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WEST FORD COMMUNICATION TECHNIQUES:

Cost, Effectiveness and Potential vs. Competing Systems

13 May 1965

Report of the

Subcommittee on Project West Ford
Defense Science Board

Office of the Director of Defense Research and Engineering
Washington, D. C. 20301

[redacted]

[redacted]

Membership
of
Defense Science Board Subcommittee on Project West Ford

Daniel Alpert, Chairman	Director Coordinated Science Laboratory University of Illinois
Leo Goldberg	Higgins Professor of Astronomy Harvard University
Kenneth M. Watson	Professor of Physics University of California
George L. Salton, Secretary	Office of the Director of Defense Research and Engineering
Duane H. Cooper, Consultant to the Chairman	Coordinated Science Laboratory University of Illinois

[redacted]

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

13 May 1965

TO: THE SECRETARY OF DEFENSE

THROUGH: THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

The Defense Science Board herewith respectfully submits its report on West Ford Communication Techniques. This report is the work of a Subcommittee on Project West Ford that was appointed last December in response to Dr. Brown's request for this study. We trust that it is fully responsive to that request.

The members of the Subcommittee agree unanimously that, in the main, the West Ford type of system for use as a possible backup communication system by the Department of Defense does not compare favorably with the active-satellite communication system that could be placed in operation at comparable cost and in an equivalent time period. This conclusion is stated more fully in section 2 of the report, entitled, "Recommendations"; the discussion leading up to this finding constitutes the bulk of the remainder of the report.

It has been a pleasure for the Board to review this important problem, and we wish to express our appreciation to Dr. Brown and his staff for their fine cooperation in this study.

F. Seitz

Frederick Seitz
Chairman
Defense Science Board

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

12 May 1965

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of Subcommittee on Project West Ford

The Subcommittee on Project West Ford submits herewith its final report on West Ford Communication Techniques.

The Introduction to the report contains a statement of the task with which the Subcommittee was charged and a short account of our activities. Section 2 contains our conclusions and final recommendations, reached after careful weighing of the technical evidence presented to us or available in the literature. The remainder of the report is given over to a discussion and evaluation of the problem and the evidence. The appendices include a copy of the original memorandum from Dr. Brown requesting the study and some additional material inappropriate for inclusion in the text.

We wish to acknowledge the full cooperation extended to us by members of the Lincoln Laboratory and other knowledgeable groups, and by the staff of the Office of the Director of Defense Research and Engineering.

In particular we wish to acknowledge the efforts of Dr. Duane H. Cooper, who served as technical consultant to the Chairman and prepared much of the language of the technical discussion, and those of Mr. George L. Salton who served as our capable and informed staff assistant.

In our opinion, the West Ford test was a good, useful and important experiment—well designed and well conducted—that explored an important area in communications techniques. The experimenters cooperated fully with the scientific community in their evaluation of the implications of the experiment for radio and optical astronomy. The experimenters have cooperated as fully with the Subcommittee in this study.

In submitting the accompanying report, we believe we have completed the task assigned the Subcommittee.

Daniel Alpert, Chairman

Leo Goldberg

Kenneth M. Watson

CONTENTS

1. INTRODUCTION

In response to a memorandum from the Director of Defense Research and Engineering (DDR&E) dated 17 December 1964 (Appendix I), the Defense Science Board established a Subcommittee on Project West Ford, with Dr. Daniel Alpert as Chairman. The Subcommittee was charged with the following task:

> Conduct a study and evaluation of the West Ford system of communication as a possible back-up system for use by the Department of Defense, giving due weight to possible harmful effects of the dipole belt as well as to the cost/effectiveness of the system compared with satellite communication or other systems.

At its two meetings the Subcommittee conferred with representatives of the DDR&E and with other knowledgeable persons to gather information germane to the problem at hand. The reports and presentations of participants in the study are summarized in section 3 of this report. These contributions, along with Subcommittee discussions, conferences between the Chairman and individual members and other selected inquiries, formed the basis of the recommendations set forth in section 2.

2. RECOMMENDATIONS

The Subcommittee examined the relative merits and cost of establishing an orbiting belt of dipoles to serve as a protective backup for the planned satellite communication system and compared them with the advantages of obtaining the desired backup, at a comparable cost, through the incorporation of greater multiplicity and redundancy in the planned satellite system. The conclusion of the Subcommittee is that, unless evidence is brought forward that there is a specific and pressing military requirement laying special emphasis on the relatively small region of operational jamming conditions in which the orbiting dipole belt indicates better performance, such an enhanced repeater-satellite system offers the greater promise as a communications backup.

The Subcommittee therefore recommends that, in the absence of such evidence, no further consideration be given to establishing an orbiting-dipole-belt communication system. Any resources of effort and money that might be expended in that undertaking would be used to better effect in exploiting the inherent potential of communication systems incorporating additional or redundant active repeater satellites.

3. DISCUSSION OF THE PROBLEM

3.1 Background

The development of a scattering dipole belt and associated transmission techniques—later carried out successfully in Project West Ford—was proposed some 5 to 6 years ago, predicated in the technological and operational context then existing. The technological state at that time suggested that special emphasis be given to the use of passive devices placed in orbit with a minimum of launching operations. The initial assumptions were based on the relatively low reliability of rocket launches and the short life of active satellites. The proposed system's operational context indicated special emphasis on very secure, low-capacity point-to-point communication channels, which might require a large investment in fixed terminal equipment.

The situation today is different. One now has more confidence in the reliability of launching vehicles as well as the payload capabilities that may be hypothesized. Also, the present operational context, while not suggesting any softening of prior requirements, does call for more emphasis on higher data rates and on smaller, transportable terminal equipment that would offer flexibility in deployment. Although the smaller terminals may be unable to tolerate the large path losses that the larger terminals could handle, they can nevertheless be expected to provide reasonable information rates when used with the currently projected active satellite systems.

Based on these changes in technological and operational environments, one can foresee that primary reliance in this area may be on a system consisting of a dozen or more simple, active repeater satellites. Indeed, there is now a commitment to place a system called IDCSP (Initial Defense Communication Satellite Project) in operation within the next year. This system can reach the point of usability in far less time than it would take to design and orbit a space segment based on results of the West Ford program. When not being jammed, the active repeaters would provide a much higher data rate and, even in an environment of intense jamming, would be capable of a low-data-rate mode. A more advanced system, the ADCSP (Advanced Defense Communication Satellite Project) is now in the planning stage.

Thus it is quite clear that, because of the time required for its implementation, a system using one or more orbiting dipole belts would either have to compete with the advanced system or be used only as a backup for the active-satellite systems, which are farther along with respect to plans, development and testing.

3.2 Capabilities of Active Repeater Satellites

For the IDCSP system, a dozen or more active repeater satellites would be launched into nearly synchronous orbits. Since a single TITAN III launching could put eight satellites in orbit, one might expect that three launches, with a probability of two successes in three, would make at least 16 satellites available for the system.

Using a bandwidth of some 20 megacycles, these repeater satellites would operate in the neighborhood of 8 kilomegacycles. They would perform frequency translation and amplification for reradiation at power levels of a few watts, but their capability for signal processing would be restricted to hard limiting. Suitable for frequency-shift-coded signals, the satellites could handle only a few carrier signals each — but at a high data rate, about 80,000 bits per second, compared with that of West Ford, which is typically tens or hundreds of bits per second per channel.

Active-repeater-satellite systems now planned or readily foreseen would use terminal equipment similar to, but not identical with, that required for an orbiting dipole-belt system. Antennas would be from 6 to 60 feet in size, and transmitter power would range from 100 down to 2 kilowatts. Terminals employing the smaller antennas, 15 feet or less, could be readily transported; it is expected that 6-foot antennas would be installed on aircraft carriers.

The system of active repeater satellites would be more susceptible to intensive, active electronic countermeasures, i.e., jamming, than one using West Ford techniques. In Appendix II, the two systems are compared with respect to jamming resistance. The indication is that, under an X-band "uplink" jamming attack, the active-satellite systems are clearly superior in data rate for jamming powers up to 250 kilowatts (for 15-foot, 10-kilowatt terminals), the superiority being greater for the larger antennas. The West Ford type of system shows a clear superiority in data rate only in the limited area of even higher jamming powers, e.g., above 1 megawatt for the 15-foot antenna.

Other jamming tactics, such as the placement of mobile (i.e., airborne) jammers to directly incapacitate the receiving terminals and thus mitigate power requirements, are not analyzed here. This "downlink" jamming would require efforts of comparable magnitude for both systems.

The two kinds of communication systems may also be compared in regard to antenna-aiming requirements and continuity of service. The antenna-aiming requirements of West Ford are not more severe than those of a synchronous-satellite system. The active-satellite system considered here, however, would not be synchronous, as it entails a drift rate of about 30 degrees per day—although this is thought close enough to synchronism that there would be little trouble in tracking. With West Ford, no question of continuity of service arises. For the active-satellite system, though, this is an involved statistical problem; it appears that a half-dozen channels could be maintained with 90-percent continuity, together with a comparable number with less continuity, but the expected outages could persist for a few hours.

3.3 Capabilities of West Ford

One of the strongest justifications for a possible system of the West Ford type is that the availability of a nearly invulnerable operational system, even one with a low channel capacity (i.e., for military command and control), would tend to discourage serious attempts to disable the active-satellite system. This being the case, the less vulnerable, low-capacity system could be used in a backup role and to provide a capability which, although offering only a marginal increment, would justify prime reliance upon it in times of extreme emergency. Also in backup status, but of much less strategic significance, would be the HF systems now widely used.

In discussing the West Ford technology, the Subcommittee explored the possibility of withholding the actual deployment of the dipoles until an emergency situation arose. It was thought that a technique could be developed for sowing several dispensers from a parent satellite in a neighboring orbit in such a way that the full belt would be essentially complete in one day. Otherwise, it would be more reasonable to think of a few weeks as the time necessary to fully deploy the dipole belt. These limitations would handicap the system in responding to an unpredicted and rapidly developing emergency.

A more serious handicap foreseen in connection with this idea of adaptive deployment is that our capability for rapidly putting such a system into service would be limited by the absence of realistic operational experience. West Ford terminal equipment is at least as sophisticated as equipment having full antijamming resources, largely because special modulation techniques are needed to cope with the dispersive reflection properties of the dipole belt. Reliable performance in the operation, tuning and maintenance of equipment may be predicated only on the basis of continuing operational experience. Similarly, for personnel used to other procedures, the routine handling of messages routed over low-capacity channels would not go smoothly. In addition, even for experienced personnel, there are special difficulties in the original setup of such a link, for example, the initial inaccuracy of orbital parameters, etc. All these factors suggest that, before it could be considered in operational readiness, a West Ford system must have existed for some time and must have been exercised rather frequently. Thus, adaptive deployment does not appear attractive.

One form of deployment proposed is the establishment of an equatorial belt of copper wires (0.7 inch by 0.7 mil) at a height of two earth radii. The belt would have an in-plane width of a few hundred miles and an out-of-plane width of a few dozen miles. Its density would be a dozen or so wires per cubic mile, representing about one ton of copper deployed in the system.

Taking the dispersive reflection properties of such a belt into account—and if 40 kilowatts of transmitting power were available—a 20-megacycle bandwidth would allow establishing a channel capacity of about 500 bits per second between terminals spaced some 3000 miles apart, using antennas with an aperture of 40 feet and using receiver noise temperatures of 100°K to 200°K. Assuming a jamming antenna of similar aperture size, a jamming power of 40 megawatts per channel would be needed to reduce channel capacity to negligible proportions. Under a wide variety of conditions, the cost of successful jamming may be considered prohibitive, though it may be assumed that antennas of requisite aperture and mounting are already in good supply and widely deployed.

The possibility of direct physical attack on the space components of communication systems was also examined. While an orbiting dipole belt is virtually invulnerable, radiation damage of semiconducting elements in active repeater satellites could leave some permanent effects, including a derangement of the circuits' memory states. The latter might be fixable from the ground, but permanent device damage could be serious.

It was agreed that almost any kill range that could be reasonably postulated for direct physical damage would call for picking off the satellites one by one and so would be prohibitively expensive. Also, by launching such an enterprise, an enemy would be deprived of any surprise value in subsequent hostile actions. In view of these circumstances, the Subcommittee thought it unnecessary to continue with a more precise appraisal of the risk of physical attack on the space components of a communication system.

Considering the survivability of ground installations in the event of a general nuclear attack, it appears likely that the small terminals, which might also be more numerous, would survive. This might include some terminals for use with active repeater satellites, along with the usual HF terminals. A physical attack co-ordinated with an electronic attack, however, would prejudice the effective survivability of the smaller terminals as well.

To make plans ready for an active West Ford communication system, two steps would be required: (1) the development of a specific set of proposals, with cost estimates, and the drawing up of specifications and (2) a significant program to develop a large-scale dispenser unit and improved needles of low reflectivity. Such activities would certainly place the deployment of a West Ford system at a point in time when an advanced active repeater system would be possible.

Finally, if both a dipole-belt system and an active-satellite system were in being, the West Ford installations could share some terminal facilities with the active system. During times when the active system was inoperative, the West Ford system could be exercised for purposes of maintaining equipment and training readiness. In any case, it would be important to exercise the West Ford system frequently, not only for reasons of readiness but because it would otherwise tend to fall into disuse in competition with the higher-data-rate systems. Similar observations apply to the operating modes into which the active system would be forced in the face of jamming.

3.4 Comparison of West Ford and Active-Repeater-Satellite Systems

In order to evaluate the merits of an orbiting-dipole-belt system as a protective backup for the presently planned satellite communication system, it is necessary to estimate the cost of such an undertaking and then to consider alternate solutions to the problem that could be obtained at comparable expense. The cost of developing the space component and terminals, together with the cost of the launchings required to establish the long-life dipole-belt system, is estimated as the "cost equivalent" of three TITAN launches.

Some saving in terminal cost could be obtained by retrofitting already planned terminals. On the other hand, the specification of a dipole-belt system with a limited lifetime would add two more TITAN cost units. Thus, the cost falls in the price range of two to four TITAN launches. It is estimated that, for a corresponding price, the number of active repeater satellites presently planned to be put in orbit could be doubled. Such an enhanced active-repeater-satellite system, through its greater multiplicity and redundancy, would offer an alternate solution to the problem of providing a protective backup for the planned communication system.

It is possible to make a reasonable comparison of the two systems, each specifically considered as a possible backup for the presently planned system. This conclusion was reached despite the fact that there are a few areas in which quantitative appraisals are difficult and the latitude for subjective evaluation is considerable.

The most important of the considerations falling into this category—because of relatively little quantitative data—involve vulnerability to direct attack. With respect to attack on the space component, it seems clearly impossible to physically damage the orbiting dipole belt under any circumstances. In the case of the active repeater satellite, a physical attack would probably be prohibitively expensive—surely it would be if the satellites were destroyed one by one. Thus, short of a new breakthrough in mass attack, the advantage of the West Ford type of system in this respect seems problematic.

Detailed studies regarding physical attack on earthbound facilities were not available, but the advantage, if any, seems to lie with the smaller and more diversified facilities that can be envisioned with a repeater-satellite system and with other, more conventional systems.

The Subcommittee tabulated its comparison of the two potential backup systems in three categories as follows:

(1) Factors definitely favoring a West Ford type of system:

(a) Great cost of a determined electronic attack on uplink
(b) Continuity of service
(c) Tendency of backup status to protect repeater-satellite system from attack

(2) Factors tending to place both systems on an equal footing:

(a) Electronic attack on downlink
(b) Physical attack on downlink (but see item 3g below)
(c) Cost

(3) Factors definitely favoring an enhanced repeater-satellite system:

(a) High data rate (even under jamming attack on uplink, up to about 1 megawatt)
(b) Easily maintained operational experience
(c) Potential for further development
(d) Probability of attaining better performance than presently calculated
(e) Possibility that modification for added redundancy need not involve unusual costs for ground equipment
(f) Smaller terminal equipment, more flexibly deployed
(g) Higher survival potential of small terminal facilities against physical attack

In the foregoing discussion and listing of alternatives, advantages and disadvantages, the following considerations were given greatest weight:

- In favor of the orbiting-dipole-belt system, the strongest technical advantage is its insensitivity to direct jamming attack on the uplink at very high levels of jamming power—more specifically, in the restricted regions of power, as indicated in Figures 1, 2 and 3 (Appendix II). A major weakness of the West Ford type of system is that because of its low-data-rate capability, maintaining operational readiness would be exceedingly difficult.

• In favor of a redundant repeater-satellite system, there are at least three major arguments:

(1) The higher data rates mean not only that the system will be more useful under noncrisis conditions but that this operational experience will be directly applicable in most emergencies.

(2) Whereas the dipole system, in effect, represents a technological dead end, the repeater satellites can be visualized as increasing in sophistication with successive generations. That is, the maximum sophistication to be expected of the orbiting-dipole-belt system has been fairly well established. On the other hand, the development effort invested in later generations of active satellites would not only enhance their own performance but contribute to satellite technology in general.

(3) The terminal equipment for the active-satellite system may be smaller and more flexibly deployed.

4. CONCLUSIONS

It is the opinion of the Subcommittee that, unless evidence is brought forward that there is a specific and pressing military requirement laying special emphasis on the relatively small region of operational jamming conditions in which the orbiting dipole belt indicates better performance, the repeater-satellite system shows the greater promise as a communications backup. For these reasons the Subcommittee recommends that, in the absence of such evidence, no further consideration be given to establishing an operational orbiting-dipole-belt communication system. Efforts that might be expended in such an undertaking would be used to better effect in exploiting the inherent potential of active-repeater-satellite communication systems. Successive launches of future generations of active satellites, in themselves, constitute the ingredients of redundant systems, if the time between launches is less than the mean lifetime of existing satellites.

These conclusions are based solely on the Subcommittee's consideration of military cost/effectiveness and estimated future potential of the systems studied. It is common knowledge that, if it were considered in the best military interests to proceed with the West Ford system, there are certain other important nonmilitary considerations that would have to be taken into account. Those factors relate to the possible effects of an orbiting dipole belt on various space-related scientific investigations and the reaction of individuals and groups in the scientific community. In view of the findings of this Subcommittee, it was not considered relevant to enter into those areas. For the record, a résumé of policy statements relating to that aspect of the problem is presented as Appendix III to this report.

APPENDIX I

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D.C. 20301

17 December 1964

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Defense Science Board Tasks

In accordance with your conversations with Dr. Fubini, I would like the Board to undertake the following task and to report their findings by 1 June 1965:

> Conduct a study and evaluation of the West Ford system of communication as a possible back-up system for use by the Department of Defense, giving due weight to possible harmful effects of the dipole belt as well as to the cost/effectiveness of the system compared with satellite communication or other systems.

I understand that to this end a DSB Subcommittee will be established with Dr. Daniel Alpert as chairman. I would like this subcommittee to review material prepared by the Lincoln Laboratory and staff elements of the Department of Defense, using a full-time staff assistant for this review if necessary.

/s/
Harold Brown

APPENDIX II

Comparison of West Ford vs. Active Satellite Systems in Resistance to Jamming

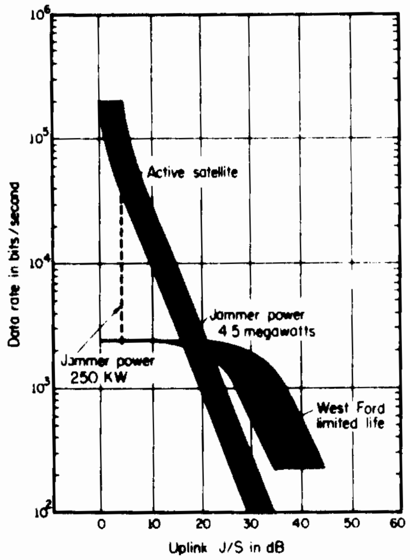

Fig 1 - Fixed terminals (60' antennae, 100 kilowatts)

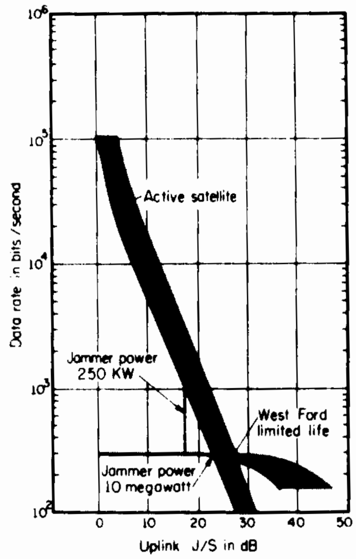

Fig 2 - Transportable terminals (30' antennae, 20 kilowatts)

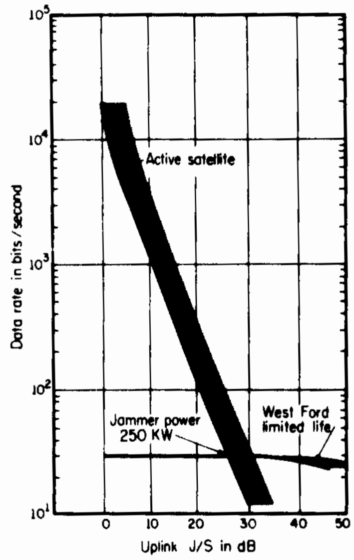

Fig. 3 - Highly transportable terminals (15' antennae, 10 kilowatts)

Figures 1, 2 and 3, which compare the performance of West Ford and the IDCSP under jamming conditions, are based on the following assumptions:

(1) General

(a) All jammers will have a transmitting antenna 60 feet in diameter.
(b) The required probability of bit error is 10^{-5}.
(c) The receiver noise temperature is 100°K.
(d) More sophisticated processing techniques for a system like the IDCSP could impose an extra 5-db loss against the jammer (indicated by shading).
(e) Preprogramed beam slewing along the belt for a system like West Ford could impose an extra 10-db loss against the jammer (indicated by shading).

(2) IDCSP (Initial Defense Communication Satellite Project)

(a) A pseudonoise system of the type now available is used to provide antijam protection. It is assumed that the maximum digital rate of this equipment is extended for purposes of this comparison.
(b) Bandwidth of the pseudonoise system is 10 Mc.
(c) The required E/N_0 = 11.3 db. This includes a 1-db implementation loss.
(d) For 99 percent of the time, C/kT will exceed the value given below:

C/kT = 69.9 db for the 60-foot receiving antenna
C/kT = 64.4 db for the 30-foot receiving antenna
C/kT = 58.4 db for the 15-foot receiving antenna

(3) West Ford

(a) Bandwidth of the system is 20 Mc.

(b) Data rates for the limited-life West Ford system in the absence of jamming are taken from a memorandum, "Operational Dipole Belts," Reiffen to Morrow, dated 17 August 1964.

(c) The required E/N_0 = 13 db (based on "The Lincoln Experimental Terminal Signal Processing System," Drouilhet and Lebow).

(d) The figures give an upper limit to the antijam performance of the West Ford system based on the foregoing considerations.

APPENDIX III

Résumé of Policy Statements on the Effects of a Belt of Orbiting Dipoles on Science

In August 1961, in response to concern expressed by the international scientific community over the possible harmful effects of an operational belt of dipoles, a statement of policy by the U.S. Government, approved by President Kennedy, was released by the Space Science Board of the National Academy of Sciences (Appendix III-A). The policy is, in effect, that no additional dipole belts will be launched subsequent to the West Ford experiment without the provision of necessary safeguards against harmful interference with space activities or with any branch of science. The policy statement also implies—although it does not specifically state—that the scientific community will be given an opportunity to pass judgment upon the possible harmful effects of another dipole belt before it is launched.

Both the International Astronomical Union and the Committee on Space Research (COSPAR) have passed resolutions (Appendixes III-B and III-C) requesting that proposals for future experiments with orbiting dipoles be evaluated in advance by the scientific community in order to check their harmlessness to scientific research.

There has been general agreement that no interference to optical or radio astronomy has resulted from the original West Ford experiment in May 1963. The $2r_e$ belt, however, recently studied by the Lincoln Laboratory as the most economical dipole-belt system, would contain 800 kilograms of dipoles in an orbit of indefinite lifetime. It is difficult to imagine that such a belt would not pose a serious hazard to more than one branch of science; at the very least, the burden would be upon the U.S. Government to prove that there would not be "harmful interference with space activities or with any branch of science."

APPENDIX III-A

THE WHITE HOUSE
Washington

August 11, 1961

Dear Dr. Berkner:

I would like to acknowledge the recommendations and assistance of the Academy's Space Science Board in its studies of the proposed West Ford experiment. In particular, I should like to note with appreciation the consideration given to this topic, at my request, during the last few months as to the effects of the experiment and possible other experiments from the standpoint of science as a whole.

As a result of these technical studies, a statement of policy was prepared by the National Aeronautics and Space Council—a body whose Chairman is the Vice President of the United States and whose members include the Secretary of State, the Secretary of Defense, the Administrator of the National Aeronautics and Space Administration, and the Chairman of the Atomic Energy Commission. This statement, which I believe expresses the interest of all parts of the Government in continued development of basic science, has been approved by the President.

I would be pleased if you would disseminate the statement, a copy of which is enclosed, to members of the scientific community.

Sincerely yours,

/s/ Jerome B. Wiesner

Enclosure

Dr. Lloyd V. Berkner
Chairman, Space Science Board
National Academy of Sciences
Washington 25, D.C.

Enclosure to Appendix III-A

Project West Ford: U.S. Policy

"Project West Ford is a communications experiment designed to place about 75 pounds of hair-like filaments (dipoles) into a short-lived belt around the earth. This project has been planned in such a way that no harmful effects can be expected. It is being performed for the United States Government by the Lincoln Laboratory of the Massachusetts Institute of Technology and is a single experiment for the purpose of:

"a. Investigating the technical feasibility of utilizing orbiting dipoles as passive reflectors for relaying communications; and

"b. Providing an opportunity for an objective assessment of the possible effects of the dipole technique on space activities or on any branch of science.

"The United States Government, in conducting the West Ford Project, will be guided as follows:

"1. No further launches of orbiting dipoles will be planned until after the results of the West Ford experiment have been analyzed and evaluated. The findings and conclusions of foreign and domestic scientists (including the liaison committee of astronomers established by the Space Science Board of the National Academy of Sciences) should be carefully considered in such analysis and evaluation.

"2. Any decision to place additional quantities of dipoles in orbit, subsequent to the West Ford experiment, will be contingent upon the results of the analysis and evaluation and the development of necessary safeguards against harmful interference with space activities or with any branch of science.

"3. Optical and radio-astronomers throughout the world should be invited to cooperate in the West Ford experiment to ascertain the effects of the experimental belt in both the optical and radio parts of the spectrum. To assist in such cooperation, they should be given appropriate information on a timely basis. Scientific data derived from the experiment should be made available to the public as promptly as feasible after the launching."

APPENDIX III-B

Resolution 26: COSPAR position with regard to the Florence Report of its Consultative Group on Potentially Harmful Effects of Space Experiments

The following quotation from COSPAR Information Bulletin No. 20, November 1964, p. 25, is the relevant part of this resolution:

> 3. COSPAR
>
> welcomes the conclusion of the Consultative Group that no interference to optical and/or radio astronomy has resulted from the belt of orbiting dipoles launched in May 1963, and recommends to its Members that any proposals for future experiments of this sort also be given the benefit of thorough evaluation by the scientific community and notably by the International Astronomical Union, in order to check in advance their harmlessness to other scientific research; ...

APPENDIX III-C

INTERNATIONAL ASTRONOMICAL UNION

From: The General Secretary (D. H. Sadler)
International Astronomical Union
Royal Greenwich Observatory
Herstmonceux Castle
Hailsham, Sussex, England

September 1961

To:

At its final session, on Thursday 24 August 1961, the General Assembly of the International Astronomical Union unanimously adopted two Resolutions concerning possible interference with astronomical observations by certain space projects. I am directed formally to bring these Resolutions to your attention, and to request that you use your utmost endeavour to ensure that all Governments comply with the appeal in the final paragraph of Resolution No. 1. Resolution No. 2, which is concerned with a single specific project, is communicated solely for your information.

The English and French texts /the French is not given here/ of the two Resolutions are given on the following pages.

This communication is being addressed to:

(a) Governments, either direct, or through a National Academy of Sciences or other appropriate organization;

(b) the United Nations Organization;

(c) UNESCO;

(d) the International Council of Scientific Unions, its component Scientific Unions, and its Special Committees;

(e) the I. T. U., W. M. O. and other Governmental and Non-Governmental International Organizations.

RESOLUTION NO. 1

Viewing with great concern the grave danger that some future space projects might seriously interfere with astronomical observations in the optical as well as in the radio domain,

and believing that a degree of contamination of space which at the present time would be hardly detectable, might, if long-lived, will be disastrous to future observations with improved techniques,

and maintaining that no group has the right to change the Earth's environment in any significant way without full international study and agreement;

the International Astronomical Union gives clear warning of the grave moral and material consequences which would stem from a disregard of the future of astronomical progress,

and appeals to all Governments concerned with launching space experiments which could possibly affect astronomical research to consult with the International Astronomical Union before undertaking such experiments and to refrain from launching until it is established beyond doubt that no damage will be done to astronomical research.