, and they depend on two integration constants, K_3 and K_4 and on two Lagrange multipliers, λ_1 and λ_2. If r_1 and r_2 are two solutions of the characteristic equation of the homogeneous system,

$$r_{1,2} = \frac{(c_{33}+c_{44}) \pm \sqrt{(c_{33}-c_{44})^2 + 4c_{34}c_{43}}}{2} \qquad (5.3.-16)$$

and if they are real and different, then the $\psi_1^*(t)$ and $\psi_2^*(t)$ solutions are:

$$\psi_1^*(t) = K_3 e^{r_1 t} + K_4 e^{r_2 t} + h_5 \lambda_1 + h_6 \lambda_2$$

$$\psi_2^*(t) = h_3 K_3 e^{r_1 t} + h_4 K_4 e^{r_2 t} + h_7 \lambda_1 + h_8 \lambda_2 \qquad (5.3.-17)$$

The coefficients, h_3, h_4, ... h_8, result by solving the whole non-homogeneous system and they are given in the following list:

$$h_3 = \frac{r_1 - c_{33}}{c_{34}}$$

$$h_4 = \frac{r_2 - c_{33}}{c_{34}} \qquad (5.3.-18)$$

$$h_5 = -\frac{c_{35}}{c_{33}} - \frac{c_{34} h_7}{c_{33}}$$

$$h_6 = -\frac{c_{36}}{c_{33}} - \frac{c_{34} h_8}{c_{33}}$$

$$h_7 = \left(-c_{45} + \frac{c_{43} c_{35}}{c_{33}}\right) / \left(c_{44} - \frac{c_{43} c_{34}}{c_{33}}\right)$$

$$h_8 = \left(-c_{46} + \frac{c_{43} c_{36}}{c_{33}}\right) / \left(c_{44} - \frac{c_{43} c_{34}}{c_{33}}\right)$$

The next step for solving the (5.3.-14) system consists in the substitution of the (5.3.-16) optimal paths of $\psi_1^*(t)$ and $\psi_2^*(t)$ in the first two equations of that system. After one makes all the necessary computations, and one conveniently groups one obtains the following non-homogeneous system of two differential equations:

$$\dot{o}_1(t) = c_{11} o_1(t) + c_{12} o_2(t) + g_1 K_3 e^{r_1 t} + g_2 K_4 e^{r_2 t} + $$
$$+ g_3 \lambda_1 + g_4 \lambda_2 + c_{17} \qquad (5.3.-19)$$

$$\dot{o}_2(t) = c_{21} o_1(t) + c_{22} o_2(t) + g_5 K_3 e^{r_1 t} + g_6 K_4 e^{r_2 t} + $$
$$+ g_7 \lambda_1 + g_8 \lambda_2 + c_{27}$$

where the following notations are used:

$$g_1 = c_{13} + c_{14} h_3$$

$$g_2 = c_{13} + c_{14} h_4$$

$$g_3 = c_{13} h_5 + c_{14} h_7 + c_{15}$$

$$g_4 = c_{13} h_6 + c_{14} h_8 + c_{16}$$

$$g_5 = c_{23} + c_{24} h_3 \qquad (5.3.-20)$$

$$g_6 = c_{23} + c_{24} h_4$$

$$g_7 = c_{23} h_5 + c_{24} h_7 + c_{25}$$

$$g_8 = c_{23} h_6 + c_{24} h_8 + c_{26}$$

If z_1 and z_2 are the solutions of the characteristic equation of the (5.3.-19) system,

$$z_{1,2} = \frac{c_{11} + c_{22}) \pm \sqrt{(c_{11} - c_{22})^2 + 4c_{12} c_{21}}}{2} \qquad (5.3.-21)$$

and if they are real and different, then the general solutions of the (5.3.-19) system are

$$o_1^*(t) = K_1 e^{z_1 t} + K_2 e^{z_2 t} + s_1 K_3 e^{r_1 t} + s_2 K_4 e^{r_2 t} +$$
$$+ s_3 \lambda_1 + s_4 \lambda_2 + w_3 \qquad (5.3.-22)$$

$$o_2^*(t) = h_1 K_1 e^{z_1 t} + h_2 K_2 e^{z_2 t} + s_5 K_3 e^{r_1 t} + s_6 K_4 e^{r_2 t} +$$
$$+ s_7 \lambda_1 + s_8 \lambda_2 + w_4$$

where K_1 and K_2 are two constants of integration.

The h_1 and h_2 constant coefficients may be immediately obtained by using the following two relations,

$$h_1 = \frac{z_1 - c_{11}}{c_{12}}$$
$$(5.3.-23)$$
$$h_2 = \frac{z_2 - c_{11}}{c_{12}}$$

The constant coefficients: s_1, s_2, ... s_8, w_3 and w_4 can be computed by solving the following five algebraic systems derived by applying the identification method,

$$\begin{cases} (c_{11} - r_1)s_1 + c_{12} s_5 = -g_1 \\ c_{21} s_1 + (c_{22} - r_1)s_5 = -g_5 \end{cases}$$

$$\begin{cases}(c_{11} - r_1)s_2 + c_{12}s_6 = -g_2 \\ c_{21}s_1 + (c_{22} - r_2)s_6 = -g_6\end{cases}$$

$$\begin{cases}c_{11}s_3 + c_{12}s_7 = -g_3 \\ c_{21}s_3 + c_{22}s_7 = -g_7\end{cases} \qquad (5.3.-24)$$

$$\begin{cases}c_{11}s_4 + c_{12}s_8 = -g_4 \\ c_{21}s_4 + c_{22}s_8 = -g_8\end{cases}$$

$$\begin{cases}c_{11}w_3 + c_{12}w_4 = -c_{17} \\ c_{21}w_3 + c_{22}w_4 = -c_{27}\end{cases}$$

If one analyses the (5.3.-21) general solutions, one remarks that they depend on four constants of integration: K_1, K_2, K_3, and K_4 and two Lagrange multipliers that are also constant. These six constants are uniquely determined by the four initial and final conditions and by the two financial constraints. For computing them, one writes the two optimal control variables $d_1^*(t)$ and $d_2^*(t)$ depending on the (5.3.-16) and (5.3.-21) optimal solutions and one obtains their expression depending on K_1, K_2, K_3, K_4, λ_1 and λ_2 as it is shown below.

$$d_1^*(t) = \frac{1}{q}(h_1K_1e^{z_1t} + h_2K_2e^{z_2t} + s_5K_3e^{r_1t} + s_6K_4e^{r_2t} +$$

$$+ s_7\lambda_1 + s_8\lambda_2 + w_4) +$$

$$\frac{b_{11}}{2q_1^2}\left(K_3 e^{r_1 t} + K_4 e^{r_2 t} + h_5 \lambda_1 + h_6 \lambda_2\right) +$$

$$\frac{b_{21}}{2q_1^2}\left(h_3 K_3 e^{r_1 t} + h_4 K_4 e^{r_2 t} + h_7 \lambda_1 + h_8 \lambda_2\right) -$$

$$\frac{p_{12}}{2q_1^2}\lambda_1 + \frac{w_2}{q_1} \qquad (5.3.-25)$$

$$d_2^*(t) = \frac{1}{q}\left(K_1 e^{z_1 t} + K_2 e^{z_2 t} + s_1 K_3 e^{r_1 t} + s_2 K_4 e^{r_2 t} + \right.$$

$$\left. + s_3 \lambda_1 + s_4 \lambda_2 + w_3\right) +$$

$$\frac{b_{12}}{2q_2^2}\left(K_3 e^{r_1 t} + K_4 e^{r_2 t} + h_5 \lambda_1 + h_6 \lambda_2\right) +$$

$$\frac{b_{22}}{2q_2^2}\left(h_3 K_3 e^{r_1 t} + h_4 K_4 e^{r_2 t} + h_7 \lambda_1 + h_8 \lambda_2\right) -$$

$$\frac{p_{22}}{2q_2^2}\lambda_2 + \frac{w_1}{q_2}$$

One continues the resolution of the problem by substituting the $d_1^*(t)$, $d_2^*(t)$, $o_1^*(t)$ and $o_2^*(t)$ optimal trajectories in the (5.3.-3) financial constraints and by conveniently grouping with respect to the six unknown constants. One finally obtains:

$$\int_{t_o}^{t_1} [(p_{11} + \frac{p_{12}h_1}{q_1})e^{z_1 t} K_1 +$$

$$(p_{11} + \frac{p_{12}h_2}{q_1})e^{z_2 t} K_2 +$$

$$(p_{11}s_1 + \frac{p_{12}s_5}{q_1} + \frac{p_{12}b_{11}}{2q_1^2} + \frac{p_{12}b_{21}h_3}{2q_1^2})e^{r_1 t} K_3 +$$

$$(p_{11}s_2 + \frac{p_{12}s_6}{q_1} + \frac{p_{12}b_{11}}{2q_1^2} + \frac{p_{12}b_{21}h_4}{2q_1^2})e^{r_2 t} K_4 +$$

$$(p_{11}s_3 + \frac{p_{12}s_7}{q_1} + \frac{p_{12}b_{11}h_5}{2q_1^2} + \frac{p_{12}b_{21}h_7}{2q_1^2} - \frac{p_{12}^2}{2q_1^2})\lambda_1 +$$

$$(p_{11}s_4 + \frac{p_{12}s_8}{q_1} + \frac{p_{12}b_{11}h_6}{2q_1^2} + \frac{p_{12}b_{21}h_8}{2q_1^2})\lambda_2 +$$

$$(p_{11}w_3 + \frac{p_{12}w_4}{q_1} + \frac{p_{12}w_2}{q_1})]dt = M_1 \qquad (5.3.-26)$$

$$\int_{t_o}^{t_1} [(p_{21}h_1 + \frac{p_{22}}{q_2})e^{z_1 t} K_1 + \quad (5.3.-26)$$

$$(p_{21}h_2 + \frac{p_{22}}{q_2})e^{z_2 t} K_2 +$$

$$(p_{21}s_5 + \frac{p_{22}s_1}{q_2} + \frac{p_{22}b_{12}}{2q_2^2} + \frac{p_{22}b_{22}h_3}{2q_2^2})e^{r_1 t} K_3 +$$

$$(p_{21}s_6 + \frac{p_{22}s_2}{q_2} + \frac{p_{22}b_{12}}{2q_2^2} + \frac{p_{22}b_{22}h_4}{2q_2^2})e^{r_2 t} K_4 +$$

$$(p_{21}s_7 + \frac{p_{22}s_3}{q_2} + \frac{p_{22}b_{12}h_5}{2q_2^2} + \frac{p_{22}b_{22}h_7}{2q_2^2})\lambda_1 +$$

$$(p_{11}s_4 + \frac{p_{22}s_4}{q_1} + \frac{p_{22}b_{12}h_6}{2q_2^2} + \frac{p_{22}b_{22}h_8}{2q_2^2} - \frac{p_{22}^2}{2q_2^2})\lambda_2 +$$

$$(p_{21}w_4 + \frac{p_{22}w_3}{q_2} + \frac{p_{22}w_1}{q_2})]dt = M_2$$

If one notes,

$$n_{11} = p_{11} + \frac{p_{12} h_1}{q_1}$$

$$n_{12} = p_{11} + \frac{p_{12} h_2}{q_1}$$

$$n_{13} = p_{11} s_1 + \frac{p_{12} s_5}{q_1} + \frac{p_{12} b_{11}}{2q_1^2} + \frac{p_{12} b_{21} h_3}{2q_1^2}$$

$$n_{14} = p_{11} s_2 + \frac{p_{12} s_6}{q_1} + \frac{p_{12} b_{11}}{2q_1^2} + \frac{p_{12} b_{21} h_4}{2q_1^2}$$

$$n_{15} = p_{11} s_3 + \frac{p_{12} s_7}{q_1} + \frac{p_{12} b_{11} h_5}{2q_1^2} + \frac{p_{12} b_{21} h_7}{2q_1^2} - \frac{p_{12}^2}{2q_1^2}$$

$$n_{16} = p_{11} s_4 + \frac{p_{12} s_8}{q_1} + \frac{p_{12} b_{11} h_6}{2q_1^2} + \frac{p_{12} b_{21} h_8}{2q_1^2}$$

$$n_{17} = p_{11} w_3 + \frac{p_{12} w_4}{q_1} + \frac{p_{12} w_2}{q_1} \qquad (5.3.-27)$$

$$n_{21} = p_{21} h_1 + \frac{p_{22}}{q_2}$$

$$n_{22} = p_{21} h_2 + \frac{p_{22}}{q_2} \tag{5.3.-27}$$

$$n_{23} = p_{21} s_5 + \frac{p_{22} s_1}{q_2} + \frac{p_{22} b_{12}}{2q_2^2} + \frac{p_{22} b_{22} h_3}{2q_2^2}$$

$$n_{24} = p_{21} s_6 + \frac{p_{22} s_2}{q_2} + \frac{p_{22} b_{12}}{2q_2^2} + \frac{p_{22} b_{22} h_4}{2q_2^2}$$

$$n_{25} = p_{21} s_7 + \frac{p_{22} s_3}{q_2} + \frac{p_{22} b_{12} h_5}{2q_2^2} + \frac{p_{22} b_{22} h_7}{2q_2^2}$$

$$n_{26} = p_{11} s_4 + \frac{p_{22} s_4}{q_1} + \frac{p_{22} b_{12} h_6}{2q_2^2} + \frac{p_{22} b_{22} h_8}{2q_2^2} - \frac{p_{22}^2}{2q_2^2}$$

$$n_{27} = p_{21} w_4 + \frac{p_{22} w_3}{q_2} + \frac{p_{22} w_1}{q_2}$$

and if one calculates the two (5.3.-26) integrals one obtains:

$$\frac{n_{11}}{z_1} e^{z_1 t} K_1 \Big|_{t_o}^{t_1} + \frac{n_{12}}{z_2} e^{z_2 t} K_2 \Big|_{t_o}^{t_1} + \frac{n_{13}}{r_1} e^{r_1 t} K_3 \Big|_{t_o}^{t_1} +$$

(5.3.-28)

$$\frac{n_{14}}{r_2} e^{r_2 t} K_4 \Big|_{t_o}^{t_1} + n_{15} \lambda_1 t \Big|_{t_o}^{t_1} + n_{16} \lambda_2 t \Big|_{t_o}^{t_1} + n_{17} t \Big|_{t_o}^{t_1} = M_1$$

$$\frac{n_{21}}{z_1} e^{z_1 t} K_1 \Big|_{t_o}^{t_1} + \frac{n_{22}}{z_2} e^{z_2 t} K_2 \Big|_{t_o}^{t_1} + \frac{n_{23}}{r_1} e^{r_1 t} K_3 \Big|_{t_o}^{t_1} +$$

$$\frac{n_{24}}{r_2} e^{r_2 t} K_4 \Big|_{t_o}^{t_1} + n_{25} \lambda_1 t \Big|_{t_o}^{t_1} + n_{26} \lambda_2 t \Big|_{t_o}^{t_1} + n_{27} t \Big|_{t_o}^{t_1} = M_2 \qquad (5.3.-28)$$

If one associates these two relations with the (5.3.-2) initial conditions written for the o*(t) and o*(t) optimal trajectories of state, one obtains a system of six algebraic equations with six unknown variables,

$$\mathcal{A} x = y \qquad (5.3.-29)$$

With x and y are noted the following two vectors:

$$x = \begin{pmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \\ \lambda_1 \\ \lambda_2 \end{pmatrix} \qquad y = \begin{pmatrix} o_1^o - w_3 \\ o_2^o - w_4 \\ o_1^o - w_3 \\ o_2^o - w_4 \\ M_1 - n_{17} t_1 \\ M_2 - n_{27} t_1 \end{pmatrix}$$

and with $\mathcal{A}$ the matrix presented in Table 5.3.-1. The solutions of this algebraic system are: K_1^*, K_2^*, K_3^*, K_4^*, λ_1^*, λ_2^*, and they allow the complete determination of the optimal state and control trajectories. Similarly to the preceding model, some of these

Table 5.3.-1.

1	1	s_1	s_2	s_3	s_4
h_1	h_2	s_5	s_6	s_7	s_8
$e^{z_1 t_1}$	$e^{z_2 t_1}$	$s_1 e^{r_1 t_1}$	$s_2 e^{r_2 t_1}$	s_3	s_4
$h_1 e^{z_1 t_1}$	$h_2 e^{z_2 t_1}$	$s_5 e^{r_1 t_1}$	$s_6 e^{r_2 t_1}$	s_7	s_8
$\frac{n_{11} e^{z_1 t_1}}{z_1} - \frac{n_{11}}{z_1}$	$\frac{n_{12} e^{z_2 t_1}}{z_2} - \frac{n_{12}}{z_2}$	$\frac{n_{13} e^{r_1 t_1}}{r_1} - \frac{n_{13}}{r_1}$	$\frac{n_{14} e^{r_2 t_1}}{r_2} - \frac{n_{14}}{r_2}$	$n_{15} t_1$	$n_{16} t_1$
$\frac{n_{21} e^{z_1 t_1}}{z_1} - \frac{n_{21}}{z_1}$	$\frac{n_{22} e^{z_2 t_1}}{z_2} - \frac{n_{22}}{z_2}$	$\frac{n_{23} e^{r_1 t_1}}{r_1} - \frac{n_{23}}{r_1}$	$\frac{n_{24} e^{r_2 t_1}}{r_2} - \frac{n_{24}}{r_2}$	$n_{25} t_1$	$n_{26} t_1$

optimal trajectories might not be admissible because the non-negativity constraints were not taken into consideration by the algorithm based on Pontryagin principle. Consequently, the computer program which I wrote for computing the optimal solutions checks if the solutions are admissible or not. If at one point in time one trajectory becomes negative, the program immediately indicates this situation, and the computations are stoped. This means that the set of entry data that was employed does not allow one the derivation of an optimal admissible solution, and that some data should be changed before making another attempt.

Three illustrative scenarios, in which the model is employed for studying an R&D program are included in the following pages. In addition to the data employed in the optimization problem, there are given the paths of the total stocks of strategic offensive weapons (nuclear warheads) owned by the two opponents. One assumes that they are decreasing at fixed annual rates. The initial stocks are (in brackets are the notation used in the outprints): [OOO1(0)] = 11,000 and [OOO2(0)] = 10,000. The annual rates of decrease are: [IN1] = -.1 and [IN2] = -.1. In the first scenario one considers that the efficiency of the R&D program would be between moderate and good. In the second example one presumes that the efficiency would be unsatisfactory. In the third scenario I made the opposite hypothesis, by assuming that the efficiency would be high. As the numerical results and the graphs included in the outprints (pp. 305 - 361) show, the annual allocation of funds changes significantly from one scenario to another. This means that not only the efficiency problem is taken into consideration in the model, but also that the model is remarkably sensitive to variations in R&D program's efficiency. As I specified before I do not have access to classified information, and consequently all the data used in these scenarios are hypothetical. Therefore the results must be regarded only as illustrations of the model, and not as predictions based on rigorous empirical data. From this point of view, these scenarios are comparable to those included in the preceding section.

* * * * * * * * *

MODEL FOR THE STUDY OF TWO POWERS//COALITIONS BEHAVIOR

SCENARIO N0. 1

A11= .01
A12= .03
A21= .02
A22= .02
B11=-8.8
B12= .4
B21= .48
B22=-8.4
P11= 7.5E-03
P12= 1
P21= 8.1E-03
P22= 1
ME1= 50
ME2= 53
Q1= 30
Q2= 25
T1= 10
OOO1(0)= 11000
OOO2(0)= 10000
IN1=-.1
IN2=-.1

O1(0)= 325
O2(0)= 350
O1(T1)= 200
O2(T1)= 225

DD1(T1+)= 100
DD2(T1+)= 100

TABLE 1
TOTAL ME1 FOR (T0-T1) ARE $BILLIONS 50

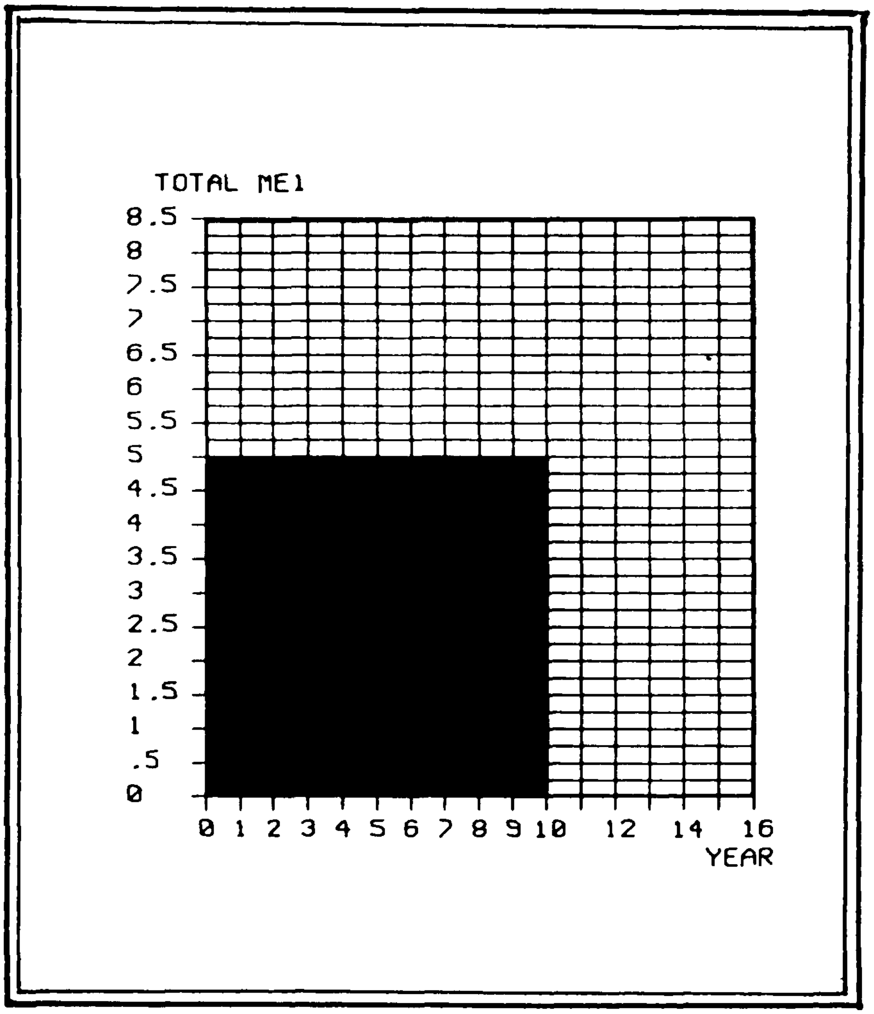


TABLE 2
TOTAL ME2 FOR (T0-T1) ARE: $BILLIONS 53

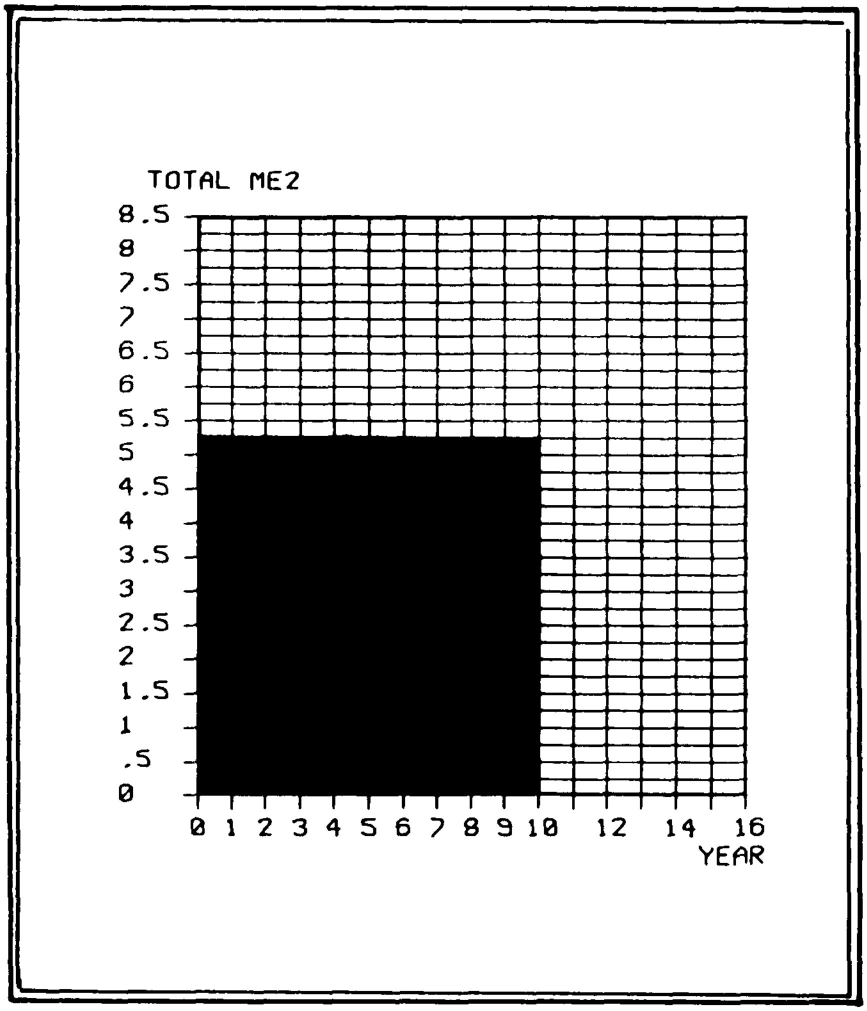
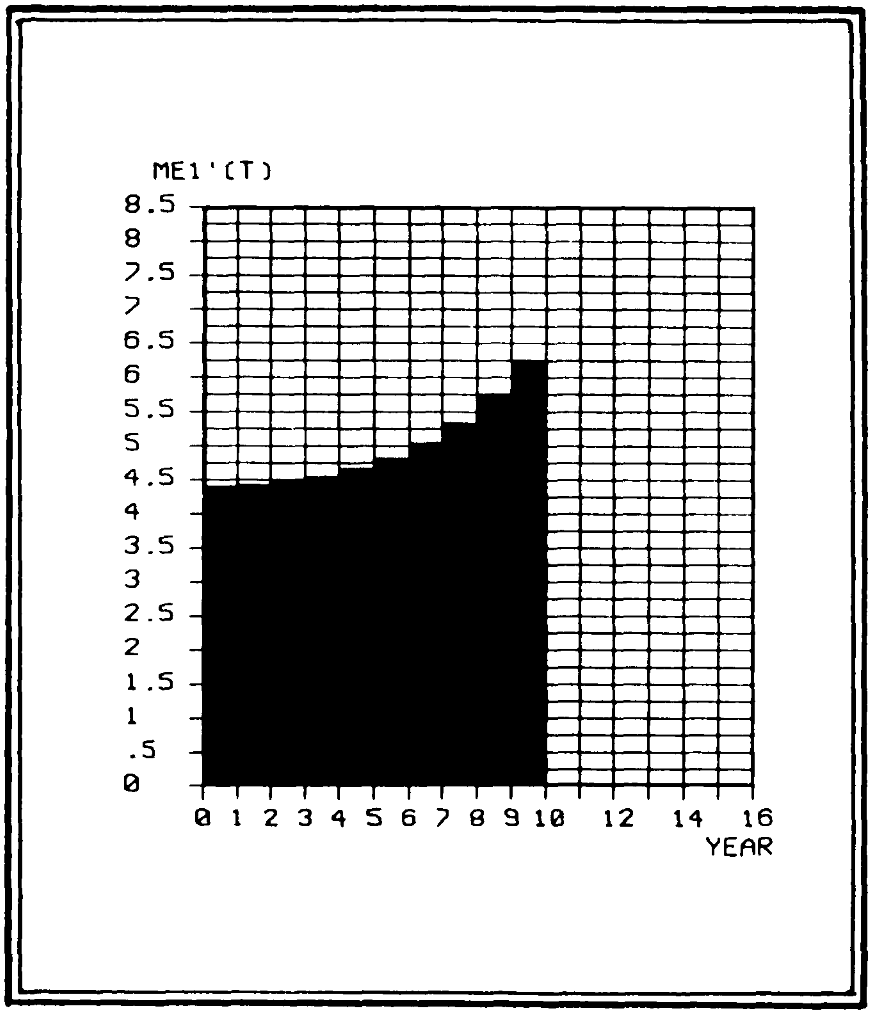


TABLE 3: OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME1(T)=	ME1'(T)=
.5	4.43398737	4.42707352
1.5	4.45595955	4.45159791
2.5	4.5011798	4.49885679
3.5	4.57643452	4.57583335
4.5	4.68950613	4.69046896
5.5	4.84997644	4.85248182
6.5	5.07007605	5.07422858
7.5	5.36565724	5.37168821
8.5	5.75737229	5.76565035
9.5	6.27214757	6.28319987

TOTAL ME1(T)= 49.972297
TOTAL ME1'(T)= 49.9910794

ME1(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME1'(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXI-MATION THE FOLLOWING FORMULA:
ME1'(T) = (ME1(T)+2*ME1(T+.1)+2*ME1(T+.2)+.....
+2*ME1(T+.9)+ME1(T+1))/20



ME1'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 4: OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME2(T)=	ME2'(T)=
.5	6.85357642	6.86722742
1.5	6.12127878	6.13211029
2.5	5.59537282	5.60441327
3.5	5.22622877	5.23430353
4.5	4.97862675	4.98643603
5.5	4.82831625	4.83649849
6.5	4.75960229	4.76878882
7.5	4.7637148	4.77458076
8.5	4.83779261	4.85110845
9.5	4.98436991	5.00105747

TOTAL ME2(T)= 52.9488794
TOTAL ME2'(T)= 53.0565245

ME2(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME2'(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:
ME2'(T) = (ME2(T)+2*ME2(T+.1)+2*ME2(T+.2)+..... +2*ME2(T+.9)+ME2(T+1))/20

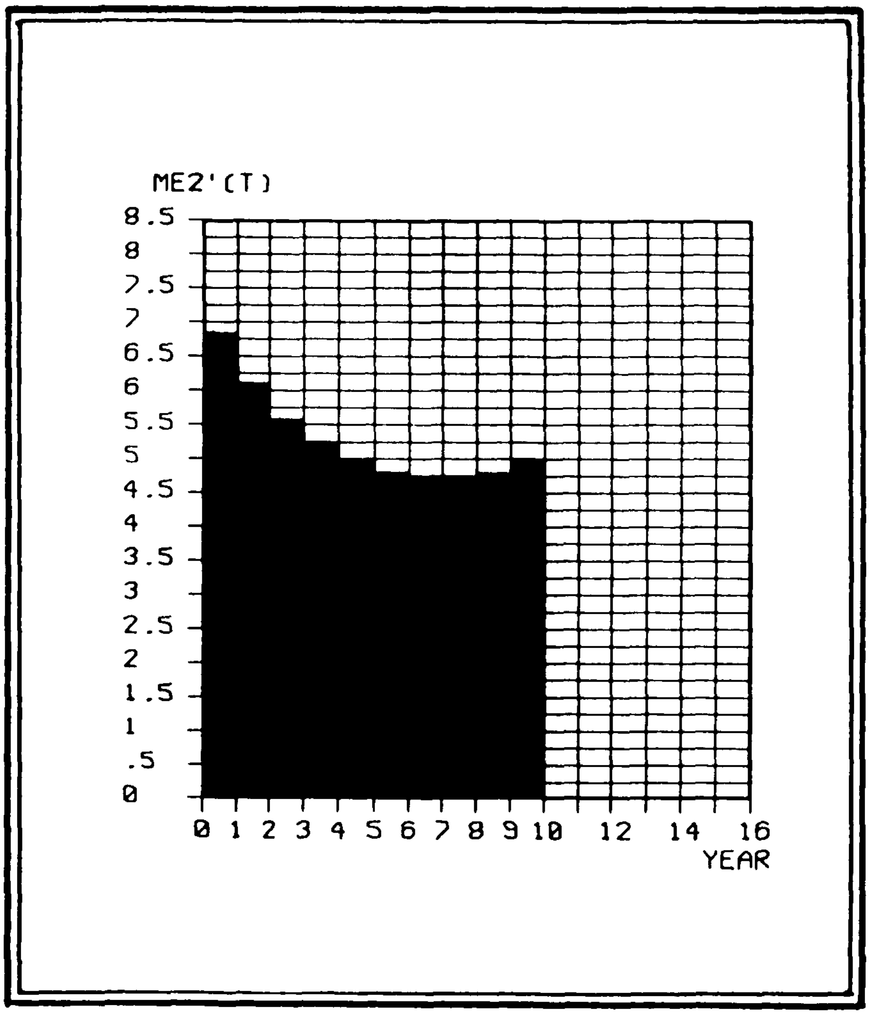

ME2'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 5: OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P11*O1(T)=	P11*O1'(T)=
.5	2.4289143	2.42853375
1.5	2.40500419	2.40460734
2.5	2.37168943	2.37123558
3.5	2.32762872	2.32707717
4.5	2.27051725	2.26982357
5.5	2.19699828	2.1961105
6.5	2.10248575	2.10134035
7.5	1.98089104	1.97940822
8.5	1.82423893	1.82231699
9.5	1.62214952	1.61965777

T=	P12*D1(T)=	P12*D1'(T)=
.5	2.00507307	1.99853976
1.5	2.05095536	2.04699057
2.5	2.12949036	2.12762122
3.5	2.2488058	2.24875618
4.5	2.41898888	2.42064539
5.5	2.65297816	2.65637131
6.5	2.96759029	2.97288823
7.5	3.3847662	3.39228
8.5	3.93313337	3.94333336
9.5	4.64999805	4.66354211

P11*O1(T), P11*O1'(T) = FIRST OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P12*D1(T), P12*D1'(T) = FUNDS FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT
O1'(T+.5) = (O1(T)+2*O1(T+.1)+2*O1(T+.2)+..... +2*O1(T+.9)+O1(T+1))/20
D1'(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+..... +2*D1(T+.9)+D1(T+1))/20

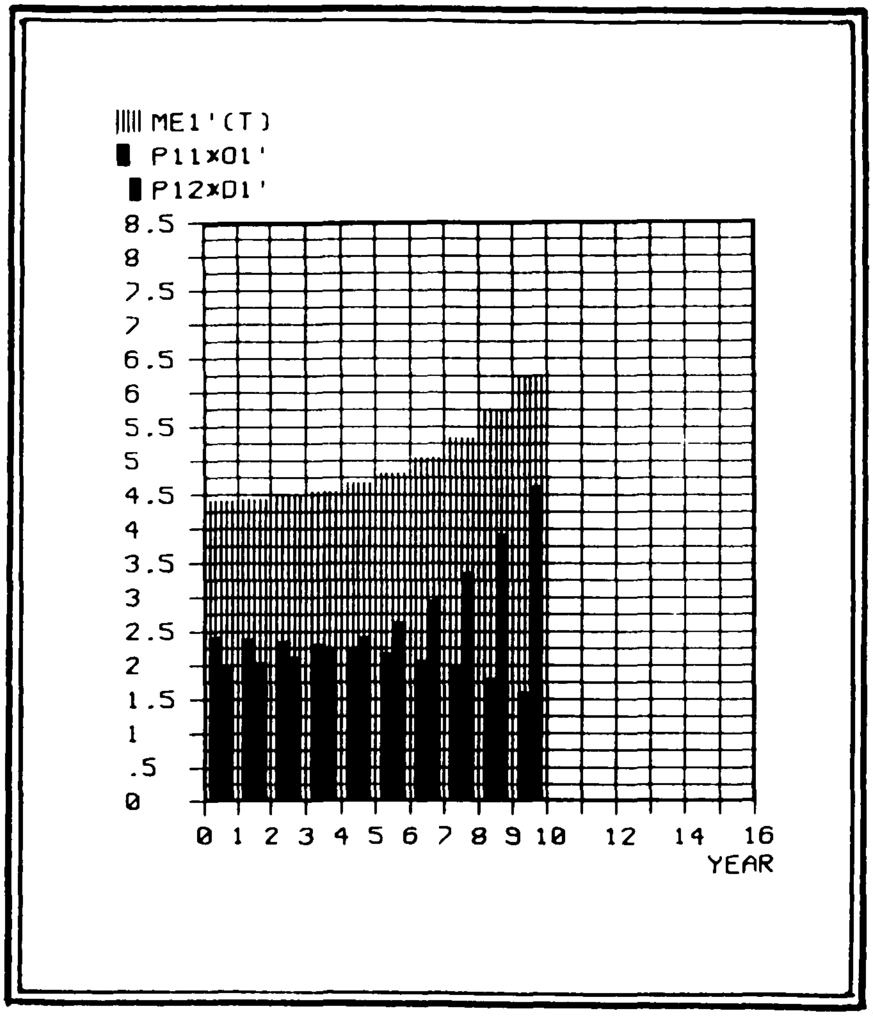
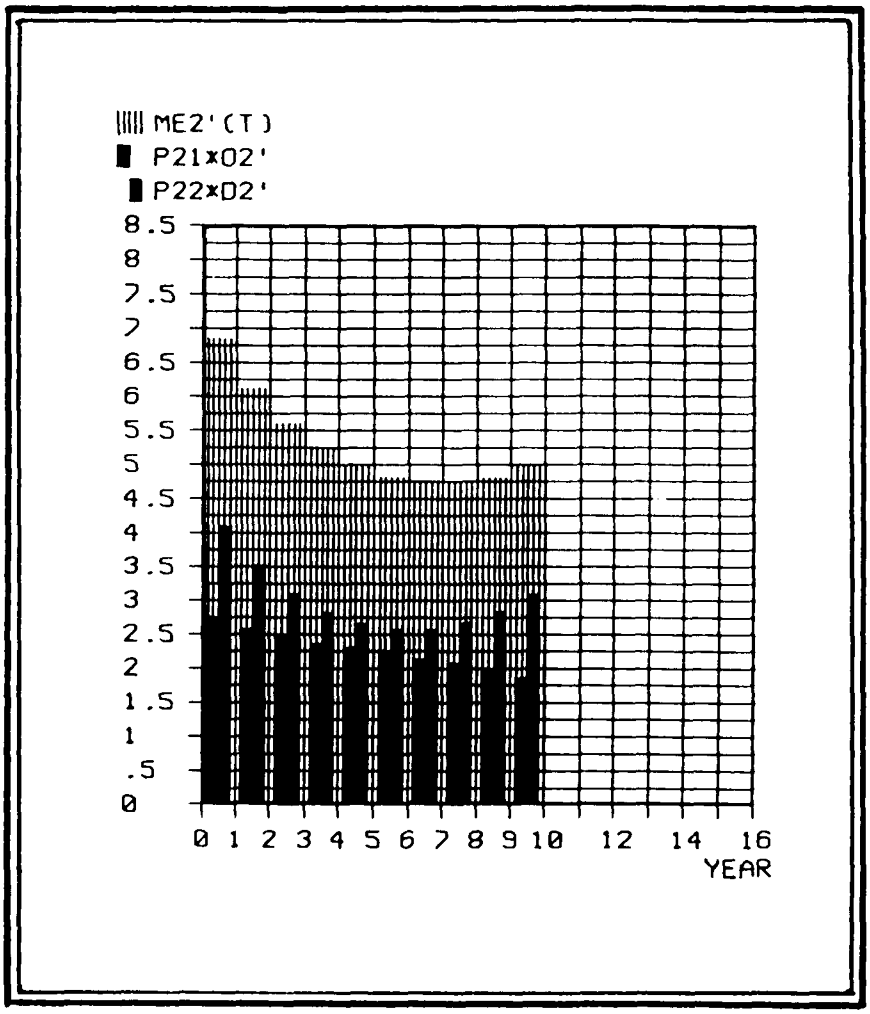

ME1'(T)
P11×O1'
P12×D1'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 6: OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P21*D2(T)=	P21*D2'(T)=
.5	2.74713908	2.74899134
1.5	2.60239228	2.60369212
2.5	2.48843806	2.489312
3.5	2.39519073	2.39572607
4.5	2.31463311	2.31488675
5.5	2.24009667	2.24010108
6.5	2.16568332	2.16545034
7.5	2.08577663	2.08529941
8.5	1.99459987	1.99385334
9.5	1.88578468	1.88472455

T=	P22*D2(T)=	P22*D2'(T)=
.5	4.10643733	4.11823608
1.5	3.5188865	3.52841817
2.5	3.10693476	3.11510127
3.5	2.83103805	2.83857747
4.5	2.66399363	2.67154928
5.5	2.58821958	2.59639741
6.5	2.59391897	2.60333848
7.5	2.67793817	2.68928135
8.5	2.84319274	2.85725511
9.5	3.09858523	3.11633292

P21*D2(T), P21*D2'(T) = SECOND OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P22*D2(T), P22*D2'(T) = FUNDS FOR STRATEGIC DEFENSIVE WEAPONS' RESEARCH AND DEVELOPMENT
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+.....
+2*D2(T+.9)+D2(T+1))/20
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+.....
+2*D2(T+.9)+D2(T+1))/20



ME2'(T)
P21*O2'
P22*D2'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 7: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE FIRST OPPONENT

T=	O1(T)=	O1'(T)=
.5	323.85524	323.8045
1.5	320.667225	320.614312
2.5	316.225258	316.164743
3.5	310.350496	310.276956
4.5	302.735633	302.643142
5.5	292.933104	292.814734
6.5	280.331434	280.178713
7.5	264.118805	263.921096
8.5	243.231857	242.975599
9.5	216.286603	215.954369

T=	D1(T)=	D1'(T)=
.5	20.0507307	19.9853976
1.5	20.5095536	20.4699057
2.5	21.2949036	21.2762122
3.5	22.488058	22.4875618
4.5	24.1898888	24.2064539
5.5	26.5297816	26.5637131
6.5	29.6759029	29.7288823
7.5	33.847662	33.9228
8.5	39.3313337	39.4333336
9.5	46.4999805	46.6354211

O1(T), O1'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D1(T), D1'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM

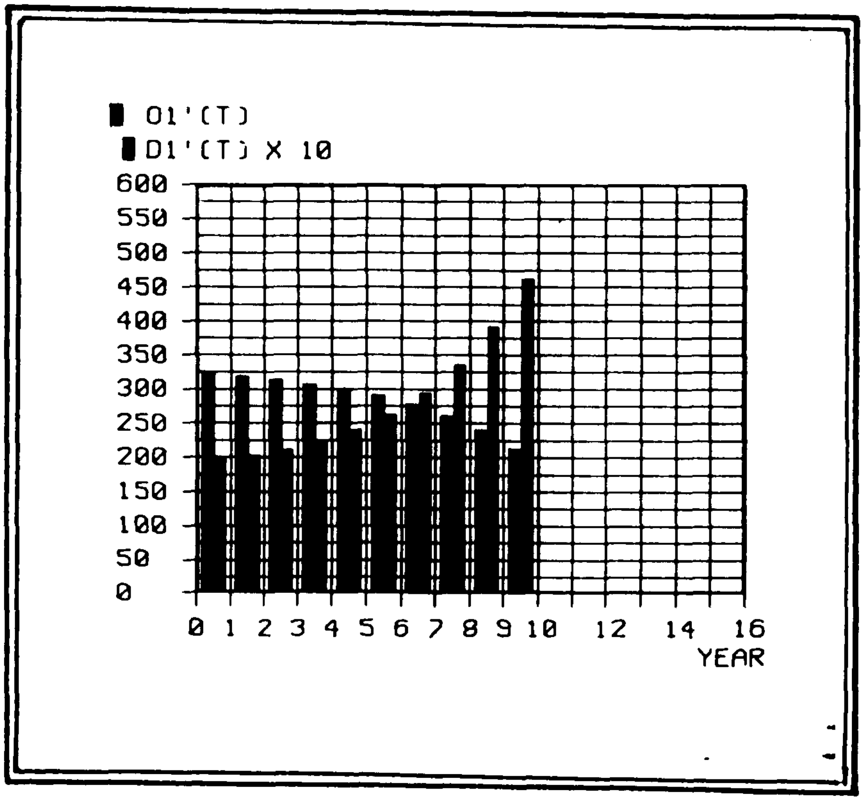
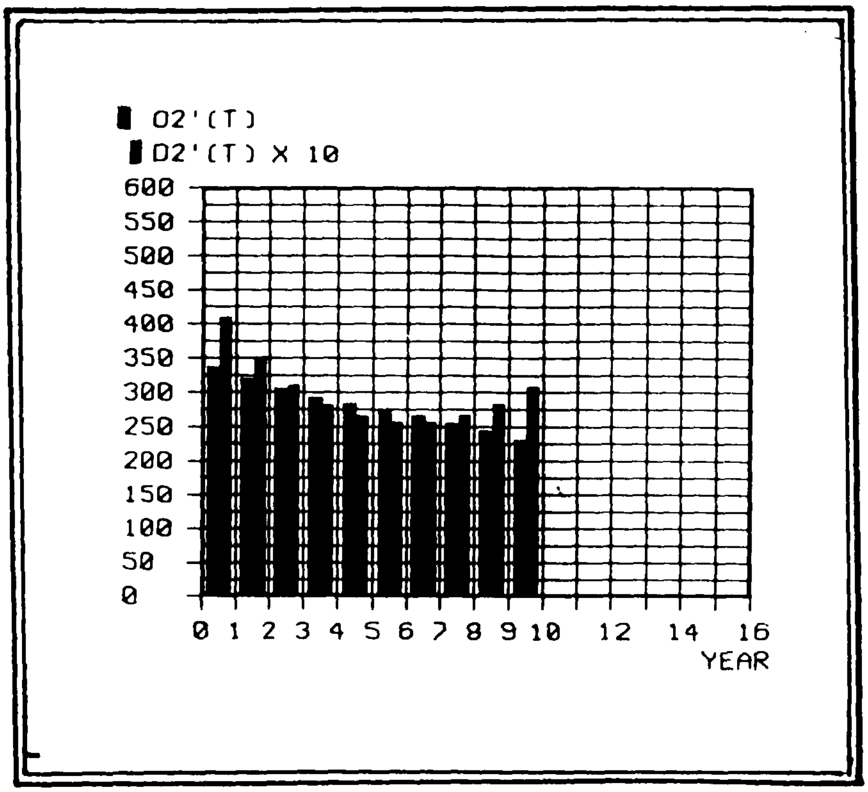

O1'(T)
D1'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 8: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE SECOND OPPONENT

T=	O2(T)=	O2'(T)=
.5	339.152973	339.381646
1.5	321.282997	321.443472
2.5	307.214575	307.322469
3.5	295.702559	295.76865
4.5	285.757174	285.788487
5.5	276.555144	276.555689
6.5	267.368312	267.339548
7.5	257.503288	257.444371
8.5	246.246897	246.154733
9.5	232.812923	232.682043

T=	D2(T)=	D2'(T)=
.5	41.0643733	41.1823608
1.5	35.1888651	35.2841817
2.5	31.0693476	31.1510127
3.5	28.3103805	28.3857747
4.5	26.6399363	26.7154928
5.5	25.8821958	25.9639741
6.5	25.9391897	26.0333848
7.5	26.7793817	26.8928135
8.5	28.4319274	28.5725511
9.5	30.9858523	31.1633292

O2(T), O2'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D2(T), D2'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSIVE SYSTEM



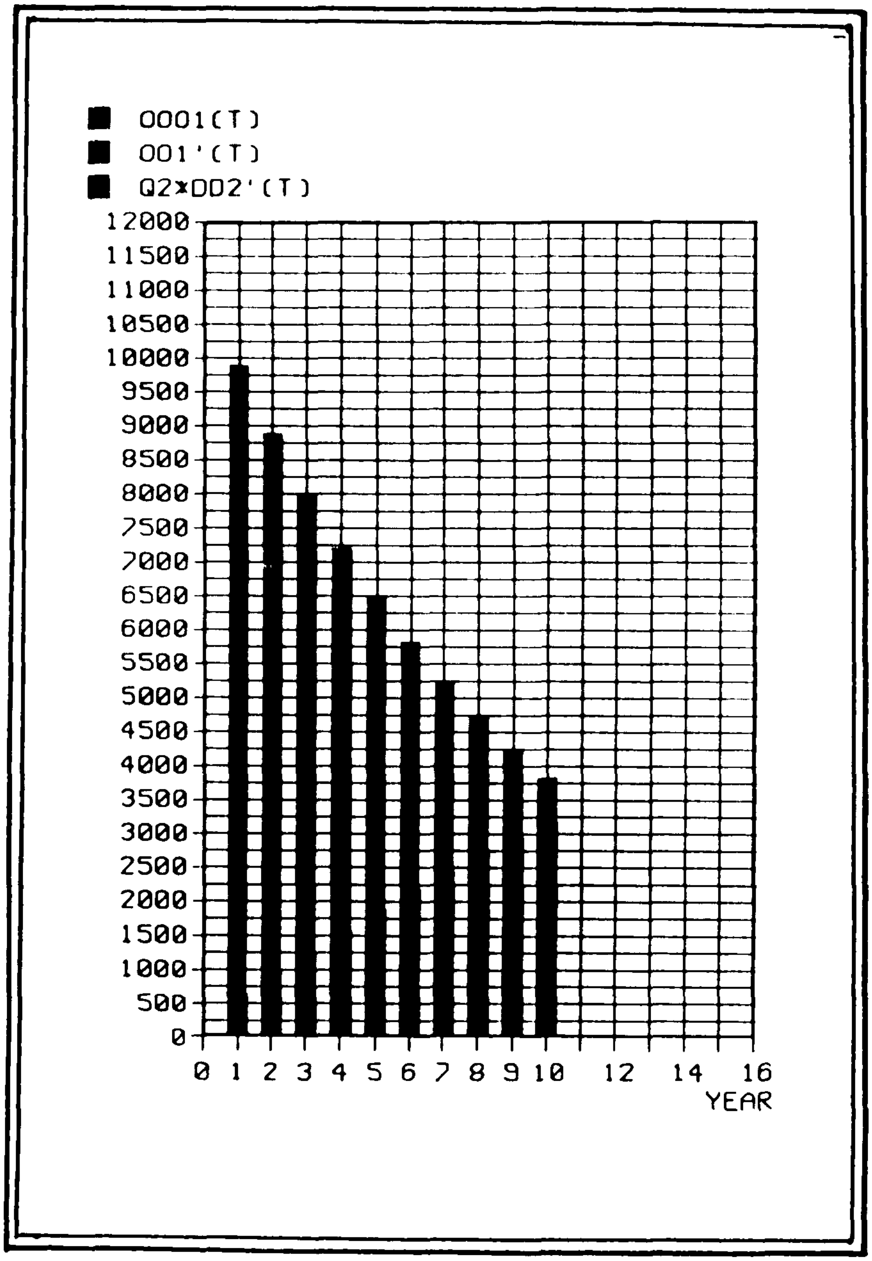
O2'(T)
D2'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 9: OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE FIRST OPPONENT AND THE SECOND OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO1(T)=	OO1(T)=	Q2*DD2(T)=
0	11000	325	0
1	9900	648.85524	102.660933
2	8910	969.522466	190.633096
3	8019	1285.74772	268.306465
4	7217.1	1596.09822	339.082416
5	6495.39	1898.83385	405.682257
6	5845.851	2191.76696	470.387747
7	5261.2659	2472.09839	535.235721
8	4735.13931	2736.2172	602.184175
9	4261.62538	2979.44905	673.263994
10	3835.46284	3195.73566	750.728624

T=	OOO1(T)=	OO1'(T)=	Q2*DD2'(T)=
0	11000	325	0
1	9900	648.8045	102.955902
2	8910	969.418811	191.166356
3	8019	1285.58356	269.043888
4	7217.1	1595.86051	340.008325
5	6495.39	1898.50365	406.797057
6	5845.851	2191.31839	471.706992
7	5261.2659	2471.4971	536.790454
8	4735.13931	2735.41819	604.022488
9	4261.62538	2978.39379	675.453866
10	3835.46284	3194.34816	753.362188

OO1(T), OO1'(T) = TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q2*DD2(T), Q2*DD2'(T) = SHARE OF OO1(T) WHICH MIGHT BE NEUTRALIZED BY THE SECOND OPPONENT
OO1'(T+1) = OO1'(T)+O1'(T+.5); OO1'(0) = OO1(0)
DD2'(T+1) = DD2'(T)+D2'(T+.5); DD2'(0) = DD2(0)



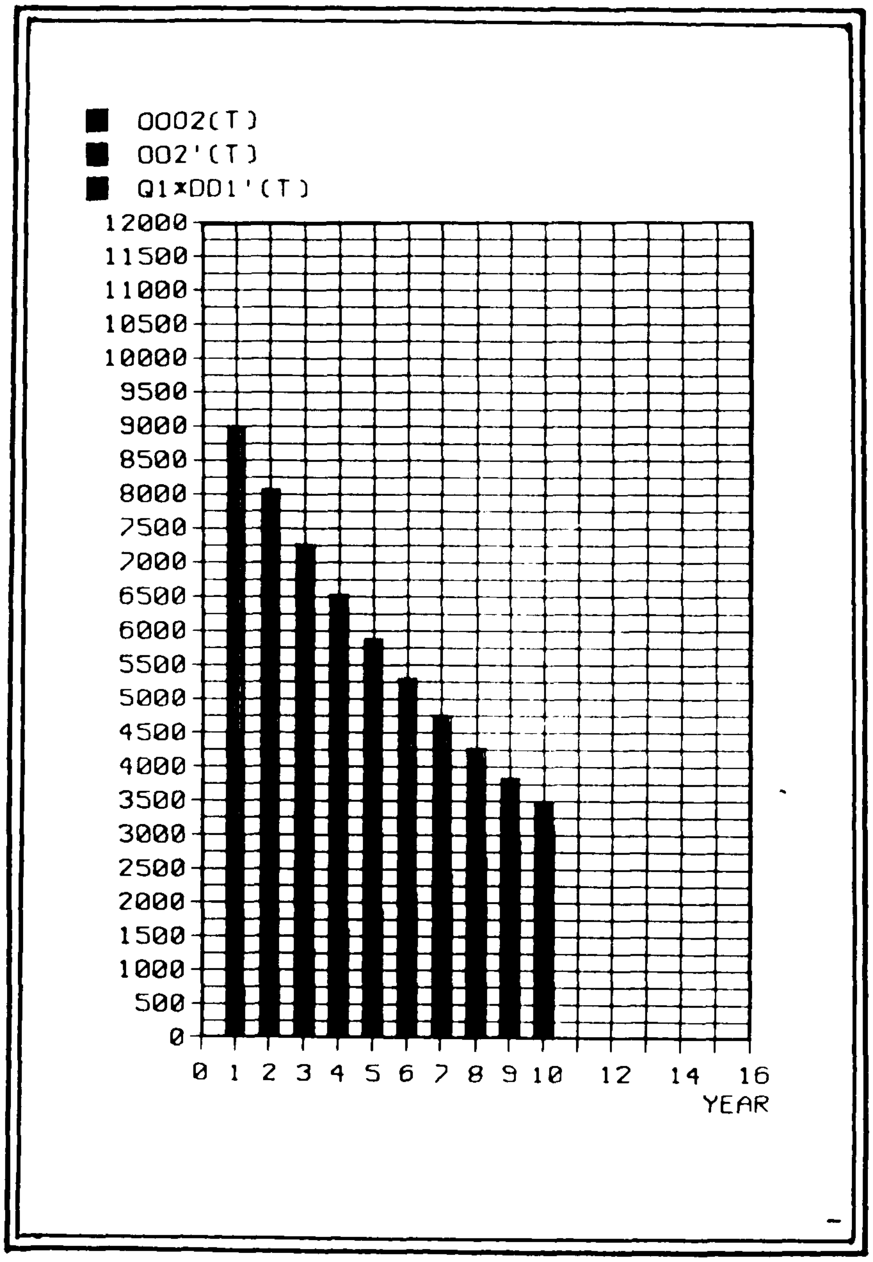
OOO1(T)
OO1'(T)
Q2×DD2'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 10: OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE SECOND OPPONENT AND THE FIRST OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO2(T)=	OO2(T)=	Q1*DD1(T)=
0	10000	350	0
1	9000	689.152973	60.1521922
2	8100	1010.43597	121.680853
3	7290	1317.65054	185.565564
4	6561	1613.3531	253.029738
5	5904.9	1899.11028	325.599404
6	5314.41	2175.66542	405.188749
7	4782.969	2443.03373	494.216458
8	4304.6721	2700.53702	595.759444
9	3874.20489	2946.78392	713.753445
10	3486.7844	3179.59684	853.253386

T=	OOO2(T)=	OO2'(T)=	Q1*DD1'(T)=
0	10000	350	0
1	9000	689.381647	59.956193
2	8100	1010.82512	121.36591
3	7290	1318.14759	185.194547
4	6561	1613.91624	252.657232
5	5904.9	1899.70473	325.276594
6	5314.41	2176.26041	404.967733
7	4782.969	2443.59996	494.15438
8	4304.6721	2701.04433	595.92278
9	3874.20489	2947.19907	714.222781
10	3486.7844	3179.88111	854.129045

OO2(T), OO2'(T) = TOTAL STOCK OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q1*DD1(T), Q1*DD1'(T) = SHARE OF OO2(T) WHICH MIGHT BE NEUTRALIZED BY THE FIRST OPPONENT
OO2'(T+1) = OO2'(T)+O2'(T+.5); OO2'(0) = OO2(0)
DD1'(T+1) = DD1'(T)+D1'(T+.5); DD1'(0) = DD1(0)



OOO2(T)
OO2'(T)
Q1×DD1'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

MODEL FOR THE STUDY OF TWO POWERS'/COALITIONS BEHAVIOR

SCENARIO NO. 2

A11= .01
A12= .03
A21= .02
A22= .02
B11=-8.8
B12= .4
B21= .48
B22=-8.4
P11= 7.5E-03
P12= 1
P21= 8.1E-03
P22= 1
ME1= 50
ME2= 53
Q1= 12.5
Q2= 10
T1= 10
OOO1(0)= 11000
OOO2(0)= 10000
IN1=-.1
IN2=-.1

O1(0)= 325
O2(0)= 350
O1(T1)= 200
O2(T1)= 250

OO1(T1+)= 100
OO2(T1+)= 100

TABLE 1
TOTAL ME1 FOR (T0-T1) ARE: $BILLIONS 50

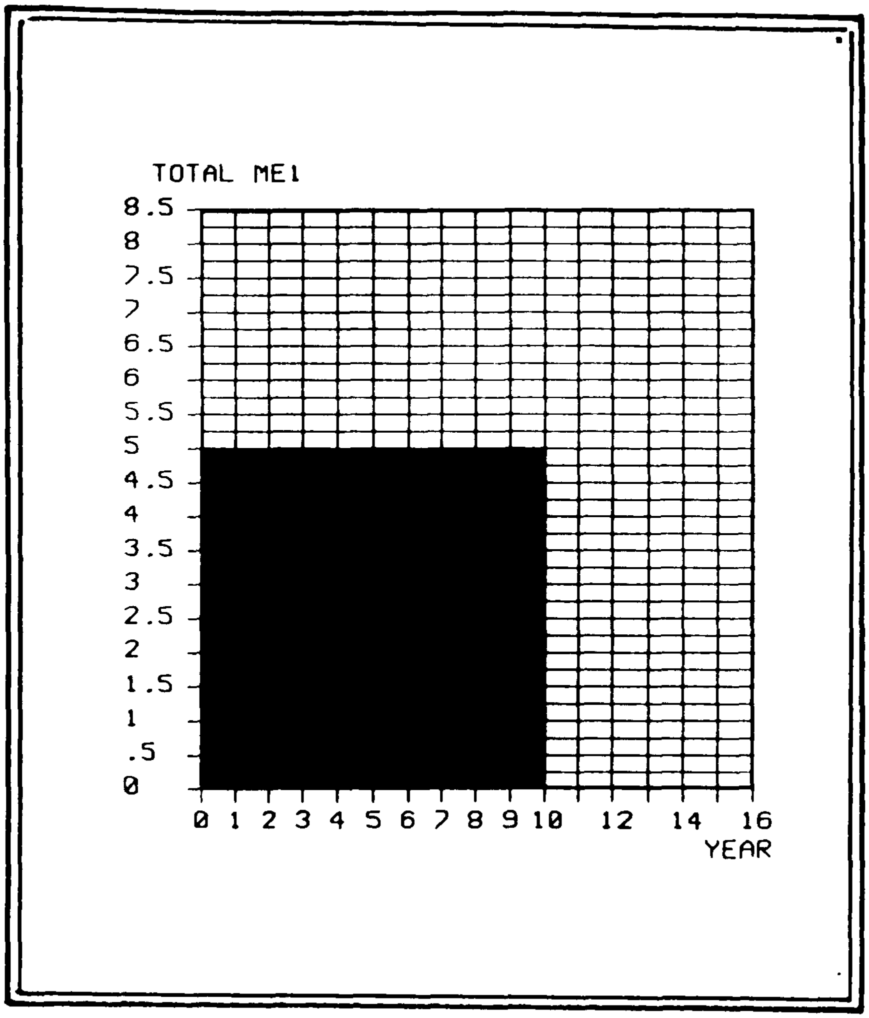


TABLE 2
TOTAL ME2 FOR (T0-T1) ARE: $BILLIONS 53

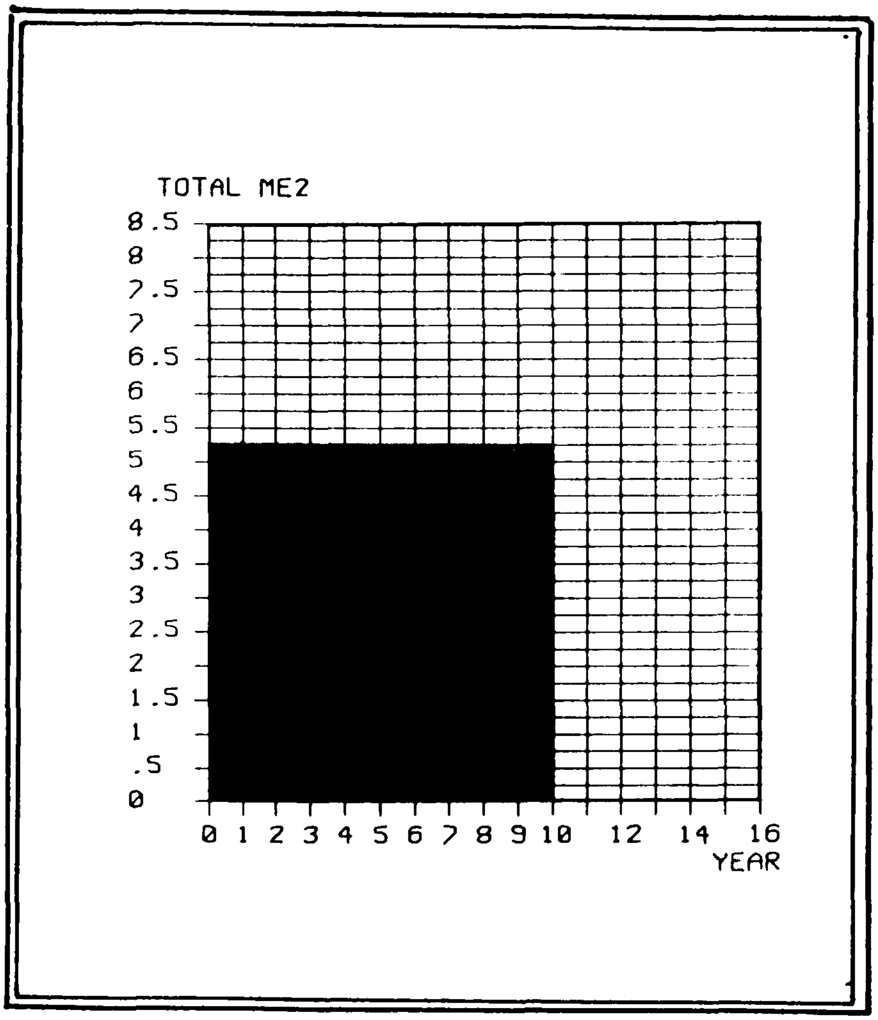
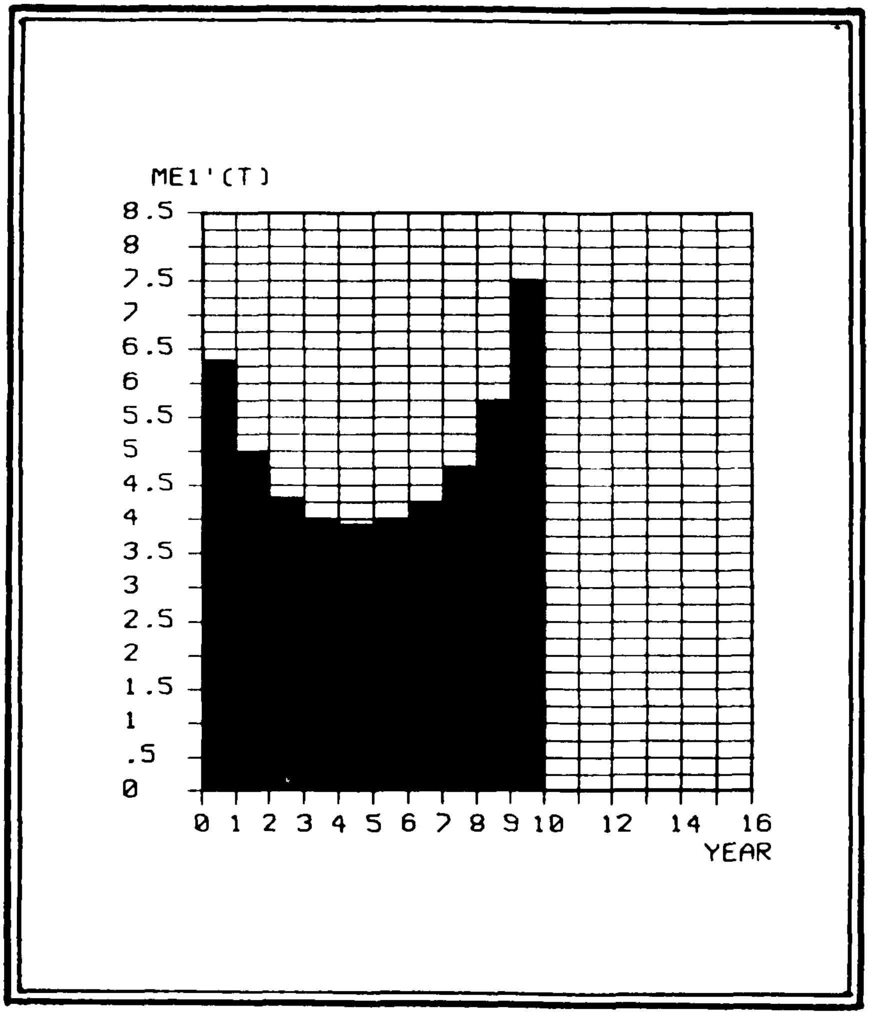


TABLE 3: OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME1(T)=	ME1'(T)=
.5	6.34328965	6.3637121
1.5	4.99745605	5.00734227
2.5	4.33616174	4.34164264
3.5	4.03467393	4.03902376
4.5	3.94256988	3.94820369
5.5	4.00843786	4.01828341
6.5	4.25051674	4.2695573
7.5	4.75611078	4.793927
8.5	5.7030555	5.77867478
9.5	7.39930296	7.55083026

TOTAL ME1(T)= 49.7715751
TOTAL ME1'(T)= 50.1111972

ME1(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME1'(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:
ME1'(T) = (ME1(T)+2*ME1(T+.1)+2*ME1(T+.2)+.....
+2*ME1(T+.9)+ME1(T+1))/20



ME1'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

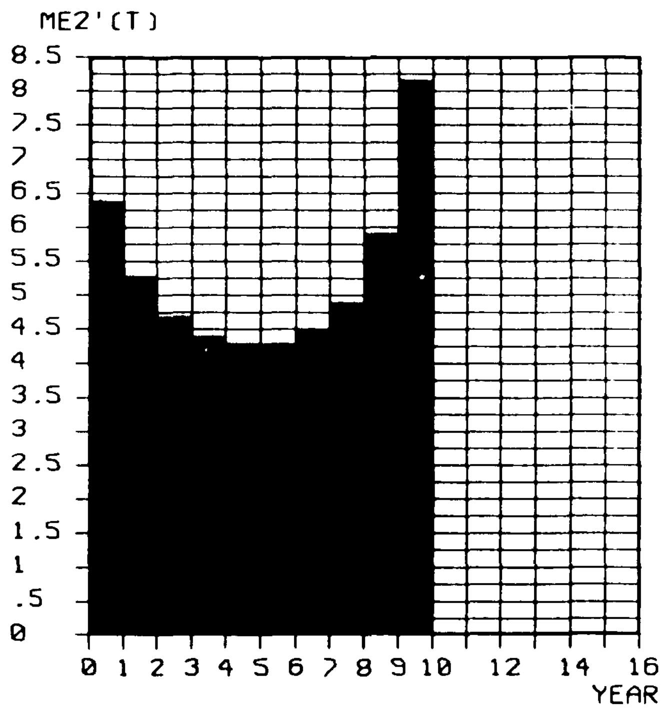
TABLE 4: OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME2(T)=	ME2'(T)=
.5	6.43003889	6.41264809
1.5	5.30695938	5.30005193
2.5	4.72477607	4.72309544
3.5	4.43497811	4.4368579
4.5	4.31465458	4.32063418
5.5	4.31936731	4.33219745
6.5	4.47126617	4.49713085
7.5	4.88332715	4.93479535
8.5	5.84060904	5.94270308
9.5	7.99573402	8.19801925

TOTAL ME2(T)= 52.7217107
TOTAL ME2'(T)= 53.0981335

ME2(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME2'(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:

ME2'(T) = (ME2(T)+2*ME2(T+.1)+2*ME2(T+.2)+.....
+2*ME2(T+.9)+ME2(T+1))/20



ME2'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 5. OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P11*D1(T)=	P11*D1'(T)=
.5	2.34653789	2.35098089
1.5	2.23556333	2.23775794
2.5	2.17797205	2.17900329
3.5	2.145473	2.14585559
4.5	2.12230054	2.12223666
5.5	2.09762082	2.09710887
6.5	2.06059199	2.05944584
7.5	1.99591454	1.99371643
8.5	1.87828197	1.87427574
9.5	1.66433827	1.65727704

T=	P12*D1(T)=	P12*D1'(T)=
.5	3.99675176	4.0127312
1.5	2.76189272	2.76958433
2.5	2.1581897	2.16263935
3.5	1.88920093	1.89316817
4.5	1.82026934	1.82596703
5.5	1.91081704	1.92117454
6.5	2.18992475	2.21011146
7.5	2.76019624	2.80021057
8.5	3.82477353	3.90439904
9.5	5.7349647	5.89355323

P11*D1(T), P11*D1'(T) = FIRST OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P12*D1(T), P12*D1'(T) = FUNDS FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT
D1'(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+..... +2*D1(T+.9)+D1(T+1))/20
D1'(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+..... +2*D1(T+.9)+D1(T+1))/20

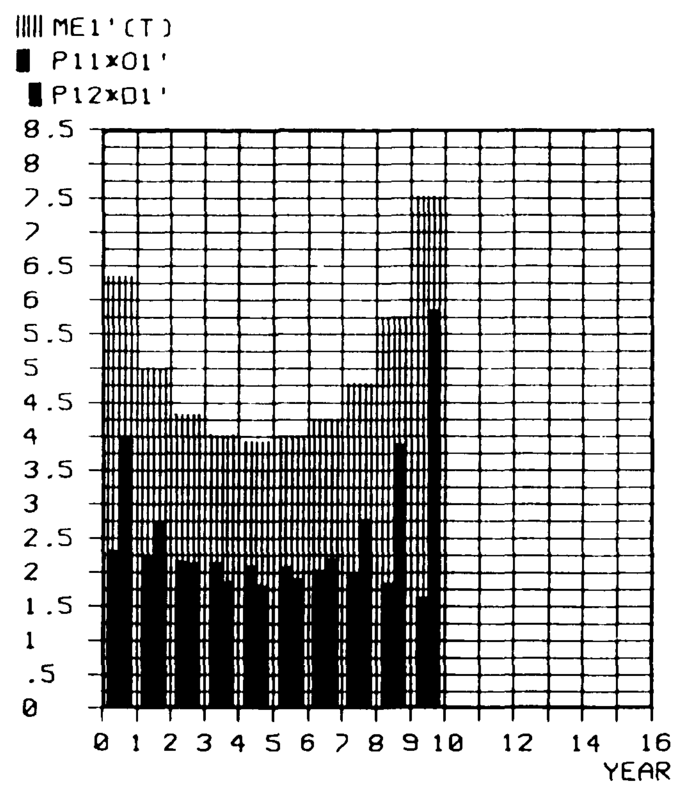
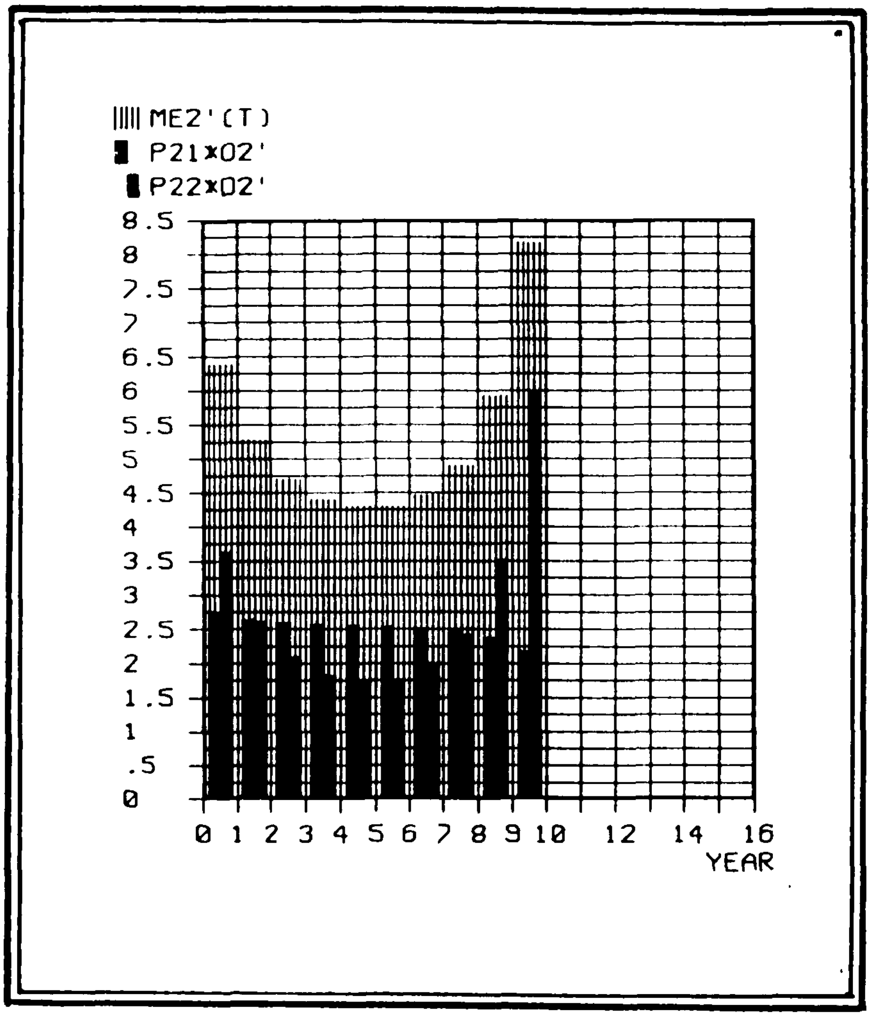

ME1'(T)
P11*O1'
P12*D1'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 6: OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P21*O2(T)=	P21*O2'(T)=
.5	2.7593334	2.76285702
1.5	2.66467644	2.66652613
2.5	2.61478507	2.61572874
3.5	2.5877366	2.58816891
4.5	2.57113362	2.57122296
5.5	2.55662752	2.55636887
6.5	2.53569625	2.53487571
7.5	2.49452519	2.49255653
8.5	2.40485235	2.40036618
9.5	2.20469283	2.19459383

T=	P22*D2(T)=	P22*D2'(T)=
.5	3.67070549	3.64979106
1.5	2.64228294	2.6335258
2.5	2.109991	2.10736669
3.5	1.84724152	1.84868899
4.5	1.74352097	1.74941122
5.5	1.76273979	1.77582858
6.5	1.93556992	1.96225514
7.5	2.38880196	2.44223882
8.5	3.43575668	3.5423369
9.5	5.79104118	6.00342542

P21*O2(T), P21*O2'(T) = SECOND OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P22*D2(T), P22*D2'(T) = FUNDS FOR STRATEGIC DEFENSIVE WEAPONS' RESEARCH AND DEVELOPMENT
O2'(T+.5) = (O2(T)+2*O2(T+.1)+2*O2(T+.2)+.....+2*O2(T+.9)+O2(T+1))/20
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+.....+2*D2(T+.9)+D2(T+1))/20



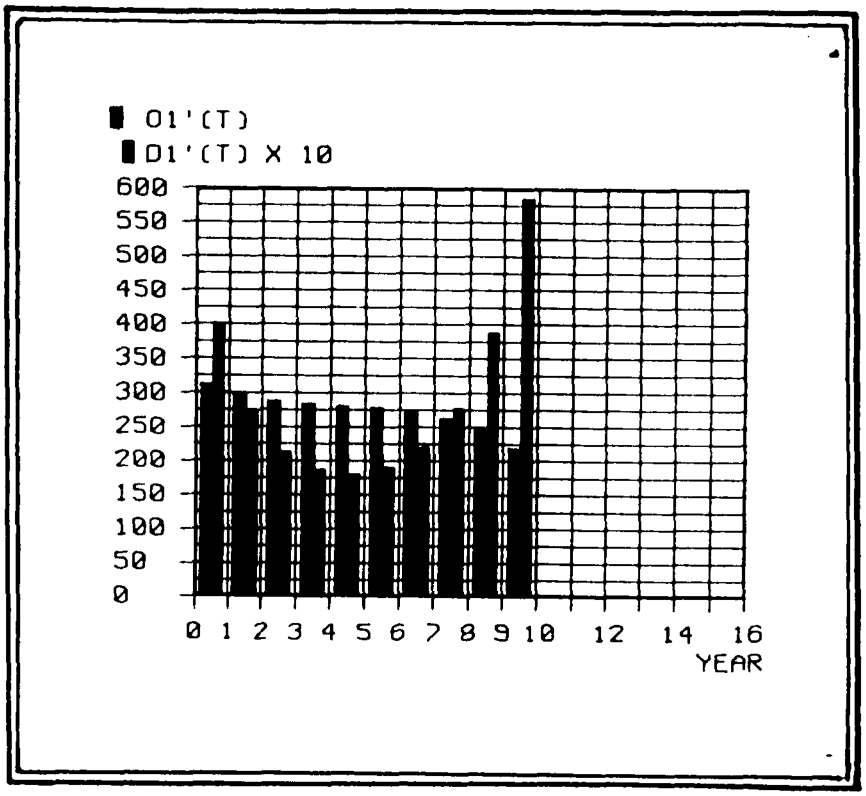
ME2'(T)
P21*O2'
P22*O2'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 7: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE FIRST OPPONENT

T=	O1(T)=	O1'(T)=
.5	312.871719	313.464119
1.5	298.07511	298.367726
2.5	290.396273	290.533772
3.5	286.063067	286.114079
4.5	282.973405	282.964889
5.5	279.682776	279.614516
6.5	274.745598	274.592778
7.5	266.121938	265.828857
8.5	250.437596	249.903432
9.5	221.911769	220.970272

T=	D1(T)=	D1'(T)=
.5	39.9675176	40.127312
1.5	27.6189272	27.6958433
2.5	21.581897	21.6263935
3.5	18.8920093	18.9316817
4.5	18.2026934	18.2596703
5.5	19.1081704	19.2117454
6.5	21.8992475	22.1011146
7.5	27.6019624	28.0021057
8.5	38.2477353	39.0439904
9.5	57.349647	58.9355323

O1(T), O1'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D1(T), D1'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM



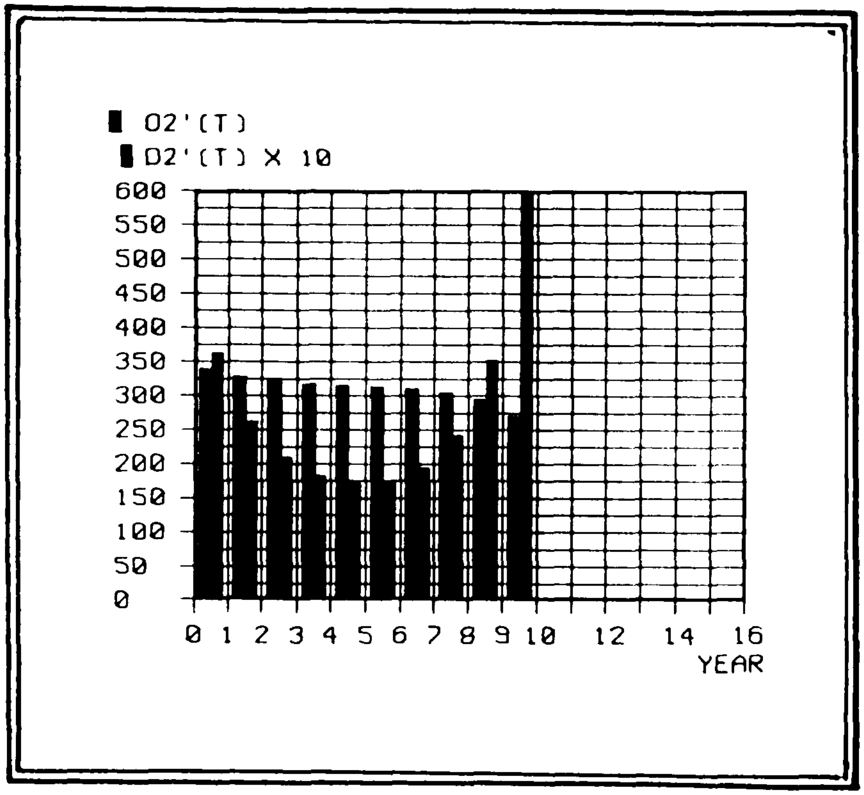
O1'(T)
D1'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 8: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE SECOND OPPONENT

T=	O2(T)=	O2'(T)=
.5	340.658444	341.093459
1.5	328.9724	329.200757
2.5	322.812972	322.929474
3.5	319.473654	319.527026
4.5	317.423903	317.434934
5.5	315.633027	315.601094
6.5	313.04892	312.947618
7.5	307.966073	307.723029
8.5	296.895352	296.341503
9.5	272.1843	270.93751

T=	D2(T)=	D2'(T)=
.5	36.7070549	36.4979106
1.5	26.4228294	26.335258
2.5	21.09991	21.0736669
3.5	18.4724152	18.4868899
4.5	17.4352097	17.4941122
5.5	17.6273979	17.7582858
6.5	19.3556992	19.6225514
7.5	23.8880196	24.4223882
8.5	34.3575668	35.423369
9.5	57.9104118	60.0342542

O2(T), O2'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D2(T), D2'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSIVE SYSTEM



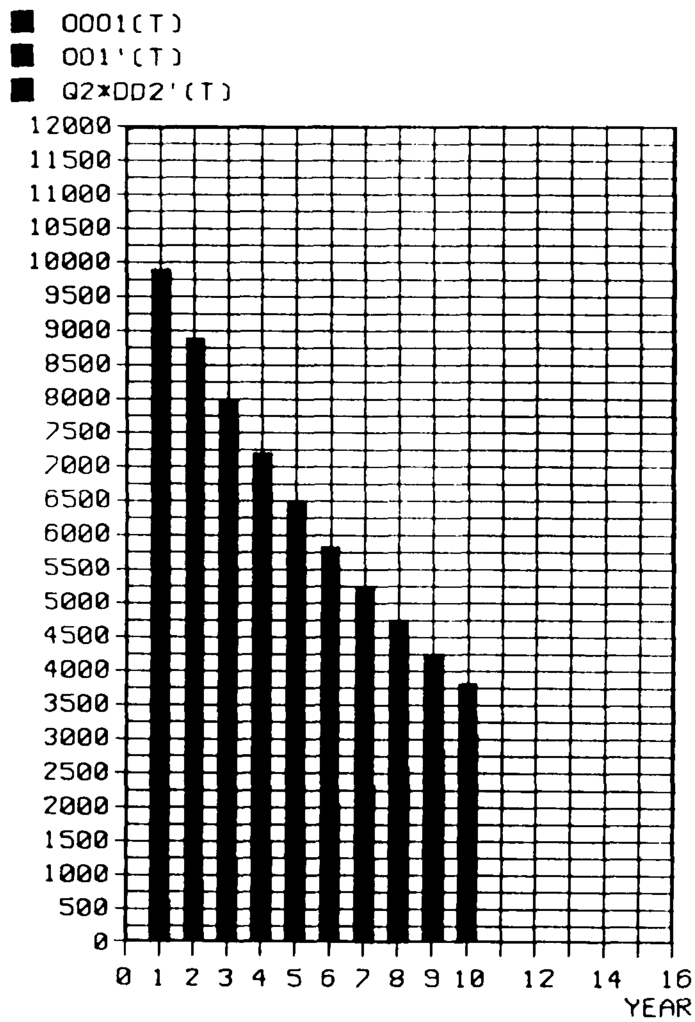
O2'(T)
D2'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 9: OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE FIRST OPPONENT AND THE SECOND OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOD1(T)=	OD1(T)=	Q2*DD2(T)=
0	11000	325	0
1	9900	637.871719	36.7070549
2	8910	935.946829	63.1298844
3	8019	1226.3431	84.2297943
4	7217.1	1512.40617	102.702209
5	6495.39	1795.37958	120.137419
6	5845.851	2075.06235	137.764817
7	5261.2659	2349.80795	157.120516
8	4735.13931	2615.92989	181.008536
9	4261.62538	2866.36748	215.366103
10	3835.46284	3088.27925	273.276515

T=	OOD1(T)=	OD1'(T)=	Q2*DD2'(T)=
0	11000	325	0
1	9900	638.464119	36.4979106
2	8910	936.831845	62.8331686
3	8019	1227.36562	83.9068356
4	7217.1	1513.4797	102.393725
5	6495.39	1796.44459	119.887838
6	5845.851	2076.0591	137.646123
7	5261.2659	2350.65188	157.268675
8	4735.13931	2616.48074	181.691063
9	4261.62538	2866.38417	217.114432
10	3835.46284	3087.35444	277.148686

OD1(T), OD1'(T) = TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q2*DD2(T), Q2*DD2'(T) = SHARE OF OD1(T) WHICH MIGHT BE NEUTRALIZED BY THE SECOND OPPONENT
OD1'(T+1) = OD1'(T)+O1'(T+.5), OD1'(0) = OD1(0)
DD2'(T+1) = DD2'(T)+D2'(T+.5), DD2'(0) = DD2(0)



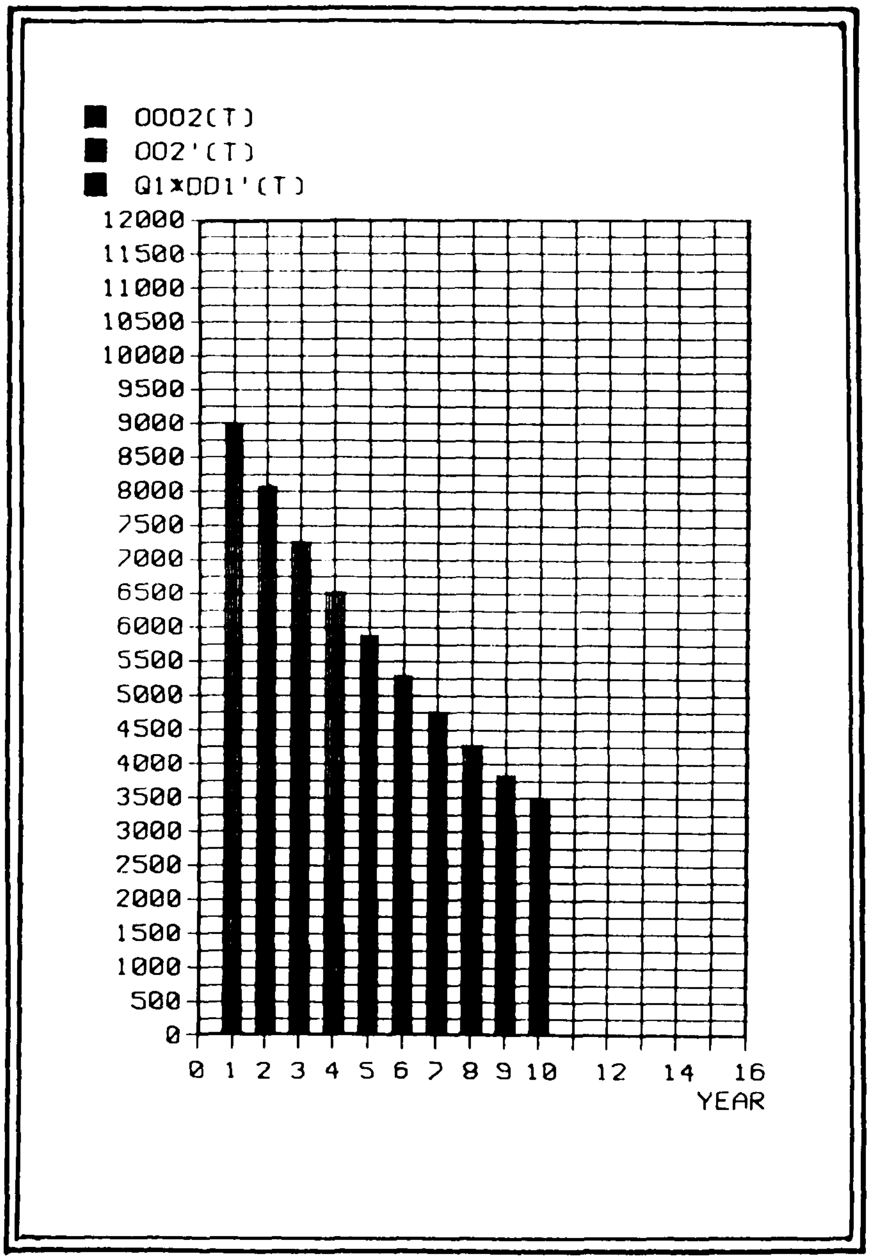
OOO1(T)
OO1'(T)
Q2*DD2'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 10 OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE SECOND OPPONENT AND THE FIRST OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO2(T)=	OO2(T)=	Q1*DD1(T)=
0	10000	350	0
1	9000	690.658444	49.959397
2	8100	1019.63084	84.483056
3	7290	1342.44382	111.460427
4	6561	1661.91747	135.075439
5	5904.9	1979.34137	157.828805
6	5314.41	2294.9744	181.714019
7	4782.969	2608.02332	209.088078
8	4304.6721	2915.98939	243.590531
9	3874.20489	3212.88475	291.4002
10	3486.7844	3485.06905	363.087259

T=	OOO2(T)=	OO2'(T)=	Q1*DD1'(T)=
0	10000	350	0
1	9000	691.093459	50.15914
2	8100	1020.29422	84.7789441
3	7290	1343.22369	111.811936
4	6561	1662.75072	135.476538
5	5904.9	1980.18565	158.301126
6	5314.41	2295.78674	182.315808
7	4782.969	2608.73436	209.942201
8	4304.6721	2916.45739	244.944833
9	3874.20489	3212.7989	293.749821
10	3486.7844	3483.7364	367.419236

OO2(T), OO2'(T) = TOTAL STOCK OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q1*DD1(T), Q1*DD1'(T) = SHARE OF OO2(T) WHICH MIGHT BE NEUTRALIZED BY THE FIRST OPPONENT
OO2'(T+1) = OO2'(T)+O2'(T+.5); OO2'(0) = OO2(0)
DD1'(T+1) = DD1'(T)+D1'(T+.5); DD1'(0) = DD1(0)



OOO2(T)
OO2'(T)
Q1*OO1'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

MODEL FOR THE STUDY OF TWO POWERS//COALITIONS BEHAVIOR

SCENARIO NO. 3

A11= .01
A12= .03
A21= .02
A22= .02
B11=-8.8
B12= .4
B21= .48
B22=-8.4
P11= 7.5E-03
P12= 1
P21= 8.1E-03
P22= 1
ME1= 50
ME2= 53
Q1= 150
Q2= 125
T1= 10
OOO1(0)= 11000
OOO2(0)= 10000
IN1=-.1
IN2=-.1

O1(0)= 325
O2(0)= 350
O1(T1)= 200
O2(T1)= 225

DD1(T1+)= 100
DD2(T1+)= 100

TABLE 1
TOTAL ME1 FOR (T0-T1) ARE: $BILLIONS 50

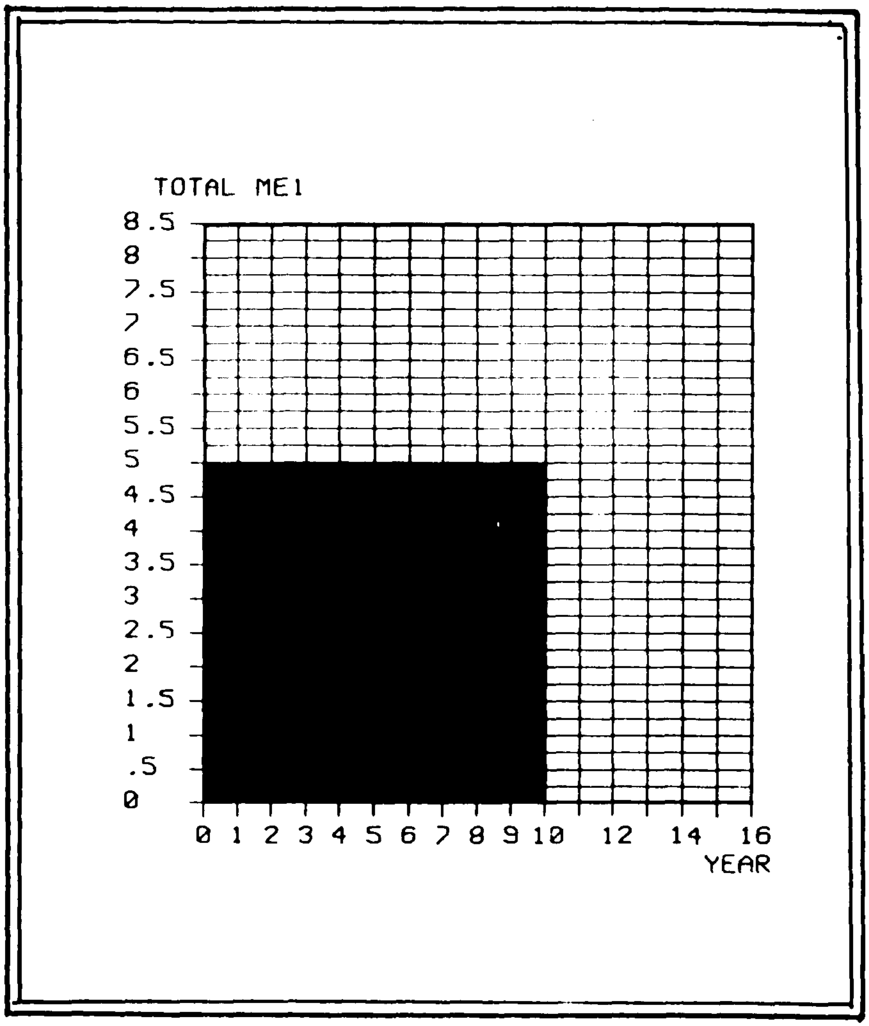


TABLE 2
TOTAL ME2 FOR (T0-T1) ARE: $BILLIONS 53

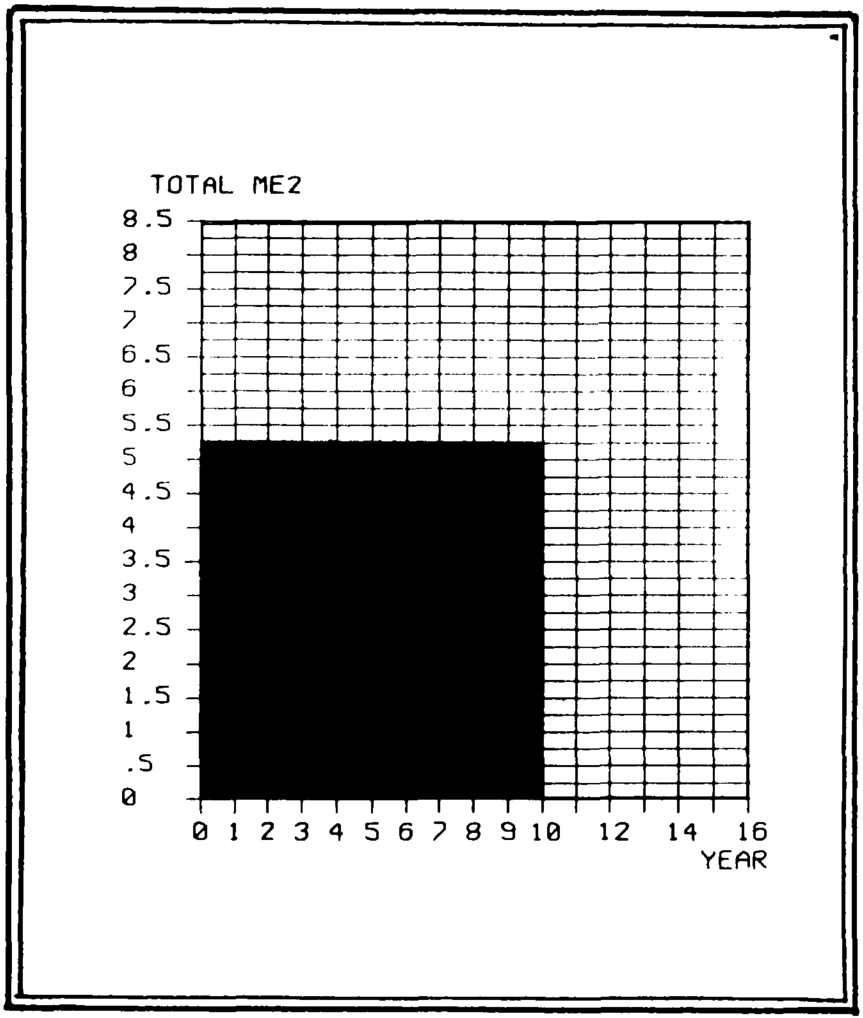


TABLE 3   OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME1(T)=	ME1'(T)=
.5	4.0601356	4.0588828
1.5	4.33417268	4.33295295
2.5	4.58251924	4.58132938
3.5	4.80597743	4.80481434
4.5	5.00531191	5.00417253
5.5	5.1812522	5.18013358
6.5	5.33449505	5.33339425
7.5	5.46570644	5.46462062
8.5	5.57552394	5.57445027
9.5	5.66455854	5.66349424

TOTAL ME1(T)= 50.009653
TOTAL ME1'(T)= 49.9982449

ME1(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME1'(T) = NUMERICAL VALUE OF ME1 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:
ME1'(T) = (ME1(T)+2*ME1(T+.1)+2*ME1(T+.2)+.....
+2*ME1(T+.9)+ME1(T+1))/20

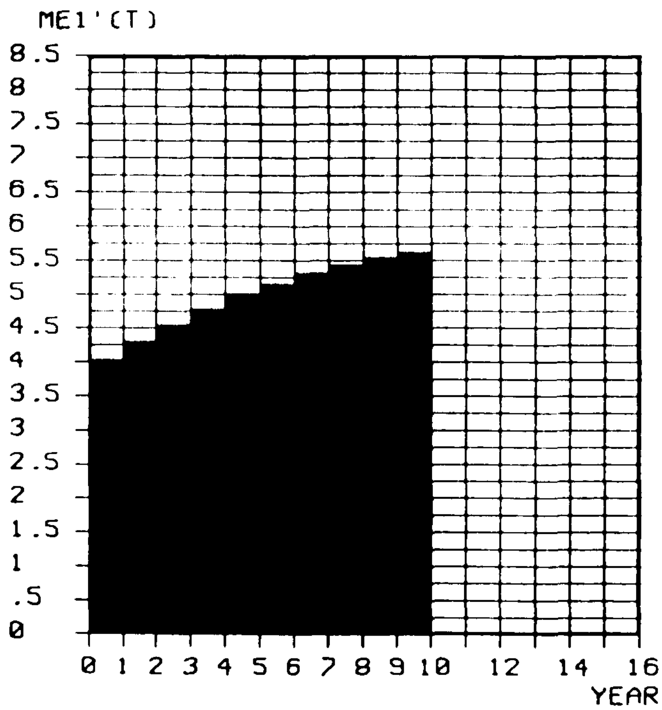
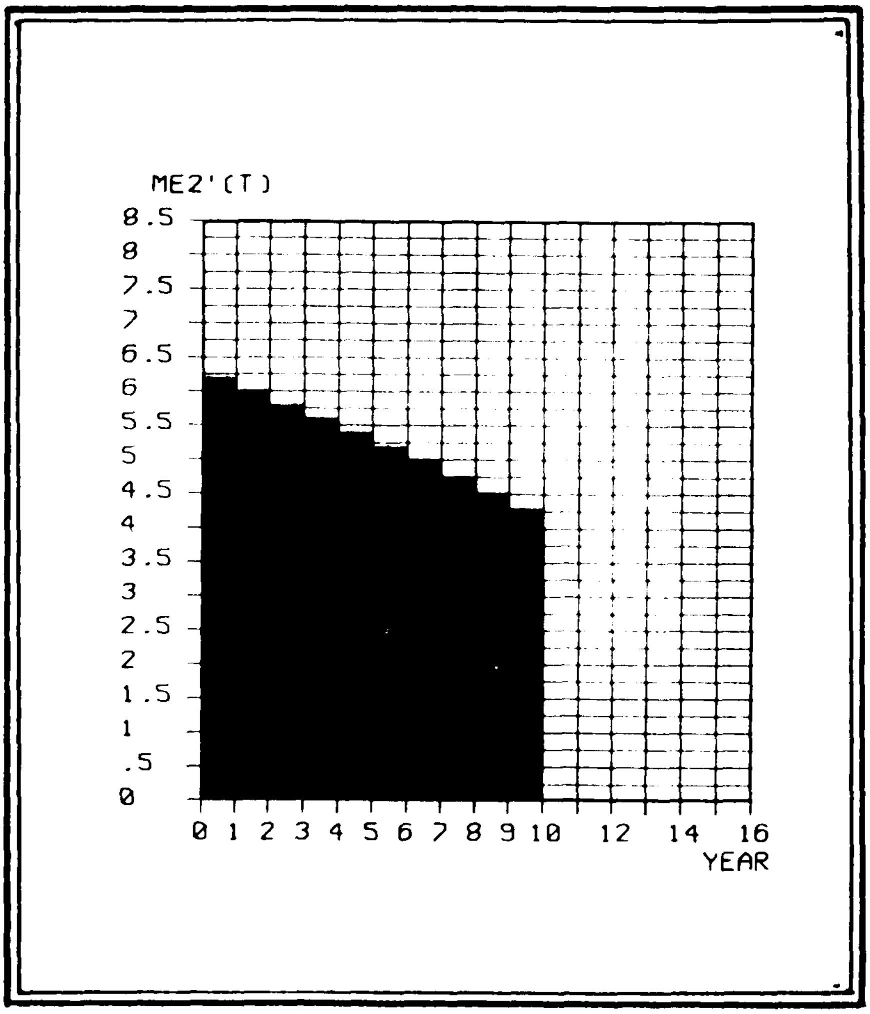

ME1'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 4. OPTIMAL ALLOCATION OF TOTAL FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	ME2(T)=	ME2'(T)=
.5	6.21675058	6.21760551
1.5	6.02522467	6.02605483
2.5	5.82979615	5.83060506
3.5	5.63005236	5.63084348
4.5	5.42561418	5.42639093
5.5	5.21613502	5.21690075
6.5	5.00129985	5.00205787
7.5	4.78082422	4.78157787
8.5	4.55445378	4.55520634
9.5	4.32196339	4.32271815

TOTAL ME2(T)= 53.0021142
TOTAL ME2'(T)= 53.0099608

ME2(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING ITS ANALYTICAL FORMULA
ME2'(T) = NUMERICAL VALUE OF ME2 AT THE MIDDLE OF THE T YEAR COMPUTED BY USING FOR A BETTER APPROXIMATION THE FOLLOWING FORMULA:
ME2'(T) = (ME2(T)+2*ME2(T+.1)+2*ME2(T+.2)+.....
+2*ME2(T+.9)+ME2(T+1))/20



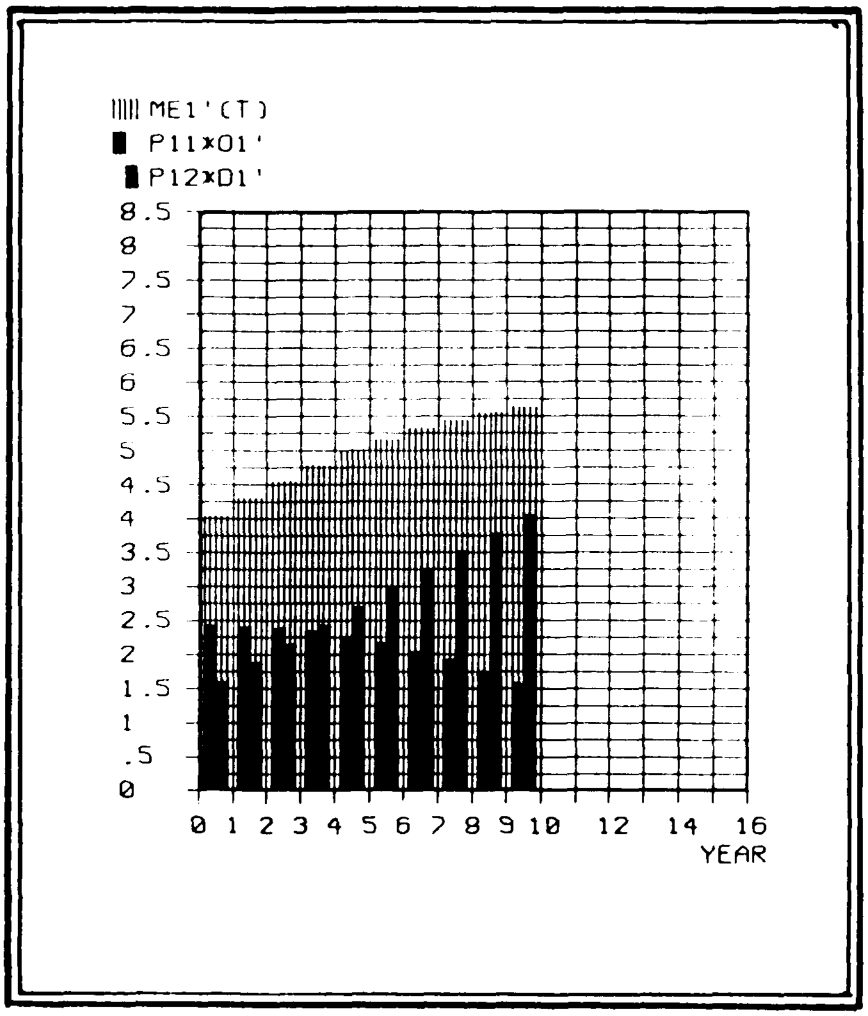
ME2'(T)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 5: OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE FIRST OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P11*O1(T)=	P11*O1'(T)=
.5	2.44280882	2.44186955
1.5	2.4368684	2.43593454
2.5	2.40895151	2.40802112
3.5	2.35914	2.35821118
4.5	2.28747093	2.28654179
5.5	2.19393668	2.19300533
6.5	2.07848505	2.07754957
7.5	1.94101912	1.94007762
8.5	1.78139712	1.78044768
9.5	1.59943205	1.59847273

T=	P12*D1(T)=	P12*D1'(T)=
.5	1.61732679	1.61701325
1.5	1.89730427	1.89701841
2.5	2.17356773	2.17330826
3.5	2.44683744	2.44660315
4.5	2.71784098	2.71763074
5.5	2.98731553	2.98712825
6.5	3.25601	3.25584468
7.5	3.52468732	3.524543
8.5	3.79412681	3.79400259
9.5	4.06512648	4.06502151

P11*O1(T), P11*O1'(T) = FIRST OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P12*D1(T), P12*D1'(T) = FUNDS FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT
O1'(T+.5) = (O1(T)+2*O1(T+.1)+2*O1(T+.2)+..... +2*O1(T+.9)+O1(T+1))/20
D1'(T+.5) = (D1(T)+2*D1(T+.1)+2*D1(T+.2)+..... +2*D1(T+.9)+D1(T+1))/20



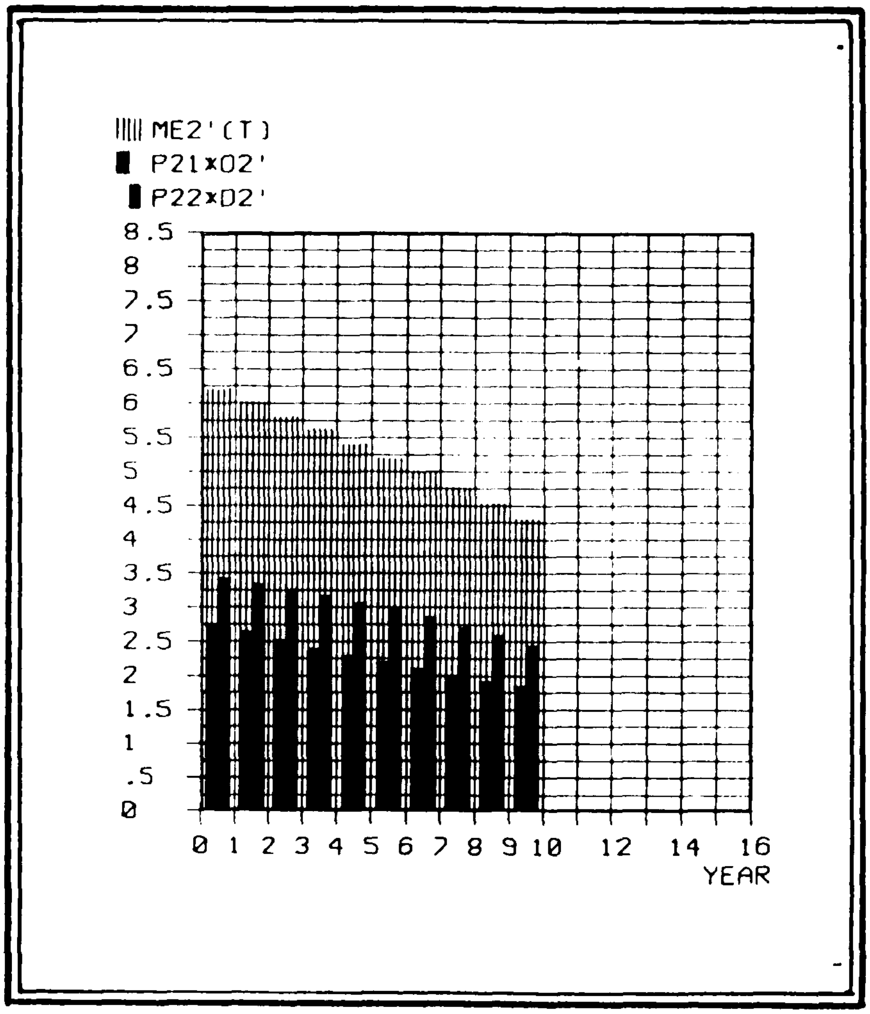
ME1'(T)
P11*01'
P12*D1'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 6 OPTIMAL ALLOCATION OF FUNDS FORECASTED TO BE SPENT BY THE SECOND OPPONENT FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION AND FOR STRATEGIC DEFENSIVE SYSTEMS' RESEARCH AND DEVELOPMENT DURING THE (T0-T1) INTERVAL OF TIME

T=	P21*O2(T)=	P21*O2'(T)=
.5	2.77472954	2.77488177
1.5	2.65688367	2.65703919
2.5	2.54270014	2.54286078
3.5	2.43229938	2.43246698
4.5	2.32584531	2.32602177
5.5	2.22354615	2.22373336
6.5	2.12565512	2.12585504
7.5	2.03247145	2.03268609
8.5	1.94434158	1.944573
9.5	1.86166037	1.86191068

T=	P22*D2(T)=	P22*D2'(T)=
.5	3.44202104	3.44272374
1.5	3.368341	3.36901564
2.5	3.28709601	3.28774429
3.5	3.19775298	3.19837651
4.5	3.09976886	3.10036916
5.5	2.99258887	2.99316739
6.5	2.87564473	2.87620283
7.5	2.74835277	2.74889178
8.5	2.6101122	2.61063334
9.5	2.46030303	2.46080747

P21*O2(T), P21*O2'(T) = SECOND OPPONENT'S FUNDS FOR STRATEGIC OFFENSIVE WEAPONS' MODERNIZATION
P22*D2(T), P22*D2'(T) = FUNDS FOR STRATEGIC DEFENSIVE WEAPONS' RESEARCH AND DEVELOPMENT
O2'(T+.5) = (O2(T)+2*O2(T+.1)+2*O2(T+.2)+.....
+2*O2(T+.9)+O2(T+1))/20
D2'(T+.5) = (D2(T)+2*D2(T+.1)+2*D2(T+.2)+.....
+2*D2(T+.9)+D2(T+1))/20



ME2'(T)
P21*O2'
P22*O2'
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 7: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE FIRST OPPONENT

T=	O1(T)=	O1'(T)=
.5	325.707842	325.582606
1.5	324.915787	324.791272
2.5	321.193534	321.069482
3.5	314.552	314.428158
4.5	304.996124	304.872239
5.5	292.52489	292.40071
6.5	277.131339	277.006609
7.5	258.802549	258.677016
8.5	237.519617	237.393024
9.5	213.257607	213.129697

T=	D1(T)=	D1'(T)=
.5	16.1732679	16.1701325
1.5	18.9730427	18.9701841
2.5	21.7356773	21.7330826
3.5	24.4683744	24.4660315
4.5	27.1784098	27.1763074
5.5	29.8731553	29.8712825
6.5	32.5601	32.5584468
7.5	35.2468732	35.24543
8.5	37.9412681	37.9400259
9.5	40.6512648	40.6502151

O1(T), O1'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D1(T), D1'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM

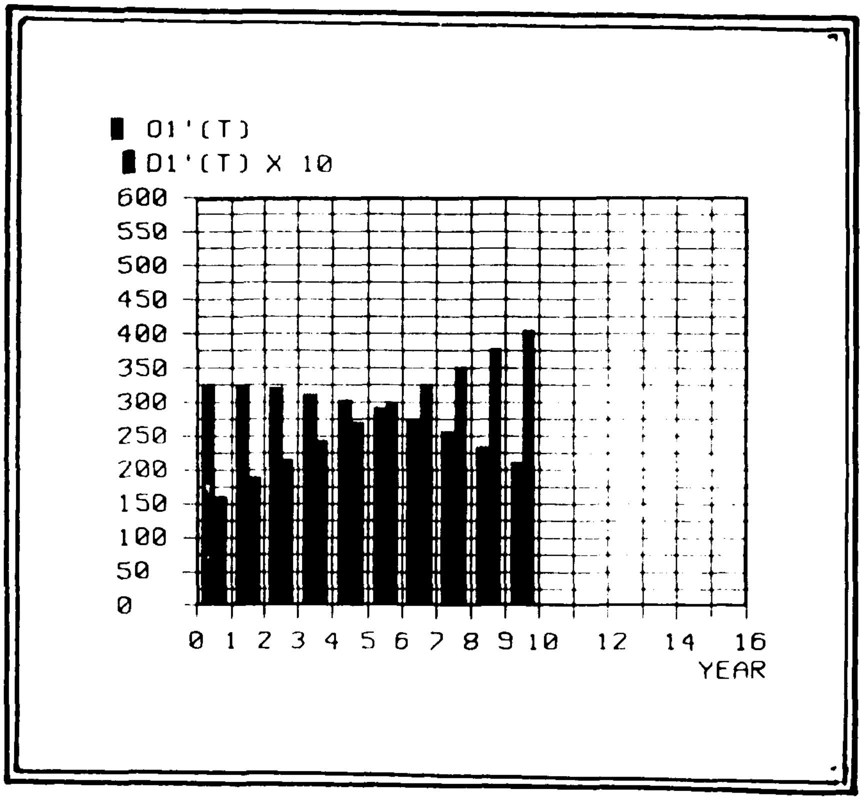
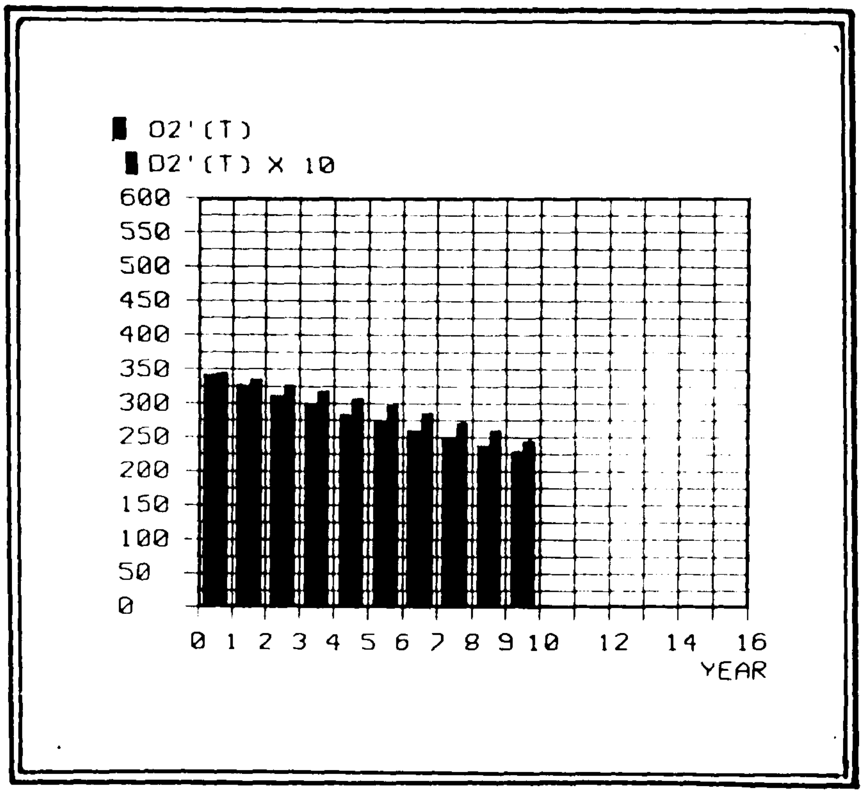

O1'(T)
D1'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 8: FORECASTED OPTIMAL TRAJECTORIES OF THE STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS AND R&D EXPENDITURES PER STRATEGIC DEFENSE SYSTEM IN THE CASE OF THE SECOND OPPONENT

T=	O2(T)=	O2'(T)=
.5	342.559203	342.577997
1.5	328.01033	328.029529
2.5	313.913598	313.933429
3.5	300.283874	300.304565
4.5	287.141397	287.163181
5.5	274.511871	274.534983
6.5	262.426558	262.451239
7.5	250.922401	250.9489
8.5	240.04217	240.07074
9.5	229.834613	229.865516

T=	D2(T)=	D2'(T)=
.5	34.4202104	34.4272374
1.5	33.68341	33.6901564
2.5	32.8709601	32.8774429
3.5	31.9775298	31.983765
4.5	30.9976886	31.0036916
5.5	29.9258887	29.9316739
6.5	28.7564473	28.7620283
7.5	27.4835277	27.4889178
8.5	26.101122	26.1063334
9.5	24.6030303	24.6080747

O2(T), O2'(T) = MODERNIZED STRATEGIC OFFENSIVE WEAPONS
D2(T), D2'(T) = R&D EXPENDITURES PER STRATEGIC DEFENSIVE SYSTEM



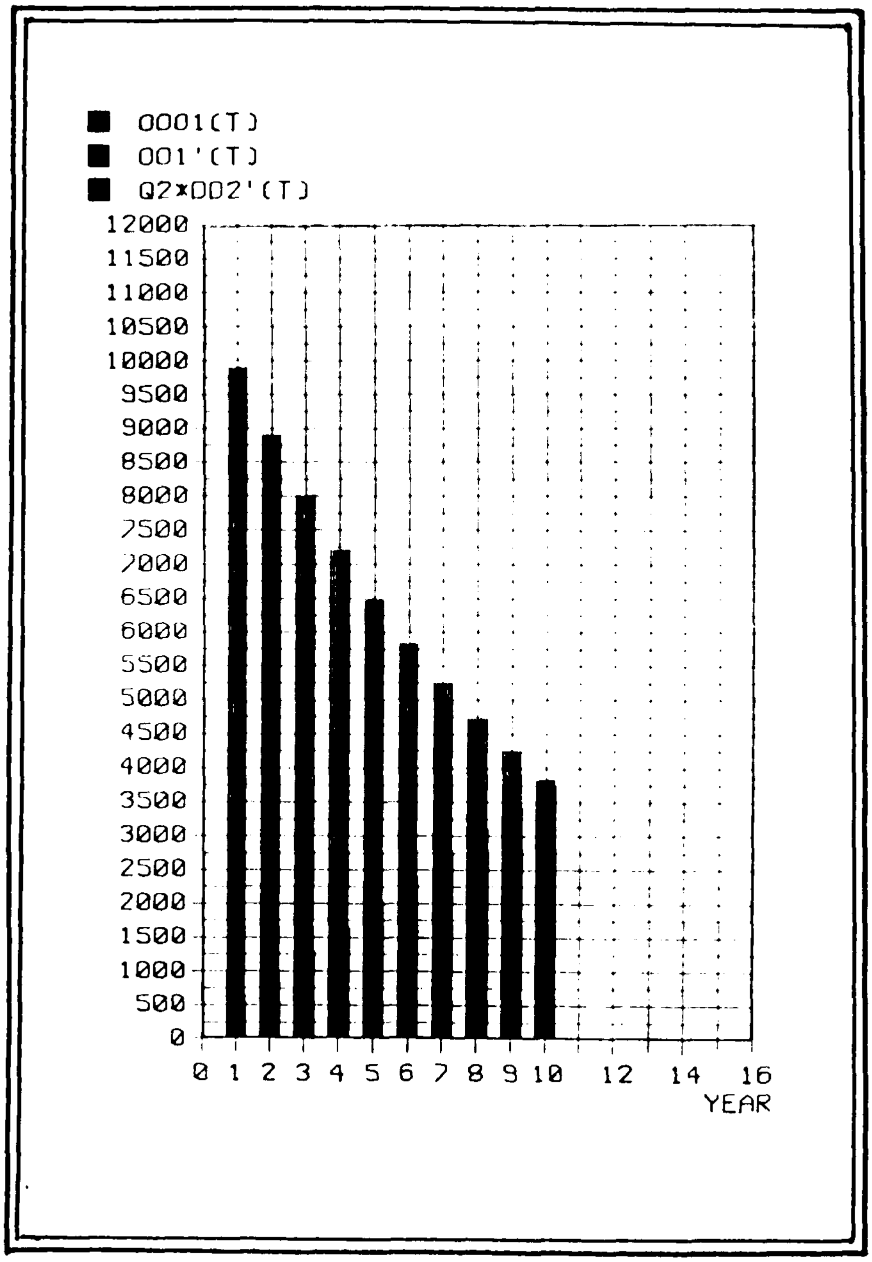
O2'(T)
D2'(T) X 10
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 9: OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE FIRST OPPONENT AND THE SECOND OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO1(T)=	OO1(T)=	Q2*DD2(T)=
0	11000	325	0
1	9900	650.707843	430.25263
2	8910	975.62363	851.295255
3	8019	1296.81716	1262.18226
4	7217.1	1611.36916	1661.90138
5	6495.39	1916.36529	2049.37249
6	5845.851	2208.89018	2423.4461
7	5261.2659	2486.02152	2782.90169
8	4735.13931	2744.82407	3126.44579
9	4261.62538	2982.34368	3452.70981
10	3835.46284	3195.60129	3760.24769

T=	OOO1(T)=	OO1′(T)=	Q2*DD2′(T)=
0	11000	325	0
1	9900	650.582606	430.340467
2	8910	975.373878	851.467422
3	8019	1296.44336	1262.43546
4	7217.1	1610.87152	1662.23252
5	6495.39	1915.74376	2049.77867
6	5845.851	2208.14447	2423.92459
7	5261.2659	2485.15108	2783.44994
8	4735.13931	2743.82809	3127.06142
9	4261.62538	2981.22112	3453.39058
10	3835.46284	3194.35082	3760.99152

OO1(T), OO1′(T) = TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q2*DD2(T), Q2*DD2′(T) = SHARE OF OO1(T) WHICH MIGHT BE NEUTRALIZED BY THE SECOND OPPONENT
OO1′(T+1) = OO1′(T)+O1′(T+.5), OO1′(0) = OO1(0)
DD2′(T+1) = DD2′(T)+D2′(T+.5), DD2′(0) = DD2(0)



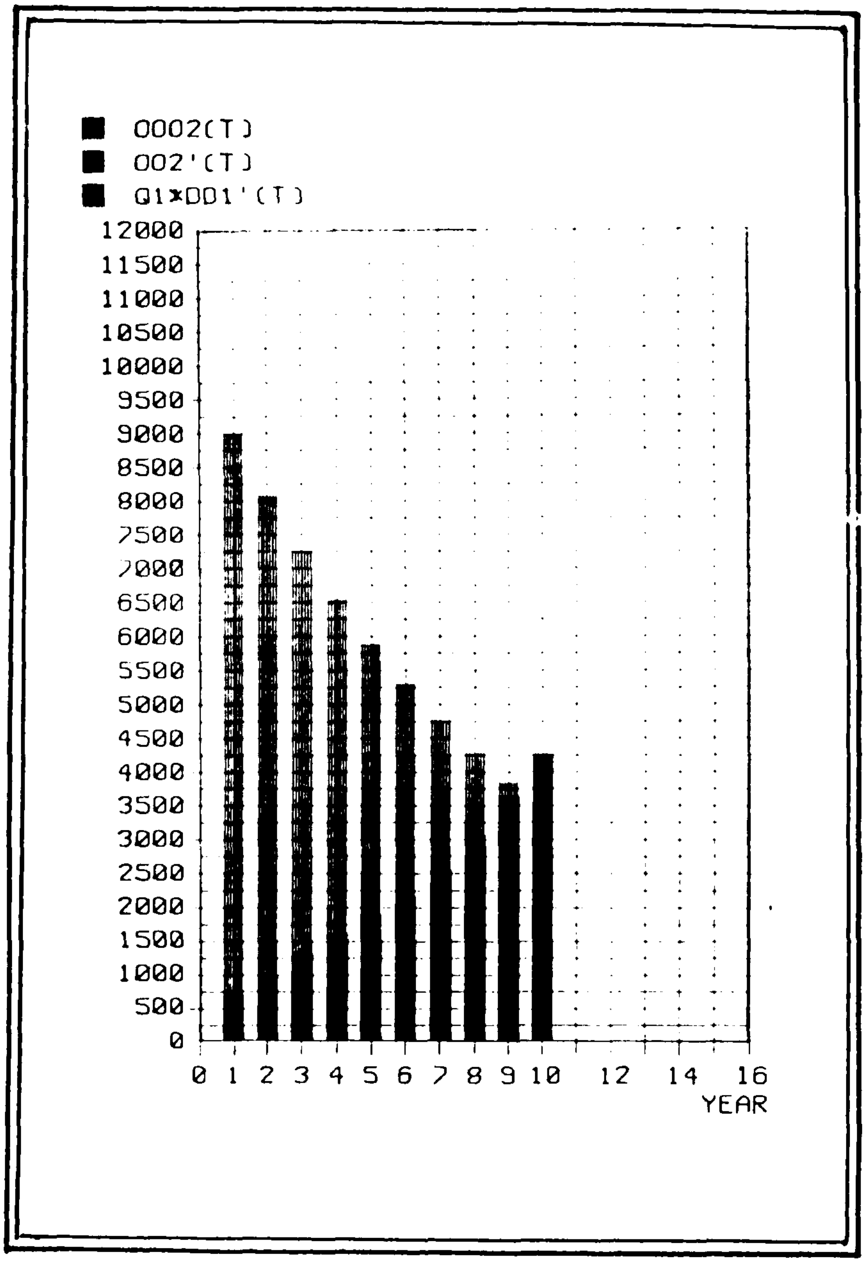
OOO1(T)
OO1'(T)
Q2*OO2'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

TABLE 10: OPTIMAL TRAJECTORIES OF THE TOTAL STOCKS OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS FORECASTED TO BE OWNED BY THE SECOND OPPONENT AND THE FIRST OPPONENT'S POTENTIAL CAPABILITY TO BUILD STRATEGIC DEFENSIVE SYSTEMS IN ORDER TO NEUTRALIZE THEM

T=	OOO2(T)=	OO2(T)=	Q1*DD1(T)=
0	10000	350	0
1	9000	692.559203	242.599018
2	8100	1020.56953	527.194659
3	7290	1334.48313	853.229819
4	6561	1634.767	1220.25543
5	5904.9	1921.9084	1627.93158
6	5314.41	2196.42027	2076.02891
7	4782.969	2458.84683	2564.43041
8	4304.6721	2709.76923	3093.13351
9	3874.20489	2949.8114	3662.25253
10	3486.7844	3179.64601	4272.0215

T=	OOO2(T)=	OO2'(T)=	Q1*DD1'(T)=
0	10000	350	0
1	9000	692.577997	242.551987
2	8100	1020.60753	527.104749
3	7290	1334.54096	853.100988
4	6561	1634.84552	1220.09146
5	5904.9	1922.0087	1627.73607
6	5314.41	2196.54368	2075.80531
7	4782.969	2458.99492	2564.18201
8	4304.6721	2709.94382	3092.86346
9	3874.20489	2950.01456	3661.96385
10	3486.7844	3179.88008	4271.71708

OO2(T), OO2'(T) = TOTAL STOCK OF MODERNIZED STRATEGIC OFFENSIVE WEAPONS
Q1*DD1(T), Q1*DD1'(T) = SHARE OF OO2(T) WHICH MIGHT BE NEUTRALIZED BY THE FIRST OPPONENT
OO2'(T+1) = OO2 (T)+O2'(T+.5); OO2'(0) = OO2(0)
DD1'(T+1) = DD1 (T)+D1'(T+.5); DD1'(0) = DD1(0)


OOO2(T)
OO2'(T)
Q1×DD1'(T)
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16
YEAR

CONCLUSIONS

In the last section of the second chapter (p. 133), I remarked that six scenarios can be conceived by associating three types of policies regarding strategic offensive weapons with two concerning strategic defensive systems. I have also specified that in order to select the optimal scenario, an analysis of MAD doctrine, of strategic offensive arms race (in)stability, and of the relationship between strategic offense and defense have been necessary. Therefore, after having tried to make this analysis in the chapters 3, 4, and 5, I have to indicate which scenario should be preferred.

It is normal to start with the assumption that the strategic defense systems are not developed, and that the strategic offensive systems are maintained at the present level (scenario 2), and to check if this situation might be stable or not. The models developed in the sections 4.2.3. indicate that in a balance of power system, in conditions of real adversity, there is a natural tendency toward a quantitative and/or qualitative increase of strategic offensive forces. Therefore, the policy implied by scenario 2 can not be sustained, and one must switch to scenario 3 (increase the number of strategic offensive weapons, do not develop strategic defense). But this last kind of policy would cause a similar answer from the adversary. As a result, an escalation, the most probable in a technological qualitative version, of the arms race would occur. But such an escalation might be highly destabilizing and very dangerous, and it should be avoided. Therefore, if one supposes that strategic defense is not developed, one should switch to scenario 1.

The first scenario (diminish the number of strategic offensive weapons, do not develop strategic defense) can realistically be implemented only if a substantial disarmament agreement is reached. Without such an agreement, this scenario means unilateral disarmament, and it is improbable that it might be accepted by a responsible government. But even under the assumption that a major disarmament agreement (like, for example, that recently signed between the United States and Russia) could be concluded, some important risks could persist if the agreement is not multilateral and/or unpredictable changes take place in the co-signatories, or in some other countries. According to the conclusions derived in the third chapter, the vulnerability based deterrence, embodied in the MAD doctrine, would have a relatively more limited role in a multipolar balance of power system including an increased number of nuclear powers than it had during the Cold War. Therefore, any disarmament treaty, although it would be very desirable and useful, would also imply risks. Three or four thousand strategic nuclear warheads represent an extraordinary force and they are sufficient to cause unimaginable destruction. To this risk concerning the main potential adversary should also be added that associated with the possibility of an accidental launch, or of one done by a renegade country or rogue commander. Consequently, the risks associated with this scenario make it necessary to take into consideration the scenarios implying the development of strategic defensive systems.

One observes that the fifth scenario (maintain strategic offensive weapons at the same level, develop strategic defensive systems) might be destabilizing during the transition (research, development and beginning of deployment) period, as both proponents and opponents of SDI argued. Any relative advance in the development and deployment of strategic defensive systems by one power would be rightly regarded by the other(s) as an obvious tendency toward achieving first strike capability and as a rejection of MAD principles. As shown in the numerical examples illustrating the models developed in sections 5.2. and 5.3., there might be a considearble period of time in which the strategic defense will be only partial. And it is largely accepted that a partial strategic defense would be used to protect the strategic offensive systems, increasing in this manner the first strike capability. As a natural result, the adversary would increase the number of its strategic offensive weapons, and would try to accelerate its own program of developing strategic defense. Therefore, this policy would finally cause the replacement of the fifth scenario by the sixth.

This last one (increase the number of offensive strategic weapons, develop strategic defense) does not imply only a generalized escalation of the arms race. It might be also financially impossible. It is very probable that in normal international circumstances, it would be unrealistic to expect that the lawmakers would allocate the considerable financial resources required by such an extensive armament program. In other words, the financial constraints included in the models developed in sections 5.2. and 5.3. could not be met. Being financially untenable and highly destabilizing strategically, this scenario would be undoubtedly avoided by a governement willing to remain in power. Consequently scenario 4 must be preferred as being the optimal one.

This scenario (decrease the number of strategic offensive weapons, develop strategic defense) allows adversaries not only to stop the strategic offensive arms race but also substantially to reduce the number of such weapons. The transition instability could be kept in reasonable limits, and a new version of the ABM Treaty could be conceived in order to improve the security for an increased number of countries. Such a policy could at the same time allow the transition from a world dominated by strategic offense to a more stable one in which a mixed strategy associating strategic offense with strategic defense might prevail. Instead of relying on the highly dangerous threat of mutual destruction in order to preserve peace, it would be possible to achieve the same objective by relying on strategic defense in an increasing number of situations. And it is also probable that such a program can receive the necessary funding, even without very tense international conditions. Summarizing its advantages and disadvantages, and comparing them, one can assert that the first are more significant than the second. Therefore, it seems to me that this scenario should be preferred.

Finally, because this is a dissertation and not a regular book, I have the relatively embarrassing duty of summarizing my "original contribution." Therefore, I would like to stress that I do this only for formal reasons associated with the dissertation's defense. I am fully convinced that what I have achieved represents only a small and modest part of what could be done for studying these topics, and I also realize my scientific limitations.

I consider that my contribution directly concerning the dissertation's topics consists in using the Optimal Control Theory (a principal component of Dynamic System Analysis) for building models. These models allow one to simulate various policies regarding the development of strategic defensive systems in relationship with the offensive ones. Associated to this contribution is the construction of the two models which explain and illustrate the manner in which the spiral of a strategic offensive arms race occurs.

An equally significant original element, but which is indirectly related to the dissertation's topics, is the use of utility and disutility functions (curves). I employ them for theoretically evaluating the gain from the first strike and the loss caused by the corresponding counterstrike. On this basis, I analyse the main assumptions of the MAD doctrine, and I make predictions regarding its relatively limited role in the emerging international system.

The third principal contribution creates the general framework in which the problem of strategic defensive systems' development is studied. It consists in the application of the entropy theory for studying the strain existing in specific types of international systems. The model built on this basis shows that the total strain existing in a balance of power international system might be larger than that existing in a bipolar one.

I would like also to mention that I wrote all the computer programs (that are relatively difficult) for solving and testing my models. That was not an "especially pleasant" work, but it was a necessary one.

For formal reasons associated with the dissertation's defense I include a list of my original contributions in the succession in which they appear in the dissertation, starting with the second chapter. As I wrote in the Introduction, I consider that the first chapter is only a summary of various informations concerning SDI, and not an element of my original argumentation. With these specifications, I consider that my original contributions are the following (those which in my opinion, are the most important are printed in bold face type):

(in the second chapter)

- the association between prediction made by political analysts studying empirical information with the theoretical conceptions of Kaplan and Waltz for predicting the characteristics of the emerging international system;

- **the use of Dynamic System Analysis for studying the international system's stability and the role of strategic defensive systems;**

- the distinction between internal, structural and global stability;

- the interpretation of Waltz's concept of stability as structural stability;

- the remark that international system's structural instability and strain are similar to system's entropy;

- the construction of a mathematical model in which the entropy is used to evaluate the structural instability and strain of an international system;

- the derivation of several formal properties of the international system suggesting that the structural instability of a balance of power international system might be higher that that of a bipolar system, and that the alliances increase system's structural stability;

(in the third chapter)

- the system of utility and disutility curves for analysing the first strike and the corresponding counterstrike;

- the classification of nuclear powers by using the net disutility curve;

- the use of the utility and disutility curves for explaining the relatively limited role that MAD might play in preventing a nuclear war in a balance of power multipolar international system;

- the explanation of the necessity of strategic defense by the potential partial failure of MAD within the framework defined by the utility and disutility curves;

(in the fourth chapter)

- the use of the concept of dynamic system for analysing the dynamic relationship between strategic offense and strategic defense (I applied this concept in my 1986 unpublished manuscript: USCO Registration Number: TXU 239-905, and in the paper delivered in 1987 at the Annual Convention of the Eastern Economic Association; the article of Saperstein and Mayer-Kress was publiblished in 1988);

- the identification of strategic offensive weapons as state variables, and of strategic defensive systems as control variables;

- the contruction of a dynamic model for studying the (in)stability of a strategic offensive arms race;

- the building of a mathematical model which shows the manner in which the strategic offensive arms race's spiral and/or acceleration occur;

- the use of the systemic framework in order to indicate that the development and deployment of strategic defensive systems might be used as a means to control the escallation of strategic offensive arms race (to scale down it);

(in the fifth chapter)

- the construction of a dynamic model for studying the optimal development of strategic defensive systems by several powers, having a criterion of optimum defined at the system level;

- the building of a dynamic model for analysing one power's optimal allocation of funds for modernizing its strategic offensive weapons and for developing strategic defensive systems such as its security in relationship with its potential adversaries would be improved;

- the construction of a model for studying the optimal allocation of funds by two opponents for modernizing their strategic offensive weapons and developing strategic defensive systems, such as their security would be improved.

Finally, on the basis of my general analyses, of the results derived from my mathematical models, and of the scenarios generated by using my computer programs, I can conclude as follows. The international system is in a process of transition. It is probable that the future international system will be a balance of power one. By reinforcing Waltz's theory, my entropy model suggests that the emerging system might be less stable than the former system. There are also significant reasons to consider that an increased number of countries will have nuclear capabilities and adequate means of delivery in the foreseeable future. Therefore a reasonable military power must be maintained in order to protect our national interests. The internal characteristics of some of the future nuclear powers and the structure of the emerging international system will probably limit the role of the vulnerability based deterrence (mutual assured destruction) in preventing a nuclear war. To compensate for a even very limited failure of MAD, different kinds of confidence building measures and/or disarmament agreements should be associated with the development and future deployment of strategic defensive systems. Those systems would allow one to control and to scale down the strategic offensive arms race, and would improve the deterrent character of our forces on short term. In the long term, they would be elements on which an incipient population defense might be developed. The set of mathematical models developed in this dissertation might be used for simulating various policies regarding the dynamics of strategic offense and defense.

* * * * * * * * *

* * * * * * *

BIBLIOGRAPHY

OFFICIAL PUBLICATIONS

Ballistic Missile Defense Technologies: Summary, Washington, D.C.: Congress of the United States, Office of Technology Assessment, 1985.

Defense Against Ballistic Missiles: An Assessment of Technologies and Policy Implications, Washington, D.C.: US Government Printing Office, April 1984.

The President's Strategic Defense Initiative, Washington, D.C.: US Government Printing Office, January 1985.

BOOKS

Anzovin, Steven, editor, The Star Wars Debate, New York: H. W. Wilson, 1986.

Aspen Strategy Group, On the Defensive ? The Future of SDI, Lanham, MD.: University Press of America, 1988

Athans, M., P.L. Falb, Optimal Control: An Introduction to the Theory and its Applications, New York, McGraw-Hill Book Company, 1966

Brown, Harold, editor, The Strategic Defense Initiative: Shield or Snare ?, Boulder, CO.: Westview Press, 1987.

Calin, S., C. Belea, Sisteme Automate, Adaptive si Optimale, Bucuresti, Editura Tehnica, 1971

Codevilla Angelo, While Others Build: the Common-sense Approach to the Strategic Defense Initiative, New York: Free Press, 1988.

Brzezinski, Zbigniew, editor, Promise or Peril, the Strategic Defense Initiative, Washington, D.C.: Ethics and Public Policy Center, 1986.

Cimbala, Stephen J., editor, The Technology, Strategy and Politics of SDI, Boulder, CO.: Westview Press, 1987.

Drell, Sidney S., Philip J. Farley and David Holloway, The Reagan Strategic Defense Initiative: A Technical, Political and Arms Control Assessment, Cambridge, Mass.: Ballinger, 1985.

Gill, Thomas C., editor, Essays on Strategy VI, Washington, D.C.; National Defense University Press, 1989.

Graham, Daniel, High Frontier: A Strategy for National Survival, Washington, D.C.: High Frontier, 1982.

Hartmann, Frederick H. and Robert L. Wendzel, Defending America's Security, Washington, D.C.: Pergamon-Brassey's, 1988.

Hestenes, M.R., Calculus of Variations and Optimal Control Theory, New York; John Willey, 1966.

Holdren, John and Joseph Rotblat, Strategic Defenses and the Future of the Arms Race: A Pugwash Symposium, New York, St. Martin's Press, 1987.

Hughes, Robert C., SDI: A View from Europe, Washington, D.C.: National Defense University Press, 1990.

Kalman, R. E., P. L. Falb and M. A. Arbib, Topics in Mathematical System Theory, New York, McGraw-Hill, Inc., 1969.

Kaplan, Morton, System and Process in International Politics, Huntington, N.Y.: R.E. Krieger Publishing Co., 1975, <c 1957>

Khinchin, A.I., Mathematical Foundations of Information Theory, Dover Publications, Inc., 1957.

Lackey, Douglas P., editor, Ethics and Strategic Defense: American Philosophers Debate Star Wars and the Future of Nuclear Deterrence, Wadsworth Pub. Co., 1989.

Laird, Robbin F. and Dale R. Herspring, The Soviet Union and Strategic Arms, Boulder, CO.: Westview Press, 1984.

Luongo, Kenneth N., and W. Thomas Wander, editors, The Search for Security in Space, Ithaca, N.Y.: Cornell University Press, 1989.

Mikheyev, Dmitry, The Soviet Perspective on the Strategic Defense Initiative, Washington, D.C.: Pergamon-Brassey's, 1987.

Milton, Albert Fenner, M. Scott Davis and John A. Parmentola, Making Space Defense Work: Must the Superpowers Cooperate ?, Washington, D.C.: Pergamon-Brassey's, 1989.

Morgenthau, Hans J., and Kenneth W. Thompson, Politics Among Nations, New York: Alfred A. Knopf, sixth edition, 1985.

Pontryagin L.S., V.G. Boltianskii, R.V. Gamkrelidze, The Mathematical Theory of Optimal Processes, New York, Interscience, 1962.

Pontryagin L.S., Ordinary Differential Equations, Reading, Mass.; Addison Wesley, 1961.

Richardson, L.F., Arms and Insecurity, Chicago; Quadrangle Books, 1960

Simon, Jeffrey, editor, Security Implications of SDI, Washington, D.C.: National Defense University Press, 1990.

Snow, Donald M., National Security: Enduring Problems of US Defense Policy, New York: St. Martin's Press, 1987.

Snyder, Craig, editor, The Strategic Defense Debate: Can "Star

Wars" Make Us Safe, Philadelphia: University of Pennsylvania Press, 1986.

Snyder, William P. and James Brown, Defense Policy in the Reagan Administration, Washington, D.C.: National Defense University Press, 1988.

Teller, Edward, Better a Shield than a Sword, New York, Free Press, 1987.

John Tirman, editor, Empty Promise: The Growing Case Against Star Wars, Boston: Beacon Press, 1986.

Vlahos, Michael, Strategic Defense and the American Ethos: Can the Nuclear World Be Changed, Boulder, CO.: Westview Press, 1986.

Velikhov, Yevgeny, Roald Sagdeev and Andrei Kokoshin, editors, Weaponry in Space: The Dilemma of Security, Moscow, Mir Publishers, 1986.

Waltz, Kenneth, Theory of International Politics, Reading, Mass.: Addison-Wesley, 1979.

Worden, Simon P., SDI and the Alternatives, Washington, D.C.: National Defense University Press, 1991.

York, Herbert, Does Strategic Defense Breed Offense, Lanham, MD.: University Press of America, 1987.

Zadeh, Lofti A. and Ch. A. Desoer, Linear System Theory, New York, McGraw-Hill, Inc., 1963

Zadeh, Lofti A., E. Polak, System Theory, New York, McGraw-Hill, Inc., 1969

Zinnes, Dina A. and John V. Gillespie, editors, Mathematical Models in International Relations; New York, Praeger Publishers, 1976.

ARTICLES

Brown, Harold, Is SDI Technically Feasible ?, Foreign Affairs, Vol. 64, No. 3, 1986, pp. 435-454.

Brown, Harold, The Strategic Defense Initiative, Survival, Vol. 27, No. 2, 1985.

Bundy, McGeorge, George F. Kennan, Robert C. McNamara and Gerard Smith, The President's Choice: Star Wars or Arms Control, Foreign Affairs, Vol. 63, No. 2, 1984, pp 264-278.

Carter, Ashton, Directed Energy Missile Defense in Space, Washington, D.C.: Office of Technology Assessment, 1984.

Delors, Jacques, Europe's Ambitions, Foreign Policy, Number 80, 1990, pp. 14-27.

Hoffmann, Stanley, A New World Order and its Troubles, Foreign Affairs, Vol. 69, No. 4, 1990, pp. 115-122.

Gaddis, John Lewis, Toward the Post-Cold War World, Foreign Affairs, Vol. 70, No. 2, 1991, pp. 102-122.

Ikle, Fred C., Nuclear Strategy: Can There Be a Happy Ending ?, Foreign Affairs, Vol. 63, No. 4, 1985, pp. 810-826.

Intriligator, Michael D. and Dagobert L. Brito, Can Arms Races Lead to the Outbreak of War ?, Journal of Conflict Resolution, Vol. 28, Nr. 1, 1984, PP. 63-84.

Kaifu, Toshiki Japan's Vision, Foreign Policy, Number 80, 1990, pp. 28-39.

Krauthammer, Charles, The Unipolar Moment, Foreign Affairs, Vol. 70, No. 1, 1990/1991, pp. 23-33.

Mandelbaum, Michael, The Bush Foreign Policy, Foreign Affairs, Vol. 70, No. 1, 1990-1191, pp. 5-22.

Maynes, Charles William, America Without the Cold War, Foreign Policy, Number 78, 1990, pp. 3-25.

Maynes, Charles William, The New Decade, Foreign Policy, Number 80, 1990, pp. 3-13.

McFarlane, Robert C., Effective Strategic Policy, Foreign Affairs, Vol. 67, No. 1, 1988, pp. 33-48.

McNamara, Robert C., The Military Role of Nuclear Weapons: Perceptions and Misperceptions, Foreign Affairs, Vol. 62, No. 1, 1983, pp. 59-80.

Nitze, Paul, America: An Honest Broker, Foreign Affairs, Vol. 69, No. 4, 1990, pp. 1-14.

Paine, Keith W., and Colin S. Gray, Nuclear Policy and the Defense Transition, Foreign Affairs, Vol. 62, No. 4, 1984, pp. 820-842.

Pfaff, William, Redefining World Power, Foreign Affairs, Vol. 70, No. 1, 1990/1991, pp. 34-48.

Postol, Theodore A., Lessons of the Gulf War Experience with Patriot, International Security, Vol. 16, No. 3, 1991-1992, pp. 119-171.

Rosecrance, Richard, A New Concert of Powers, Foreign Affairs, Vol. 71, No. 2, 1992, pp. 64-82.

Sagan, Carl, Nuclear War and Climatic Catastrophe: Some Policy Implications, Foreign Affairs, Vol. 62, No. 2, 1983/1984, pp. 357-392.

Sagan, Carl. The Case Against SDI, Discover, September, 1985, pp. 67-75.

Saperstein, Alvin M. and Gottfried Mayer-Kress, A Nonlinear Dynamical Model of the Impact of SDI on the Arms Race, Journal of Conflict Resolution, Vol. 32, No. 4, 1988, pp. 636-670.

Schlesinger, James R., Rhetoric and Realities in the Star Wars Debate, International Security, Vol. 10, No. 1, 1985, pp. 3-12.

Tsipis, Kostas and Matthew Bunn, The Uncertainties of a Preemptive Nuclear Attack, Scientific American, No. 5, 1983.

Waltz, Kenneth N., Nuclear Myths and Political Realities, American Political Science Revue, Vol. 84, Number 3, 1990, pp. 731-745.

Zinnes, Dina A., and Robert G. Muncaster, The Dynamics of Hostile Activity and the Prediction of War, Journal of Conflict Resolution, Vol. 28, No. 2, 1984, pp. 187-246.

* * * * * * * * *

* * * * *

ORIGINAL RESEARCH PAPERS

Strategic Defense in a Multipolar International System, paper delivered at the 1992 Annual Convention of the International Studies Association, Atlanta, Georgia, April 1992.

A Theoretical Interpretation of Equilibrium and Reform in Eastern Europe and (Former) Soviet Union, paper delivered at the 1992 Annual Convention of the International Studies Association, Atlanta, Georgia, April 1992.

A Quantitative Interpretation of Structural Stability in Waltz's Theory, paper delivered at the 1991 Annual Convention of the International Studies Association, Vancouver, British Columbia, Canada, March 1991.

The Mutual Assured Destruction Doctrine in a Multipolar International System, paper delivered at the Conference of the International Security Studies Section of the International Studies Association, Columbus, Ohio, November 1990.

A System of Models for Arms Race and Defense Expenditures Analysis, paper delivered at the 8th International Congress of Cybernetics and Systems, New York City, June 1990.

The Swedish Model and the Reforms in Eastern Europe, paper deliveredat the Conference on Scandinavia and the Common Market, CUNY, Graduate Center, April 1990.

Equilibrium and Reform in Eastern Europe and Soviet Union, paper deliverd at the Annual CUNY/Political Science Conference, March 1990.

A Remark on the Propensity to Use Nuclear Weapons During a Crisis, paper delivered at the Correlates of War Seminar, University of Michigan at Ann Arbor, August 1989.

Dynamic System Theory - A Methodological Basis for Inter-disciplinary Economic, Social, and Political Analysis, paper delivered at the Fourteenth Annual Meeting of the History of Economics Society, Harvard University School of Business, June 1987.

A Model for the Study of Strategic Defense Expenditures, paper delivered at the Thirteenth Annual Convention of the Eastern Economic Association, Arlington, Virginia, March 1987.

Mathematical Models and Computer Simulation for Arms Race and Defense Expenditures Analysis, manuscript and software (USCO Reg. Number: TXU 239-905), May 1986. (I presented a summary of this study at the ICPSR Summer Program in Quantitative Methods at the University of Michigan at Ann Arbor, in August 1988).