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Defense Against Ballistic Missiles

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1992 Theodore von Karman Lecture

American Institute of Aeronautics and Astronautics

DEFENSE AGAINST BALLISTIC MISSILES

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1992 Theodore von Karman Lecture

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DEFENSE AGAINST BALLISTIC MISSILES

Hans Mark

The University of Texas System

I. Introduction

Theodore von Karman was without doubt one of the great practitioners of applied science in this century. He was a superb mathematician who applied his unique talent to problems that increased our understanding of basic aerodynamics as well as developing ideas that ultimately paid off handsomely in practice. The Karman Vortices are an example of the former and his pioneering work with solid fuel rockets illustrates the latter.

Throughout his long life, von Karman also retained a strong interest in the application of science and technology to military problems. He served in the Austro-Hungarian Army during the First World War (1914-1918) and was one of the young officers who founded the Army's Air Service (Figure 1). Always a person of great originality, he and his colleagues devised a primitive helicopter that they thought could be substituted for the then commonly used observation balloons (Figure 2). They felt that helicopters would be less vulnerable than balloons to enemy fire. They succeeded in building a helicopter that could fly, but that was as far as it went because the formidable control problems inherent in flying helicopters could not be dealt with using technology available at the time.

During the Second World War (1939-1945), von Karman was in a position to make much more important contributions. By this time, he had come to the United States and joined the faculty at the California Institute of Technology. It is not an exaggeration to say that from this influential position, he had great impact on the creation of the American air arm of more than a quarter of a million aircraft that was so decisive in achieving victory in World War II. After the end of the conflict, then Air Force Chief-of-Staff, General Henry H. (Hap) Arnold, asked von Karman to look into the future. The result was the famous "Toward New Horizons" study which was carried out under von Karman's direction. Completed in 1946, the study foresaw an Air Force, not only with bombers that would carry nuclear bombs but it also predicted the advent of nuclear weapon armed ballistic missiles. Most of the things foreseen by von Karman and his collaborators in 1946 have come to pass.

For these reasons, it is entirely appropriate to devote this lecture to national security and also to take a longer look into the future. I only met Theodore von Karman once and I cannot claim the thorough approach of the "Horizon" study, but I do hope that his ghost will forgive me for this attempt to follow in his footsteps. (For an excellent account of von Karman's career see Ref. 1.)

II. Early Ideas About Defense Against Nuclear Armed Ballistic Missiles

The topic of my lecture is defense against ballistic missiles armed with nuclear warheads. I would like to start by discussing for a short time the air defense problem and how it was solved during the Second World War. Ground based defenses against aircraft using anti-aircraft artillery turned out not to be very effective. Fighter aircraft, on the other hand, that could shoot down long-range bombers sent over enemy territory caused casualty rates among attacking aircraft that were unacceptably high. It is, of course, for this reason that the RAF Fighter Command won the Battle of Britain in 1940 and the Luftwaffe prevented a really massive bombing campaign against continental Europe by the Allies until the Allies were able to provide long-range fighter escorts for their bombers. Air defense, therefore, depended on having fighter aircraft that could deal with escorting fighters and could shoot down bombers.

After the conclusion of the Second World War, air defense became much more important than it had been in the past. The advent of nuclear weapons and long-range bombers to carry them made it absolutely essential that a strong air defense system be built. In the United States this started with the SAGE System which was developed during the decade of the 1950's. Two new technologies turned out to be critical. One was long-range radar which made it possible to detect incoming bombers early on. A network of radars was constructed to inform military commanders about the air traffic so that appropriate defensive measures could be taken. The second technology was one that von Karman helped to create. These were small and agile solid-fueled missiles with appropriate guidance systems that could be sent against high altitude bombers. Later on, these became known as Surface to Air Missiles (SAM) and they have been the centerpiece of any defense against aircraft since World War II. What ultimately evolved as a result of the air defense effort was called the Army's Nike System which consisted of the radar picket line that I mentioned earlier and Nike SAM missile sites scattered around the continental United States. This system was judged to be effective against all of the long-range bombers then available. (For a good discussion of this era, see Ref. 2.)

All of this changed with the advent of

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ballistic missiles. In the decade of the 1950's, both the Soviet Union and the United States created a stable of missiles capable of carrying nuclear warheads. Generally speaking, these were divided into two classes, the Intermediate Range Ballistic Missiles (IRBM's) with ranges of less than one thousand miles and the Intercontinental Ballistic Missiles (ICBM's) with ranges in excess of one thousand miles, up to perhaps six thousand miles. While the Nike System was effective against aircraft, it could not do anything about an attack by ballistic missiles. The SAM missiles available were not capable of intercepting fast moving warheads launched using IRBM's or ICBM's. In short, "shooting down bullets with bullets" was at the time too hard from a technical viewpoint. Therefore, ideas that were based on evolutionary developments from anti-aircraft artillery were abandoned.

As early as 1957, there were people who began to look at the missile defense problem from a different viewpoint. One of these was Dr. Nicholas C. Christofilos of the University of California's Lawrence Livermore National Laboratory. Christofilos felt very strongly that some kind of a "global" solution to the problem had to be found. He believed that "point defense" systems that could be evolved from anti-aircraft artillery would not be effective in protecting whole populations from missiles that could be launched from anywhere in the world. Christofilos knew that energetic charged particles such as those emitted by a nuclear explosion could be trapped in the earth's magnetic field above the atmosphere. He reasoned that placing enough energetic charged particles into trapped orbits in the geomagnetic field would create a radiation field strong enough to damage the guidance and control electronics of nuclear warheads passing through that radiation field.

The idea proposed by Christofilos was deemed important enough to warrant an experiment. Plans were made to detonate three small nuclear devices (in the 2 kiloton yield range) above the atmosphere and then to make measurements of the resulting trapped charged particles. In addition to using sounding rockets and other techniques, the fourth American orbiting satellite, Explorer IV, was instrumented to look at these radiations. The whole effort was code named "Project Argus".

The Argus experiment was conducted in the summer of 1958. The bombs were mounted on top of rockets launched from a ship in the South Atlantic Ocean. The bombs were detonated at an altitude of 130 miles and the worldwide detection network that had been established began to collect relevant data. There is no doubt that the predictions of Christofilos were confirmed. Figures 3 and 4 illustrate the geometry of the experiment and show how the orbit of Explorer IV (1958 e) intersected the earth's magnetic field lines along which the trapped charged particles moved. Energetic charged particles could be trapped for long periods of time in the geomagnetic field and in terms of the intensity of the radiation field created, the quantitative predictions of Christofilos were verified. The Argus experiment was successful. (Ref. 3)

During the nuclear weapons test series conducted in 1962 by the United States, a larger nuclear explosion was detonated above the atmosphere. This test was code named "Starfish" and the experiment this time confirmed the conjecture by Christofilos that the radiation intensity created by the trapped particles in the geomagnetic field would be sufficiently high to disable electronics on space vehicles. Several satellites flying in 1962 were temporarily disabled by the "Starfish" radiation field. (Ref. 4)

As things turned out, however, there was a relatively easy countermeasure that could be employed to defeat energetic charged particles trapped in the geomagnetic field. The electronic systems of the day were relatively "soft" to radiation damage but fairly simple measures could be employed to "harden" them in such a way that they could survive the radiation fields created by nuclear explosions above the atmosphere. Progress in hardening electronics was so rapid that the whole Argus idea was quickly abandoned. Nevertheless, the Argus experiment was important because it was, indeed, the first effort to create a global defense system against ballistic missiles.

III. <u>The Nike X-Sentinel-Safeguard System</u>

At the same time that the Argus experiments and the "Starfish" shot were being conducted, more traditional ways of creating defenses against ballistic missiles were being developed. Most important of these was the "Nike X" project which was simply an upgrade of the Nike System that had been built to defend the continental United States against airplanes to one that could also deal with ballistic missiles. The Nike X project was managed by the U.S. Army and it was conceived to follow the tradition of anti-aircraft artillery. The objective of Nike X was, simply put, to learn how to "shoot down bullets with bullets." I have already said that this was a difficult proposition from a technical viewpoint. It was clear to those of us that participated in thinking about Nike X that not much had changed since the use of anti-aircraft artillery to shoot down missiles was abandoned.

The Nike X approach was conventional. It consisted of a radar detection system with two components along with a "two level" defensive Anti-Ballistic Missile (ABM) System. There was a Perimeter Acquisition Radar (PAR) designed to detect and then track incoming missile warheads. The information from this radar would then be handed over to something called a Missile Site Radar (MSR) located at the site where the ABM missiles were placed. Both of these radar systems were large phased array radars based on the ground. The Perimeter Acquisition Radars would, of course, be supplemented by existing radars intended for defense against airplanes. There were two ABM missiles, the Spartan and the Sprint, intended to intercept incoming warheads. The Spartan missile was a large long-range liquid-fueled missile that would intercept warheads well above the atmosphere. The Sprint was a smaller, very high energy solid-fueled rocket intended to intercept warheads at altitudes of the order of 10,000 feet after they had entered the atmosphere. Both of these missiles carried nuclear warheads which would destroy incoming missiles. In the case of the Spartan, the warhead was quite large with a yield in excess of five megatons, and in the case of the Sprint, it was hundreds of kilotons.

The Spartan and Sprint missiles were controlled using the Missile Site Radars. The fact that large nuclear warheads had to be used on the defensive missiles is an indication of the relatively poor accuracy with which the Spartan and Sprint missiles could be guided toward the incoming target warheads.

The final element of the Nike X System was a very large and sophisticated ground-based computer which tied together all of the other components in such a way that the engagement with incoming warheads could be controlled. It is interesting that people recognized even in the 1960's that a new kind of computer would have to be invented to do this job. It was, in fact, the first time that "parallel" computing had been considered for a practical application. Unfortunately, the computer built for this purpose on an experimental basis failed to meet its objectives. The architecture of the Nike X-Sentinel-Safeguard System is shown in Figure 5. (Note: Nike X was named "Sentinel" in 1967 and renamed "Safeguard" in 1969.)

The work done on the Nike X program yielded some important results. The Sprint rocket was very successful and it really was the first time that a high energy rocket in excess of 70 g's was successfully flown. Large phased array radars were built and tested. These were successful but no feasible way of "hardening" them against high altitude nuclear explosions was discovered. New nuclear warheads with enhanced radiation features were developed for the Spartan missile which were successfully tested and would be very lethal against incoming warheads.

In spite of the technical successes, the general conclusion was that the Safeguard System would be very difficult to operate in practice. At about the same time, the Soviet Union began to deploy a system similar to Safeguard around Moscow. This was called the "Galosh" System and the Soviet work on ABM missiles of this kind spurred further efforts in this country. Thus, in spite of technical difficulties and serious doubts about the ultimate value of such defensive systems, both the United States and the Soviet Union worked hard to develop and deploy them.

In parallel with the technical work I have described, diplomatic efforts aimed at limiting the deployment of ABM systems were initiated. These negotiations precipitated a major public debate about the proper role of nuclear weapons and defensive systems to maintain a stable peace. As part of the debate, President Nixon on March 14, 1969, made the decision to start work on deploying the Safeguard type ABM system. This decision was taken partly to build something which might make a real contribution to the defense of the nation and partly to provide an incentive for the Soviets to become serious in their negotiations with us over strategic arms limitations and ABM systems.

No one knows whether the deployed system would have enhanced our defensive posture, although given the technology at the time, I suspect that the useful addition would have been marginal. There is no doubt, however, that in political terms, President Nixon's decision to deploy the Safeguard System was successful. The Russians did finally agree to the strategic arms limitation treaty called SALT I and, in addition, both the United States and the Soviet Union concluded a treaty that in effect banned most of the work on anti-ballistic missiles (the ABM Treaty). The first strategic arms limitation treaty (SALT I) was successful in slowing the growth of strategic nuclear weapon deployments. In that sense, it served its purpose well. The ABM Treaty was, in the end, not something which, I believe, enhanced the national security of the United States. The basic idea behind the treaty was to ensure nuclear "stability" and perhaps it did make a contribution to that end, at least in the early years of its being enforced. The major problem with the ABM Treaty is that it had no time limit at which it would terminate. Therefore the treaty remains in force today even though both the political and the technical situations have changed beyond recognition in the almost twenty years since the treaty was concluded. There are many who now believe that the 1972 ABM Treaty should be revised or abrogated. I will return to a discussion of this topic a little bit later, after we have looked at some of the technological developments that have occurred since 1972. (For a good discussion of the events leading to the 1972 ABM Treaty see Ref. 5.)

IV. The Strategic Defense Initiative

On March 23, 1983, President Ronald Reagan delivered a remarkable speech. In that speech, he proposed the development and deployment of a defensive system against ballistic missiles which would ultimately protect populations. In his words, he wanted something that would make nuclear weapons "impotent and obsolete." This was a formidable challenge to the nation's technological community. It is worthwhile perhaps to look at what happened between May of 1972 when President Nixon concluded the ABM Treaty and March 1983 when President Reagan made his speech. There were four major technical developments that made many people change their minds about the ultimate feasibility of strategic defense systems. These developments came to fruition in a practical sense between 1972 and 1983. Included in the list are the following items:

(1) Great progress was made in the development of sensing devices in all regions of the electromagnetic spectrum. Exquisitely sensitive infra-red bolometers were built which could be mounted on ABM missiles to detect incoming warheads. This development made it possible for ABM missiles to home in on the incoming warheads. Similar infra-red detectors are also used to detect missile launches by mounting them on satellites placed in geosynchronous orbits.

(2) The revolution in microelectronics came to fruition in the decade of the 1970's. The

commercial development of micro chips with great computer capacity made it possible to build very small and very powerful computational devices. This development along with the sensors meant that missiles aimed at incoming ballistic warheads no longer had to be guided from the ground. The computers as well as the sensors could be installed in the missiles themselves so that the guidance system could be completely self contained in the ABM missile. This eliminated the necessity for large and vulnerable ground based detection and guidance radars.

(3) The ability to conduct space operations was greatly improved in the decade from 1972 to 1982. Large geosynchronous satellites were perfected and a broad band space-based communications system was built. Sensors mounted on these satellites now could detect missile launches anywhere in the world and provide the early warning necessary much more effectively than the ground based radars of Nike X-Safeguard-Sentinel.

(4) The development of high intensity lasers and certain high intensity particle beam devices provided the hope that it might become possible to produce what are called "directed energy weapons" that could be used in anti-ballistic missile systems. Several "system" type tests were conducted such as the Airborne Laser Laboratory (ALL) that built technical confidence in directed energy systems.

President Reagan, therefore, could point to technical developments since 1972 which perhaps justified taking a new look at developing strategic defensive systems. In addition to the technical developments that I have described, President Reagan also had some good political reasons for making his strategic defense proposals. In the early 1980's, there were strong movements to "freeze" the development and testing of nuclear weapons. At one point, the U.S. House of Representatives came within one vote of approving such a "freeze." President Reagan felt that he had to guard against the success of the movement to institute a "freeze" and one way to do that would be to start serious work on defensive systems. There is also some reason to believe that President Reagan was influenced by the American Conference of Catholic Bishops which at about this time, issued a draft circular letter which criticized the then current military doctrine of "Mutually Assured Destruction" (MAD). The Bishops made the point that the MAD doctrine condemned people to live in fear forever. This, they claimed was immoral and there is at least some reason to believe that President Reagan agreed with them.

The essential point is that by 1983, there were both technical and political reasons that moved President Reagan to make his speech in which he proposed the "Strategic Defense Initiative" (SDI). Even though the President never mentioned space or space operations in his speech, the press quickly dubbed the program "Star Wars" after a movie that was then at the height of its popularity. After the President delivered his address, a high-level technical committee chaired by former NASA Administrator, Dr. James C. Fletcher, was established to formulate a technical program. The Fletcher Committee reported back early in 1984 with the statement that it would be technically feasible to eventually create a militarily effective ABM system. Although no single "architecture" for the system was proposed at the time, a mixture of space based and ground based systems was suggested.

To manage the technical program, the Strategic Defense Initiative Organization (SDIO) was established in the Department of Defense. The Director of the SDIO reports directly to the Secretary of Defense and all of the programs related to strategic defense were moved from the military services and placed under the direction of the SDIO.

At the same time, work continued on the Safeguard System although at a reduced funding level. The work had to be performed within the constraints of the ABM Treaty that was now in force. In spite of these limitations, much progress was made. One of the objectives of the Army's research was to improve the guidance systems built into ABM missiles in such a way that it would become possible to eliminate the nuclear explosives on the old Sprint and Spartan missiles which were necessary to kill incoming warheads. These were called "kinetic energy kill" weapons which destroyed their targets by actually hitting them directly. In the old Safeguard System there was always something absurd about detonating large numbers of nuclear explosives above your own territory in order to provide a defense against somebody else's nuclear warheads!

During these same years, the U.S. Air Force conducted a similar program to shoot down satellites. An anti-satellite system was conceived and developed in which a small homing vehicle was launched using a rocket carried by an airplane and would home in on and destroy a satellite with a direct hit using no explosive warhead. Eventually, this system called the "Miniature Homing Vehicle" (MHV) was successfully tested.

A third important effort that was carried on during this time was to continue improving air defense systems of various kinds. New surface to air missiles with better sensors were built. The Patriot System fielded by the U.S. Army intended for battlefield anti-aircraft artillery is perhaps the best example. In the late 1970's a decision was taken to upgrade the Patriot System so that it could also be used effectively against ballistic missiles. It is this upgraded Patriot System that was used successfully in the Desert Storm operation in the spring of 1991. I will return to this topic and discuss it more in detail later on.

In the nearly ten years that the SDIO has existed, there have been some major technical successes. One of the interesting features of the program has been that both the traditional ground-based "anti-aircraft artillery" approach and the "global" approach initiated by Christofilos more than thirty years ago have been pursued by the SDIO. Because of President Reagan's emphasis on population protection, "global" systems have tended to dominate the thinking at the SDIO. However, work on many aspects of strategic defense starting with the anti-aircraft artillery problem and the Nike X-Safeguard-Sentinel program has also been incorporated into the program pursued by the SDIO. Therefore, there is a very solid record of achievement in technical terms that can be attributed to the Strategic Defense Initiative since President Reagan made his speech in 1983. I will list the technical achievements which I believe are most important:

(1) The Homing Overlay Experiment and Miniature Homing Vehicles.

These experiments demonstrated that it is possible to build and launch homing vehicles that are capable of directly striking incoming warheads or satellites in earth orbit. In the case of the Homing Overlay Experiment (HOE), a missile fired from the ground destroyed an incoming intercontinental ballistic warhead. This experiment was conducted by the Army in 1984 with a warhead launched at Vandenberg Air Force Base in California and an ABM missile fired from Kwajalein Island (Figure 6). The success of this experiment provided the necessary technical confidence to go ahead with homing vehicle technology. In the case of the Miniature Homing Vehicle (MHV), a small homing device launched from a rocket carried to altitude by an F-15 fighter aircraft, hit and destroyed an earth-orbiting satellite. This experiment also was carried out successfully in 1983. Both of these experiments were started long before the SDIO was established. There is some question, therefore, whether "credit" should go to SDI and opponents of the program have argued that these experiments would have been done in any event, whether SDI as a program existed or not. This is an argument which can go on forever with no useful conclusion in sight. What is important is that the experiments were done and that the technical success provided a strong argument for those of us who believe strategic defense against ballistic missiles is important. Figure 7 shows the Homing Overlay Experiment kill vehicle and some possible future evolutionary steps.

(2) The Upgrade of the Patriot Anti-Aircraft Missile.

The Patriot anti-aircraft missile was originally designed for use against airplanes. It was recognized that it would be possible to upgrade the missile for use against Intermediate Range Ballistic Missiles (IRBM) of relatively low performance by taking some relatively inexpensive steps from a technical viewpoint. This job was undertaken in the early 1980's and when the SDIO was established, the Patriot program was moved to that organization. The upgrade was accomplished by developing better sensing devices, more responsive controls, and more energetic propulsion systems. The use of upgraded Patriot missiles against modified SCUD missiles launched by Iraq during the Gulf War in the spring of 1991 was perhaps the best testimony to the technical success of the Patriot upgrade. While there were still technical problems with the guidance system, particularly with respect to trying to find the right target as the various components of the modified SCUD missiles used by the Iraqis broke up on reentry, there is no doubt that the Patriot missiles demonstrated that it is possible to shut down "bullets with bullets." Furthermore, what was even more important about the Iraqi experience is that this feat can be accomplished by soldiers in the field who are not highly trained scientist or technicians. The successful operation of the Patriot missiles in the Gulf War also provided a major boost for a strategic defense program. A picture of Patriot missiles in action is shown in Figure 8.

(3) Light Exo-Atmospheric Projectiles (LEAP).

In developing the ideas for strategic defense, there has always been a "global" component focused on space-based systems. The concept of choice has come to be a dispersed satellite system which contemplates orbiting several hundred, or even thousands, small but "smart" satellites that could hit ICBMs and IRBMs as they are launched in the boost phase. These so-called "Brilliant Pebbles" would patrol the earth from orbit and would descend to hit missiles that are launched before they could even deploy their warheads. In the last two years, tests of such light exo-atmospheric projectiles (LEAPs) have been conducted. One of them was able to hover above the ground for seventeen seconds, and to demonstrate that the tracking and pointing system mounted on the vehicle worked properly. What is important is that this projectile fully fueled weighted only 22 lbs. The important technical achievement in this case is the miniaturization of the components and the propulsion systems in such a way that very small satellites can perform from the intended function. This experiment is one of the confidence building factors which eventually will lead to the development and hopefully the deployment of something like "Brilliant Pebbles". A picture of the LEAP experiment is shown in Figure 9.

(4) Laser Communications Experiments.

The purpose of this experiment was to show that lasers could be used as communication devices between satellites in earth orbit. In this experiment, a ground-based laser was focused on an object in space and the laser beam was reflected back to the ground to a receiving station elsewhere. The success of this experiment demonstrated that laser communications could be used over very long distances to control large numbers of satellites and to perform the battle management function for such a satellite system.

(5) The Firepond Laser Radar.

One of the most significant experiments in space-based strategic defense related systems was the Firepond system launched early in 1991 on a Delta rocket. In the experiment, a laser was aimed at various vehicles deployed by the payload of the rocket and it was demonstrated that the laser could discriminate between simulated warheads and simulated decoys. The important point about this systems test is that it provides strong evidence that the discrimination problem can eventually be solved using laser radars. Figure 10 shows the arrangement of the Firepond laser radar experiment.

I do not want to imply that this is a complete list of successful systems tests that can be attributed to work done under the Strategic Defense Initiative. What is important is that they are systems tests which go beyond simple concepts and the development of components. It is, of course, systems tests of this kind that will eventually give people the necessary confidence that strategic defense can have important military values. The success of these experiments and many others like them have made it possible to evolve an ABM system architecture such as the one shown in Figure 11. This is a much less complex system than Safeguard was twenty years ago (see Figure 5).

In addition to the systems tests that I have mentioned, there has been much technology development performed under the auspices of the Strategic Defense Initiative Organization. Some of this work has been performed in university laboratories and therefore has contributed to the strengthening of this particular portion of our technical base. Let me briefly mention two programs at institutions of The University of Texas System that have contributed to this kind of technology development. One of the them is an electromagnetic rail gun that has accelerated projectiles to speeds up to 10 kilometers per second. At these kinetic energies, such projectiles are lethal and if electromagnetic guns can be made efficient enough, they may be used both as ground-based or space-based interceptors. These rail guns were constructed at the Center for Electromechanics at The University of Texas at Austin. Another development, this one at The University of Texas at Dallas, was a creation of a new form of carbon, the so-called "diamond film." This development will have many applications, particularly in the manufacturing of micro miniaturized electronic components. The Diamond Film actually came as a by-product of SDIO sponsored work in the area of gamma-ray lasers. These are examples of hundreds of small projects sponsored by the Strategic Defense Initiative Organization programs which serve to strengthen the nation's technical capabilities. A useful compendium of recent experimental results is provided in Ref. 6.

V. Where Do We Go From Here?

I would like to conclude this lecture by making some assessments of where we are and then perhaps some suggestions as to what should be done next in the important area of strategic defense. The first question to ask, of course, is whether we will eventually achieve President Reagan's dream of being able to defend our population centers against nuclear armed ballistic missiles. Will we ever make nuclear weapons "impotent and obsolete"? I believe that the prospects of achieving that objective are real but still far in the future. Developing a defense against thousands of attacking missiles is a formidable technical challenge. Nevertheless, the work I have described has given us confidence that eventually something of this kind can be achieved. However, the Strategic Defense program that has been mounted by the United States has had two important results. One is political and the other is technical and military.

There can be little doubt that the initiation of the strategic defense program by President Reagan was one of the reasons why President Gorbachev and his colleagues in the Soviet Union decided to end the "Cold War". The Reykjavik summit meeting between President Reagan and President Gorbachev in 1986 was probably the decisive event. President Reagan's refusal to bargain away strategic defense for other "benefits" that would accrue from a comprehensive bargain with the then Soviet Union was very probably one of the factors that caused the collapse of the Soviet Union in 1989. Our clear willingness to make the investment in strategic defense demoralized the Soviet leadership and, I believe, that this will be remembered as a major political success of the strategic defense program.

The military success of the upgraded Patriot missiles against the Iraqi SCUDS in the Gulf War and the technical successes of various experiments that have been performed must also be taken into account in planning for the future. There is a changing threat in the world. The Soviet Union even as it is collapsing is still dangerous but the proliferation of nuclear weapons and the means to deliver them to other nations may be a greater threat in the future. The recent example of what the Iraqis were able to do in the development of nuclear explosives and in the production of delivery systems is only one example. Iran, North Korea, Libya, South Africa, Israel, Pakistan and Brazil are all nations that either already possess nuclear weapons or are on the threshold of development nuclear capabilities. All of these nations may eventually be capable of mounting attacks using nuclear weapons on their neighbors and in some cases on the continental United States as well. The failure of our intelligence organizations to pick up what was going on in Iraq should deliver a strong message to the leadership of our military and intelligence organizations. We must at the highest level of priority improve our intelligence gathering and analysis in such a way that we know much more precisely what is going on in the world with respect to development of nuclear weapons and their delivery systems. At the same time, we must restructure our strategic defense program so that in the first instance it can meet a small but determined attack, probably a surprise attack, from a source or a nation that is not now on the "suspect" list of threats. The analysis of these new threats is absolutely essential for the national security (Ref. 7).

Another step that must be taken is to either modify or abrogate the ABM Treaty of 1972. While the missiles that are located in the former Soviet Union are still an important threat, the real threat is now likely to come from people who were never parties to the 1972 ABM Treaty. The United States must be free to build a defensive system against this threat and perhaps design it in such a way that it can defend other nations around the world as well. Developing the means to meet this threat and performing the necessary experiments to create the technical systems requires that the ABM Treaty be modified or abrogated.

In the coming years, defense of the continental United States will become more important that it has been in the past. Both air defense and missile defense will be critical elements of this new military priority. The world situation is developing in such a way that we must once again pay great attention to this problem. There are people all over the world who will have the capability to deploy exceedingly destructive advanced weapons systems. Many of these people nurture an implacable hatred of the United States and of what it stands for. If these people ever come into possession of nuclear weapons and their means of delivery, they will do whatever they can to attack the United States itself. It has been seventy-five years since we have had to be concerned about the defense of our borders. The last time was in 1916 when a fair fraction of the U.S. military was deployed along the Mexican border to deal with incursions by Mexican revolutionaries. The threat is different this time, but it is still a threat to our own borders and the development of highly capable air and missile defense systems is the first important step that must be taken.

The end of the Cold War demands the same kind of disciplined and intellectual attention that von Karman provided in the "Horizon Study" at the end of World War II. We must follow the example that he set and we must be worthy of the legacy that he left to us (Figure 12).

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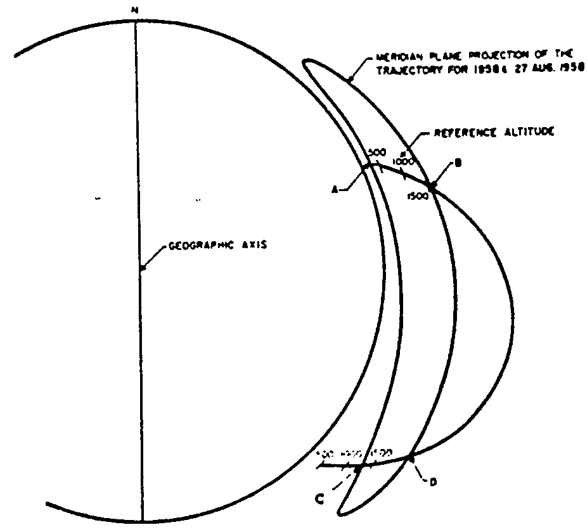
Fig. 1

Second Lieutenant Theodore von Karman in the uniform of the Austro-Hungarian Army circa 1914.



INTERSECTION OF SATELLITE ORBIT WITH A GEOMAGNETIC SHELL

FIG. 3—Illustrative diagram showing sample geometric relationship between the orbit of satellite 1958ε and a chosen magnetic shell at a given longitude.

Close-up of engines and counterrotating propellers of von Kármán helicopter.

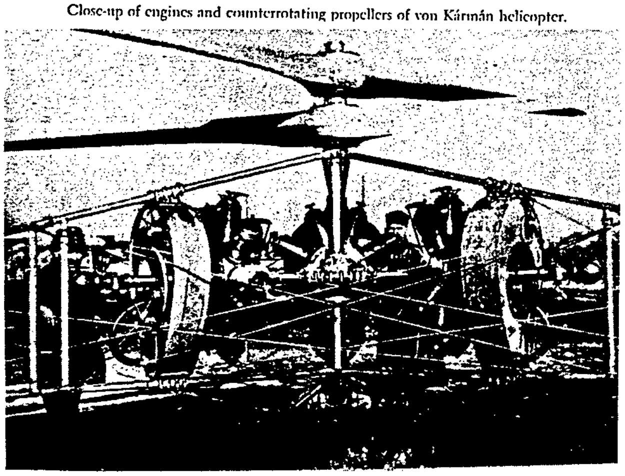
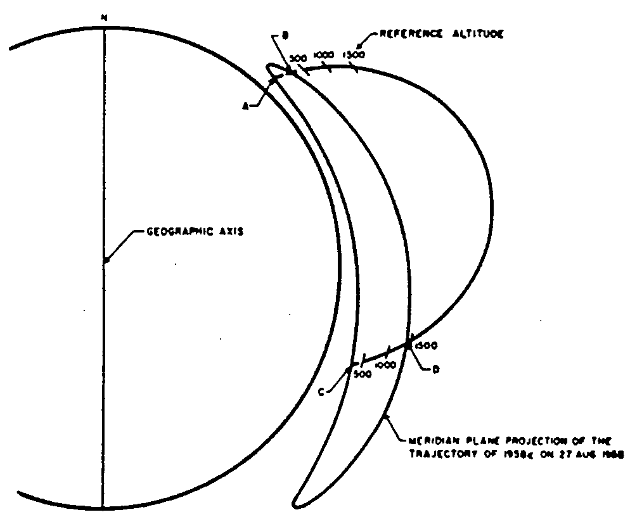


Fig. 2

Von Karman's Helicopter circa 1916.



INTERSECTION OF SATELLITE ORBIT WITH A GEOMAGNETIC SHELL

FIG. 4—Same as Figure 3, except at a different longitude.

Nike X – Sentinel–Safeguard Architecture.

Proposed in 1969.

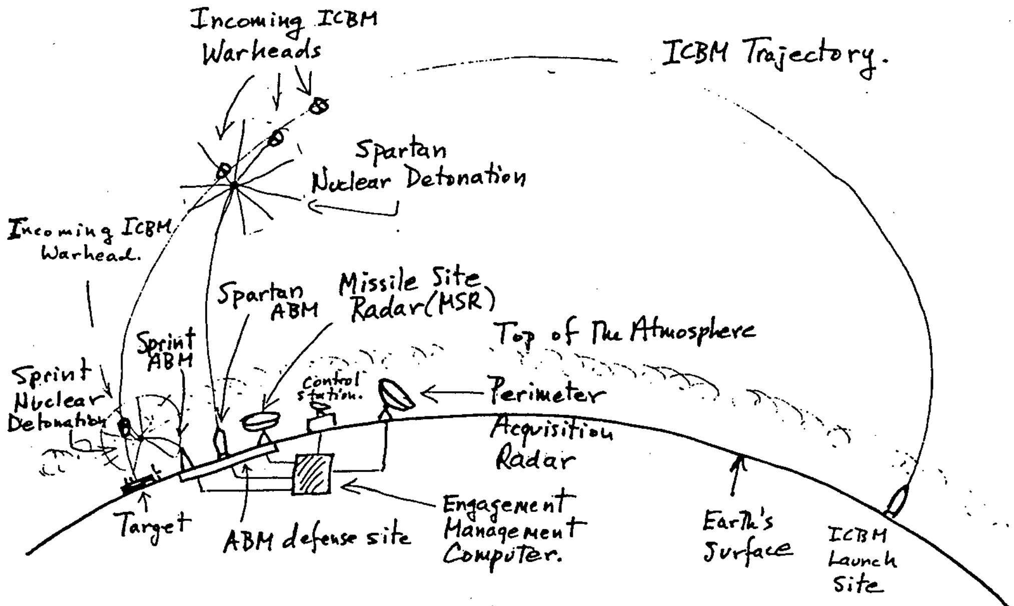


Fig. 5

Drawing Not to Scale.

Architecture of the Safeguard System as proposed in 1969.

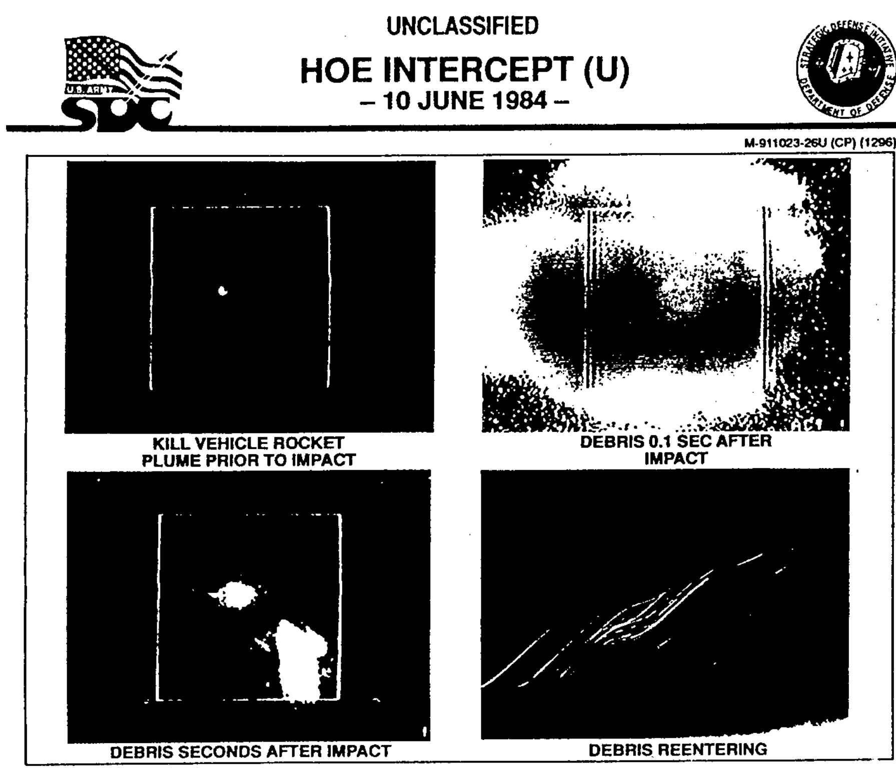


Fig. 6

This picture shows an ABM missile striking an incoming warhead directly during the Homing Overlay Experiment.

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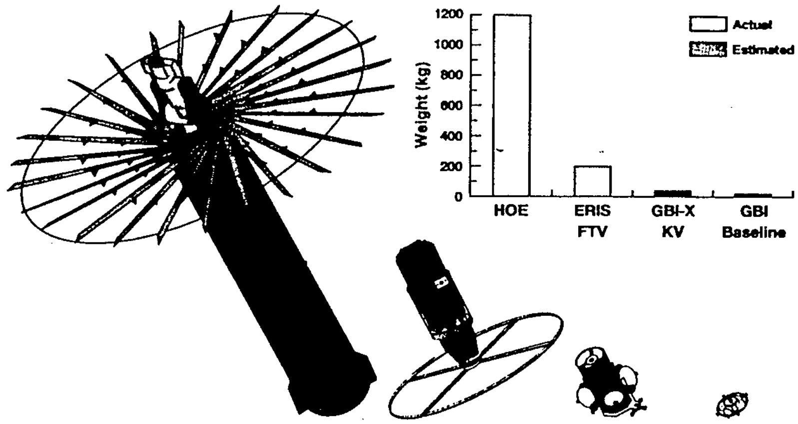
GBI TECHNOLOGY HISTORY



Technology	1978	1986	1990	1994
GBI Evolution	HOE Kill Vehicle	ERIS FTV Kill Vehicle	GBI-X Kill Vehicle	GBI Baseline Kill Vehicle
Proven / Tested	1984	1991	1995	1998

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Fig. 7

The Homing Overlay Experiment kill vehicle is shown in this picture as well as some possible evolutionary future steps.

Fig. 8

The Patriot ABM missile system is shown in this picture.

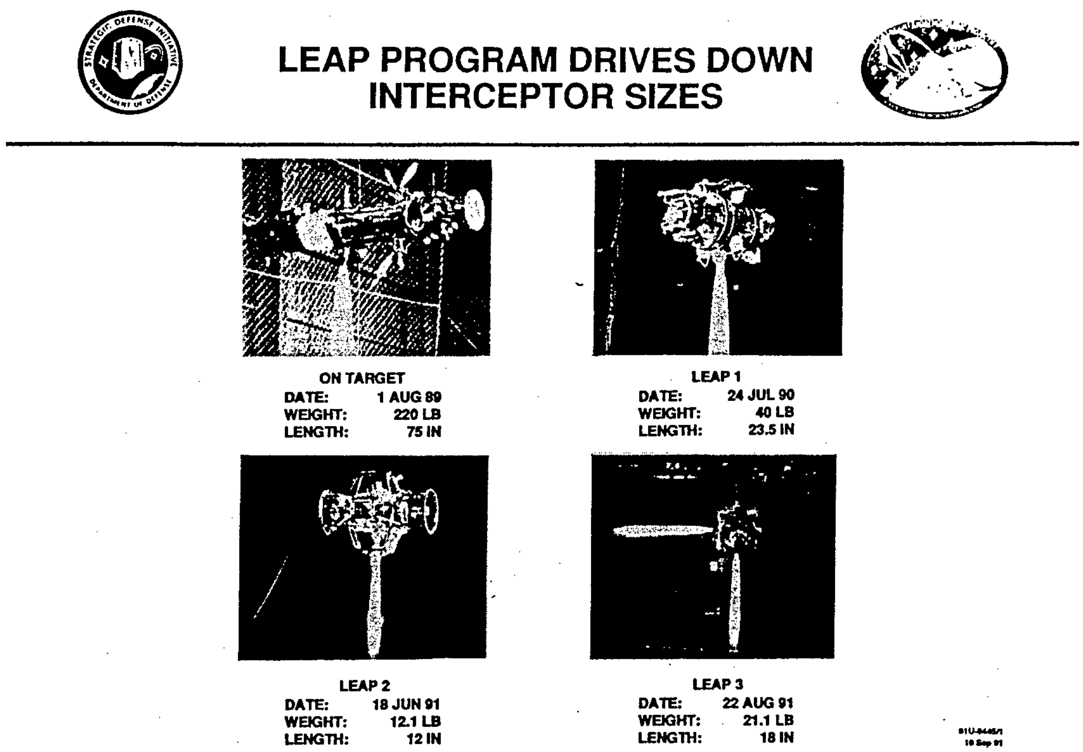

Fig. 9

The LEAP hover and pointing experiment is shown in this picture.

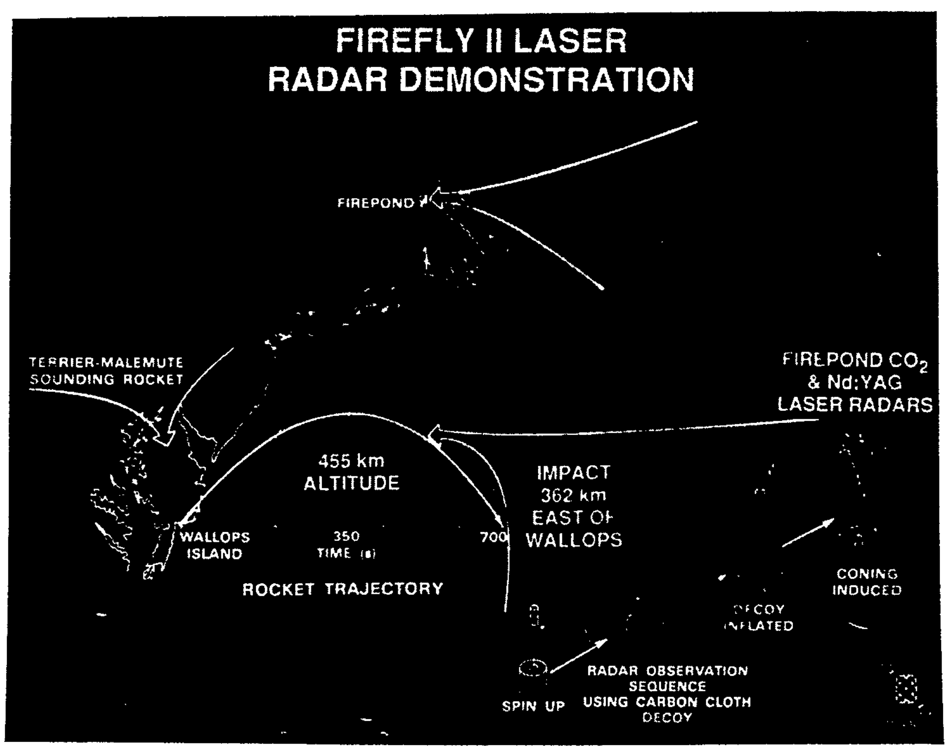

Fig. 10

The Firepond laser radar experiment is shown in this picture.

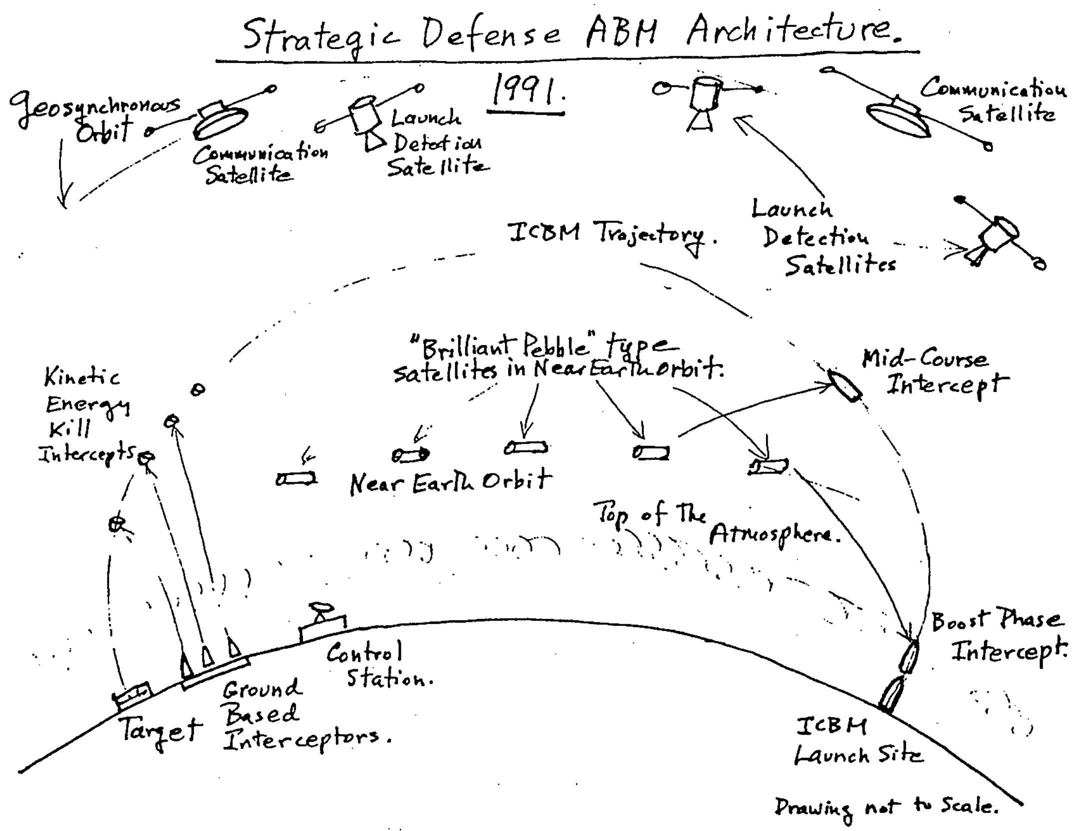

Fig. 11

ABM system architecture as contemplated in 1991.

Fig. 12

Theodore von Karman receiving the National Medal of Science from President John F. Kennedy in 1962.