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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROBLEMS OF AIR DEFENSE

Final Report
of
PROJECT CHARLES

VOLUME I
of
Three Volumes

1 August 1951

Contract No. DA36-039sc-5450

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CAMBRIDGE MASSACHUSETTS

SECURITY INFORMATION

LETTER OF TRANSMITTAL

TO

CHIEF OF STAFF, U.S. ARMY
CHIEF OF NAVAL OPERATIONS
CHIEF OF STAFF, U.S. AIR FORCE

1 August 1951

To:

The Chief of Staff, U.S. Army
The Chief of Naval Operations
The Chief of Staff, U.S. Air Force

The task of PROJECT CHARLES has been to study air defense. In the four months available to us, we have found it necessary to limit ourselves to specific subjects within this very large field. Our primary concern has been with the air defense of the continental United States, with only occasional attention to the protection of overseas areas and of naval task forces. While the group represented experience in many fields of science and engineering, the dominant background was electronics, and our Report reflects a major interest in problems of detection and control.

A strong air defense system is costly in men as well as in dollars, but it is a necessary element of our military strength. It is easy to assert that the United States cannot long engage in warfare without protecting its vital industrial and military installations. It is much more difficult to state how much protection will be obtained at a given level of expenditure. We do not believe that the results of future air warfare are quantitatively predictable. The problem, as we see it, is to develop the best system of air defense that the country can provide with the funds available. Within such limits, great improvements are feasible by correcting known weaknesses and exploiting technological advances.

We are unable to point to any new invention, comparable with radar, that would provide a simple solution to the air defense problem. Indeed, the virtues of radar, which contributed immensely to air defense in World War II, have been rather thoroughly exploited, and much of the development effort must now be devoted to making up for its intrinsic weaknesses in low cover and in identification. Infrared techniques have great possibilities, especially for terminal guidance of air-to-air missiles; past difficulties have often been the consequence of unrealistic demands. Guided missiles will not be fully operational for many years. Their tactical role can be fully determined only after their technical capabilities have been demonstrated. Long-range surface-to-air missiles will

not become reliable area defense weapons until it is possible for field commanders to have a choice between several alternative tactics and guidance systems.

Our restrained views regarding any spectacular solution of the air defense problem are counterbalanced by considerable optimism about the contributions to air defense that will be made by new basic technology. We think the electronic high-speed digital computer will have an important place in air defense, and the revolution that the transistor will bring about in electronics will open up quite new possibilities in aircraft and weapons control.

The situation to be feared more than any other in air defense is loss of knowledge and command of events as they occur in the air. Without complete, accurate, and up-to-date knowledge of the air situation and adequate control capacity, the weapons of our air defense system are substantially useless. A competent aircraft control and warning network must therefore be established and maintained even if its cost is a significant fraction of the entire air defense system.

The severest test of such a network, and indeed of our entire air defense system, is a surprise attack. We do not consider it technically feasible to provide unequivocal warning of all possible attacks in time to ground all friendly air traffic. Without such warning, the enemy can take advantage of the present deficiencies of our detection and identification procedures to mask his presence in the general confusion of routine friendly traffic, and proceed without effective opposition to his target. The present chaos of unidentified flights must and can be ended by tightening our operational procedures, civil as well as military. All aircraft crossing the defense perimeter must be regarded as dangerous; friendly aircraft should be permitted to proceed to critical target areas only after successful identification and explicit clearance. Rigorous enforcement of such rules would give the air defense forces at all times the freedom they need to inflict upon enemy bombers the strongest action of which our weapons are capable.

We feel that the principal difficulty now faced in air defense operations lies in the complex and difficult problems of air surveillance and control, and we feel it is in this area that large increases in effectiveness can be obtained

by a comparatively modest investment in money and manpower. To this end, the Report has proposed a short-term and a long-term program.

The Project feels that a short-term program cannot include any new complicated and elaborate electronic devices. We are much impressed with the great increase in capacity and efficiency to be gained by the introduction into present systems of photographic presentation and of existing methods of rapid remote display by facsimile and teleregister techniques. We recommend that these techniques be combined in a limited modification of the radar stations, and we plan to demonstrate this modification at the station in North Truro, Massachusetts.

There remains, however, the very real danger that the system will not have sufficient tracking capacity for a heavy raid. Once the system becomes saturated, close control of interception will be impossible. To avoid complete paralysis of the interceptor force, plans should be made to use "broadcast control" as an emergency alternative. This method requires the use of a navigation aid by the interceptor. This cannot be a navigation aid requiring the ground facilities of the "common system" for navigation of civil and nontactical military aircraft; for the present plan, which we consider sound, is to turn off these ground facilities during a raid. Unless a clear and irrevocable national decision were to be made now to leave on the "common system" ground facilities at all times, the interceptors must have independent navigation aids. We recommend an immediate program to provide such equipment to the interceptor force.

A dangerous feature of the present system is its insufficient offshore radar coverage in the vicinity of certain vital targets. This situation prevents the effective use of interceptors against overwater attacks. The Project believes that five picket vessels are immediately required to be continuously on-station in these areas.

Another dangerous feature of the present network and one most difficult to correct is its poor performance against aircraft at low altitudes. At present, the only available method for the detection of low-altitude attack is the use of ground observers. The potential value of a ground observer system is very great, but the present U.S. Ground Observer Corps is handicapped by poor

organization and inadequate equipment. It will take a major effort to make the Ground Observer Corps effective, but we believe it can be done. We recommend establishing a model ground observer system in a selected area.

Looking beyond the immediate difficulties of the warning and control system, we have re-examined the fundamental requirements of such systems and have concluded that great advances in speed and traffic capacity are possible by modifying the organizational and technical structure. We endorse the concept of a centralized system as proposed by the Air Defense Systems Engineering Committee, and we agree that the central coordinating apparatus of this system should be a high-speed electronic digital computer. A system of this general type provides a logical answer not only to the problem of combining the information from many sources, including small and closely spaced radars with good performance against aircraft at low altitudes, but also to the need for extreme speed in directing weapons against the fast targets of the future. To evaluate this concept and demonstrate the performance of such a system, we plan to construct a model system in Eastern Massachusetts with a number of small radars and a central computer.

Among the weapons currently under consideration for air defense we regard the interceptor as the weapon most vital to our immediate needs. It is the most formidable and the most versatile solution to the problem of defense in depth.

Plans for the future interceptor force of the United States are directed toward a single-place all-weather aircraft. While we recommend research and development toward this goal, we believe that only a modest part of the program for continental and overseas defense should be committed to the single-place all-weather concept until it has been thoroughly evaluated in operational trials. Meanwhile, there should be further work on improving the performance of single-place day interceptors, especially for use overseas, and of two-place all-weather interceptors.

The present armament of our interceptors does not give them a sufficiently high single-pass kill probability against bombers. We recommend immediate efforts to install 20-mm rapid-fire cannon in current interceptors, and accelerated development of guns of larger calibers. Rocket weapons show

great promise of more lethal interceptor performance in the near future, and research, development and evaluation of rocket systems should be intensified while work on air-to-air guided missiles continues as a long-term program.

Antiaircraft guns and ground-to-air rockets should be viewed as effective weapons only against attacks at low to medium altitudes. Uncertainties in predicting the future position of fast aircraft, even without deliberate evasive action, indicate that the proper field of usefulness of these weapons is at times of flight shorter than about ten seconds.

Against aircraft flying at very low altitudes, our present ground-to-air weapons are inadequate. For local defense against attacks below 1500 feet we advocate the development of a special weapon (PORCUPINE). This will fire a salvo of about 100 rockets at a time computed for maximum kill probability. A simple radar of novel design will alert the system, and visual or infrared tracking will supplement the data furnished by the radar.

With the technical improvements that have been outlined, the warning, control, and weapons systems can be expected to inflict heavy damage on an enemy bombing force attacking the United States. However, we do not believe that any foreseeable air defense system will achieve total annihilation of the attacking force. With atomic bombs, the residual threat to our cities and our other targets is sufficiently severe to justify passive measures that will further reduce our losses. We recommend measures to achieve a gradual dispersal of industry by placing new construction at least ten miles away from existing plants, and an adequate shelter and warning policy for the reduction of urban casualties.

While our survey of the air defense system has been almost entirely concerned with its technical aspects, we have not remained unaware of the formidable problems of organization and manpower that must be solved before any system can become fully effective. The organization required for air defense extends across so many traditionally independent units that weakness across boundaries of responsibility is a very real danger. Such boundaries occur, for example, between U.S. forces and other NATO nations in the defense of our military establishments overseas, between Canada and the United States in the defense of the North American continent, between Air Force and

Navy in the surveillance of offshore areas, and between Federal and state agencies in the management of civil defense. Smooth operation across these boundaries in an emergency can be ensured only by making plans in advance, and by testing these plans in realistic joint exercises.

The cost of defense in manpower may be a more important ultimate limitation than its cost in dollars. We suggest extensive utilization of civilian manpower and resources to supplement the military personnel in the air defense system. Above all, this will release combat personnel for offensive warfare.

The formal report of PROJECT CHARLES, which is transmitted with this letter, contains detailed discussions of these and other subjects related to air defense. Experimental work on certain of these problems is planned in a laboratory to be operated by the Massachusetts Institute of Technology jointly for the Army, the Navy, and the Air Force, to be known as PROJECT LINCOLN.

Sincerely,

(Signed) F. W. Loomis
Director,
PROJECT CHARLES

Cambridge, Massachusetts
1 August 1951

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PREFACE

For the first time in its history, as a consequence of the atomic explosion in the Soviet Union, the United States is confronted with a really serious threat of a devastating attack by a foreign power. This new danger has necessitated major changes in the scale and methods for the defense of this country, particularly on the part of the Air Force which has the primary responsibility for defense against air attack.

Since air defense requires a variety of complex technical devices, such as radar, radio, interceptors and weapons, which are required to operate quickly and yet as parts of a highly integrated system, the technical problems involved in planning an effective system of air defense and in designing the components thereof are formidable indeed.

As one part of the processes of planning and development, and as an extension and implementation of the studies of the Air Defense Systems Engineering Committee (ADSEC, Professor G. E. Valley of MIT, Chairman), General Vandenberg, by letter of 15 December 1950 to President Killian of MIT, requested that MIT undertake a major project on air defense problems.

In response to this request, and with the scope somewhat broadened in recognition of the considerable responsibilities of the Army and Navy for air defense, and also of the importance of air defense for our military forces outside the United States, the following mode of operation evolved. It consisted, for administrative reasons, of three somewhat separate phases.

Phase I, known as PROJECT CHARLES, was a study project. Its formal statement of work was as follows:

> "PROJECT CHARLES, jointly sponsored by the Army, Navy and Air Force, shall investigate the general problem of defense against air attack. Special attention shall be given to the defense of continental North America, but the Project shall not be limited to this problem.
>
> "The Project will have the full cooperation and support of the Air Force, Navy and Army and other agencies of the Department of Defense, and full access to all necessary information."

Without awaiting the completion of PROJECT CHARLES, MIT undertook to continue and expand those activities of its Research Laboratory of Electronics that originated in the ADSEC studies and are directed toward experimental

solutions of air defense problems. This interim operation, called Phase II, ran concurrently with PROJECT CHARLES, and is to continue until superseded by Phase III.

Phase III will be a program of research and development, operated as PROJECT LINCOLN by MIT jointly for the Army, the Navy and the Air Force. The primary mission of the project will be Air Defense. The laboratory facility will be provided by the Air Force within a research center which is to be established near Bedford, Massachusetts.

PROJECT CHARLES was jointly supported by the three Services through a Signal Corps contract (DA36-039sc-5450) and formally supervised by a policy committee consisting of Dr. I. A. Getting of the Air Force (Chairman), Brigadier General S. R. Mickelsen of the Army, and Rear Admiral C. F. Coe of the Navy.

Dr. F. W. Loomis, Head of the Department of Physics at the University of Illinois, served as Director of PROJECT CHARLES. The study group consisted of 28 scientists and engineers; 11 of these were from MIT, the remainder from other institutions, both academic and industrial (see p. xxi). Some members of the staff served on a full-time basis, others assumed responsibilities of varying duration. In addition, the Project has been assisted by a group of consultants and specialists in particular areas.

Of particular importance to the Project was a group of liaison officers who not only made military information accessible to the Project, but displayed great initiative in participating in many of the group's discussions, so that the present report reflects to a considerable degree their experience with the realities of air defense. A complete list of consultants, liaison personnel, and administrative staff is given in Appendix P-1.

PROJECT CHARLES began its study of the air defense problem in February, 1951 with an intensive briefing that lasted one month (see Appendix P-2). The briefing period included lectures and discussions on policy, general systems, individual components, and specific areas of interest of the Army, Navy and Air Force. Field visits to various installations and laboratories allowed the group to witness demonstrations of systems and equipments, countermeasures, missiles, etc.

Following the briefing sessions, the Project membership was divided into four major working groups:

Committee A (Prof. G. E. Valley, Chairman),
Aircraft Control and Warning: Long-Term Program;

Committee B (Prof. J. C. Street, Chairman),
Aircraft Control and Warning: Early Improvements;

Committee C (Prof. J. R. Zacharias, Chairman),
Passive Defense;

Committee D (Prof. G. S. Brown, Chairman),
Air Defense Weapons.

While the scope of PROJECT CHARLES included air defense of naval task forces and military installations overseas as well as air defense of the continental United States, it soon became apparent that air defense in its most comprehensive terms was too broad a subject for a group of this size within so short a time span. Thus, while certain phases of the Project's investigation have necessarily involved scrutiny of such areas as Fleet problems and air defense of forward bases, the major emphasis of the study has been on defense of the continental United States against air attack.

Even within this narrower field, the attention of the study group had to be concentrated on specific subjects, while others had to be neglected. For example, defensive measures against air attack with biological warfare agents have not been considered; in active defense, where the prime objective is destruction of enemy aircraft regardless of cargo, this may be a less serious omission than in passive defense, where biological attack may require techniques quite different from those applicable to atomic attack. It should not be inferred that a subject not covered by PROJECT CHARLES was considered unimportant; the limitations of time and membership simply necessitated a somewhat arbitrary selection of subjects for detailed study.

The committee organization of PROJECT CHARLES is reflected in the structure of the report presented by the group. A review of the problem of air defense is presented in Section I. Section II deals with the special problems involved in meeting a surprise attack, and is closely related to Section III which discusses early improvements feasible in the aircraft control and warning system. Sections II and III comprise the report of Committee B,

which was appropriately nicknamed the "Quick Fix" Committee. The long-term approach to improvements in control and warning was studied by Committee A, whose report is given in Section IV. The weapons involved in an air defense system are surveyed in Section V which represents the conclusions of Committee D. This is followed by briefer sections on electronic warfare, and on passive defense (Committee C). These reports are supplemented by Appendices in which special subjects are treated in more detail than seemed appropriate for the main presentation. The principal findings of each committee have been abstracted and are presented in a preliminary section, SUMMARY OF MAJOR CONCLUSIONS (p. xxiv).

The conclusions of the working committees were reviewed with the entire Project in a number of general meetings and in many instances modified as a result of such discussion. The final conclusions thus represent a fair consensus of the entire group. Preliminary oral presentations of these conclusions were given to representatives of the sponsoring agencies on 18 June and 21 June in Cambridge, and on 28 June 1951 in Washington.

Few, if any, of the ideas embodied in this report will be found new or original. The Project is indebted to so many sources and authorities that individual acknowledgment has not been practical. The friendly and close collaboration of officers from different Services and countries with a group of civilian scientists and engineers has been an experience that will long be remembered with pleasure by all members of the group.

It is the hope of PROJECT CHARLES that its conclusions will be helpful in guiding research and development effort in the field of air defense, and that its report will thus contribute toward greater strength in our country's defense against air attack.

PROJECT CHARLES STUDY GROUP

Prof. F. W. Loomis, Director
University of Illinois

Prof. Gordon S. Brown	Massachusetts Institute of Technology
Dr. George C. Comstock	Airborne Instrument Laboratories
Mr. Gordon C. Dewey	Weapons Systems Evaluation Group
Mr. D. E. Dustin	Research and Development Board
Mr. Jay W. Forrester	Massachusetts Institute of Technology
Prof. Kenneth I. Greisen	Cornell University
Mr. David S. Grey	Polaroid Corporation
Miss R. Joyce Harman	Massachusetts Institute of Technology
Prof. William R. Hawthorne	Massachusetts Institute of Technology
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Dr. H. M. Mott-Smith	Atomic Energy Commission
Dr. Harry Nyquist	Bell Telephone Laboratories
Dr. Carl F. J. Overhage	Eastman Kodak Company
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Prof. H. Guyford Stever	Massachusetts Institute of Technology
Prof. Jabez Curry Street	Harvard University
Prof. George E. Valley, Jr.	Massachusetts Institute of Technology
Prof. S. N. Van Voorhis	University of Rochester
Mr. William Weems	Massachusetts Institute of Technology
Mr. Vernon C. Westcott	Trans-Sonics, Incorporated
Prof. Jerrold R. Zacharias	Massachusetts Institute of Technology

SUMMARY OF MAJOR CONCLUSIONS

MEETING A SURPRISE ATTACK

Problem

The air defense system of the continental United States is highly vulnerable to an initial surprise attack. In the confusion caused by routine friendly traffic, and under present operational procedures, it is possible that the attack would be undetected and unopposed until after bomb release.

Identification

Positive identification of all aircraft crossing the defense perimeter is a fundamental requirement of air defense. Primary reliance must be on procedural doctrine rather than apparatus, which calls for:

(1) Automatic diversion away from critical target areas of all friendly flights except those identified and given specific clearance;

(2) Improved navigation facilities for friendly aircraft;

(3) The allocation of an air defense communication frequency to aid in identification and clearance.

Early Warning

A few hours' early warning will greatly improve the effectiveness of the air defense system because:

(1) The readiness of interceptors and ground weapons can be stepped up, and patrol activities intensified;

(2) Strategic Air Command strike aircraft can be dispersed;

(3) Civil air traffic can be diverted from critical areas;

(4) Wartime rules of engagement can be established;

(5) Prearranged plans for ground observers, for electromagnetic-radiation control, and for civil defense can be executed.

Remote Radars

It is not feasible to provide an ideal early-warning system that gives unequivocal warning of all possible attacks. A less-than-ideal but valuable system that has a fair probability of detecting likely forms of enemy attack is recommended; this requires augmentation of the facilities now planned or proposed by:

(1) Two picket-vessel stations southeast of Newfoundland,

(2) Two long-range airborne early-warning squadrons, one in Iceland and one in Alaska.

Present plans for the Canadian stations contiguous to our border and for the Alaskas stations should be strongly supported, as should be the ground observers in Northwestern Canada. No stations are recommended for the Aleutian Islands.

AIRCRAFT CONTROL AND WARNING: EARLY IMPROVEMENTS

Extension of Radar Cover

In several important coastal regions, present U.S. shore-based radars fail to provide sufficient cover. Extended coverage at the perimeter will greatly improve the warning system by allowing more time for interception and by making it possible to use better identification procedures.

Three picket-vessel stations off the East Coast and two off the West Coast should be established at the earliest possible time. Two additional ground radars are recommended in the Northwest.

Data Processing

Better data-processing techniques including better communications appear to be essential to the early improvement of the existing aircraft control and warning system. The low traffic capacity of manual plotting by voice telling can be overcome by the use of photographic procedures logically fitted into the system as a whole.

Transmission of clear air-situation data from GCI station to Air Defense Control Center could be improved by facsimile methods already developed.

Ground-Weapons Control

Local antiaircraft defenses can be more effective if the AA operations room is made part of the GCI station.

The AA controllers at the GCI station should have their own PPI presentations to direct the acquisition of targets by the batteries' fire-control radar. This procedure should be introduced now so that it can be fully operational when more effective local defense weapons become available.

Fleet Problems

To overcome current difficulties in picket-to-main force data transmission, the Navy should pursue the development of a narrow-band, high information-efficiency data-transmission system capable of early application in the Fleet.

The capacity and clarity of the data-reporting system used in naval Combat Information Centers should be improved by adaptation of the photographic techniques and physical rearrangements recommended for land-based radar stations.

Control of Interceptors

Saturation of the Aircraft Control and Warning system may prevent control of interceptors by the present "close control" method. As an emergency alternative, "broadcast control" operation should be planned, and interceptors should be equipped with the necessary navigational aids, as discussed in Section V.

Ground Observers

The inherent value of a ground observer system is very great, and for low-altitude cover there is no alternative now or in the near future. The present Ground Observer Corps in the United States is not organized or equipped in such a way as to permit it to be effective.

Given a determination to succeed, and a willingness to pay the necessary costs, an effective Ground Observer Corps is possible. We recommend that such a Corps be established in a selected area.

AIRCRAFT CONTROL AND WARNING: LONG-TERM PROGRAM

Current Projects

Consolidation

Integrated AC&W systems are currently under development in four major projects sponsored by the National Military Establishment: U.S. adaptations (USN and USAF) of the British CDS, BOMARC Test Phase (USAF), Project 414A, etc., SYSNET (USA), Ground Reporting System (USAF).

All these programs should be consolidated under a single management to work toward a single integrated system.

Future Aircraft Detection Apparatus

Low Cover Over Land

The detection of aircraft flying at low altitudes over land can best be achieved by the use of relatively small radars, relatively closely spaced, and mounted close to the earth's surface.

Offshore Cover

Satisfactorily uniform and reliable offshore coverage can be obtained from a network consisting of pairs of blimps and picket ships anchored about 100 miles offshore.

The Department of Defense should initiate a study of the operational problems involved in the use of blimps, and should determine the most suitable hull for radar picket ships used to provide offshore radar coverage.

Future Centralized AC&W System

Information and Control Center

The Information and Control Center of a centralized AC&W system should be able to correlate information from all sources, of which the radar network is only one. It must keep track of all aircraft in the air space under its supervision. It should be able to put all defense weapons on-target.

Digital Computer

The coordinating apparatus of a centralized system should be a general-purpose, high-speed electronic digital computer.

Identification

As much as possible of the identification function should be performed automatically, leaving only the doubtful cases to be judged by a man. Future centralized AC&W systems in conjunction with improved operational procedures should permit identification by machine in most cases.

Time Scale

A full-scale centralized system covering approximately the area of a present Air Division can be installed before the end of 1956.

Peacetime Operation

Since the air defense system should be kept in top operating condition and ready for action at any time, the centralized AC&W system should be kept in continuous operation to observe and provide information on civilian air traffic.

Implementation

"Cape Cod" Model System

For early operational evaluation of the centralized-system concept, an experimental AC&W network of this type should be established in Eastern Massachusetts by connecting between 10 and 15 radars and height finders to the WHIRLWIND digital computer at MIT.

Computer Design

Based on experience with WHIRLWIND and other electronic computers, and on the results of the Cape Cod experiments, a new digital computer should be designed with special features uniquely suited to the air defense problem.

AIR DEFENSE WEAPONS

Interceptor Aircraft

USAF Program

The selection of interceptor types for service in Air Defense Command and in the tactical air forces, and the program for improving their performance capabilities during the next two years, appear reasonable in view of present technical limitations.

Interceptors scheduled to be in service in Spring 1953 are not capable of much further major development and will be inadequate to counter the threat expected by 1956.

In overseas areas, high-performance enemy aircraft will be encountered earlier than in the United States. For air defense overseas the USAF should plan forces that include the most advanced day-interceptor tactical-fighter types.

Single-Place All-Weather Concept

Single-place all-weather interceptors play important roles in the USAF and USN aircraft programs. The operational soundness of the single-place all-weather concept should be evaluated by exhaustive trials at the earliest possible date.

Power Plants

Turbojet power plants with afterburning are indicated for the propulsion of transonic or moderately supersonic aircraft in the future. High-altitude high-speed afterburner operation urgently requires further development work; this should be supported by making suitable test facilities available to contractors.

MX 1554

The MX 1554 program depends on the successful accomplishment of major technical advances. Delays should be expected in this program, and at least two designs should be carried to the prototype stage and flown.

Improvement of Existing Types

In view of the advanced character of the MX 1554 program, we recommend that the Air Force insure its interim interceptor program by obtaining the maximum possible improvements in the speed, rate of climb, and control characteristics of carefully selected existing interceptor types. These should include a two-place all-weather interceptor.

Air Refueling

At least a proportion of the land-based interceptor force should be equipped to permit air refueling, and a suitable number of air tankers should be provided.

Unorthodox Aircraft

Unconventional interceptor designs may offer important advantages in special situations. We recommend close attention to developments in rammers, rocket-driven interceptors, vertical take-off, and interceptors without undercarriages. Particular emphasis should be given to the development of low-altitude interceptors.

Airborne Fire-Control Equipment

AI Radar

For two-place interceptors, the search and fire-control functions of the AI radar set should be separated as much as vehicle limitations will permit. This will optimize radar performance, help defeat jamming, and give the pilot fire control during combat while search continues independently.

In single-place interceptors, set operation must be made as simple as possible, and the search and fire-control functions may have to be combined. The radio frequency should be chosen to enhance the firing accuracy at the expense of search coverage.

Predicted Flight Ordnance for Interceptors

Aircraft Guns

Continued development of aircraft guns is essential and should be concentrated on 20-mm and larger calibers. A fresh effort should be made to equip current fighters with the best available 20-mm rapid-fire cannon. Future aircraft should permit interchangeable installation of guns, rockets, and guided missiles.

Gun-Line Control

Limited automatic vernier control of the gun line should be studied as a means of decreasing the large aiming errors in the present fire-control system.

Aircraft Rockets

Rocket weapons show great promise of more lethal interceptor performance in the near future. Research, development, and evaluation of rocket systems should be intensified, with particular stress on problems of ballistics and installation, and on the selection of optimum sizes.

Evaluation and Training

Obtaining good assessment of the relative effectiveness of various weapons is an urgent problem. Greater attention should also be given to gunnery ability in the selection and training of pilots. Both for weapons evaluation and for pilot training, fast high-altitude targets should be provided that match existing and potential enemy aircraft.

Engineering Resources	Air ordnance in the United States does not command a research, development, and design effort commensurate with its importance. More incentive should be given to civilian talent in American industry to work aggressively in this field.

Air-to-Air Guided Missiles

Development Program	Air-to-air guided missiles are potentially the most effective armament for interceptors, and the development of both small and large missiles should be vigorously pursued. The operation of guidance and control systems at low altitudes demands close attention, and the possibilities of passive infrared terminal guidance should be explored.

Navigation Aids

Status	Neither the Air Force nor the Navy has at present, or will have within three years, a navigation aid satisfying all the needs of all-weather interceptors in air defense operations.
Self-Contained Systems	The future aids that best fulfill Air Force tactical requirements are "Doppler" and "inertial" navigation systems that require no ground equipment. Their development should be carried on with high priority, and their suitability for interceptors should be evaluated as soon as feasible.
Omni-DME	The ARN-21/URN-3 program should be given full support to fulfill service tactical requirements until self-contained aids are in full use.
UHF Homing	As an immediate expedient, all interceptor aircraft should be equipped with the ARA-25 UHF homing aid.

Return to Base

Traffic Control	The scheduling of return operations should become a function of the AC&W system as soon as adequate track capacity is available. Meanwhile, all interceptor bases should be equipped with a traffic-control radar.
Landing and Approach Aids	Until automatic GCA equipment becomes available, all interceptor bases should have ILS and GCA facilities.

Predicted-Fire Surface-to-Air Weapons

High Altitude	For defense against high-altitude attacks, emphasis should be directed toward improvements in interceptor aircraft and their control, rather than in predicted fire surface-to-air weapons.
Low to Medium Altitude	Conventional AA units of all types allocated or projected for the defense of the United States should be sited primarily to meet the low- to medium-altitude threat. All AA units allocated for the defense of the United States should be placed on-site now to be of value against a surprise attack.
Maximum Effective Range	The maximum range of effective coverage of guns and rockets that are aimed at a predicted position of the target appears to be limited to a time of flight of about 10 seconds, even in the absence of intentional target maneuver.
Short Time-of-Flight Principle	Development of predicted-fire weapons should be limited to low- and medium-altitude weapons for maximum times of flight of about 10 seconds. Tactical doctrine and employment of existing 90-mm and 120-mm guns should be based primarily on a maximum time of flight of about 10 seconds.
"Family of Air Defense Weapons"	The Department of Defense should undertake a study to determine the ultimate "Family of Air Defense Weapons" with due consideration for the capabilities and limitations of interceptors, guided missiles, and predicted-fire weapons, with the object of providing the maximum effective air defense at minimum cost.
Low-Altitude Threat	Our present weapons are inadequate against aircraft at low altitudes. For the near future, new types of predicted-fire surface-to-air weapons offer the best hope for local defense against this threat.
PORCUPINE I	The development of a new weapon called PORCUPINE is recommended for local defense against low-flying aircraft. In its simplified form, it will use a CW radar to alert the system, manually operated tracking, and a computer to select the optimum time to fire a salvo of about 100 rockets.
PORCUPINE II	In its advanced form, PORCUPINE is conceived as using a completely automatic fire-control system, comprising a keyed CW radar, an infrared tracker, a computer, and a multiple rocket mount. Selection of the time of firing for maximum kill probability will again be the key concept.

Guided Surface-to-Air Missiles

Specifications vs. Performance	Final decisions on tactical application of guided missiles should be made only on the basis of actual performance in full-scale operational tests.
Common Problems	The objectives of the guided missile program are generally sound, but the chances of their realization would be greater if efforts were concentrated toward the solution of radar, fuze, and aerodynamics problems common to many missile programs.
Long-Range Surface-to-Air Program	Research and development on long-range surface-to-air missiles such as BOMARC should be pursued. The problems are manifold and will require considerable research, but any large expansion of effort at this time must be weighed against its effect on shorter-term guided missile projects. In any case, the BOMARC program should be coordinated with long-term plans for the AC&W system.

ELECTRONIC WARFARE

Organization for Development	Success in the application of electronic countermeasures demands numbleness and flexibility. A development laboratory and limited production shops for crash programs should be established now and maintained as stand-by facilities.
Enemy Equipment	Information on enemy electronics equipment is scant and poorly disseminated. More data are needed. and an information center should be organized in this field.
Ground-to-Air Communications	The vulnerability of the present ground-to-air communication links is such that enemy airborne jammers could easily disable our intercept system. The maximum power of ground transmitters must be greatly increased.
Homing Interceptors	Homing interceptors might be a powerful deterrent to the enemy's use of navigation and bombing radars, and should be provided for early operational tests.
Operator Training	The training of operators to work through interference is one of the best available protective measures.

PASSIVE DEFENSE

Dispersal	We advocate a long-term policy of limited dispersal. New residential construction should be channeled into areas of low population density. New industrial construction should be so located that vital plants are separated by at least ten miles.

Shelters

A major factor in reducing urban casualties is the provision of shelters. With proper warning and other protective techniques, these will greatly reduce the loss of life in bombing raids.

Recuperation

Plans, equipment, and training should be provided for recuperation from bomb damage, and for rapid conversion of nonessential facilities to strategic production.

MANPOWER IN AIR DEFENSE

Noncombat and Civilian Personnel

The cost of defense in manpower may be a more important limitation than its cost in dollars. To release combat personnel for offensive warfare, we recommend extensive utilization of noncombat and civilian personnel in the air defense system.

SECTION I

THE PROBLEM

SECTION I

THE PROBLEM

1001 The problem of defense of the United States against air attack is characterized above all by lack of knowledge of what we have to defend against. The enemy has the initiative. Our intelligence tells us essentially nothing about his plans; informs us only partially about his present capabilities; and as to his future capabilities leaves us essentially dependent on assumptions that he can, if he chooses, do about as well in any aspect as we expect to do ourselves. Moreover, we have to assume that he is informed in detail about our present air defense and its weak points and has considerable information about our plans for the future. The consequences are that we have to strive to maintain as uniform a level of defense as possible, leaving no weak points through which he can penetrate while avoiding our major defenses, and that we have to maintain as much flexibility as is compatible with the necessity for large quantities of elaborate equipment.

1002 PROJECT CHARLES has been briefed by intelligence officers and by others on the enemy's war potential and on the probable threat, but we have not had access to the data on which the conclusions were based, and hence have not been in a position to form critical judgments on their validity or completeness. The following paragraphs should therefore be taken as an exposition of the assumptions on which we have based our study of air defense measures, rather than as any new contribution of information or of judgment.

1003 We have been informed that the Soviet long-range air force now consists almost wholly of some 400 to 500 TU-4 heavy bombers, which are copies of our B-29's, with speeds of 345 knots, maximum altitudes of 35,000 feet and ranges of 4000 miles, and that, until about 1953, the enemy will be limited to these or to ship-launched guided missiles, similar to LOONs, with 350-knot speed and about 500-foot altitude. Improvements in the performance of TU-4's are to be expected, and there are indications that larger bombers have been produced and may be available in significant numbers after 1953. It is estimated that by that time the enemy might also have available subsonic air-launched guided missiles. He may be capable, by about 1958, of producing supersonic high-altitude long-range bombers or guided missiles.

1004 It is well established that the enemy possesses atomic bombs, and we have heard the official estimate of the modest U.S.S.R. stockpile and of its rate of increase. The Soviet Union is believed to have the facilities and knowledge to manufacture nerve gases and weapons of biological warfare, and these, as well as atomic bombs, are probably, from the enemy's point of view, worth-while payloads.

1005 We do not know whether aerial refueling has yet been developed in the Soviet Union. If not, the enemy will be limited for some years to one-way missions; but we do not believe that this will deter him.

1006 We do not know whether his first blow will be a sudden sneak attack on the continental United States or whether it will be elsewhere. It is possible that after the first attacks the most critical phases of the war may occur abroad, and the air defense problem then may become principally that of defending our forces overseas. In that case, the air threat will become much more severe, since the enemy will be able to use bombers of shorter range and high performance and to accompany them by fighters, and to subject our Navy to major attacks by land-based torpedo-carrying planes.

1007 If, on the other hand, the enemy is able to continue severe attacks on the continental United States, the outcome of the war may be essentially determined by the balance between destruction and reconstruction.

1008 Our only indication of the enemy's probable choice of targets derives from our own estimates of their relative importance and vulnerability. We believe that the possible targets of consequence in the United States are Strategic Air Command air bases, Atomic Energy Commission production plants, strategic industrial plants, and centers of population and government; but we find wide divergences of opinion about the relative priority that the enemy is likely to attach to these targets. We do not believe that there is any set of key targets so vulnerable and so vital to us that a small number of bombs dropped on these could knock us out of the war.

1009 The enemy has a wide choice of routes, limited, we assume, by his range and the necessity of starting from present Soviet or Soviet-controlled territory. He may elect to come in at his maximum altitude or, with his presumed knowledge of the weak points of our air defense system, at an altitude of one or two hundred feet.

1010 We know that present Soviet aircraft are equipped to navigate by direction finding on broadcast transmitters and habitually do so within the Soviet Union. We cannot know whether the enemy will plan to depend on this type of navigation near this country or to resort to some more elaborate system of his or ours, but we must assume that he will know whether or not we plan to turn off our broadcast stations and navigation aids.

1011 In view of all these unknowns and the additional uncertainties in the estimates of performance of the components of our still-undeveloped air defense system, we are skeptical of attempts at quantitative predictions of the results of the air battle and of their usefulness in deciding what level of defense is necessary to attain the necessary attrition.

1012 Rather, we believe that the decision as to the level of expenditure in air defense will be and must be made essentially by the public and its representatives, and that it is then the problem of technical people to see that the funds are spent in ways that will be most effective. It is to this latter purpose that PROJECT CHARLES has devoted its efforts.

SECTION II

MEETING A SURPRISE ATTACK

SECTION II

MEETING A SURPRISE ATTACK

A. INTRODUCTION

2001 Soviet conduct is unpredictable and, considering the threat described in Sec. I, we must consider the possibility of a sudden surprise attack occurring as the transition from peace to war. This is an enduring threat which weighs heavily upon the population and industrial resources of the United States and its Allies and upon the retaliatory forces of Strategic Air Command (SAC). The advent of weapons of mass destruction has greatly increased the possible severity of such an air attack, and we feel that at some time, now or in the near future, a possible atomic surprise attack could, for example, largely cripple SAC or cause casualties in excess of those suffered by American forces in the second World War.

2002 The problems peculiar to meeting an unforewarned attack are of two general kinds. The first has to do with the difficulty and cost of maintaining a condition of routine and continuous combat readiness that would allow an initial and perhaps largest air battle to be fought at a few minutes' notice. The second has to do with those areas of commerce and public life in which substantial interference with normal activities may be necessary in order to allow the efficient detection and countering of the attack. This latter class of problem is more complicated to solve, since it involves many elements of the government and the public which do not traditionally accept peacetime repression of their activities for military purposes. These problems, as well as those of the continuous combat readiness, must be solved by procedures that are practical for peacetime use on a continuing basis.

2003 A surprise attack would fall on the defense forces while they are in routine peacetime operation, that is, in a condition in which only a small fraction of the interceptors and antiaircraft artillery (AAA) are available for combat, in which the initial onslaught is obscured in the confusion caused by friendly air traffic, and in which peacetime rules of engagement are binding. Thus, there is a possibility that the attack would be essentially unopposed and that no warning would be given to the population.

2004 The hazard inherent in this situation can and should be reduced by modification of peacetime operational procedures in directions indicated below. That discussion will be followed by a consideration of the great value of a few hours' advance warning, and a review of methods by which such warning might be obtained.

2005 The air defense system of the continental United States is highly vulnerable to an initial surprise attack. In the confusion caused by routine friendly traffic, and under present operational procedures, it is possible that the attack would be undetected and unopposed until after bomb release.

B. INTERCEPTOR AND AAA AVAILABILITY

2006 When an air attack is concentrated in time and space, the defender is at a considerable disadvantage, since he is limited to the use of weapons that are immediately available. For the fighter resources in Air Defense Command (ADC), about 24 per cent of combat-ready fighter forces are maintained at "available" during the day and 8 per cent at night, according to current data.*

2007 Similarly, of the AAA to be used in defense of the United States, only a few battalions are deployed on-site, and the remainder would require a day or two to be deployed and become ready for engagement. Of those gun battalions deployed on-site, only a small proportion is maintained with personnel and fire control apparatus in a condition where immediate fire would be possible.

2008 In our present situation in which we cannot rely on having advance warning of an attack, the benefits of improved readiness of existing forces are obviously very large.

2009 We have not examined the problems connected with interceptor availability and have no specific recommendation, except that the principle of readiness should apply.

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*ADC Command Data Book, March 1951, p. 109

2010 The role of predicted-fire weapons in the defense against low-altitude attack is discussed in Para. 5206; we conclude that all AAA units allocated to the defense of the United States should be placed on-site now to be of value against a surprise attack.

C. PEACETIME ROUTINE FRIENDLY AIR TRAFFIC

1. Identification

2011 There have been extensive studies of aircraft operations in the country by the Civil Aeronautics Authority (CAA) and others, and it appears that the amount of the internal air traffic is, at times and in important regions, wholly beyond the capacity of the present aircraft control and warning system to track and identify. This situation places the entire burden of detecting and assessing an attack on the radar stations on the perimeter of the system where air traffic is lighter, particularly in the overwater approaches. The mechanism by which this is done is to require all aircraft flying through or into Air Defense Identification Zones (ADIZ) to file flight plans. These are relayed to the appropriate radar stations and are there correlated as well as possible with observed tracks. Some typical data on the current operations of this system are shown in Table II-1.

TABLE II-1

Unidentified Traffic in Air Defense Identification Zones

January through March 1951*

	Number	Per Cent
Tracks Unidentified According to the Rules**	7900	
Unidentified Tracks on Which Interception Was Attempted	2700	34
Unidentified Tracks Intercepted and So Identified	1600	20

*Based on ADC Command Data Book (March, 1951)

**Of these 7900 nominally unidentified tracks, an undetermined but large proportion were tentatively identified, but not strictly according to the rules (cf. Para. 2017).

2012 It is seen that there is a very large number of nominally unidentified tracks in the ADIZ's, and that the aircraft control and warning system has of necessity become accustomed to the incidence of unidentified entering traffic which may be of a magnitude sufficient to obscure the appearance of an actual attack. Furthermore, there are indications, which we have been unable to assess, that many aircraft flying through the radar cover are not detected at all. Although this situation is improving, it appears entirely possible that a surprise attack would penetrate the perimeter and, once inside, would become lost in the routine friendly air traffic. The identification problem as a whole is more complex than set forth here; certain other aspects of it are discussed in Appendix II-1.

2013 The requirement on the identification procedures, in the period until the first attack, is that they be perfect to about one case in 100,000 in distinguishing friend from foe. Entering traffic in the ADIZ's is about 300 per day, or 100,000 per year. Very few accidents would be tolerated. On the other hand, we need an efficiency approaching 100 per cent in recognizing the enemy when and if he comes. This degree of excellence cannot be achieved by any single electronic device such as Mk X IFF.* The failure rate of complex electronic devices is thousands of times too high, and, in addition, the condition of combined military and civil traffic would make it practically impossible to maintain the security of the system.

2014 The necessary degree of excellence can be obtained only by the combined employment of several different procedures, each being of high reliability and each being largely independent of the others, so that failure of one procedure is not highly correlated with failure of the others.

2015 To obtain particularly high reliability in the application of a specific system, it is desirable to have the procedure be one that automatically provides protection in the event of failure of one of the elements in the system. This principle ("fail safe") is realized below in the suggestion of automatic diversion of each aircraft entering an ADIZ unless it receives a specific clearance by radio to proceed.

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*The proper functions of electronic devices are discussed in Appendix II-1.

TABLE II-2

Character of Unidentified Traffic in ADIZ's

	32nd AD Northeastern U.S. Area April 1951	26th AD N. Y. - Washington Area April 1951	28th AD* San Francisco Overwater Flights January 1951
Number of Recorded Tracks Unidentified According to the Rule	39**	166**	242**
Number of Tracks from the Above Identified or Tentatively Identified after Being Carried as Unidentified	17	158	124
Number of Above Identified Tracks Operated by			
USAF (Incl. Air National Guard)	6	23	unknown***
USN (Incl. Coast Guard and Marine)	1	25	unknown***
Commercial and Private	8	110	38
MATS (Military Air Transport Service)	unknown***	unknown***	48
Other	unknown***	unknown***	38
Number of Tracks That Remained Wholly Unknown	22	8	118

*These data were furnished through the cooperation of the Operations Analysis Unit of Headquarters, ADC.

**The number of tracks reported in this item depends on the method by which the records were kept at the various Air Divisions. There is no completely standardized method in ADC. The total number entered in the table here may not be significant, but the breakdown of the traffic is believed to be reliable.

***The method of keeping the records has made it impossible to break down the traffic into the same categories for the three Air Divisions.

SECRET

SECRET

2. Errors in Navigation

2016 The composition of the unidentified traffic, discussed in Para. 2011 above, is not accurately known, but some data for limited areas are shown in Table II-2. It is seen that the tabulated traffic consists of: (a) Commercial aircraft; (b) Service overwater flying; (c) Wholly unknown traffic.

2017 The rule used for identifying a flight as friendly from flight-plan information is to require that the aircraft pass along a self-predicted track, within ±5 minutes and ±10 miles. For flights of appreciable length, considerable navigational skill is required to make good the predicted track in time and space. Much of the unidentified traffic entering the ADIZ's consists of aircraft that have failed to navigate with sufficient accuracy to make good the estimated time and position over the established check points. Some operational data are shown in Table II-3 which gives the time errors of flights arriving in the 26th Air Division area.

TABLE II-3

Time Errors of Aircraft in Making Good Proposed Flight Paths*

(14 March to 3 April 1951)

Time Interval (within plus or minus)	Per Cent Making Good the Time of Proposed Flight Path
2.5 min.	34
5.0	71**
10.0	89

*Based on data from 26th Air Division, which have been obtained from the Operations Analysis Unit at Headquarters, Air Defense Command

**Regulation tolerance

It is seen that 70 per cent of the flights made good their times according to the rule. The distribution of distance errors is similar, and there appears to be significant correlation between the flights making time errors and the flights making distance errors. In view of the large number of aircraft entering the ADIZ's, the fraction that is not identified by rule actually amounts to a very large number of aircraft.

3. Means for Improvement in Navigation

2018 A comprehensive system of powerful low-frequency radio beacons would permit the making of fixes prior to penetration of the radar cover.* This would allow entering aircraft to check their position and amend their flight plans. It seems entirely feasible to establish this network of beacons by modification of existing types of radio navigational aids. The most promising aids for this purpose are those installed on Coast Guard light vessels. By this method, the incidence of unidentified traffic due to navigational failures can probably be greatly reduced. Whether the proposed navigational aids are turned off or allowed to continue during an attack, or whether they are completely turned off in wartime, in no way affects the need for them in a prewar period that may end in a surprise attack.**

2019 It is clear that not all unidentified traffic will be removed by this means, nor will the system function without errors. However, the addition of more navigational aids is a step that can be taken within the framework of existing procedures.

4. Operational Procedures for Diverting Unidentified Aircraft

2020 Further steps will require alteration of the current procedures and understandings between ADC on one hand and, on the other hand, the CAA, the commercial operators and the military organizations operating aircraft in the ADIZ's. The following discussion sets forth a proposed method for reducing the remaining amount of unidentified traffic and for dealing with the residue. This proposed method is in contrast to other procedures wherein the aircraft keeps coming in until told to divert to another airport. If these suggested rules

*A detailed list of the recommended beacons is given in Appendix II-2.

**The control of electromagnetic radiation in wartime is discussed in Appendix VI-1. The proposed scheme is recognized as a "quick fix" only, taking into account the fact that practically all aircraft are equipped to make use of low-frequency radio beacons. For overwater approaches, the general use of Loran would be a better solution, since it provides more accurate fixes at greater range. However, the problem of equipping a significant fraction of the aircraft in question with Loran gear would involve considerable time and effort.

are strictly adhered to, no aircraft will enter a defended area without first being identified as friendly.

2021 The essence of the method is to establish regulations for diverting all friendly aircraft on which normal flight identification is unsuccessful. For any plane penetrating an ADIZ boundary, the rule should be to require a special flight clearance before the plane may continue to a destination in an important target area. It should be established by standing regulation that any aircraft failing to receive such clearance will proceed to and hold over a specified check point well within radar cover but outside critical defense areas. If, after holding for a specified time, clearance has not been established, the aircraft is required by the proposed regulations to automatically divert to an alternate airport not within a critical target area, to land and be identified.

2022 The clearances should be issued over special very-high or ultra-high frequencies (VHF or UHF), preferably clear channels established for this purpose, which all aircraft entering identification zones must monitor until clearance has been established. The successful operation of this procedure will require the closest liaison between the ground-control-of-interception (GCI) identification officer and the CAA or Military Flight Service personnel verbally issuing the clearance.

2023 For the normal flight that has been observed making good its flight plan within the prescribed rules, identification would be established shortly after radar contact, and clearance to proceed to destination would be issued without disturbing in any way the aircraft's original plan.

2024 On the other hand, for any aircraft for which such identification could not be quickly established, additional procedures would be undertaken. It is suggested that VHF or UHF direction finding (DF) facilities be provided at appropriate perimeter GCI stations so that DF bearings on radio communications can be directly correlated with radar bearings. The aircraft would then be directly interrogated on the special air defense frequency and identification attempted from the ensuing conversation and direction-finding procedures. If these measures, coupled with the continued radar observation of the flight track as the aircraft proceeds to the holding point, fail to establish identification, the aircraft must divert to its alternate airport. In any case, within a short interval

(dependent on the speed of data processing - perhaps three to four minutes) after the establishment of a track, a decision must be made whether or not to scramble.

2025 A residue of unidentified friendly traffic would occur only as a consequence of flight emergency or gross personnel error. A rigorous policy probably can be adopted to intercept in all such cases, even under conditions of poor visibility. This would be feasible because

(a) The number of fighter sorties required would be small;

(b) In the event of accidents or complaints, the burden can be placed on the unknown aircraft by showing its failure to divert when not cleared.

2026 An aircraft that has been intercepted can be either identified and permitted to proceed or, failing this, can be accompanied by fighters until landed at the appropriate alternate airport. An aircraft that is not identified by any of the preceding steps and continues to proceed into a possible target area should be made subject to attack by fighters, at the discretion of the Division Commander and according to prescribed rules of engagement.

2027 Positive identification of all aircraft crossing the defense perimeter is a fundamental requirement of air defense. Primary reliance must be on procedural doctrine rather than apparatus, which calls for:

(a) Automatic diversion away from critical target areas of all friendly flights except those identified and given specific clearance.

(b) Improved navigation facilities for friendly aircraft.

(c) The allocation of an air defense communication frequency to aid in identification and clearance.

D. RULES OF ENGAGEMENT

2028 At present no aircraft may be fired upon unless

(1) It is manifestly hostile in intent, or

(2) It commits an overt hostile act, or

(3) It carries U.S.S.R. markings and appears without prior arrangement.

The consequence of these rules* is to reduce greatly the chances of a hostile aircraft's being taken under fire either by interceptors or AAA prior to bomb drop, especially since the present procedures for identification are unreliable.

2029 A further limitation of current peacetime operations prevents interception of unknown aircraft under Instrument Flight Rules (IFR) or at night, and consequently an attack occurring under these conditions is almost certain to go un opposed.

2030 Under certain conditions, especially after the introduction of stricter identification procedures, the adoption of different rules of engagement would reduce the time delays involved and allow a more positive chance of destruction of enemy aircraft. However, the difficulty of this problem is understood and the following remarks are made with the awareness that there may be command and responsibility factors that make alteration in the existing rules of engagement undesirable. The proposed rules are as follows:

(1) The flight commander on obtaining a tallyho will report to the ground, stating what he has been able to ascertain about the nature of the aircraft.

(2) The ground controller must then reply (within a short time, perhaps two minutes) whether or not the apprehension procedure is to continue.

(3) Upon receipt of authorization from the ground, the flight then splits off a single fighter who proceeds to order the unknown aircraft to land by maneuver, lowering of the landing gear, and the use of lights at night.

(4) If no response to this maneuver is obtained, the detached aircraft will fire "across the bow" of the unknown aircraft.

(5) If the unknown aircraft finally fails to respond and does not proceed to land, the balance of the flight of aircraft will open fire.

The use of these rules requires interception of unknown aircraft by more than

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*See, for instance, EADF Standing Operating Procedure Number 60-2, 26 January 1951, "Interim Rules for Fighter Pilots Active Air Defense."

one interceptor, but this appears to be necessary from the point of view of ensuring a reasonable probability of kill of the bomber. There is still a difficulty under conditions of poor visibility, but the high degree of reliability of the proposed plan for preventing friendly aircraft from appearing hostile in intent makes it much easier for the responsible officer to decide whether or not to fire.

E. EARLY WARNING FROM REMOTE RADARS

2031 The operational procedures that have been discussed are characteristic of the difficulties involved in preparing the air defense system to meet a surprise attack. These difficulties would be very much reduced if the attack were preceded by advance warning. Even a diffuse warning, perhaps of some days' duration, of the impending commencement of hostilities is useful for a general alerting of the air defense system and an intensification of patrol activities. Very much larger benefits would be derived from a warning that an attack is committed and is to be expected in a few hours.

2032 A few hours' early warning will greatly improve the effectiveness of the air defense system because:

(1) The readiness of interceptors and ground weapons can be stepped up, and patrol activities intensified;

(2) Strategic Air Command strike aircraft can be dispersed;

(3) Civil air traffic can be diverted from critical areas;

(4) Wartime rules of engagement can be established;

(5) Prearranged plans for ground observers, for electromagnetic radiation control, and for civil defense can be executed.

2033 These actions are difficult and costly, and the warning system must therefore be virtually free of false alarms. At the same time, the advantages of reducing the surprise element of the attack are so substantial that methods of

obtaining early warning must become as much a part of the air defense system as are the radar net and the interceptors and the AAA.

1. Intelligence

2034 The members of PROJECT CHARLES have not been apprised of the intelligence activities that might be expected to produce the required warning. The Project has been given the statement of the Commanding General, ADC, that no intelligence warning is likely to be available. The Project is unable to make remarks on this subject other than to note that:

(a) In view of the magnitude of the present threat, air defense appears to require more emphasis on tactical and operational rather than on general political and strategic intelligence.

(b) The means for obtaining suitable intelligence warning appears to be a fruitful subject for study by a group of a nature similar to PROJECT CHARLES, so as to ensure that no technical resources remain unexploited.

2. Remote Detection Systems

2035 A survey has been made of many schemes that have been proposed for providing such warning in the absence of information from intelligence sources. An ideal early-warning system would give several hours' unequivocal advance warning of enemy attacks at all times over all possible routes. It would not give false alarms either by malfunction or by enemy interference. The physical and technical difficulties of providing a complete and absolutely dependable early-warning system have been found so great that we are led to making limited recommendations for a less-than-ideal but feasible system, which we believe to be worth while.

2036 The early-warning schemes that have been discussed differ from one another in respect to several variables as shown in the following list.

Type of detection equipment: – Pulsed radar, continuous-wave (CW) radar, ground observers, passive radar and radio reception, acoustic detectors, infrared detectors.

Type of station or vehicle: – Manned ground stations, unmanned ground stations, picket vessels, airborne early-warning (AEW) planes, blimps and balloons.

Geographical region: – Alaska, including Aleutian Islands, Northwestern Canada, proposed Newfoundland-Labrador chain and an extension seawards,

Greenland-Iceland-Faroes-Shetland Islands chain, North Cape-Spitsbergen chain, mobile stations (see Fig. II-1).

Surveillance time continuity: – Continuous, random intermittent, intermittent on call.

2037 Early-warning systems are faced with four great difficulties which are discussed below: (a) the danger arising from false alarms; (b) the ease with which any feasible single fixed chain can be avoided; (c) the present impossibility of airborne radar detection over land, and (d) the inaccessibility of some geographical regions.

3. Dangers Arising from False Alarms

2038 The steps to be taken when warning is received are drastic, and the consequent hazards necessitate that the system be virtually free of false alarms. These may be caused, for example, by:

(a) Equipment failure.

(b) Reports not caused by aircraft.

(c) Reports of friendly aircraft (which fly frequently over most of the regions where it is desirable and feasible to place the early-warning equipment).

(d) Intentional confusion by the enemy.

2039 Unmanned detectors, such as microphones, infrared detectors and simple unmanned radars, are particularly liable to equipment failure and are not able to recognize friendly aircraft. The false alarms would be so frequent, that it does not seem feasible to direct aircraft out to verify the alarms before taking the defensive measures. Therefore, such unmanned devices do not at present afford adequate means for early warning. It is possible that in the future one of these devices, such as CW radar or directional microphones, may be developed to the point where it can reliably count the passing aircraft. In such case, the probability of false reports due to friendly aircraft and other causes could be reduced by reporting only large groups of planes, on the assumption that any large group of friendly planes would have a known flight plan. Such a scheme would give early warning only of concentrated attacks.

4. Ease of Avoiding Detection

2040 Stations that would afford several hours' early warning probably would have to be located in the middle portion of the approach routes. There the routes can fan out widely without adding much to the range required of the aircraft, especially when effects of prevailing winds are considered. Therefore, a detection chain must be of very great length if the warning is to be dependable.

2041 Certain types of detectors are also avoidable in another sense. Enemy planes can avoid radio and radar listening devices by turning off their radios and radars while traversing the warning region. Under common weather conditions, accustical and infrared detectors can be avoided by flying high.

2042 It is clear from these and other considerations that a complete and dependable early-warning system requires a discriminating type of detector, such as manned, pulsed radar stations, and necessitates chains of great extent.

5. Present Impossibility of Airborne Radar Detection Over Land

2043 Presently known airborne moving-target-indication (MTI) techniques do not offer a real prospect of ground-clutter elimination. Without ground-clutter elimination, AEW cannot be expected to detect aircraft over land.

6. Inaccessibility of Many Essential Regions

2044 To complete an ideal system of early-warning stations requires putting some of them in regions that for physical or for political reasons are practically inaccessible. Stations in Norway and Sweden may be ruled out politically, and stations in Northern Canada or Northern Greenland for physical reasons. Airborne radar over such ground regions would be ineffective because of ground clutter; and, over the rough ice of the far North, it is doubtful that airborne radar would be very satisfactory. Furthermore, aircraft operating conditions would preclude continuous surveillance. Ocean chains involving very numerous stations would be extremely costly, and ocean regions in the far North present almost insurmountable difficulties for the continuous maintenance of either fixed or airborne early-warning stations.

2045 Because of these fundamental difficulties, we do not have any practical proposal for a completely reliable remote early-warning system covering all

possible approaches to targets in the U.S. However, we believe there are great advantages to be derived from certain less-than-ideal systems which are proposed below.

7. Approach from the East

2046 A chain of radar stations on the Labrador-Newfoundland coast has already gone through planning stages but has not yet been agreed upon. The value of such a chain would be greatly enhanced if it were extended southeastwards over the Atlantic Ocean by two or three picket vessels as shown on the map in Fig. II-1. Then Soviet planes from the Murmansk area could not approach New York and New England from the Atlantic side, or on a Great Circle route, without giving early warning for a few hours. They could not fly south of the picket ships without needing more range than is believed possible (without aerial refueling) for a TU-4 carrying an atomic bomb. Because of the great distance from the Soviet Union to the United States, it is unlikely that the enemy would deliberately trigger the system to set off a false alarm.

2047 Even without the picket vessels, avoiding Newfoundland and approaching the New York area from the Atlantic Ocean requires a range of almost 4000 nautical miles against probable head winds. Since this is estimated to be nearly but not quite impossible for a TU-4 at present, the Labrador-Newfoundland chain in itself loses value by the possibility of avoidance; thus a small extension would increase the value of the chain by much more than the proportionate cost of the extension. The two picket vessel stations would add about 300 miles to the required range, and a third station would add nearly another 200 miles, whereas a seaward course that avoids the land-based chain alone is only about 300 miles longer than the Great Circle route.

2048 The need for continuous, dependable surveillance over long periods of time indicates that the proposed ocean stations should be picket vessels rather than aircraft.

2049 Even at a future time when the enemy may be capable of aerial refueling, these outpost radars will be of some value by forcing the enemy to use longer and more difficult routes to avoid early detection.

2050 At present, enemy aircraft might avoid the extended chain by following an alternate route over Northern Greenland and over the Hudson Bay, on which

route the possible tail winds, replacing the probable head winds met on the Atlantic course, would partly compensate for the extra distance. However, this route would take them through the planned Canadian double chain of stations, in addition to our own radars. Once the Canadian stations are installed, we could count on early warning of about one and one-half hours' duration, which may be sufficient to implement most of the measures desirable. Furthermore, active interceptions could be carried out throughout this area.

8. Approach from the Northwest

2051 The future radar chain in Alaska will provide early warning and possibly interception of planes flying the Great Circle route from Anadyr to the United States. This chain can easily be avoided by one-way missions, but will be in the path of any two-way missions to the United States.

2052 An Aleutian early-warning chain would have the effect of extending the routes from Chukotski to the West Coast targets. Since these targets are within range of logistically more convenient bases on the Kamchatka peninsula, we can see little utility in an Aleutian radar chain.

2053 Northwestern Canada is physically inaccessible for permanent manned radar stations, and airborne radar over land is unsatisfactory. However, ground observers now operating in this region have some probability of being effective, and should be given every encouragement.

9. Intermittent Patrols

2054 Further protection can be obtained by intermittent cover over critical approach routes on an irregular schedule. This service can be performed by submarines, surface vessels and AEW planes, and in some cases can be combined with antisubmarine patrols.

2055 The intermittent cover, in addition to giving some probability of detecting an attack, would serve to make the enemy less confident of his ability to achieve a surprise. The irregular schedule would be of particular value for this purpose.

2056 A specific proposal is for an AEW squadron stationed on Iceland and flying at irregular intervals to the neighborhood of Spitsbergen and back. This course

is about 1000 miles each way, and covers all the likely approach routes from the Murmansk area. In addition, it surveys the area in which aerial refueling by the enemy is likely to be attempted. On a conservative estimate, a single squadron could support one such flight per day on a routine basis, and more over short periods during times of unusual stress.

2057 A calculation explained in Appendix II-3 shows that, at a rate of one flight per day, the probability of the AEW plane's being in a position to see a crossing stream of bombers is around 20 per cent. This is enough to make the enemy uncertain of his ability to achieve a surprise attack. The probabilities are doubled when two flights per day are run, and might be further improved by increasing the range of the airborne radar.

2058 This degree of protection should be balanced against the effort involved in maintaining the squadron of AEW aircraft, which we are told is about equal in this respect to a fighter group.

2059 A second proposal is for a similar squadron to be based in Alaska. Here we lack the full information necessary to make a definite recommendation, but two possibilities for its use seem attractive and should certainly be investigated. One of these possibilities is to make flights northwards over the Beaufort Sea, going about 400 to 500 miles off the coast and back. This would give intermittent cover over the likely routes from the Chukotski peninsula, to points in the central and eastern United States, avoiding the fixed Alaskan radars. Probabilities of detecting a raid would be similar to those for the Iceland-to-Spitsbergen patrol if the flights were equally frequent. The unknown factor here is the performance of the airborne radar over ice, which should at once be thoroughly studied. The second possibility is much closer surveillance of the likely enemy base area, by flying a course around the Chukotski peninsula. On the northward side, the performance over ice again comes into question, but does not on the southern side near the Gulf of Anadyr. Another unknown to us, however, is whether there will be an appropriate air base far enough west in Alaska to make these flights feasible. If such patrols should indeed be possible, they would afford a high probability of detecting a major attack from the west.

2060 It is not feasible to provide an ideal early-warning system that gives unequivocal warning of all possible attacks. A

less-than-ideal but valuable system that has a fair probability of detecting likely forms of enemy attack is recommended; this requires augmentation of the facilities now planned or proposed by:

(a) Two picket-vessel stations southeast of Newfoundland,

(b) Two long-range airborne early-warning squadrons, one in Iceland and one in Alaska.

2061 Present plans for the Canadian stations contiguous to our border and for the Alaskan stations should be strongly supported, as should be the ground observers in Northwestern Canada. No stations are recommended for the Aleutian Islands.

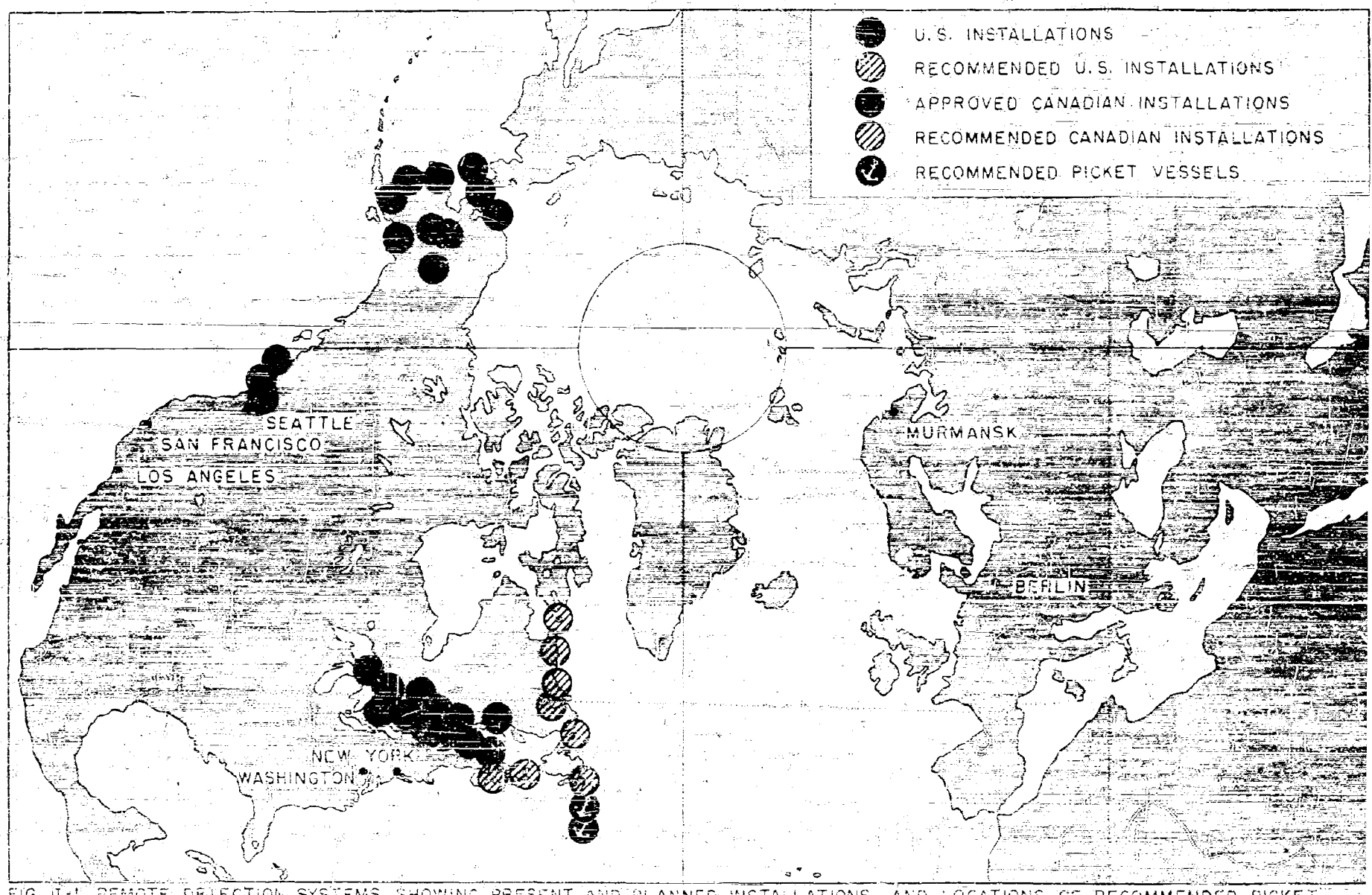


FIG. II-1. REMOTE DETECTION SYSTEMS, SHOWING PRESENT AND PLANNED INSTALLATIONS, AND LOCATIONS OF RECOMMENDED PICKET VESSELS AND GROUND-RADAR STATIONS.

SECTION III

AIRCRAFT CONTROL AND WARNING EARLY IMPROVEMENTS

SECTION III

AIRCRAFT CONTROL AND WARNING EARLY IMPROVEMENTS

A. INTRODUCTION

3001 PROJECT CHARLES has divided its consideration of the problems of air defense into three principal areas:

(1) Aircraft control and warning (AC&W) systems,

(2) Interceptors and other weapons for action against attacking planes,

(3) Passive defense measures.

These are not independent, for interceptors and weapons are of little or no use without a successful control and warning system, and many measures of passive defense are ineffective without reliable warning.

3002 The over-all problem is formidable in scope, especially when broadened to include applications to overseas and naval operations. Within the limitation of available effort, some examination has been made of the whole problem, closely in some phases but only casually in others. However, this presentation has been very sharply filtered to eliminate all points except those on which significant conclusions and recommendations could be reached.

3003 The control and warning systems have been treated in two time phases:

(1) The present U.S.-Canadian system including extensions in progress, which, with only minor equipment modifications, must serve our needs for at least three or four years;

(2) A proposed system, regarded from a broader point of view and not necessarily bounded by present equipment and concepts of operation.

For phase (1), major weaknesses and limitations of the present system are evaluated, and recommendations for action to alleviate some of these are cited. Doctrine and operational procedures are an important part of this consideration, just as they were in Section II on meeting a surprise attack. The long-term problem is approached from the other end, that is, the characteristics of an optimum warning and control system are set up and an attempt is made to arrive at a solution which, within economic and technical limitations, most nearly meets the requirements.

3004 Examination of the control and reporting system has been made from the point of view of achieving improved operation in the next few years by means of modest improvements and extensions of the existing equipment and systems. This examination has indicated that significant returns can be obtained in the following fields:

(1) Extension of radar cover;
(2) Data processing in the radar stations;
(3) Integration with antiaircraft artillery (AAA);
(4) Communications and data processing in the Fleet;
(5) Control of interceptors;
(6) Improvement of ground-radar equipment;
(7) Use of ground observer corps (GOC).

Additional improvements, especially as results of long-term development, may be possible in other fields which we have not considered.

B. EXTENSION OF RADAR COVER

3005 Radar coverage is most important at the perimeter.* Here it must be extended enough to provide adequate time both to insure combat with hostile planes before bomb release on important targets and to effect the more important of the civil defense measures. Such warning would also be adequate for on-site local air defense weapons. Considering the present threat, the first of these objectives requires that initial detection should occur about 200 miles out from the target. The requirement for civil defense is more difficult to set, since the procedures are not so definite; it can hardly be much less because these procedures cannot be initiated until identification has been completed. Reliable detection of a TU-4 except at low altitude (less than 5000 feet) with our present radars can be expected out to about 100 miles. This figure is used in the following discussion.

3006 Along the northern part of our defense perimeter, adequate depth of cover can and should be obtained from land-based radars. The completion of the Canadian chain and its integration into the continental defense system will be

*Remote radar surveillance systems have been discussed in Section II.

an important step toward attaining satisfactory coverage. No real evaluation of the present coverage of this part of the system could be made, since data are not available. Along the east and west coasts, there are several regions where critical target areas are so near the coast that the shore-based radars cannot furnish sufficient coverage. In parts of these same regions, the normal friendly traffic is often too heavy for the radar stations to track, and it is possible, with the detection perimeter so near, for a plane on a penetrating course to become mixed with this local traffic and be lost before identification or interception can take place.

3007 The situation with respect to low-flying attacking planes is particularly bad. With the permanent sites all equipped and operating, paths will exist along which low-flying planes can reach important targets with very small probability of detection. (See Para. 3150 about the possible use of ground observers in this connection.)

1. The East Coast

3008 On the East Coast, in the neighborhood of New York and Boston, there are places where the detection perimeter is only about one radar range from critical target areas. In these same regions, there are gaps in the low coverage through which low-flying planes could reach both cities, with very small probability of detection. Actual coverage measurements at each site would be required to determine the extent of these gaps; the circles shown in Fig. III-1 indicate a rough average estimate of coverage.

3009 The desired increase in coverage on high-altitude bombers could be obtained by three properly placed radar picket vessels, one east of Boston, one southeast of Nantucket, and one southeast of New York. The suggested positions are shown on the map in Fig. III-1. The approximate latitudes and longitudes are: 42° 50' N, 68° 30' W; 40° 30' N, 70° 10' W; and 39° 30' N, 72° 30' W. These vessels should be capable of performing the normal detecting and filtering functions of a ground-control-of-interception (GCI) station. With these pickets on-station, the protection against low-flying attack would also be greatly improved.

2. The West Coast

3010 On the West Coast, there is one place (near San Francisco) where the detection perimeter for high-flying planes is much too near the target, and there are a few paths along which low-flying attacks could be carried out with little chance of detection. A need for additional radars to fill these gaps is indicated.

3011 In the Northwest, the targets are inland and the coastal radars appear to afford adequate warning on high-flying planes. There is, however, a gap in the coverage on low-flying planes just south of the Olympic Mountains. A plane coming in here, on a reasonable route, could get to within 40 miles of Tacoma and 60 miles of Seattle before detection would be possible. An even more serious situation exists in the neighborhood of Portland, Oregon. A low-flying bomber following a natural course perpendicular to the shore line could reach Portland and Bonneville Dam without being detected on any radar. Two new radars, one at the site of the present lash-up at Pacific Beach, Washington (lat. 47° 12' N; long. 124° 12' W, approx.), and another near Oceanlake (at approx. lat. 44° 59' N, long. 124° 00' W), would fill these gaps and result in rather good perimeter coverage for both high and low attacks in the Northwest. The lash-up station at Portland should certainly stay in service until these are operational.

3012 In the San Francisco area, there are no gaps in either high or low coverage, but the detection perimeter needs to be extended for both. A single picket ship almost directly west of the city (approximately at lat. 37° 10' N, long. 124° 15' W) (see Fig. III-1) would provide the desired extension of high coverage and greatly improve the low coverage. The only remaining opening for low flying planes would be from the south.

3013 In the vicinity of Los Angeles, the radars on Santa Rosa and San Clemente Islands provide nearly adequate high coverage. However, their separation of approximately 125 miles may leave a bad gap in the defense against low attack. This can be checked by observing whether or not San Nicholas Island can always be seen by both radars. If not, a radar picket should be placed about 75 miles outside San Nicholas (approximately at lat. 32° 30' N, long. 120° 15' W). Whatever the result of the observations on San Nicholas Island, this picket vessel would very greatly improve both high and low coverage.

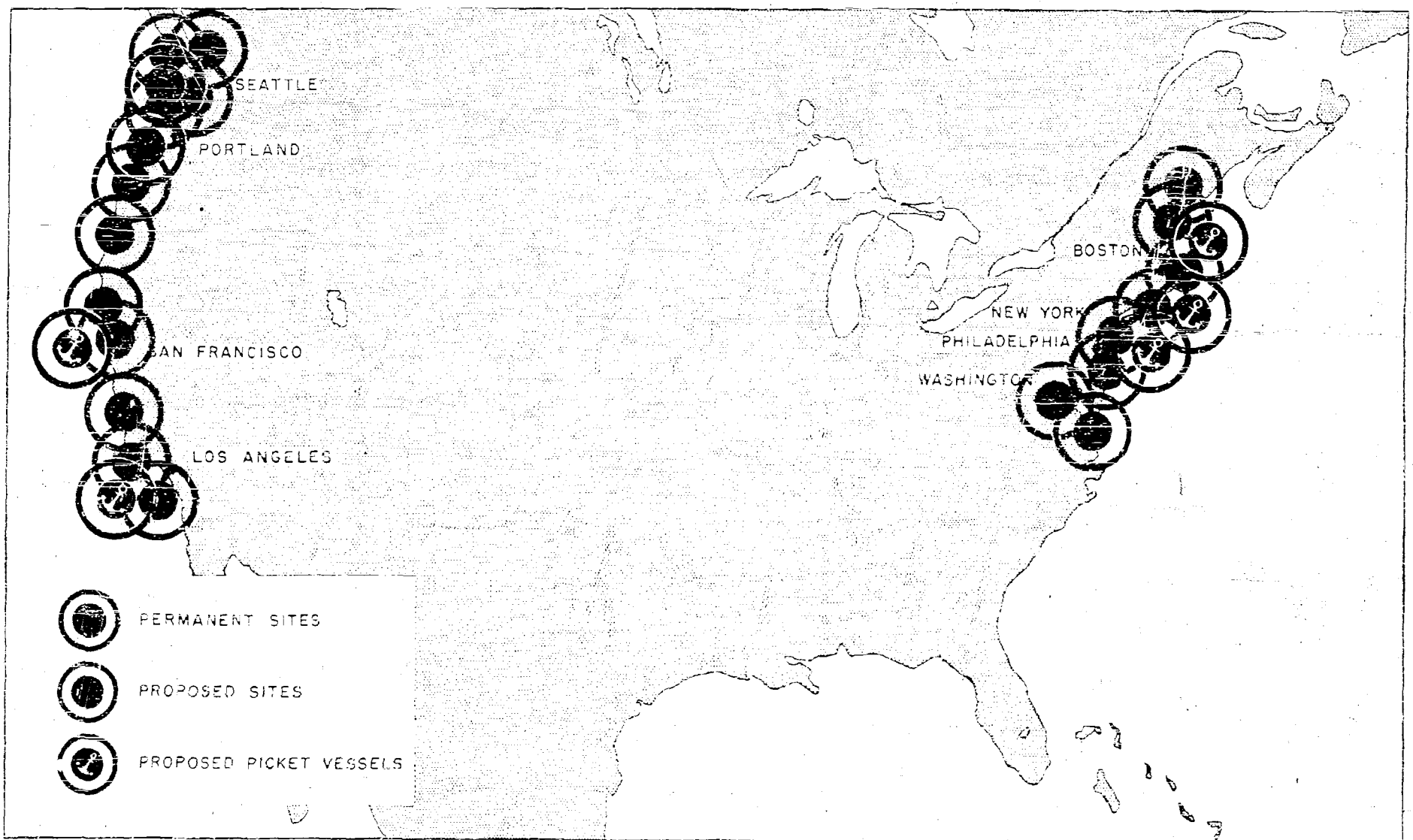


FIG. III-1 PLANNED PERMANENT RADAR SITES, PLUS PROPOSED PICKET VESSELS AND TWO ADDITIONAL RADARS.

3. Picket Ship-to-Shore Communications

3014 The approximate locations recommended for the picket vessels are about 100 miles from the nearest land-based radars and, except for the one southeast of Nantucket, about the same distance from the nearest land. It is realized that at this distance there may be serious difficulty with communications. Since reliable communications between pickets and shore stations is essential, this difficulty must be overcome, even if it requires moving the picket vessels closer to the land. If medium- and high-frequency radio prove unsatisfactory, very-high or ultra-high frequency (VHF or UHF) with high antennas or relays could be tried. Eventually, if blimps with airborne early-warning (AEW) radars are incorporated in the defense system as suggested in Section IV, these might be used as relay stations for communications.

4. Proposed Extensions

3015 The number of picket vessel stations recommended at this time to extend the radar cover at the continental defense perimeter is thus five, three on the East Coast and two on the West. These are in addition to the remote noncontiguous picket vessel stations that may be used for early warning (cf. Section II).

3016 These five picket vessel stations off the East and West Coasts are needed more urgently than the remote ones, and vessels should be placed on-station at the earliest possible time, both to provide extended radar cover and to furnish operational experience for future planning.

3017 Two additional radars are recommended to fill serious gaps in the coverage in the Northwest.

3018 These additional facilities will provide the desired increase in high coverage in the neighborhood of critical targets, and will greatly improve the low coverage. They will also assist in the implementation of the identification procedures proposed in Section II. The number of picket vessels requested will make a very significant improvement in the defense system, but is small enough that they can be provided immediately without seriously interfering with other activities. If they prove to be as valuable as is expected, it might be advisable to design special ships for the purpose. For the present, destroyers or perhaps destroyer escorts would be satisfactory.

3019 In several important coastal regions, present U.S. shore-based radars fail to provide sufficient cover. Extended coverage at the perimeter will greatly improve the warning system by allowing more time for interception and by making it possible to use better identification procedures.

3020 Three picket vessel stations off the East Coast and two off the West Coast should be established at the earliest possible time. Two additional ground radars are recommended in the Northwest.

C. DATA PROCESSING IN THE RADAR STATIONS

3021 The recommendations regarding data processing are directed at obtaining some measure of increase in the effectiveness of the AC&W network already planned, without proposing major developments in equipment or radical changes in present doctrine. The specific objectives are to:

(1) Increase the traffic-handling capacity of the system;

(2) Increase the efficiency of initial detection;

(3) Separate the functions of pickup and tracking from the function of intercept control;

(4) Improve the clarity of the air-situation picture presented to the controllers;

(5) Make possible the direction of the defense effort by the Air Defense Division Commanders (in agreement with present doctrine) by presenting a clearer and more current air-situation picture to the Air Defense Command Centers (ADCC).

1. Areas of Applicability

3022 Fundamentally, the operations performed in the AC&W system, the difficulties encountered, and the limitations imposed are the same in all areas: continental United States, Canada, the United Kingdom, forward areas such as Japan and North Africa, field army locations, and the Fleet. However, certain details vary with the location. For instance, for a task force the threat is

somewhat different, the space limitations on equipment are different, corrections for moving coordinates are necessary, and a very difficult problem is the need for replacing wire telephone communications with radio channels. This point is discussed separately in Para. 3118 et seq.

3023 We have particularly considered the system for the continental United States. It seems to us that the recommendations are applicable with little or no modification in such areas as Canada, the United Kingdom, Japan, and North Africa. Some parts of the recommendations are adaptable to situations in field armies and the Fleet. The adaptation to a naval Combat Information Center (CIC) is discussed in detail in Para. 3125 et seq.

2. Present Limitations of the Reporting System

a. Capacity of First Reporting Process

3024 Verbal reporting from the scope observer to the plotter is slow. About 12 seconds is required to report and plot new data on each old track. Fluctuations of the reporting rate during a rotation of the antenna further lower the capacity, so that each observer and plotter pair can keep only about 4 tracks up-to-date within one minute. In one minute, an aircraft can travel 5 miles, and can deviate from the predicted course by several miles in distance and any amount in heading; hence, for use in acquisition by controllers or AAA, the time delay is an important consideration.

3025 At present, the capacity is increased when necessary by division of the area into sectors, in which tracking is done by different observers and plotters. This is expensive in terms of manpower. The increase in capacity is less than proportional to the number of men employed, because of crossover problems, which makes it unprofitable to use more than about four sectors. Considering also the fact that traffic is not equally divided among sectors, the total tracking capacity is about 10 tracks per radar station for data less than one minute old. Allowing greater delay does not increase the capacity very much, and leads to errors.

3026 Operator skill and concentration have a strong effect on this capacity. A station with selected personnel may be able to handle up to 15 or 20 tracks.

b. Need for Successive Filtering

3027 The total normal traffic frequently exceeds the reporting and tracking capacity To offset this, only a portion of the tracks is reported. The selection is based mainly on the area in which the track originates and the direction in which it is traveling. Even in areas under surveillance, tracks that have been identified as friendly may be erased and no longer followed. However, it is important not to have to reidentify these tracks.

3028 The end result is that the radar reporting is not automatic and involves a preliminary filtering, which places an extra load and importance on the scope observer. He must keep in mind the place of origin, direction of motion and, in some cases, the established identity corresponding to the blips that reappear, and must then make a selection of which ones to report.

3029 Following this preliminary filtering, a second filtering is done by the filter officer at the GCI station, by comparison of the tracks with flight plans of which he has been notified. Currently, however, this filtering is imperfect because he does not always have complete and up-to-date flight-plan information. As a result, many tracks of routine flights are reported to the ADCC, and there a third filtering operation is performed.

3030 The reporting of these tracks adds to the load on the telephone lines to the ADCC. Since only one or two lines are available, the telling and plotting facilities are easily saturated, leading to loss or delay of desired information. Furthermore, the presence of friendly tracks would confuse the air-situation picture at the ADCC in the case of an attack.

c. Probability of Initial Pickup

3031 The probability of detection and the distance of initial pickup depend strongly on operator attention and on whether or not the track is expected. Prior warning of the approach of a plane increases the average range for first detection by about 25 per cent, and reduces by more than a factor of two the probability of complete failure to detect approaching aircraft -- as shown by the success in correlating flight plans when compared with the incompleteness of detection of unexpected planes during exercises such as Whipstock.

3032 The efficiency of detection is also strongly dependent on how busy the observer is kept in reporting established tracks. To keep up with these, he usually draws crayon lines on the scope face, which direct his attention to the proper places to look for new blips on the old tracks. His concentration on these, especially if there are many of them, reduces the extent to which he can scan the picture for new blips.

3033 Another factor in reducing efficiency of detection is the rapid variation in brightness of the images, which gives the operator a rather short time to look at an area of the scope under optimum conditions.

3034 To improve the efficiency, we propose, below, steps that accomplish the following:

(1) Provide a display of constant brightness;

(2) Eliminate the telling of track coordinates to the plotting board, allowing more concentration on detection;

(3) Provide a distinctive sequence of colored dots to distinguish tracks from clutter.

d. Lack of Clarity in Presentation to Controllers

3035 The plotting board at present visible to the controllers is the same as the work board on which tracking and filtering are done. Its clarity is diminished by the inclusion of unfiltered data and tracks of friendly planes. Psychological tests have demonstrated the value of eliminating nonessential information from the board for improving the speed and accuracy of interpretation.

e. Confusion in the Operations Room

3036 Noise and confusion sometimes are excessive in present operations rooms because of the large number of people present and the fact that different operations are carried on in close proximity. Multiple-purpose use of telephone lines, and particularly the presence of loudspeakers in the Navy CIC's, add to the difficulty.

f. Cross-Telling Procedures

3037 The importance of cross-telling procedures may be illustrated by the following excerpt from the report on Operation Whipstock.

"Cross-telling of aircraft tracks between the Neah Bay and Pacific Beach early-warning stations and Paine Field GCI appears to have been of moderate reliability as to completeness, accuracy and speed. This accounted in appreciable part for the relatively good performance of this part of the AC&W net and the associated fighter defenses in intercepting the SAC strikes.

"Cross-telling between the remainder of the stations left much to be desired. The breakdown was so nearly complete that the stations could be considered as operating essentially as a loose aggregation rather than as a coherent net; the detection of aircraft by any one station seldom served as early warning for the next. This lapse appears to have accounted in appreciable part for the poor performance of the radar net other than the Paine, Neah Bay and Pacific Beach portion and for the poor intercept rate."*

3038 In some instances, the failure seems to have been due to lack of specific men and lines assigned to track cross-telling. The failure was also associated with overburdening of the plotters at the stations due to the antiquated plotting methods in use.

g. Imperfections in the Air-Situation Picture at the ADCC

3039 The lines from the GCI station to the ADCC are easily saturated, leading to loss, delay or inaccuracy of data. The ease of saturation is due to:

(1) Insufficient numbers of telephone lines;

(2) Imperfect filtering at the GCI station, so that line time is wasted in telling of coordinates on tracks of friendly planes, and plotter time at the ADCC is wasted in plotting these tracks;

(3) Inefficiency of the method of verbal coordinate telling for reproduction of a picture. This is aggravated by misunderstandings and queries.

3040 The imperfect filtering at GCI stations also imposes both a need to carry on filter operations at the ADCC and a reduction in clarity of the air-situation picture because of the presence of friendly tracks.

h. Division of Control of the Air Battle

3041 As a result of the limitations outlined above, the air-situation picture at the ADCC is frequently less complete and current than that at the GCI stations, so that control of the battle from the ADCC is a doctrine difficult to maintain.

*Operation Whipstock, 18-24 June 1950; Operations Analysis Report No. 3, 20 September 1950.

The local GCI's, on the other hand, see only a part of the total relevant air situation, and hence run the risk of deploying their available fighters unwisely.

3042 The present compromise solution is to have the Chief Controller at the GCI direct the scrambling of the aircraft assigned to him, but to leave the Commander at the ADCC the authority to veto or override the Chief Controller's directions. The Commander at the ADCC also influences the battle prior to its inception by directing the allocation of forces to the various airfields and to control by the various GCI stations. It seems to be agreed that a more complete control of the battle by the Division Commander would be desirable.

3. Discussion of Suggested Remedies

a. Physical Separation of the Plotting-Filtering Function from That of Intercept Control

3043 It is recommended that at the GCI station two separate rooms should be created, one containing a "dirty" or work board for the filtering operation, and the other containing a "clean" or filtered board for display to the controllers.

3044 In an AN/CPS-6 or AN/FPS-3 station, the separate rooms can be obtained by removing the end wall of the operations room, extending the building and erecting, in the larger space thus provided, a dividing partition of translucent material. The controllers and antiaircraft (AA) officers would remain in the present operations room, which would be called the control room. In the new room on the other side of the partition would be stationed the plotters, an IFF (Identification, Friend or Foe) and a height-finding operator, cross-telling personnel and the filter officer. This would be called the filter room. The work board, which should be horizontal, would be in the filter room, while the translucent partition would serve as a vertical plot board on which the filtered picture could be displayed for the controllers and AA officers in the control room. The integration of the AA personnel into this system is discussed in detail in Para. 3109 et seq.

3045 Part of the dividing wall (to the right and left of the clean air-situation picture) could be devoted to status boards and a tote board visible to the controllers, on which are displayed fighter-status information and ancillary information on the tracks appearing on the clean picture. A larger tote board in

the filter room could display the ancillary information corresponding to the more numerous tracks appearing on the work board.

3046 It is believed that this division will result in more order in the operations room, and will provide greater clarity in the presentation to the controllers. A drawing of the suggested building modification is presented in Fig. III-2 and discussed below.

b. Photographic Method of Constructing Work-Board Picture

3047 The first step in the data processing is the transfer of unfiltered track data from an oscilloscope screen to the dirty plot board. PROJECT CHARLES has been impressed with the weakness of the existing method, in which an effort is made to transfer a detailed picture point by point, with each point requiring:

(1) Recognition by the radar observer;
(2) Estimation of coordinates;
(3) Verbal expression on a telephone line;
(4) Comprehension at the receiving end of the line;
(5) Location of the corresponding point on the plotting board;
(6) Making the desired crayon mark.

3048 We are convinced of the inherent superiority of a photographic process over the telling process for reconstructing the radar picture on the work board. Electronic processes similar to television also have many of the advantages of the photographic process, in addition to further advantages in ease of "piping" the information over short distances; but the present state of development of these electronic processes has led us to discard them in favor of photography, which gives a much clearer picture with much simpler equipment, and which can be made operational in a shorter time.*

(1) The TPI Process

3049 One photographic system, known as the target position indicator (TPI) process, has been under development for some time and has undergone trial

*Other methods considered for improving the plotting operation are listed in Appendix III-1, together with our reasons for not including them here.

both at the Santini radar station and by Operations Development Force.* It has been demonstrated that such equipment increases the tracking capacity per plotter by a factor of approximately five, but that the apparatus has several defects which make it unsatisfactory in its present form:

(a) The high-speed wet development process is mechanically complex and tends to break down. This is the greatest drawback and is a purely technical fault.

(b) Elaborate servicing at frequent intervals is required.

(c) The projection is from a negative film. This makes it difficult to combine information from successive frames by additive projection.

(d) The system depends entirely on the electronic MTI (moving target indicator) for clutter rejection.

(e) The system presents the targets as blobs or points, rather than as tracks on the first projection board.

(2) The Proposed Process

3050 The photographic system herein proposed overcomes the above defects of the TPI process; it does not necessitate development of any new processes or essentially new equipment, but requires only mechanical integration of types of equipment that have already been well proven.

3051 The comparison here made is between a proposed Land process and the TPI equipment in the forms it has had in the recent trials mentioned above. Further development of the TPI equipment will probably result in great improvements and should be encouraged. However, we believe the Land system ultimately has a fundamental advantage in that the processing problems are dealt with in a photographic manufacturing plant rather than at a radar station.

3052 The photographic process here proposed is the Land process, which uses special film and a dry quick-development technique that is thoroughly tested and reliable. A transparent positive is produced directly, thereby allowing additive projection of successive exposures.

3053 Each frame of the film would be exposed to a PPI (plan position indicator) scope for one or more revolutions of the antenna, thereby integrating and

*COMOPDEVFOR Final Report on Project OP/S113/S67-5; Evaluation of the Photographic Radar Repeater, Model VP.

storing the electronic information received over a period of time between approximately 20 and 30 seconds. The advantages of keeping this period fairly long are economy of film, overcoming effects of fluctuation of reflected signal, and allowing the track-marking personnel adequate time to scan the image.

3054 The film would feed into a series of at least three projectors, which simultaneously project through differently colored filters onto the same screen. Stationary objects then appear in the mixed color (yellow if the separate projections are red and green, or white if they are red, green and blue), while moving aircraft appear as a sequence of differently colored dots. Thus, aircraft are distinguished both by color and by design of the image. (An alternate to the color method of distinguishing moving objects would be the use of a sequence shutter, causing flicker.) The tracks that are formed show the direction of motion, and the separation of the dots also allows an estimate of the speed.

3055 The projection would be from below, onto a horizontal translucent screen which is the dirty or work board. Around this board would sit track-markers who mechanically connect the projected colored dots with crayon lines. Other details of the work board will be discussed in later paragraphs.

3056 It is recognized that the making of optimum choices regarding certain of the details of the system requires tests that have not been performed.

3057 Use of the proposed photographic presentation on the dirty board is expected to accomplish the following system improvements:

Multiplication of capacity of the first plotting process:- The only human tasks remaining are the connecting of images on the board by crayon lines, the writing-in of track numbers, and the erasure of old lines. The constant brightness of the image allows these tasks to be distributed in time to produce maximum efficiency and ease.

Increase of accuracy:- Human judgment is eliminated in the transfer of data from one picture to another. (At present, two errors of estimation enter: one in converting the original blip into coordinates, the other in converting coordinates into a mark on the plotting board.)

Increase in probability and range of detection:- This should arise from several features of the photographic process, which have been supported by preliminary tests.

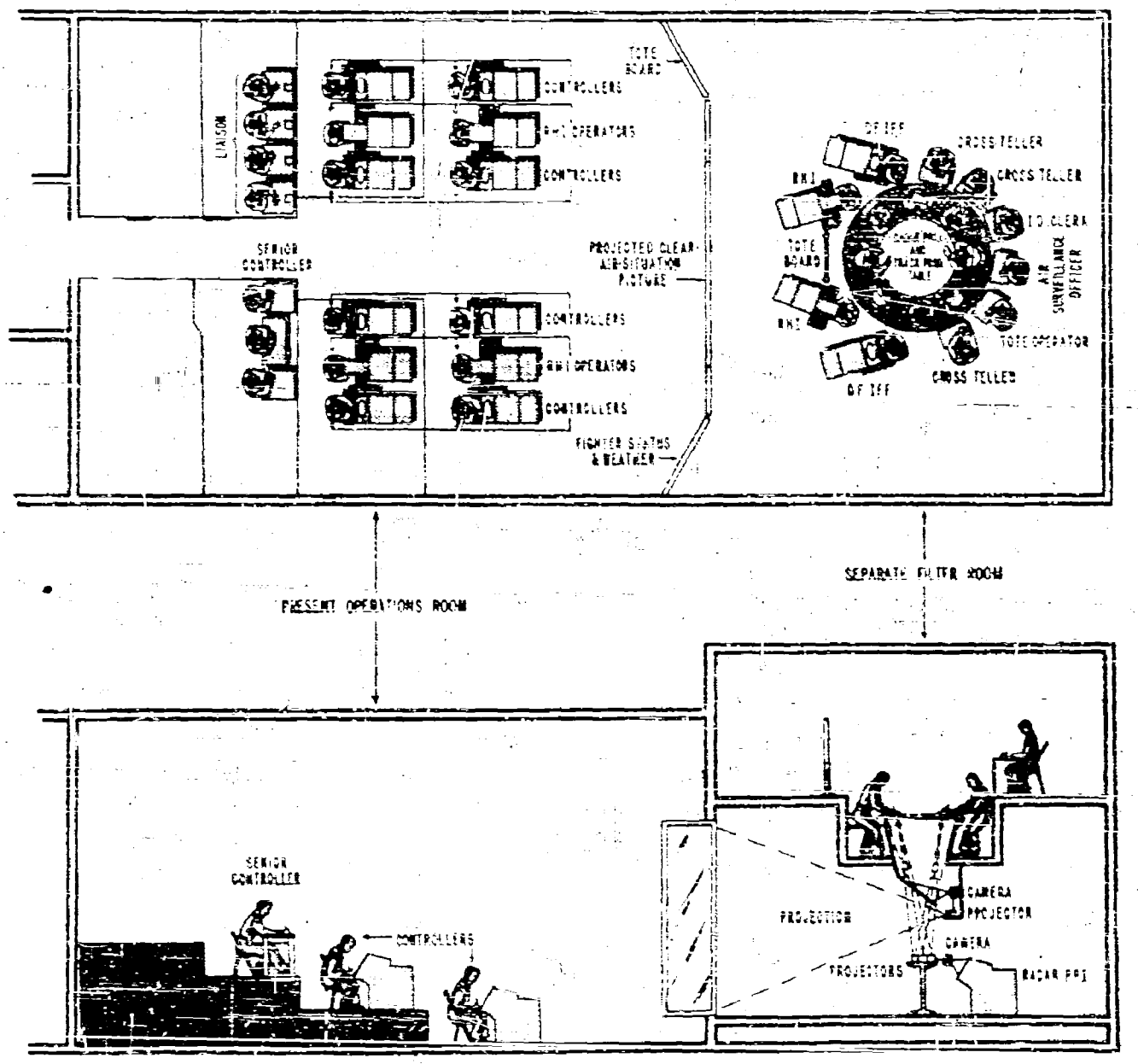


Fig. III-2 Proposed CHARLES modification of operations rooms.

(a) The distinctive appearance of the projected images;

(b) The removal of pressure from the plotters, allowing them to spend a large part of their time scanning their sectors for new tracks;

(c) The constant brightness of the image, which increases the time in which efficient detection is possible;

(d) The contrast obtainable with the photographic process;

(e) The possible exposure of each frame for several revolutions of the antenna, and the simultaneous projection of several frames, which make the track visible even when some of the returns are absent because of signal fluctuation.

Reduction in personnel involved in the first plotting process: – The radar observers are eliminated, and, for a given traffic load, the number of plotters needed is reduced.

3058 The only large demand of the proposed scheme is for film. The rate of consumption by the process has been analyzed, and does not seem to be excessive, from either the point of view of cost or of capacity of the industry.

3059 Regardless of the question of economy of film, it seems desirable to recommend limited use of the photographic scheme. In certain areas and at certain times of day, the air traffic is so low as to justify using present methods instead of the photographic system. In such areas, the photographic process could be used for only a few hours each day, so as to be in readiness in case of a heavy raid.

c. Addition of Information Received by Cross-Telling

3060 An estimate of the capacity of the track markers to draw crayon lines over the projected colored dots of the proposed process is about 20 to 30 tracks per man per minute. Therefore, even under conditions of heavy air traffic, only three or four track markers would be needed. Interspersed between these track markers around the work board should be personnel to receive and plot track data from neighboring radar stations. Such personnel are shown schematically in Fig. III-2.

3061 The personnel on the dais overlooking the work board, correspondingly, should include men with telephone facilities for the purpose of telling to neighboring GCI stations the data on tracks approaching crossover into the adjoining

areas. The doctrine or judgment as to which of all the crossing tracks should be cross-told must vary with the specific locations of the stations. As a minimum, information must be given on all hostile tracks and on tracks that may appear potentially hostile at the neighboring GCI station.

3062 The proposed work board at each station would have a diameter of about 5 feet. The local radar picture would be displayed on the central portion of this board, within a circle about 3.5 feet in diameter, leaving a peripheral area specifically for plots of approaching aircraft. The information would be received verbally over land lines and plotted manually as at present.

3063 The only recommendation regarding facilities for the application of cross-told information is that the telephone lines and men provided for the task be made adequate. Separate lines should exist for receiving and telling. In general, one of these lines should be duplicated; which one will depend on the direction of the larger amount of traffic. For instance, because of the probable approach routes of enemy planes, little track information must be told from a radar station to its northern neighbor, but a comparatively large amount must be received from this neighbor. The amount to be received can easily exceed the capacity of a single line in the event of a raid, or in some areas even with normal traffic.

3064 The handover of intercept, which may be necessary when an interception passes out of range of the station where it originated and into the range of another, must not be done over the same lines required for the cross-telling discussed above. Such handover requires a separate line to which the controllers at both stations have access, so that the information may be accurate and undelayed.

d. Reduction of Writing on Work Board

3065 It is recommended that the only written information added to the track display be the track numbers. All other ancillary information, such as height, speed, and raid size, should be displayed on tote boards. A tote board in the filter room would contain information on all the tracks on the board, while the tote board on the other side of the partition (in the control room) would contain only data on the tracks in the filtered air-situation picture.

e. Uses of Teleregister Equipment

3066 A rather large amount of data needs to be displayed in tabular form in several locations. In the filter rooms, a tote board is required, listing track number, height, speed, raid size and identification for all tracks appearing on the unfiltered picture. In the control rooms and at the ADCC, tote boards must list these data for the filtered tracks. The control rooms must also have fighter-status boards showing the readiness conditions of interceptors at the air bases, target and radio-channel assignment data for the aircraft scrambled, and status of the interceptors (time scrambled, time airborne, time of return to base, and remaining fuel and ammunition). The ADCC requires fighter-status boards showing similar fighter data in summary, or abbreviated, form. The squadron operations rooms at the airfields require status boards showing aircraft alert status and scramble data; field boards are necessary at the airfields for posting initial vector and altitude data.

3067 At present, these data are in general communicated by voice telephone and posted by handwriting. This is expensive of time, personnel and telephone lines; it leads to errors and need for repeat-backs; it takes up space and adds noise in operations rooms.

3068 It is recommended that this telephone procedure be replaced by an automatic system employing equipment of the sort manufactured by the Teleregister Corporation.* This would provide posting boards with indicators operated by electromechanical relays, controlled by keysets over telegraph lines.

3069 Using such apparatus in the filter rooms at the GCI stations, assistants to the tote board supervisor, sitting on the dais overlooking the unfiltered plot board, could automatically post, by use of keysets, the information on course, speed, altitude, raid size and identification for each track number; these items would instantly appear in tabular form on the tote board. When tracks are declared bogey, or recognized as hostiles or friendly fighters, the same data could be automatically keyed into the tote boards in the control room and at the ADCC.

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*See Technical Memorandum ENRCS – E.O. 162-16 ("Interceptor Posting System for Air Defense Centers"), 18 May 1951.

3070 In the control rooms, the controllers would have keysets with which they could set into the status boards (at the GCI and ADCC) the tabular data on the status of aircraft and interceptions, and could automatically make scramble data appear at the airfields on a field board and in the squadron operations rooms. A keyset at the squadron operations room could allow up-to-date information from the airfields to appear automatically at the control rooms and at the ADCC. A detailed plan for the various status boards is given in the technical memorandum cited. While this plan needs further study and revision, it serves as an example of the sort of layout and interconnections that would be possible.

f. The Filtering Operation

3071 At present, an initial filtering is performed by the radar observers. Use of the photographic process would eliminate these observers and would create a capacity to produce tracks of all the aircraft on the dirty plot board, thereby permitting a filter officer on the dais overlooking the board to have control of the entire filtering operation.

3072 At present, furthermore, a subsequent filtering has to be performed at the ADCC, because it is here that the most complete and up-to-date flight-plan information is available, and here that direct lines to the Civil Aeronautics Authority (CAA) traffic control centers and Military Flight Service (MFS) exist. It is recommended that such lines be made available directly to the filter rooms of the GCI stations, and that a satisfactory plan for the flow and presentation of flight plan information be effected, so that complete and up-to-date information will be available at the filter rooms. This recommendation is intended to:

(1) Permit the ADCC to take action more quickly after receipt of a plot;

(2) Reduce the amount of data that must be transmitted from each GCI station and entered on the ADCC plot board;

(3) Speed up the obtaining of identification at the GCI stations;

(4) Improve the clarity of the air-situation plot at the ADCC;

(5) Improve the cross-telling between GCI stations by increasing their capability to transmit identification.

3073 The mechanics of the filtering operation and production of a clear air-situation picture are described in greater detail in Appendix III-2.

g. Presentation of Filtered Picture to the Controller

3074 The work board would be photographed at regular intervals from below with a second Land camera, using a selective process such that only those tracks appear that are drawn with the crayon reserved for the clean air-situation picture (bogies, hostiles, and possibly friendly fighters). The resulting picture would be projected on the wall that is visible to the controllers. The filtered picture would at the same time be transmitted to the ADCC by methods discussed below.

3075 Several means for the selective photography are possible, all of which use only standard types of equipment. One familiar method is the use of color filters, with an edge-illuminated work board.

h. Communication of Filtered Picture to the ADCC

3076 Two methods of communicating the filtered picture are discussed below: the voice-telling and manual-plotting method currently in use, and the application of moderately fast automatic facsimile transmission with optical projection at the ADCC.

(1) Voice Telling and Manual Plotting

3077 Even with fairly complete filtering at the GCI stations, the tracks remaining to be told over lines in case of a concentrated attack are likely to be so numerous that, with present line facilities, only an inaccurate, incomplete and delayed air picture could be presented at the ADCC. This is suggested by the air exercises that have been performed, in which, we are told, there has never been a complete and current air-situation picture at the ADCC's.

3078 One of the fundamental current limitations of the cross-telling to the ADCC is that imposed by the existing number of telephone lines. In the present AC&W network and in the planning of the so-called "permanent" chain, one finds in almost all cases only two voice-telephone lines connecting each GCI station with the ADCC. One of these lines is likely to be tied up with the commands,

queries, identification information and the like, leaving only a single line for receiving track data. Even if the normal traffic is grounded or thoroughly filtered, this line can be saturated by a raid of just a few planes, together with the fighters scrambled to meet them. Some stations, particularly along the northwest Canadian border, appear to have only single telephone lines in the plans, and therefore are even more limited in capability.

3079 For the time interval in which the system of voice telling and manual plotting must be retained, the following recommendations are made to alleviate the difficulty.

(a) In cases when the capacity limitation is serious, there should be no telling of friendly fighter tracks, and the status of interceptions should appear only on the status boards.

(b) Ancillary information should not be communicated over the speech channels, but only track coordinates and numbers. Teleregister equipment should be used for the ancillary information and for interceptor status. This equipment can pass the information in narrow frequency bands of the voice lines or over the present teletypewriter circuits.

(c) The number of voice channels available for communication between GCI stations and ADCC should be increased.

For security of the system, it is advisable to make the new channels independent of the existing ones. Then one set of lines can also serve as a backup for the other.

The exact number of lines needed depends on a guess as to the possible magnitude of an attack, hence cannot be reliably stated. A reasonable minimum would be one line for command purposes only, plus three lines for track telling.

Looking forward to both increased enemy capability to mount a heavy attack and an improved method of picture transmission (facsimile), we recommend that the additional channels be established by installing single 30-kc bandwidth equalized lines. These can be installed by the Western Union Telegraph Company, and could be used either for facsimile transmission or to provide about eight voice-telephone channels.

(d) Men should be made available at the ADCC for increased assignment to receiving and plotting data from any GCI where the requirement is high. It is not likely that the number of hostile planes will simultaneously be large in all the GCI stations sending information to the ADCC; hence it would probably be sufficient to have about 15 plotters available for receiving and plotting the information from about 9 sources.

(2) Facsimile Transmission and Projection

3080 The discussions and recommendations given above point up the inherent

capacity limitation in the method of point-by-point voice communication of pictorial data. A method that takes no longer to transmit one hundred tracks than a single one is the method of optical scanning, with transmission of the electrical signals determined by the amount of light reaching a detector.

3081 For such facsimile transmissions, essential considerations are the resolution required and the time available for data transmission, because these two elements determine the required information bandwidth. The requirement for promptness of data limits the time of transmission to about one minute, and the requirement for clarity of the picture determines a minimum resolution of about 1000 lines.

3082 Facsimile equipment satisfying these requirements has been developed by the Radio Corporation of America (RCA) for use by the Atomic Energy Commission in rapidly transmitting graphic information from the Oak Ridge library to remote laboratories. The electronic information can be sent over high-frequency radio channels or over land lines. The information bandwidth is about 17 kc and the total bandwidth close to 30 kc, requiring equalization to within a delay tolerance of plus or minus 50 μsec over this band. Special telephone lines are required to fit these conditions.

3083 The Western Union Telegraph Company already has some lines in existence that have the required bandwidth and delay tolerance. A tentative and informal estimate of the operating cost of such lines is roughly one million dollars annually, which is small compared with the total cost of all the rest of the telephone service. Installation of the lines would involve a cost comparable to a few years' service. As mentioned above, even in the event that facsimile transmission is not used, such lines are desirable in order to increase the number of independent voice-communication channels.

3084 The existing RCA equipment makes, at the receiving end, a photographic copy on opaque paper. A desired change or addition to the process is to have the copy emerge on a transparent backing, so that it can be fed directly into optical projectors at the ADCC. Corresponding to each station that sends pictures to the ADCC, there would be a projector so oriented that the simultaneous projection of all the pictures on the wall forms a composite map of the entire area of coverage. The projected images should preferably be positives

(showing bright tracks on a dark background) because of the existence of overlap areas covered by more than one station. The simultaneous registry necessitates mechanical and optical precision in the projectors, but the requirements are not considered excessively difficult.

3085 With the system described above, the ADCC would not be able to erase tracks without having them erased at the corresponding GCI station. On the other hand, there would be assurance that the ADCC has the complete air-situation picture visible to the controllers.

i. Command of the Air Battle

3086 The question of whether the individual scramble orders should originate at the ADCC or at the GCI stations has been considered. It is clear that, at present and in the past, it has not been possible for the air-situation picture at the ADCC to be sufficiently accurate and prompt to permit placing such detailed command at the ADCC. It has seemed clear to us that, even for the exercise of a sort of supervisory control and for occasional overriding of decisions of the Chief Controllers, it was necessary to make the air-situation picture at the ADCC be as good as that visible to the controllers. If these recommendations accomplish their objectives, the capability for detailed command at the ADCC will also exist, and it will be possible to test the effectiveness of such command in air exercises.

j. Summary of Time Delays in Proposed System

3087 There are two kinds of time delay that are of interest in the reporting process: the staleness of the most recent data in the filtered air-situation picture, and the delay in evaluating a new track and issuing a scramble order.

(1) Staleness of the Data

3088 Staleness of data affects the accuracy with which present aircraft positions can be predicted. It is of utmost consequence to the controllers and antiaircraft commanders in the act of acquisition of a new track to be engaged. Once the controller or battery commander has located the track, he works entirely off his own scope and hence has up-to-date information while directing the engagement.

3089 The delay is the sum of four parts: the film exposure time, the development time of the radar picture, the time allowed for review of the radar picture on the work board, and the development time of the selective photograph of the filtered tracks. The development times are estimated to be about 15 seconds each. We have considered several alternative schemes for using the photographic process, some of which involve exposing single frames to several sweeps of the antenna. Depending on which scheme is finally adopted, the staleness of the data presented to the controllers will be from one to two minutes. This is about the same as the time delays now occurring in the stations, except under special conditions of very light or very heavy traffic.

3090 At the ADCC the data will be older by the time required for transmission, which is about one minute by the facsimile method. However, at this point the delay is not so serious as in target acquisition.

(2) Delay in Evaluating a New Track and Issuing a Scramble Order

3091 For a new track, one must add the following delays to those listed above.

(a) The delay in the filtering process at the GCI station;

(b) Time for transmission of filtered picture to the ADCC (one minute);

(c) Delay in evaluating air situation and deciding on scramble order.

3092 Of these delays, the time for transmission is the smallest. It is hoped that the delay in evaluation and decision will be reduced significantly as a consequence of increased clarity in the air-situation picture.

k. Suggested Arrangement of GCI Station, Incorporating Proposals

3093 The foregoing paragraphs have set forth the aims and techniques of the proposed early improvements in the radar station. This subsection is devoted to an actual arrangement that we believe to be integrable with the existing construction of the permanent-site radar program. It has been designed to utilize virtually all the existing indicators, cabling and facilities that are now being installed in the operations rooms of the permanent radar stations. The proposal is:

(1) To retain the existing operations rooms in toto and to utilize the facilities there for control of weapons only;

(2) To add to the back of the existing operations room a new room, roughly the size of the present operations room, which would be devoted entirely to the detection and filtering of the raw radar data, the presentation of the clear air-situation and the cross-telling of tracks of interest;

(3) To separate the two rooms by a sound-proof wall in which are installed the screen for photographic projection of the clear air-situation, and the teleregister presentation equipment for the tote and fighter status boards.

Figure III-2 shows the proposed arrangement in detail.

3094 It is seen in this illustration that the filter room uses a horizontal raid plotting table for the plotting of the unfiltered air situation. The local radar picture is projected photographically on the center part of the undersurface of the table by the camera described previously. The men sitting around the horizontal table plot cross-told track information on the outer periphery of the table, and mark new and old tracks produced by the local radar.

3095 The dais surrounding the horizontal plot provides a platform commanding a view of the horizontal plot, at which may sit the following people:

(1) The filter officer who is in charge and is responsible for the production of the air-situation picture;

(2) The tote board and identification supervisory officer. This officer is responsible for seeing that every track carries on the tote board the following ancillary information: height, speed, raid size, result of IFF interrogation, and result of attempted flight-plan correlation.

(3) One or more assistants to the tote board supervisor, who operate keysets for the teleregister equipment used for display of the tote board, and who correlate flight plan information.

(4) One or more range-height indicator (RHI) operators;

(5) One or more IFF interrogator operators;

(6) One or more VHF or UHF direction-finding (DF) operators;

(7) Personnel for cross-telling to adjacent radar stations.

3096 The actual function and number of the personnel required around the table and on the dais can be determined only by operational trials, and will be dependent on the traffic density in the area of the radar. The foregoing enumeration is mainly to set forth a possible scheme.

3097 The horizontal plotting board will have only tracks and track numbers written on it, and the ancillary information will be displayed on the tote board. New tracks, not yet assessed, will be drawn in a first or neutral color.

Those tracks that are identified as friendly and are judged to be of no interest to the controllers or the ADCC will be written in a second color; the balance of the tracks – bogies, hostiles, and friendly fighters – will be written in a third color. Tracks written in this latter color, which constitute the clear air-situation picture, are rephotographed selectively by color filters from below. The clear air-situation photographs can then be sent by high-speed facsimile wire circuits to the ADCC, and can also be projected on the screen at the radar station. The ancillary information is displayed in the tote boards in both rooms at the GCI, and is displayed remotely at the ADCC by teletype wire and teleregister display.

1. Summary of Telephone-Line Needs of Land-Based Systems

3098 In more than one section above, the need for more telephone lines has been expressed. It is thought desirable, therefore, to summarize in the present section all the needs that have been recommended for the reporting part of the system. This applies to a normal area, not an area of very low traffic density or an area of extremely high traffic density.

Lines between neighboring GCI stations: –

(a) For telling and receiving track data: 3 channels.

(b) For handover of intercept control: one channel. This line is for handover of intercepts that go out of the range of one radar station and into a neighboring area. The line should be accessible to the Chief Controllers in both areas, with switching to permit putting any individual controller on the line.

(c) Total interconnecting lines needed: 4, as compared with 2 or 1 in the present plans.

(d) Since the Canadian radar network must be regarded as an integral part of the air defense system, the cross-telling and handover procedures must be made possible by establishment of lines between adjacent stations on opposite sides of the border, as well as within our borders.

Similarly, cross-telling and handover procedures (and lines) must be just as complete for neighboring stations in different Air Division as for stations within the same Air Division.

Lines between GCI stations and control centers: –

(a) Command line: one.

(b) Lines needed for track data if voice telling is used: 3 (minimum).

(c) Line needed for facsimile: one special line, 30-kc bandwidth equalized for ±50 μsec delay tolerance. This is an alternate requirement to increasing the number of ordinary telephone lines.

(d) Teleregister data probably can be transmitted on existing lines.

(e) Summary: An addition is needed of either one 30-kc line or about 3 ordinary lines. The 30-kc line would give greater capacity, and is to be preferred.

Lines to traffic-control centers: –

(a) One line to nearest MFS traffic-control center.

(b) One line to nearest CAA traffic-control center.

Lines to future Ground Observer Corps filter center: – This number has not been calculated but lines for this purpose must be taken into consideration along with any plans for implementation of the Ground Observer Corps (GOC).

m. Use of Photographic Records for Improving the System

3099 The photographic methods proposed above possess the great advantage that they leave permanent and detailed records, both of the raw radar data and of the filtered track-boards at the GCI stations and the ADCC's. These records are available after exercises or real attacks for slow projection and careful study of the flaws in the system. It would be possible to run through situations of many varieties again and again, trying to estimate what would have occurred if certain changes in tactics had been employed or certain judgments had been altered. Such studies and rehearsals should assist materially in the continual improvement of the operations. In addition, the records could be used for the training of personnel in the AC&W net.

n. Gradual Application of Proposals

3100 The improvements recommended have the virtues of flexibility in use and of being valuable even if only partly implemented or if installed in only part of the system. This eases the problem of application, without disruption of current operations.

3101 The approximate order in which we conceive the proper steps in application of our recommendations is as follows:

(1) Further test and development of the details of some of the proposals – to proceed immediately. This program should include: (a) detailed architectural study of the proposed operations room modifications; (b) detailed study and layout of status and tote board forms; and (c) trial and modification of the Land camera and development of the projector apparatus.

(2) Letting of contracts for certain parts of the work that are not irrevocable commitments for ultimate use, particularly for engineering and beginning production of the flying-spot facsimile equipment, the Land cameras and the projectors, and installation of the 30-kc lines. If these steps are much delayed, the delay will have far-reaching consequence. The costs can be justified without regarding these steps as a commitment for acceptance of the entire group of proposals.

(3) Erection of a temporary GCI operations room setup embodying the proposed changes in apparatus and arrangement, in a temporary building near enough to the permanent operations building of a GCI station so that the video signals could be fed in-parallel into both buildings. Then, without interfering with the normal operation of the site, more complete tests of the proposals could be made under more realistic conditions than those in the laboratory. After some experimenting with the operating procedures by research personnel, operation by military personnel could be tried.

(4) If the above tests indicate that the proposals constitute worthwhile changes, modification of successive permanent stations could begin.

3102 It is recommended that a temporary operations building paralleling the permanent building at a GCI station be retained as an experimental station even beyond the needs of testing the proposals made in this Report. In this building, further developments in apparatus and suggested changes in operating procedure could be tried under realistic conditions without disturbing the air defense system. For continued improvements of the system, such a building would be a major asset, especially if it were closely allied with the laboratories in which the proposed developments are pursued.

3103 Better data-processing techniques, including better communications, appear to be essential to the early improvement of the existing aircraft control and warning system. The low traffic capacity of manual plotting by voice telling can be

overcome by the use of photographic procedures logically fitted into the system as a whole. Transmission of clear air-situation data from GCI station to Air Defense Control Center could be improved by facsimile methods already developed.

D. INTEGRATION OF LOCAL AIR DEFENSE WEAPONS

3104 The use of local defense weapons as a part of an air defense system has traditionally presented a serious problem from two points of view: the first arises in connection with target acquisition and tactical direction of fire units, and the second has to do with the problems of the use of local defense weapons in areas in which fighters are operating.

1. Information Requirements for Local Air Defense Weapon Battalions

3105 The operation of local air defense weapon battalions requires from a surveillance net the following types of information:

(a) General alerts for putting the battalions into condition where they can commence firing.

(b) Accurate target position data on targets to be taken under fire.

The requirement for alerting is a consequence of the fact that batteries cannot be maintained ready for immediate fire for long periods of time, but in general must be given an alert to allow manning and warmup of the equipment.

3106 Clear, complete and current data on the air situation are necessary for the officer who must give these alerts, since the frequency of these alerts must be balanced against fatigue and equipment-failure factors. For actual fire, coordinates of targets, relative to the batteries, must be given the firing units. The ability to give these coordinates presupposes a completely filtered air-situation picture, which implies that all friendly aircraft have been properly identified. This is a difficult problem for urban area defense in the continental United States, where the emplacement circle of the batteries is likely to surround the local metropolitan airports; consequently, the batteries may have to be able to distinguish a few hostile aircraft mixed in with a relatively large number of friendlies.

2. Present System for Control of Local Air Defense Weapons

3107 The doctrine of employment and the methods of operation of local defense weapons are being reviewed and modified. In general, however, the system involves* the provision of an operations room where the tactical operational control of the weapons is carried out, and an information service (air surveillance and intelligence) to provide the required air-situation picture for the Antiaircraft Operations Center (AAOC). Functioning of this system requires that the basic air situation with friendly and hostile tracks be provided from the Air Force AC&W net and then to be retold and replotted several times before the target coordinates are issued to the firing units. The acquisition time will be determined by the time delays and errors in this replotting process rather than by the delays and errors of the original radar data.

3108 Integration of surveillance and acquisition radar information obtained by AA-operated radar also is attempted at the AAOC. However, the magnitude of the air traffic in most areas where local defense will be used is such that little prospect exists that the AAOC can carry a complete and accurate local air situation; and the successful integration of highly complex local radar data is a remote possibility. In certain areas (notably, Hanford, Washington), it may be possible to establish a local surveillance system that is capable of developing an accurate local air-situation picture, but in general the utility of the local defenses depends on the accurate transfer of the air-situation picture developed by the perimeter radars of the Air Force net. In view of rapid degradation of an air-situation picture by repeated plotting and telling, it seems unlikely that the present system will be adequate.

3. Proposed System for Control of Local Defense Weapons

3109 We believe that the provision of data and the control of local defense weapons can best be accomplished by carrying out all the functions of the AAOC physically in the control operations room of the nearest appropriate radar station of the Air Force net.

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*See FM 44-8, AAOR and AAAIS, 10 August 1944 (currently in revision).

3110 The removal of track procuction, identification and filter personnel from the control room of the radar stations, as proposed in Para. 3043 will make available space in this room for the AA control personnel. The proposal is illustrated in Fig. III-3, where the AA Operations Officer and the Senior Fighter Controller are shown seated side by side; the upper level of the control room is made available to personnel who tell target coordinates to the AA firing units. These personnel are given standard PPI and RHI scopes; by off-centering of the PPI and the use of suitable overlays, they will be able to call target coordinates to firing batteries in range and azimuth with respect to the batteries. The data so told will be highly accurate and current. The four fire units of each battalion can probably be controlled on a party-line telephone circuit. Parallax correction will be required for some fire units, and devices exist for this purpose. Assignment of weapons to various targets and in various areas would be made by the AA Operations Officer in the radar station, and a status board for the AA units would be provided.

4. Operational Use of Local Defense Weapons as a Part of the Air Defense System

3111 The use of local defense weapons in the presence of friendly air traffic and interceptors has the same difficulties of determining when to shoot as are encountered in the interceptor case. The problem has additional complications in that visual checks are usually impossible, and in that fighter aircraft are frequently operating against the same targets.

3112 Certain rules* have been established governing the conduct of joint air defense operations and for the establishment of Army staff sections at appropriate echelons of Air Defense Command (ADC) in the continental United States. It is our opinion that this agreement, and having the AA and fighter controllers sitting together with the same air situation, will in a large measure remove the traditional difficulties associated with such joint operations.

3113 Certain administrative and other problems will be raised by the physical remoteness of the AA operations officers from the units they represent.

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*Memorandum of Agreement between the Chief of Staff, USA and Chief of Staff, USAF, 1 August 1950.

There are also other functions that probably cannot be done efficiently at the radar stations, such as the keeping of records and the dissemination of meteorological data. These functions should be retained at the AA brigade or group headquarters, with a small detachment of operations officers and enlisted personnel at the radar stations.

3114 The above arrangements are discussed in terms of the defense of the continental United States. In overseas theaters other arrangements may be required. It is Army policy that their units must be capable of deployment overseas and that they be capable of independent integrated action. We have not examined the overseas problem in detail, but the Project believes there will be very few theater operations where fighters and AA do not exist together. Consequently some Joint Air Defense Operation Center may be necessary, similar to the Joint Operations Center that is now used for the coordination of Tactical Air Commands in support of field armies.

3115 Local antiaircraft defenses can be more effective if the AA operations room is made part of the GCI station.

3116 The AA controllers at the GCI station should have their own PPI presentations to direct the acquisition of targets by the batteries' fire-control radars. This procedure should be introduced now so that it can be fully operational when more effective local defense weapons become available.

E. COMMUNICATIONS AND DATA PROCESSING IN THE FLEET

3117 The problem of air defense operations at sea has various features that make the situation different from that in the continental United States, but the basic requirements -- the production of an accurate and current air-situation picture and the control of weapons -- are the same.

1. Communications

3118 The greatest difficulty in air defense operations at sea is connected with

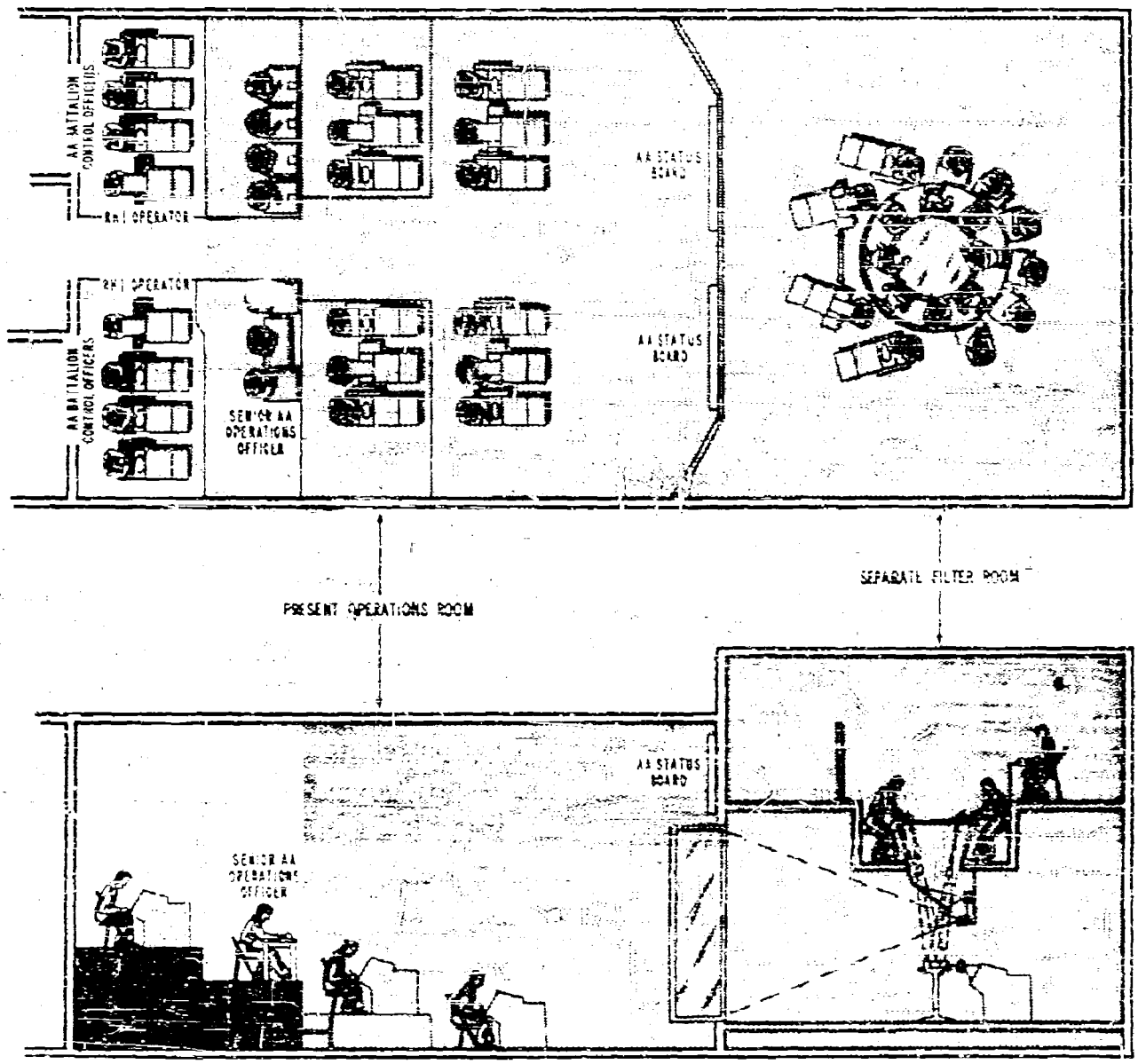


Fig. III-3 Schematic drawing of proposed CHARLES modification of operations rooms.

communications. A task force requires ship-to-ship communication for distances of 100 to 400 miles, chiefly between picket vessels and the main force. The only method currently available is radio ground-wave propagation in the 2- to 20-Mc frequency range. The frequency spectrum in this region is extremely crowded, and consequently the means of communication must be highly efficient. Neither voice transmission nor facsimile is an efficient means of communication in terms of bandwidth utilization; therefore, neither of these seems to be fundamentally suitable for communication between the main force and picket vessels. A further difficulty with these frequency bands is their insecurity, owing to long-range ionospheric propagation which makes them vulnerable to interception and jamming by the enemy.

3119 The requirements for efficient communication and for security indicate the need for powerful, high-information-efficiency and narrow-band data-transmission systems. We believe that the most important work for the Navy to undertake in this field at present is the accelerated development of one such data-transmission system capable of early application in the Fleet over existing medium- and high-frequency radio channels. We understand that PROJECT COSMOS is undertaking a study of this problem in its many aspects.

3120 Recent trials of transmission of UHF and microwave signals beyond the line of sight by means of scattering have shown such transmission to be possible, provided very high antenna gain and transmitter power are used. Knowledge of the fundamental physical processes involved in this type of radio transmission is still fragmentary. Transmission in the wavelength range between 300 and 3 cm may be feasible with large, but practical, antennas and powers, in a horizontally omnidirectional system. We recommend an intensive study and trial of this possibility. Should it prove feasible, the greater bandwidths available will allow the adaptation of facsimile, which has been recommended above for early improvement in the dissemination of air-situation information. In any case, it may make possible the relatively broad-band transmission that may be required for future weapons.

3121 To overcome current difficulties in picket-to-main force data transmission, the Navy should pursue the development of a

narrow-band, high-information-efficiency data-transmission system capable of early application in the Fleet.

2. Possible Improvements in the CIC

3122 The wide variety of CIC installations and operational situations that exist in the Navy have made a comprehensive study of this problem too large a task to be undertaken within the framework of PROJECT CHARLES. We have, however, considered the special situation of a fast carrier task force as used in recent trials,* but with the addition of a number of carriers and other capital ships in the main force.

3123 These trials have shown, in special circumstances, that a sufficiently trained force with adequately maintained equipment can achieve a high degree of defense against high-speed, high-altitude attacks.** Nevertheless, as a consequence of our limited study and the briefings given to PROJECT CHARLES, we believe that, in addition to the ship-to-ship communications problem, the following factors may need improvement:

(a) The traffic capacity of the system in the presence of complex air situations;

(b) The confusion caused by the large number of people and the variety of action and information in the CIC;

(c) The critical dependence of the operation of the task group or task force CIC upon a few key officers of particular skill and experience.

3. Proposed Early Improvements

3124 The specific example of the CV-9 Class CIC is used in this discussion. Figure III-4 shows the present typical arrangement. A particular choice has had to be made, owing to the large number of different arrangements in Naval vessels. It is believed to be a reasonable choice, since this class of vessel is likely to be used for task group command for some time to come. Two proposals are set forth in this subsection, utilizing the techniques discussed in Para. 3043 et seq.

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*OpDevFor Project OP/V42/S67-5 (Revised).

**Ibid., Fifth Partial Report, Fig. 1.

3125 The first proposal is for a limited rearrangement of the CIC which would not appreciably affect the present doctrines in use in the Fleet. The rearrangement is shown in Fig. III-5. The air plot and status boards, along with the gun liaison plot immediately in front of them, have been moved to allow direct photographic projection of the radar data on the air plot board, using the multiple-color photographic positive projection scheme outlined in Para. 3050. Men would be used behind the board to mark and label tracks exactly as they now do, and to plot tracks reported from other vessels.

3126 This scheme has the following advantages:

(a) Radar indicators used in calling plots will be freed for air control work, with corresponding increase in control capacity of the CIC (provided ground-to-air channels do not limit control capacity);

(b) Personnel used for observing radar indicators and calling plots will no longer be needed;

(c) The errors and delays of the present teller-plotter scheme* will be largely removed.

The scheme has the further advantage that it represents a modification that can be made with modest physical alteration and limited changes in doctrine of operation.

3127 The second proposal is a much more fundamental one and follows the aims set forth in Para. 3044 et seq., that is, to separate weapon control activities from the detection and identification activities. This separation is somewhat complicated by the requirement for data on the surface situation in the CIC. The proposal is made to separate the present CIC functionally and physically into two parts:

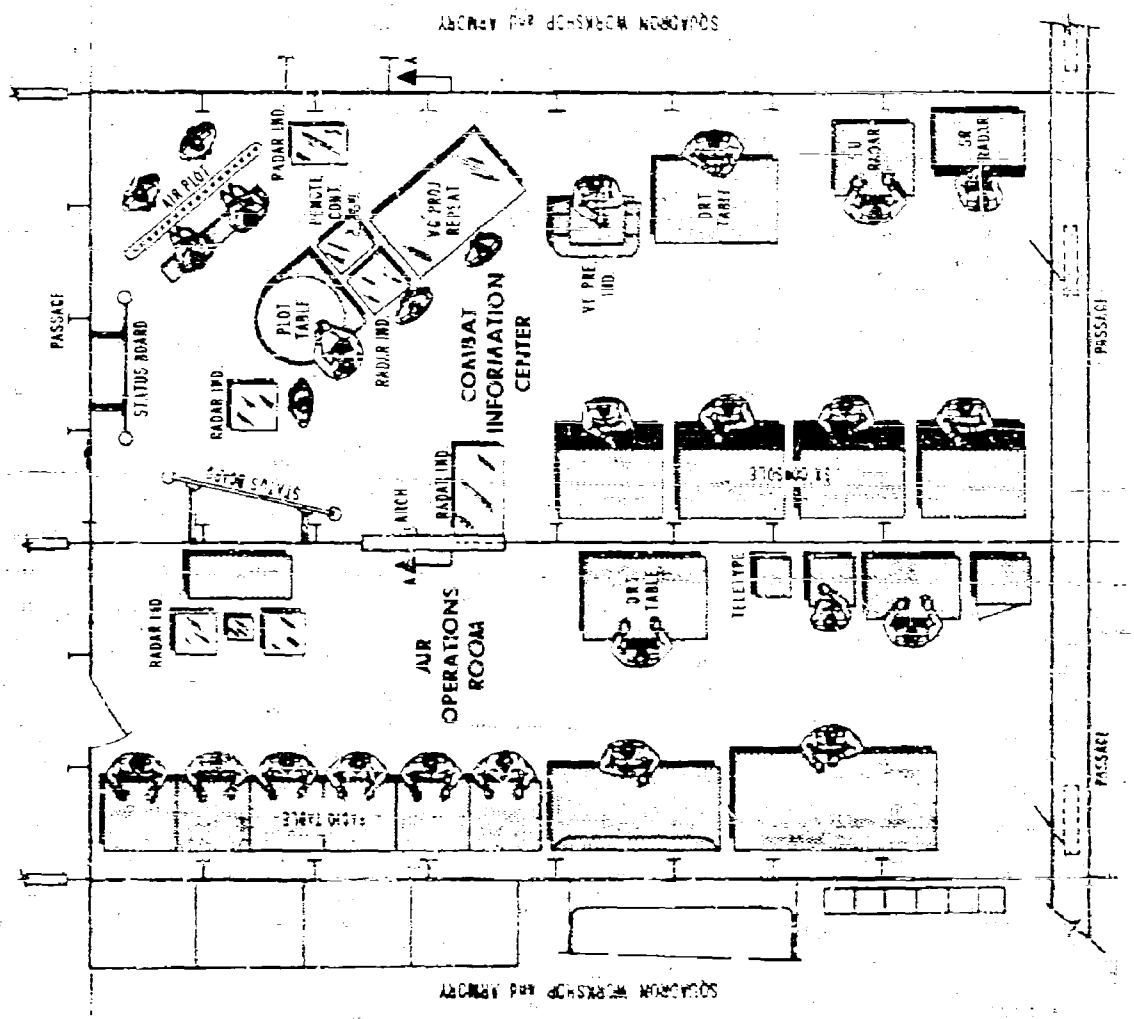
(a) The Combat Information Center, which carries out the detection, identification, filtering, and plotting necessary for the production and dissemination of the air-situation and surface-situation pictures;

(b) The Combat Operations Center, which directs the use of fighters and guns in the air battle.

The two rooms should be separated by a soundproof bulkhead with transparent screens for the projection of the situation pictures.

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*ComOpDevFor Final Report on Project OP/S113/S67-5



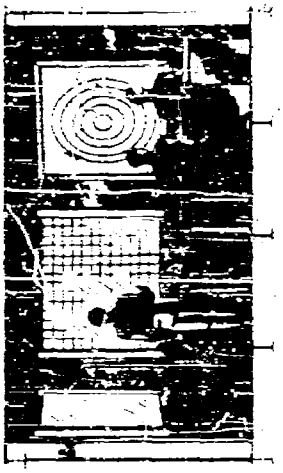


Fig. III-4 Combat information center of CV-47 PHILIPPINE SEA.

3128 We believe that such a separation will lead to a much more efficient functioning by reducing the noise, confusion, and interference that now exist in the CIC's and by clarifying the presently complex relation of informational and operational activities that take place in the CIC.

3129 Fig. III-6 shows an arrangement for such a scheme, utilizing the space now allocated to the CIC and the Air Operations Room. No investigation of the feasibility of this arrangement has been made. Whether or not this particular arrangement is possible, we believe that the Navy should consider the allocation of more space to the CIC and the separation of its functions into two parts, particularly in large vessels that are likely to serve as task force or group flagships.

3130 In Para. 3068 and 3080, the use of teleregister and facsimile equipments for remote display of air-situation information has been extensively discussed. We see no basic reason why the same techniques cannot be adopted for remote display in flag plot of task force command ships and, by VHF or UHF circuits, for display in other interested ships of the main force which are generally within a few miles of the task group center.

3131 The capacity and clarity of the data-reporting system used in Naval Combat Information Centers should be improved by adaptation of the photographic techniques and physical rearrangements recommended for land-based radar stations.

F. CONTROL OF INTERCEPTORS

1. Present Limitations

a. Communications

3132 Control of interceptors at present is handicapped by the limited number of communications channels available, by the unreliability of communications, and by their high susceptibility to jamming. Exercises in this country and in the United Kingdom have demonstrated that communications jamming can completely nullify the entire fighter effort.

b. Capacity

3133 The number of interceptions that can be handled simultaneously in a single station is severely limited by the number of controllers that can be effectively employed and the need for one controller to handle each interception.

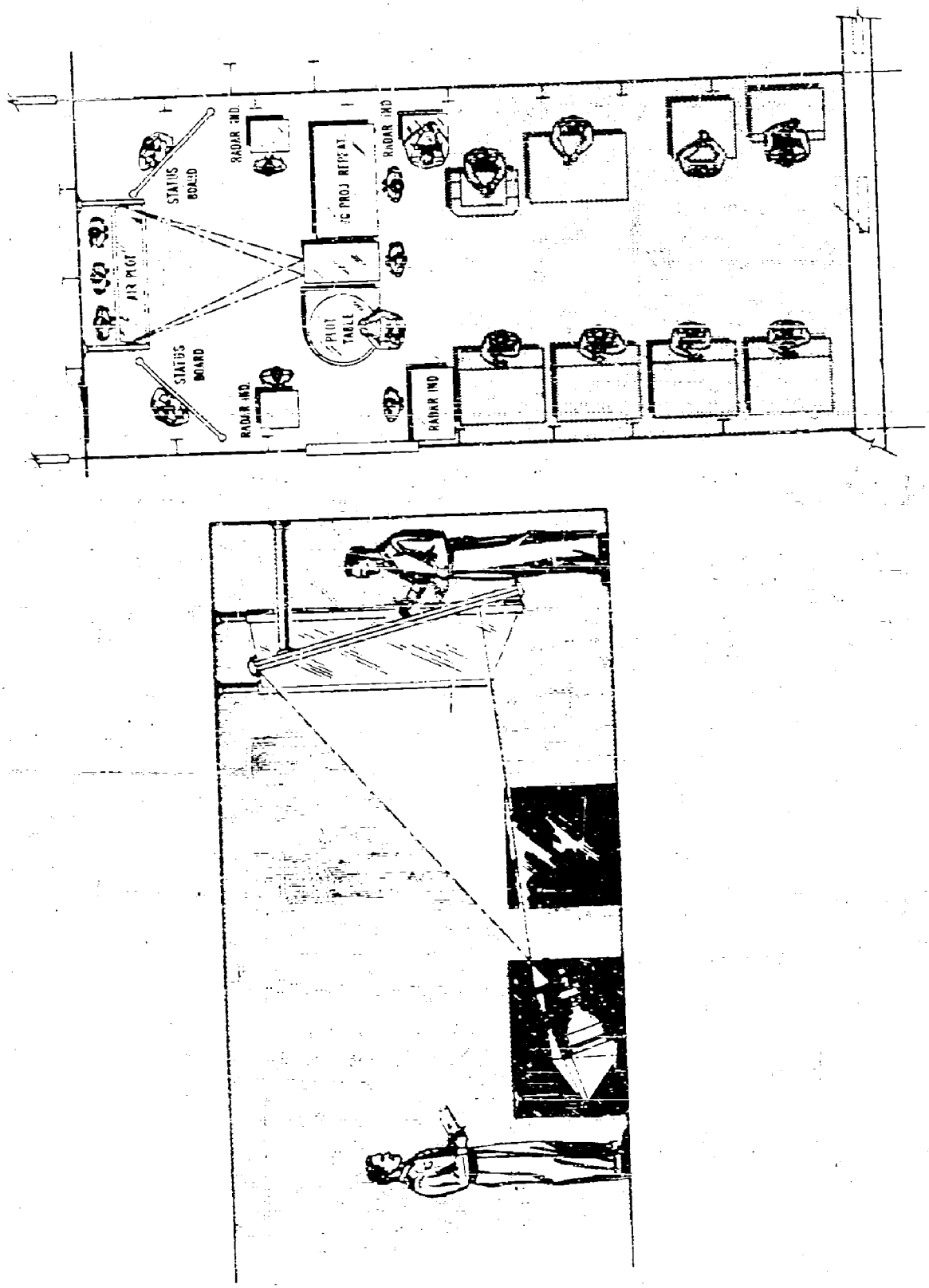


Fig. III-5 Modified CIC with multiple positive photographic projection.

2. Discussion of Possible Remedies

a. Communications

(1) UHF

3134 The communications difficulties will be eased when the change is made to the UHF band, in that many more channels will be available. This will make it possible to have enough channels available in the GCI to satisfy their control-channel needs, and will also allow employment of frequency redundancy to help with the jamming problem. However, since the equipment is very complex, and since there are certain propagation difficulties that do not occur with VHF, the unreliability of communication may be somewhat worse.

(2) Transmitter Power

3135 It has been the policy for military ground-to-air communications systems to employ low-power transmitters and very sensitive receivers. This has directly contributed to the unreliability of communication, and such a system is most susceptible to jamming. There is no doubt that for ground-to-air communications for air defense, whether in a static system for the continental United States or in an overseas system, one should employ very-high-power ground transmitters. These will increase by large factors the reliability of communication and will decrease the susceptibility to jamming.

3136 A recommendation for increasing the maximum power of ground-to-air transmitters and for exploring other protective techniques is made in Section VI.

3137 A detailed discussion of the entire ground-to-air communications problem will be found in Appendix IV-1.

b. Capacity

(1) Aided Tracking

3138 There are under development automatic tracking circuits, manual-aided tracking circuits, intercept computers and automatic data-transmission systems to ease the control problem. These devices will improve the accuracy of control of unskilled controllers only. However, an increase in the number of interceptions handled by one controller may be obtained.

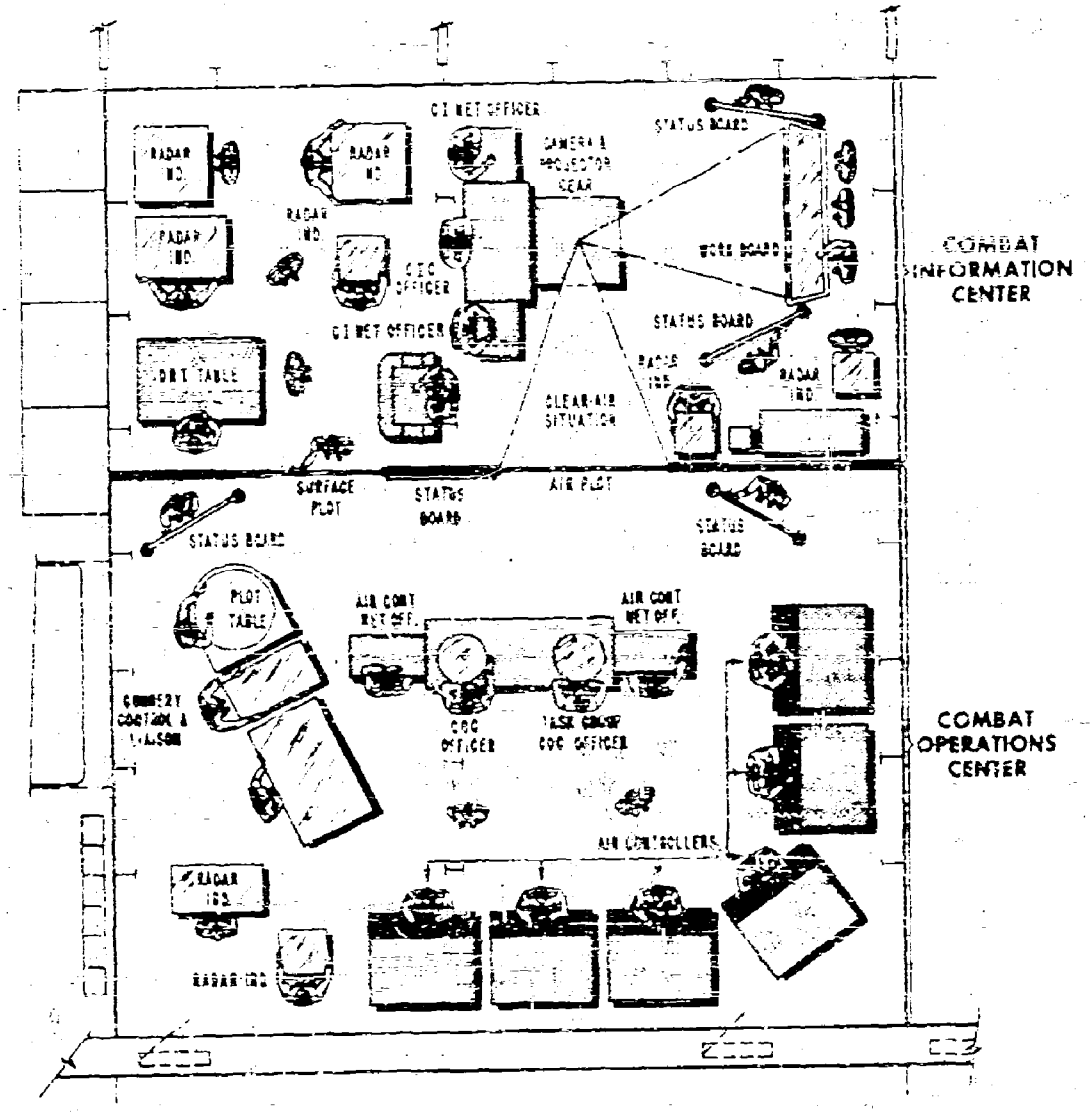


Fig. III-6 Proposed air surveillance and control rooms.

3139 It is not considered that the complication of completely automatic tracking circuits for the exclusive use of the controller is justified, particularly when the successful operation of these circuits through clutter is doubtful. Manual-aided tracking circuits, on the other hand, appear to be a more effective solution, and provision of four circuits for each controller should enable him to deal with two simultaneous interceptions.

(2) Control Methods

3140 The intercept capacity of the system, given these improvements, should be sufficient to deal with the presently anticipated enemy threat in a single GCI area, but it will not deal with a saturation attack that the enemy could possibly mount in that area. It is reasonable to expect that the enemy would employ saturation tactics if he found a diffuse attack unsuccessful. Such a saturation attack could be aggravated by the use of chaff and communications jamming. There must therefore be provided an alternative method of control to be used under saturation conditions, and the air crew should be continually exercised in its employment.

(3) Broadcast Control

3141 An alternate to the "close control" presently planned as the sole method of operation is known as "broadcast control." This is a method using ground-derived bomber position, air-derived interceptor position, air computation of steering instructions, and ground assignment of target to interceptor. The advantages of such a system under saturation conditions are:

(a) Only bomber tracks have to be continuously maintained;

(b) Many interceptors can be given target-position and target-assignment instructions over a single voice-communications channel;

(c) One controller can deal effectively with many interceptions;

(d) Reduced requirements for communications channels make possible the use of simultaneous transmission of instructions on a number of frequencies, thus increasing reliability and reducing susceptibility to jamming.

The disadvantages of this method are:

(a) Bomber and interceptor positions are determined by separate means, and there may be errors, particularly in height, between these measurements.

(b) It requires considerably more skill on the part of the air crew. A serious practical limitation to the use of this system, at present, is the lack of a suitable navigation aid. This is discussed in detail in Para. 5135 et seq.

(4) Training

3142 The extreme importance of intensive training of both controller and air crews in carrying out interceptions, particularly under conditions of imperfect communications or jamming, has been recognized, but we have no special contributions to make on this subject.

3143 Saturation of the aircraft control and warning system may prevent control of interceptors by the present "close control" method. As an emergency alternative, "broadcast control" operation should be planned, and interceptors should be equipped with the necessary navigational aids, as discussed in Section V.

G. IMPROVEMENT OF GROUND-RADAR EQUIPMENT

3144 Experience has shown that one of the major difficulties of any warning network is that of maintaining a satisfactory grade of operation of the equipment. A combination study and action group (CADS) from the Western Electric Company has been set up and charged with the responsibility of looking into the problem of equipment performance, maintenance and operational doctrine in the control and warning system for the continental United States. They have been particularly helpful in expediting supplies for maintenance and repair. We believe that the work of this group should be supported and intensified.

3145 No complete study of the technical characteristics of the equipment going into permanent sites has been made by PROJECT CHARLES, but attention is here directed to certain difficulties that have been reported to the Project by the Service laboratories, and that appear to be of importance and to require attention. A list and brief explanation of these are given in Appendix III-3.

3146 A careful and immediate examination of this list should be made by a competent technical group, such as the CADS group, to evaluate the importance of the various items and make discriminating and specific recommendations for remedial action, which should then be executed with high priority.

3147 The difficulties experienced during and since World War II with radar equipment of all types have led to widespread interest in the problem of electronic reliability. While PROJECT CHARLES has not undertaken a detailed study of the reliability of electronic components, a number of suggestions based on general considerations of the problem are outlined in Appendix III-4.

H. USE OF A GROUND OBSERVER CORPS

3148 A ground observer system has been established in the United States to supplement the present radar detection network. Because of the admittedly low effectiveness of the present ground observer organization, much doubt has been expressed concerning its ultimate value. The volunteer efforts of some half-million persons are at stake in this question, and there is danger of a widespread and lasting destruction of public willingness to support these and other community activities important to our air defense. Therefore it seems urgent that a decision be made either to reduce the observer corps drastically or to take, wholeheartedly, those steps necessary to make it effective.

3149 At the request of PROJECT CHARLES, a group from the University of Illinois made a brief study of the ground observer corps (GOC), and contributed a report which is included as Appendix III-5. By combining this work with our observations on the radar reporting and control network, we have reached certain conclusions, which are summarized in the following paragraphs.

1. Potential Value of a U.S. Ground Observer Corps

3150 In principle, ground observer data have the following virtues:

(a) The observations are best at low altitudes, where the present radar network is inadequate. Indeed, for five or ten years to come, the best low-altitude cover available will be that supplied by a GOC.

(b) Identification of aircraft categories can be accomplished by listening. With visual observation, additional details can be recognized. Identification is further facilitated by observation of the behavior of the aircraft.

(c) The number of aircraft is obtainable exactly with visual observation, and to a good estimate aurally.

(d) Detection by ground observers is invulnerable to jamming, and does not aid the enemy by emitting radiations.

(e) In an actual battle, damage and destruction of aircraft create confusion, which can be alleviated by a system for reporting visual observations.

(f) Height estimates under 20,000 feet can be reliable within 10 per cent if visual or 20 per cent if aural.

(g) Position estimates can be reliable within one mile by either visual or aural means.

(h) Directions of motion are rapidly obtainable, and speeds can be estimated quickly.

(i) The system is very flexible. Track suppression with regard to type of aircraft can be performed under a rapidly changeable set of rules. Local areas of interest can be selected at will. A great variety of observational details can be determined on request.

(j) Observers can be put in some regions (e.g., mountains) that do not afford suitable radar sites.

(k) In addition to detection, the system can provide directions for navigation by giving visual signals to interceptors.

2. Feasibility of Realizing the Potential Values

3151 The virtues listed above are not hypothetical, but have been realized in operations in the United States or in the United Kingdom during World War II. The essential remaining question is whether the reports can be sufficiently complete and prompt. The final test lies in actual interceptions made on the basis of ground observer data.

3152 In the United States during World War II (at the New York Filter Center and New York Operations Board), observations were reported, correlated with other tracks, forwarded, and plotted at the Operations Center, all within 32 seconds. In the British exercise TERRIER III (1951), total time delays as short as 30 seconds were achieved in transmission of data from the observers through the filter room to the Royal Air Force interceptors. In this exercise, which was performed at low altitudes, 70 per cent of the attacking Vampires were intercepted by fighters, using the Royal Observer Corps (ROC) plots, 57 per cent by planes specifically scrambled by the ROC plots. Forty per cent

of the raiders were intercepted before they penetrated 40 miles from the coast. One must conclude that it is possible, though not necessarily cheap or easy, to make the observer corps effective.

3. Performance Requirements of the System

3153 To determine what features of the system are essential, one must look first at the performance requirements. The most crucial of these are the first three, which are interdependent.

Track continuity: – The system must have the capability of maintaining a continuous track of an aircraft for as long a time as is necessary to intercept it; otherwise the system is useful only for civil warning.

Promptness in scramble: – New tracks must be evaluated and scramble orders issued in time to allow interceptions while the probability of maintaining continuity of the tracks is still high, and before the attack has penetrated many miles. This requirement is more stringent than in the radar network, where single observing stations can see a high-altitude plane for more than 30 minutes, and where detection may occur while the plane is 100 to 200 miles away from target areas. The delay between first observation and scramble order should not be longer than about five minutes.

Promptness in data relay to interceptor: – Low-altitude interceptions, controlled on the basis of ground observer sightings, require up-to-date positions and headings. British exercises (TERRIER II and TERRIER III) indicate that 60 seconds is too much delay and that 30 seconds is quick enough.

Depth: – Observer stations must be in sufficient depth to allow track continuity until interception occurs.

Reply to questions: – Observers must be able to answer questions; thus, two-way communication between observers and filter center is required.

Load: – The observer corps data must not overload GCI stations or command centers.

Accuracy: – The reports must have reliability as to identification, plan position, heading and height.

Readiness: – The observers and filter center personnel must be on station when needed. The most urgent single need may be at the first attack, but availability for the first attack should not be an absolute requirement.

Prompt relay: – If the observers are to be used for providing warning, it must be possible to relay the warning promptly to all who must receive it.

4. What Must Be Done to Satisfy the Performance Requirements

3154 The present ground observer system does not satisfy any of the performance requirements listed above. Some of the deficiencies are fundamental to the present organization and will not be removed by minor improvements and practice alone. The following steps are necessary to meet the performance requirements and make the observer corps effective. Suggestions as to specific means of accomplishment are discussed in greater detail in Appendix III-5.

Communications: – Provision of two-way communications on priority lines between observers and filter centers must be established in such a way that there is no delay in routing the calls through the telephone system. The average delay at present is 33 seconds. This can be cured only by providing the equivalent of private lines. The cost will be great, but it can be somewhat reduced by limited grouping of the observers in "clutches," using single lines.

Direct control of interceptors: – Provision must be made for direct control of interceptors from GOC filter centers after the interceptors are scrambled. Until radical improvements in automaticity are made (i.e., for the next few years), the time delay involved in retelling and replotting at GCI stations is too large to be tolerated. The current system requires, in addition to the first telling and the plotting and filtering at the filter center, a retelling of the plots to a GCI station where they are plotted and filtered once more before a controller can use the data to direct an interceptor. Still another telling and plotting are necessary before the information reaches an ADCC, where an evaluation may be required before a scramble order is issued and before a warning is issued for civil defense purposes. AAA commanders are equally distant along the information chain. Either by analysis or from the British experience, one may be certain that simply speeding up each individual step in this chain will not produce sufficiently short scramble times or sufficiently prompt directions to an interceptor. Satisfactory control of interceptors may also require:

(1) Provision for direct signaling between ground observers and pilots by use of devices such as Very lights;

(2) Two-place aircraft with navigation facilities suitable for broadcast control;

(3) A military officer at the GOC filter center with authority to issue scramble and fire orders (although it is conceivable that this officer could be at an ADCC);

(4) Special squadrons of fighters assigned to the GOC;

(5) Special airfields closely spaced to reduce time from scramble to interception.

Cross-telling: – Adequate lines, personnel and procedures for cross-telling between filter centers and from filter centers to command centers must be provided.

Direct lines: – Provision of direct lines for relaying warnings without delay to civil defense and other personnel who must receive it is a performance requirement.

Separate plots: – GOC plots must be kept separate from present GCI plots for the following reasons: the GCI station-plotting facilities have limited capacity and must not be overloaded; the GCI station plot would introduce further delay in handling the GOC data; and the GCI station plot of these tracks would not be useful since control of the interceptions would be done elsewhere. It may be essential also to:

(1) Restrict ground observer reporting to low altitudes;

(2) Install separate plotting facilities at ADCC's, which would carry the GOC plots of the low-altitude air situation for evaluation and command purposes. In this case, the data relay should be directly from filter center to ADCC.

Low-altitude flight restriction: – Low-altitude flights of U.S. planes that are closely similar to the Soviet TU-4's should be restricted.

Early warning: – Reliable and adequate early warning to alert the GOC when needed must be provided. Depending on the speed attainable in alerting the corps, this may require remote-outpost radar early-warning stations. These have already been recommended (see Section II) because of other advantages to be gained from early warning.

Aids: – Aids for quick and accurate measuring and reporting, and for display and filtering at the filter center must be provided. Such devices are discussed in Appendix III-5.

Extension: – The GOC should be extended to a depth of about 150 miles in important areas.

Training: – The importance of vigorous and thorough training plus frequent, realistic tests cannot be overemphasized. Interceptors should be made available for frequent practice, and realistic, simulated, low-altitude attacks should be made, both for practice and for tests of the system.

Morale: – The corps must be honestly convinced that it has a definite and important responsibility, that it is capable of being effective, and that it has the wholehearted support of the country. For this, a major public campaign is required, with encouragement from the highest civil and military authorities. Words are not enough; the provision of equipment and facilities and the creation of the organization necessary for effectiveness are essential supplements to the publicity.

Cooperation: – Complete and wholehearted cooperation by the military organization should be provided. This involves adequate indoctrination of the military personnel in the air defense system. The GOC should not be regarded as a civil defense organization, but as a part of the military defense system.

Determination: – Above all, the organizers and leaders of the GOC, and the military and civil authorities in the United States, must be determined at all costs to make the corps successful. Continuation of the ground observer corps in its present form is of little use.

5. Establishment of an Effective Ground Observer System in a Limited Area

3155 To provide both a realistic evaluation and a significant permanent usefulness, we recommend that a limited area be selected, and that in this area a thorough effort be made to establish an efficient ground observer corps that incorporates all the improvements outlined in the preceding paragraphs.

3156 The area should be one in which the observers will be of particular value. It should not be smaller than about 300 by 150 miles. Adequate time should be allowed for training of the observers, provision of the facilities, and breaking-in of the system.

6. Ground Observer Corps in Other Areas

3157 The discussion above is concerned with use of ground observers as a supplement to the radar network in the United States. (The use of microphones to obtain aircraft warning is discussed in Appendix III-6.) In remote areas, such as northwest and north central Canada, the performance requirements are very much less stringent, since these regions are far from target areas and the use of the data is limited to early warning. Moreover, in such areas the observer corps may be useful for planes at both high and low altitudes, and is not supplementary to radar cover (of which there is none), but may be the sole means of detection. In these areas, we believe there is no doubt that the ground observer activity should be vigorously supported, but we have not made a study of how to improve performance in such areas.

3158 The inherent value of a ground observer system is very great, and for low-altitude cover there is no alternative now or in the near future. The present ground observer corps in the United States is not organized or equipped in such a way as to permit it to be effective.

3159 Given a determination to succeed and a willingness to pay the necessary costs, an effective ground observer corps is possible. We recommend that such a corps be established in a selected area.

SECTION IV

AIRCRAFT CONTROL AND WARNING LONG-TERM PROGRAM

Future Developments for the Detection of Aircraft and the Management of Defensive Air Warfare

account, this knowledge must be gained by means external to the aircraft. The scattering or emission of some form of radiation by the aircraft seems to be a necessary link. Sound radiation is useful to a limited degree, but travels too slowly and is subject to too much refraction and absorption. Visible electromagnetic radiation is obviously of great utility, but is missing at night and is absorbed by fog or clouds. Infrared radiation is given off by all aircraft to some extent and forms the basis for detection systems of considerable value in their applicable field, but atmospheric absorption is still troublesome in limiting the range. It is only when the region of microwave electromagnetic radiation is reached that we find something sufficiently free from absorption, sufficiently rapid in travel, and capable of reasonable resolution. We conclude, then, that microwave radar must be the mainstay for the AC&W system. We must, at the same time, accept the limits set by fundamental laws of nature on the accuracy and resolution with which radar will gather data. These limits are considered in more detail at a later point (see Para. 4031 et seq.).

4004 The future AC&W system should be capable of integrating information from all sources. At best, the available air defense information will be incomplete, and no significant information source should be overlooked. Range and angular information from radar is most important, but the AC&W system should also accept and integrate quickly and effectively, the following types of information:

(a) Radar data from moving airborne early warning (AEW) radars providing overwater coverage,

(b) Direction-finding (DF) observations of enemy airborne radio, radar, and electronic countermeasures (ECM) equipment,

(c) Estimates of the number of aircraft in a formation, as obtained from examination of radar-echo pulse shapes,

(d) Ground observer data on position and identification, especially for low-flying aircraft,

(e) Data from flight plans, to assist in identification of friendly aircraft,

(f) Data relayed from pilots and instruments in interceptor aircraft.

4005 The uses to which a knowledge of the air situation may be put include the following.

Military use:

(a) Early warning,
(b) Threat evaluation,
(c) Interceptor guidance, including return to base,
(d) Weapon assignment and control,
(e) Navigation.

Civil Aviation:

(a) Air traffic control,
(b) Schedule for landing,
(c) Navigation,
(d) Rescue.

The inclusion of navigation in both military and civil categories assumes that it is possible to transmit to the pilot of any aircraft some of the air situation, including at least his own position and perhaps the position of other planes immediately around him.

4006 For any of these uses, with the possible exception of threat evaluation, measurement of position within ±1000 yards in any direction at intervals of five seconds seems to allow acceptable performance. For the purpose of this section of the Report, these values will be taken as the minimum limits of precision and data rate.

4007 The establishment of certain identification when there are enemy planes that may attempt deception or other interference is a difficult and nearly insoluble problem. It bears considerable resemblance to cryptographic problems. Just as there is no absolutely secure code, there is no system of identification, electronic or otherwise, that cannot be deceived. The closest approach to perfection is achieved if a continuous track is maintained for every plane from take-off to landing. To maintain such a track, the plane must be under continuous surveillance no matter what its altitude and no matter how many other planes are around. On this basis, the altitude coverage and traffic-handling capacity of the AC&W net may be set so as to require coverage at all altitudes for whatever amount of traffic may arise under any conceivable circumstances. This coverage simultaneously permits defensive action against enemy planes at whatever altitude they may be flying. The

possibility that enemy planes might fly low at some stage of their course between take-off and bomb release, thereby producing disastrous confusion in the present continental AC&W system, has seemed to PROJECT CHARLES to constitute a major threat.

4008 For appropriate air defense of the Fleet and of ground targets located on or near the seacoast, it seems necessary to gather information more or less equivalent to that specified above over the sea for a distance of at least 200 miles. This distance is obviously dependent on the nature of the attack to be countered, the weapon system by which it is to be met, and the perfection of the AC&W net itself. The figure given applies to the present time or near future, but might easily require increase if technological developments of attacking weapons proceed at the rate suggested by their more optimistic proponents. This same possibility of major development in weapons and tactics makes it imperative that the AC&W net be highly flexible in nature. It must not be committed by its initial design to operation in a rigidly prescribed manner, but must be capable of growth and on-the-spot alteration.

4009 There are two main categories of requirements for communications in an AC&W system. On the one hand, information from the data-collection system must be assembled from a sufficiently large area to permit intelligent coordination; on the other hand, information and orders resulting from this coordination and evaluation must be sent out to all users, including weapons in the most general sense. In the light of present information theory, it does not seem likely that any insuperable problem will arise, or that any requirements will be too far out of line economically. It does appear, however, that more sophisticated methods than voice communication will be required. The problems connected with the communications system as a whole are treated in more detail in Appendix IV-1.

2. Integrated Systems Now Under Development

4010 The presently existing AC&W systems are essentially systems of men interconnected by voice-telephone links. They have grown from radar sets designed primarily for visual presentation of local aircraft activity. Air defense systems have been assembled by the rather haphazard radio or telephone

interconnection of radar sets, filter centers and airfields. Such interconnections of components designed primarily for decentralized operation make use of existing facilities but are very far from optimum for the amount of men and equipment utilized. Furthermore, the capacity of such systems is totally inadequate for increased target speed and heavier traffic density.

4011 After the completely manual system, the next evolutionary step in the AC&W system is represented by those proposed systems wherein devices are added to eliminate the specific difficulties and bottlenecks appearing in the present system. There exist a number of projects that seek in this way to evolve out of the present air defense system's organizational structure something of greater capability. In all these projects, functions now poorly performed by men are to be more effectively performed by various kinds of specialized machines.

a. The British Admiralty Comprehensive Display System

4012 The British Comprehensive Display System (CDS) seeks to improve the operations of a naval CIC by allowing more men to be coordinated (by electronic devices) in their efforts to digest the data supplied by a pair of large radars (Type 984), and by increasing the effectiveness of each individual man with other electronic devices. This system is well thought out from the operational point of view.

4013 We have been informed that this system will not be installed before 1953 and will not be fully operational in the Royal Navy (RN) before 1955. This is distressing, particularly in view of the fact that the techniques employed are almost without exception at least six or seven years old. Proposed improvements to this system would make it very similar to Project 414A and to the USAF Ground Reporting System.

b. Royal Air Force System

4014 The Telecommunications Research Establishment (TRE) is preparing a system fundamentally identical with CDS but with some technical improvements of detail and with considerable added data-transmission equipment necessary to the employment of a larger number of widely dispersed radars

deployed according to the organizational scheme of the Royal Air Force (RAF). Although we are not certain at what time this is proposed for operation, it can hardly be before 1954-55, and we make the same remark about this situation as about CDS.

c. U.S. Navy Systems

4015 (1) The U.S. Navy (USN) proposes to test a first model of the CDS beginning in 1951. In so far as the adoption of the system would establish some kind of common communications between USN and RN ships in joint operations, this is to be encouraged. The notion that this system is a "quick-fix," however, is a delusion, especially if the British designs must be revis to use American components.

4016 (2) The U.S. Navy is also developing either in its own establishments or by subcontract a wide variety of manual, manual-aided, and automatic tracking devices, and of interceptor course computers, threat evaluators, and antiaircraft gun coordination devices. A study (PROJECT COSMOS) of integrated Fleet communications systems has likewise been sponsored by the USN. These efforts are under way at Naval Research Laboratory, Naval Electronics Laboratory, General Electric Company, Bell Telephone Laboratories, and Cornell Aeronautical Laboratory. The Navy has also followed with interest certain developments supported by USAF contracts. There are enough bits and pieces here to comprise several different systems but we do not know of any complete system which is actually planned to use these developments.

4017 (3) The Mark 65 Project is studying the naval antiaircraft problem. We are much impressed with the thoroughness of this program.

d. U.S. Army System

4018 Project 414A (SYSNET) is intended for immediate use only with antiaircraft artillery (AAA) but its proponents state, and correctly so, that future models could also be used with guided missiles and interceptors. This is the first all-American system to be mentioned here which attempts to deal with the complete problem. It is considerably more ambitious than the British systems but, just as they do, it represents the mechanization in detail of functions at present carried out by men. The proposed improved version is to all intents and purposes identical with the USAF "Ground Reporting System." We do not believe that this improved system will be available for shakedown operations before 1956.

e. U.S. Air Force Systems

4019 (1) The U.S. version of the British CDS is a project sponsored by the USAF with a view toward getting an interim improvement for the present continental air defense system. It apparently involves not the Admiralty but the RAF (TRE) version. This version is to be redesigned to use American parts and to accommodate American radars. If all this could be operational by 1953, it would indeed be a great step forward. Unfortunately, no such date can possibly be met, regardless of the emphasis that is given the project. With great emphasis, one Air Division could begin to "shake down" this system in 1955. Without such emphasis, 1958 would be a more probable date.

4020 (2) The University of Michigan has a subcontract from Boeing Aircraft to provide intercept computing equipment to couple the BOMARC missile to its contemporary ground environment – the BOMARC Test Phase Ground System. It is stated that prototype missiles are to be tested at the Joint Long-Range Proving Ground in 1953, and Michigan is preparing a ground system for this purpose. So far as we can determine, these tests do not require a full AC&W system but only radars, trackers and course computers. There is, in the test, little traffic to be confused with the missile, no identification problem, and only one missile will be fired at a time.

4021 This BOMARC Test Phase AC&W system is in fact practically identical with the British CDS system in philosophy and in details of technique, although conceived entirely independently and not as far advanced. Unlike the USAF version of CDS, this project is being pursued by a fairly large number of engineers.

4022 (3) Watson Laboratories' Ground Reporting System project exists in the form of a book issued by Watson Laboratories',* supplemented by contracts with Columbia University, Airborne Instrument Laboratory, and others. Models of some preliminary components have been demonstrated. The project staff employed by the Air Force is very small. This system is acknowledged to be identical in most respects with the improved version of the U.S. Army's Project 414A. It is only one of all these systems that proposes to deal in any way with low-flying bombers (down to 800 or 900 feet).

3. Consolidation of Programs

4023 The proposed systems that have been outlines bear a close resemblance to each other in functional conception as well as in many structural details.

*Now at Rome Air Development Center, Griffiss Air Force Base, Rome, N.Y.

The parallel pursuit of all these development projects will involve considerable duplication of effort; each of the Services should therefore review its own plans in relation to those of the other Services.

4024 Specifically, the U.S. Navy should review its entire development program on AC&W system integration, and establish an over-all interceptor control plan toward which this program can be directed. The need for the Navy's CDS adaptation, and the probable schedule of its availability, should then be evaluated with reference to this over-all plan.

4025 The U.S. Army should plan to perform the Fort Bliss trials of the Project 414A Model System. The improved system, which is to include interceptor control, must go forward in cooperation with the Air Force.

4026 The U.S. Air Force will be concerned with four systems. The AC&W function of the BOMARC Test Phase Ground System is practically identical with CDS; it is better staffed than the USAF adaptation of CDS, but lags in time behind the British CDS program. Both the BOMARC Test Phase System and CDS, when "improved," will resemble closely the Watson Ground Reporting System, which in turn is identical with the improved Project 414A of the Army.

4027 A shortage of electrical engineers exists at the present time in the United States. Obviously, not more than one of these systems can be bought for the air defense of the continental United States. This one system can and should be so designed that it will also be capable of application in any other theater. Between the different systems, there is not more than one year's difference in time scale if they are pushed with equal vigor. There are just about enough engineers engaged in all the four systems together to push one system to completion for shakedown in 1955-56. All these programs should be put under one management to make one system only.

4028 None of these systems is designed to make full use of the complicated and expensive machines involved; all assume that machines and men are interchangeable on a one-to-one basis. Only one of them attempts to handle low-flying bombers. Although it is recommended that a consolidation of program be achieved in order that something may eventuate from the present proposals and contracts, PROJECT CHARLES is not convinced that this eventual system

would be adequate to meet future demands nor that a much better and more economical system could not be developed in the same time.

4029 The following subsection of this Report therefore presents an analysis of the AC&W problem from first principles and without regard to past history.

4030 Integrated AC&W systems are currently under development in four major projects sponsored by the National Military Establishment: U.S. adaptations (USN and USAF) of the British CDS, BOMARC Test Phase (USAF), Project 414A SYSNET (USA), and the Ground Reporting System (USAF). All these programs should be consolidated under a single management to work toward a single integrated system.

B. A RE-EXAMINATION OF REASONABLE TECHNICAL REQUIREMENTS FOR AN AC&W SYSTEM AND OF THE POSSIBILITY OF MEETING THOSE REQUIREMENTS

1. The Aircraft Detection Apparatus

a. Precision

4031 The position of the aircraft must first of all be measured to within a certain error. The precision required depends upon the use for which the measurements are intended. Thus the requirements for fire-control radars are stringent, and the errors are sometimes held to less than ±50 feet. The precision required for the mid-course guidance of interceptors is considerably lower and is optimally related to the characteristics of the interceptor's own fire-control radar in the following way.

4032 Because the maximum range at which a fire-control radar can detect a target is markedly reduced if it has to scan through an appreciable angle, it is desirable that the AC&W system put it on target as closely as is necessary for it to "lock on." The detection ranges as well as beamwidth of various fire-control radars set the optimal limit to this precision. Any ability of the AC&W system to average its own input data and so upgrade its precision must

also be considered. Based on these factors, a precision of ±1000 yards for the AC&W detection apparatus appears adequate.

4033 Since radars have been made with precisions adequate for gun-fire control, it is technically feasible to achieve this precision.

b. Resolution

4034 By resolution is meant the ability to distinguish two or more targets as separate entities. There are two reasons why it is desirable to resolve closely spaced targets: first, to count them, to aid in evaluating their threat; second, to aim individual weapons at particular targets. The greater the extent to which we can resolve targets, therefore, the more economically we can employ our weapons.

(1) Resolution for Threat Evaluation

4035 There is clearly no need to decrease the resolution distance below the size of a single aircraft, say, one hundred feet. Such a high degree of resolution would be desirable for threat evaluation. For a radar system, this is equivalent to the statement that the radiation from the antenna must cover an area no larger than 100 feet across, at any distance up to the maximum range required. For an antenna of width W, using radiation of wavelength λ, the radiation may be confined within a region of width equal to W out to a distance W^2/λ by focussing the antenna at this distance. (The procedure bears a close resemblance to the use of the hyperfocal distance in photography.) For W = 100 feet and λ = 0.06 feet (1.8 cm) the maximum distance is 28 miles. A shorter wavelength is unusable because of absorption; a larger antenna could cause loss of resolution at nearer points, and a smaller antenna would attain the required resolution only at nearer points. The mechanical problems associated with a 100-foot antenna are considered to rule out the attainment of the prescribed degree of resolution. The resolution required for threat evaluation is thus practically unachieveable, except in the radial coordinate.

(2) Resolution for Weapons Assignment

4036 For weapon assignment, high resolution would be unusable unless the fire-control radar had comparable resolution, but this is never the case; the

resolution distance of fire-control radars is usually about thirty times as great as their precision and, in the case of the T33 Antiaircraft Director at its acquisition range, amounts to about 500 yards. For interceptors and missiles like BOMARC, the comparable figure is 1000 yards. Consequently, fire-control devices cannot be uniquely aimed at one particular target among a group all less than about 500 to 1000 yards apart. There is thus no need for having more resolution than this in the acquisition data.

4037 In order to achieve high resolution with antennas of moderate size, a short wavelength is obviously desired. However, such factors as available transmitter power, large antenna gain, and ability to see through rain storms are much more favorable at long wavelengths. A suitable compromise wavelength seems to be 10 cm.

4038 The size of antenna is also subject to practical limits. The largest antenna that we would probably ever want to make would be 50 feet wide. If a large number of small stations were to be employed to get low cover, a much smaller antenna -- say, 15 feet – would have to be employed. It is clear that the resolution distance will be much larger than the antenna width under these conditions.

4039 Based on a practically attainable beamwidth of 4° for a 6-foot antenna at 10 cm, Table IV-1 indicates some possible resolution distances perpendicular to the line of sight.

TABLE IV-1

Wavelength λ (cm)	Resolution Distance (feet) W = 15 feet R = 30 miles	W = 50 feet R = 75 miles
10	5,000	3,800
15	7,500	5,700
20	10,000	7,600

4040 None of these figures is completely satisfactory even for the resolution required for weapons assignment (including mid-course interceptor guidance), and they are nowhere near what is required for threat evaluation. However, the former function could be carried out by using a 15-foot antenna at S-band if the range were restricted to 20 miles, or by using a 50-foot antenna at S-band if the range were restricted to 60 miles. In other words, it is possible to construct radars capable of resolution suitable for weapons assignment provided they are not required to operate at very long ranges.

c. Estimation of Raid Size for Threat Evaluation

4041 Estimation of raid size from range data can sometimes be made quite simply when the aircraft are resolvable in range. (Range resolution can be made equal to 100 feet if other desiderata do not conflict.) If other requirements do degrade the range resolution so that this is not possible, a study of the character of the composite echo can yield approximate information. Present-day radar operators are skilled at making such estimates. It appears possible to make an analytical device capable of performing this function at least as well as the best operator, and the study and development of such devices should be begun.

d. The Detection of Low-Flying Aircraft

(1) Over Land

4042 The horizon-limited ranges of radars, whose antennas are located at various heights above the ground, are shown in Table IV-2 (for an aircraft target flying at 500 feet).

TABLE IV-2

Range (surface object) (miles)	Range (aircraft at 500 ft.) (miles)	Antenna Height (feet)
—	30	0
45	75	1,000
100	130	5,000
200	230	20,000

4043 Table IV-2 refers to a smooth earth's surface, such as over the sea; over rough terrain, there are additional hindrances due to shadows cast in random places by protuberances such as hills, buildings and the like.

4044 It is believed that over land a bomber can fly at least as low as 500 feet above the mean terrain level, and as low as 50 feet above the surface of the sea. The present large S- and L-band radars, spaced roughly 150 miles apart, cannot be relied upon to detect aircraft flying at less than 3000 feet altitude in all localities. It is therefore required either that a redeployment of the present radars be made or that new types of radar be introduced (or both), in order to detect aircraft flying at minimum altitudes.

4045 It is conceivable that a large radar might be mounted for overland surveillance on a tower 1000 feet high. Such a tower might cost in the neighborhood of $1,000,000. This radar would cover about six times the area covered by a radar at ground level (at 500 feet, for aircraft) but it can be shown that the cost of such an installation would be more than six times as great. Considerations of ease of maintenance, susceptibility to natural and enemy damage, time required for construction and the like make this idea of using a high tower unattractive. However, the proposal to mount very large radars on top of certain existing tall structures, (e.g., one of New York City's tallest buildings) deserves serious consideration.

4046 Proposals to mount radar antennas in captive balloons or helicopters as permanent installations are not viewed with favor because of the uncertainties of the orientation of these devices in winds, the likelihood of damage by lightning storms and the like, and a considerable uncertainty as to whether they are sufficiently immobile to permit the use of a satisfactory MTI (moving-target indicator) device. These arguments are not conclusive perhaps, but it is certain that the time required to develop such radars would be long and the results uncertain.

4047 We are concerned that operational plans may be made on the assumption that overland coverage may be obtained from AEW types of equipment (large radars mounted in large aircraft). Long-range search radars, mounted on fast-moving vehicles, are not likely to be satisfactorily demonstrated over land. This use would involve the problem of designing a satisfactory long-range airborne MTI equipment. We are doubtful as to whether a good solution

can be found for this problem. There is only a dim hope that this might be realized for radars mounted on blimps. Our conclusion is that it will be faster to develop and to install a low-altitude-coverage radar net, if equipments of moderate size and range performance are used, with the antennas placed as close to the ground as surrounding obstructions permit. Problems of serviceability will also be much lessened, as will freedom from enemy and storm damage. It will be shown below that the use of large numbers of smaller radars need be no more expensive than the use of equivalent numbers of large ones. Existing radars of whatever ownership should be used wherever possible.

4048 The detection of aircraft flying at low altitudes over land can best be achieved by the use of relatively small radars, relatively closely spaced, and mounted close to the earth's surface.

(2) Over the Sea

4049 The provision of offshore coverage for a land-based AC&W system is difficult. The use of small radars, similar to those proposed for use on land, becomes very expensive offshore because of the high cost of suitable ships. Low-altitude cover can be achieved over larger distances with airborne radars, and blimps as well as aircraft should be considered for this purpose.

4050 AEW radars installed in aircraft have been successfully used for some time in the Navy. They may be valuable as radar outposts for remote early warning (as proposed in Section II for Iceland and Alaska). This function, however, is quite separate from the problem of extending the U.S. AC&W network by providing contiguous offshore coverage to a depth of 200 miles completely integrated with the land-based system for interceptor control.

4051 The merging of these two disparate functions has been advocated by arguments somewhat along the following lines: It is obviously desirable to have warning of the enemy as far in advance as possible; therefore let us separate the offshore AEW cover from the shore-based cover by a gap of several hundred miles; this early warning will give ample time to arouse the shore

defenses, etc., then, because of the well-known tactical difficulties associated with a blind perimeter between the shore and early-warning coverage, let the pertinent AEW airplane follow the raid in to shore, a replacement going out immediately to fill its place.

4052 We believe that it will be unsound to plan future operations on this basis because (a) the AEW airplane is very likely to be much slower than the future enemy bomber; (b) the interceptors would, in many cases, have to be vectored through a blind zone, which may become more undesirable in the future than it is now; (c) most important of all, this puts the air defense in double jeopardy to enemy strategy. Normally the enemy can always do a certain amount of feinting; if we use our AEW in the way proposed, he can not only attempt to decoy our interceptors, but also the radars on which they depend. We find it repugnant to conceive of a system that, while supposed to possess great stability and dependability, has its own organizational framework at the mercy of enemy tactics.

4053 We therefore recommend that the functions of remote early warning and of contiguous offshore coverage be kept separate; for the latter, the radars should remain at least in positions known to us in advance, if perhaps not always in the same positions.

4054 We have been very much impressed by USN presentations of the possibility of employing blimps to provide offshore coverage contiguous with the main network. The slow speed, the long duty periods, and above all the possibility of installing large antennas, make this proposal most attractive. From the radar point of view, blimps are much preferable to airplanes for overwater coverage.

4055 These blimps might fly between 3000 and 5000 feet, thereby giving low-altitude cover out to 70 or 80 miles. They could be stationed 100 miles offshore and spaced 100 miles apart. However, such AEW equipments might suffer from sea return for the first 20 miles of range; moreover, it might prove difficult to get high cover from them. Both these lacunae could be filled by pairing a picket ship with each blimp (see Fig. IV-1). This ship would give fair low cover to 20 miles with little trouble from sea return except in the heaviest seas, and would be able to carry a radar capable of satisfactory

long-range high-altitude cover. In addition, one of the communications difficulties of the picket ship would be solved, since it could send its data ashore via ultra-high frequency (UHF), using the blimp as a relay station.

4056 We have not made a study of the operational problems involves in the use of blimps. We urge that the Department of Defense make such a study as soon as possible with a view toward recommending the use of blimps.

4057 The Department of Defense should also determine the most suitable type of vessel for radar picket service. The destroyer escort (DE) type is too large to be economical and too unstable to be suitable for a radar, except possibly as a temporary expedient. It may be advisable to design special ships for the purpose.

4058 The proposed blimp and ship installations should merge their coverage with the shore installations. If, as recommended in Para. 4047, the interior radars should be of short range, then some of the coastal stations should be of the long-range type now in use.

4059 There may be some places where a relatively unprecise, low-resolution surveillance radar is required to detect low-flying aircraft at ranges up to 100 miles over water. Such a device, the "Ground-Wave Radar," is described in Appendix IV-2. An RAF "Lincoln" aircraft, flying at an altitude of 500 feet, has been detected by an experimental shore station of this type at a range of 57 miles. Such radars will probably always be easy to jam because of their low frequency. There may nevertheless be advantages to be gained from this development, and it is to be hoped that it will be vigorously pursued in both the United States and Great Britain.

4060 Satisfactorily uniform and reliable offshore coverage can be obtained from a network consisting of pairs of blimps and picket ships anchored about 100 miles offshore.

4061 The Department of Defense should initiate a study of the operational problems involved in the use of blimps, and should determine the most suitable hull for radar picket ships used to provide offshore radar coverage.

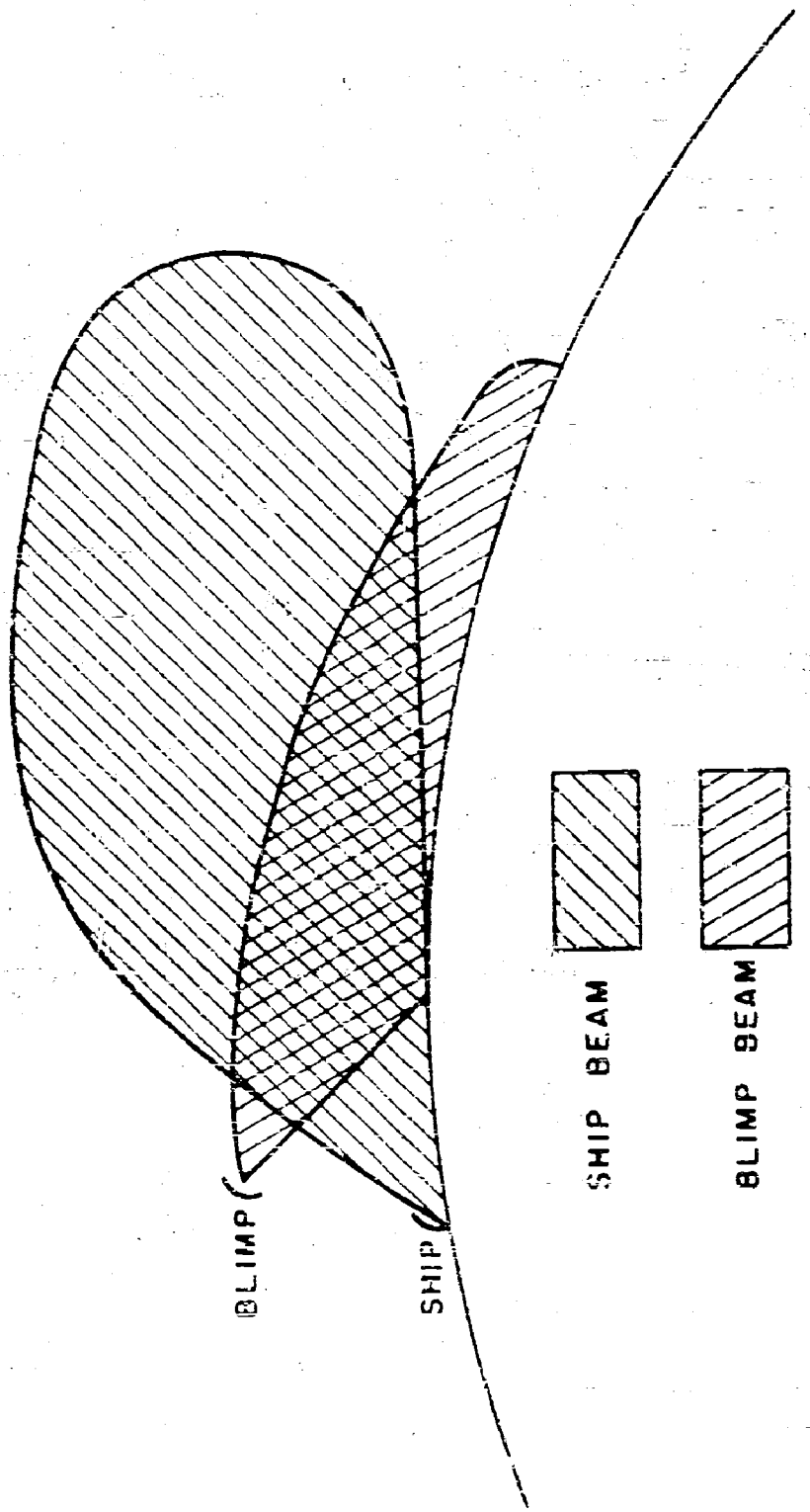


Fig. IV-1 Combination of blimp AEW and picket ship to obtain both high and low cover.

e. Ground and Cloud Clutter

4062 Detection of low-flying aircraft requires a reliable and effective device for eliminating radar ground clutter. The present MTI devices require too much maintenance and adjustment to be satisfactory. The most certain method of removing the unwanted signals depends on the Doppler effect: The radar echoes from a moving target are qualitatively different from those from stationary objects.

4063 MTI as it is now used is a most delicately adjusted apparatus of some complexity. As applied to pulse radars, it involves the use of two oscillators whose frequency stability, both over long and short periods of time, must be extremely high. In addition, it requires a delay line and a set of amplifiers the gains of which must be nicely adjusted. All these fine adjustments require constant monitoring and frequent testing. In addition, the filter characteristics of a delay line are far from optimum for the purpose.

4064 Many of these delicate adjustments can be made unnecessary, and in addition superior MTI performance can, in principle, be achieved if it is recognized that the high-range precision of present search radars is never used, and if use is made of this fact. If the range precision is made equal to the precision required for weapon assignment, namely ±1000 yards, then a system suggested by Barlow, of the RAND Corporation, can be used. This system, together with some improvements suggested by Nyquist and Van Voorhis, of PROJECT CHARLES, is described in Appendix IV-3 and in RAND Report RM-527.* This equipment in other respects would be similar to an ordinary radar of comparable power and size. Such equipment fits in naturally with the capability of transmitting the radar data over a narrow-band communication link, such as a telephone line.

4065 Another system involving the use of pure continuous-wave (CW) radar is described in the Appendix IV-4. This system, while likely to be expensive, may have advantages in very mountainous territory; it is also radically different from anything previously made, and introduces serious problems of

*"The Capabilities and Limitations of Some MTI Radar Systems," Research Memorandum RM-527, February 1, 1951, RAND Corporation.

antenna design. It is unlikely to achieve resolution as high as is desired, unless it is operable on a 3-cm wavelength. It requires a computing operation before the position coordinates become available.

4066 It is sometimes proposed to make moving-target indicators that do not make use of the Doppler effect; such devices may seek to discriminate between a previous ground-target signal intensity as remembered by a storage device and that same target's signal intensity at a later time when as aircraft signal is superimposed. Because of the fluctuating character of ground clutter, we foresee little success along these lines.

4067 A device that appears superficially the same, but whose principle and intention is quite different, may, however, prove useful under a sufficient variety of conditions to warrant its use. As in the previous method, a storage device is used to remember the ground signals. However, these are used to blank out the ground clutter, leaving only the free spaces to be displayed or transmitted. By means of this device and a sensitivity time control, it is hoped that aircraft may often be tracked through clutter, although they are invisible whenever their position coincides with the discrete clutter sources. Such a device is properly called a "clutter rejection device" and is not the same as MTI whose aim is to make the aircraft continuously visible.

4068 A final and possibly attractive possibility hinges on our having the ability to correlate the data from several radars into one display. If this is feasible, we may conceive of using radars with overlapping coverage in some locations. Then we could simply blank out the clutter of each radar and use the one to look into the other's clutter region (see Fig. IV-2).

4069 It is possible that economy, time, and the demands of the terrain involved may demand the use of all these solutions.

f. Altitude Determination and Data Rate

4070 Because of the polar-coordinate system inherent in radar, it is clear that altitude determination must be made in terms of a measured elevation angle and a measured range. Since available techniques for determining range by radar are amply precise for the purpose, it is only necessary to examine the precision to which the elevation angle must be measured.

4071 Assuming the range of the height-finding radar to be horizon-limited to 30 miles and the tolerable error in altitude to be ±1000 yards, it follows that the elevation angle must be measured to ±1°. If some sort of lobe matching is employed, as in a fire-control radar (or, more specifically, as in AN/SPS-2), the actual spread in elevation of the radar beam can be much greater, provided that the target is above the center of the lowest elevation-measuring beam. This implies that the resolution, at least of the lowest beam, must also be about 1°.

4072 The rate at which data must be obtained on the position of a given aircraft depends on its speed and maneuverability and also on the resolving power of the radar. If the radar will resolve to only 1000 yards, there is little sense in getting new data much oftener than it takes the aircraft to move 1000 yards. This corresponds to a new datum every 1.5 seconds in the case of a 1200-knot aircraft.

4073 If the aircraft moves in at constant speed and constant direction, however, data need not be obtained nearly so often. Consequently, it is desirable to inquire how long it takes an aircraft at maximum lateral acceleration to depart, from a previously flown straight course, by one resolution interval or one-half mile. In the case of an interceptor that can develop 2 g lateral acceleration, this time is approximately 7 seconds.

4074 In addition, we must consider that two resolved aircraft can be confused if they are separated by less than a distance of approximately vT, where v is their speed and T is the time between scans of the radar. For a 1200-knot airplane, this distance is about two miles if T is 6 seconds. This is another argument in favor of having the data rate such that the aircraft can just travel the resolution distance during the scan period.

4075 The determination of altitude can be less frequent. If the interceptors can be arranged to measure their own altitudes, their altitude need not be measured by ground equipment. If this is not the case, then height will have to be measured every few seconds for interceptors engaging in violent maneuvers. This latter is the worst case, since heavy aircraft do not change altitude rapidly and commerical aircraft do so only at rare intervals between take-off and touch-down.

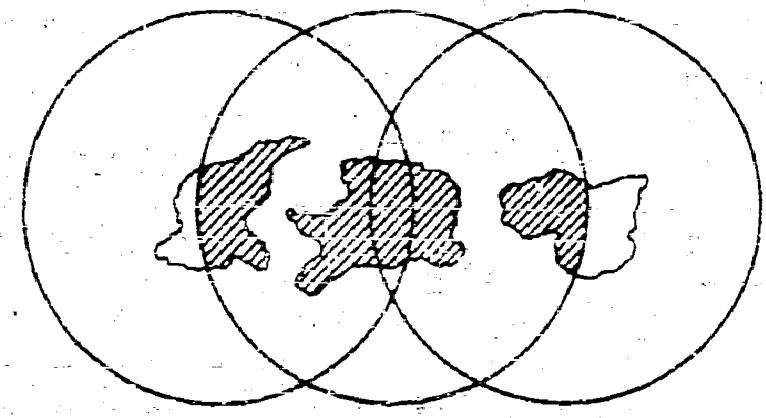


Fig. IV-2 Use of overlapping radars to overcome the ground clutter problem in certain cases.

4076 A beam width of 1.6° (i.e., 15-foot antenna at 10-cm wavelength) would yield acceptable resolution of ±1000 yards if the range were limited to 20 miles. We arbitrarily set the maximum height to be covered at 60,000 feet or 10 miles.

4077 There are several ways of scanning in order to determine the altitude. The most obvious is to helical-scan with a pencil beam. Since we have essentially to scan an entire hemisphere if we use this method, we find approximately 16,000 different possible orientations of the antenna, each separated either in azimuth or in elevation by 1.6°. Each of these must be scanned once in the time allowed by the required data rate, which for purposes of illustration will be assumed to be 5 seconds. Neglecting the requirement for MTI, we need at least one pulse per beam position. Then the repetition rate of a pulse radar must be at least 16,000/5, or 3200 pulses per second. Such a high rate just allows us to have an unambiguous radar range of 20 miles in practice (actually 26 miles if no time is allowed for the circuits to recover).

4078 The picture becomes much worse, however, if the Doppler effect is to be used to eliminate ground clutter. In such case, we must allow the beam to dwell on any target for a time τ inversely related to the spread of "blind speeds" characteristics of Doppler MTI equipment. Five milliseconds is a lower limit to what we can tolerate here, and 20 milliseconds would be much better. If the beam remains on-target for even as little as 0.005 second, we see that a total of (5×10^{-3}) (16×10^{3}), or 80 seconds, is required to complete the scanning of the hemisphere. This is far too long to wait; a 1200-knot aircraft can move 25 miles in that time. Two aircraft 25 miles apart could therefore be confused, even if they maintained straight courses.

4079 This situation could be somewhat ameliorated by scanning slowly in azimuth when the elevation angle is less than about 5°, and at the previously indicated rapid azimuth rate at other elevation angles. This procedure would, of course, further complicate the antenna machinery. The "slow" azimuth speed would then be about 120 rpm, and the fast azimuth speed would be about 850 rpm.

4080 The speeds that are mechanically practical are not much different from the required data rates, i.e., 10 to 30 rpm. Such speeds are clearly inconsistent with helical scanning, even if we restrict the range to 20 miles, so

long as we want ±1000 yards resolution at S-band. As the range is increased, the situation obviously becomes worse.

4081 It should be noted that similar considerations lead to analogous conclusions for CW radars with separate transmitters and receivers. Any other form of scanning with a pencil beam, such as rapidly in elevation and slowly in azimuth, is subject to the same limitations.

4082 We must therefore use the usual search antenna with its vertical fanned beam and employ a separate radar or radars to measure elevation.

4083 There are several ways to arrange these extra height-finding radars.

(1) All the radars may use a common reflector and scanner, as in the "stacked beam" systems.

(2) All the radars may employ the same scanner but use separate complete antennas for search and height finding, as in the "V-beam" or the SX.

(3) The search and height-finding radars may be entirely separate, as in the AN/CPS-5, AN/TPS-10 combination.

4084 The first case, stacked beams, gives unambiguous and, in principle, highly precise data. However, it is expensive to construct and requires a considerable amount of data-handling equipment to combine the results of the separate radars in a meaningful way.

4085 The second case, V-beam, does not yield entirely unambiguous data when several targets appear at the same range. It is less expensive to construct.

4086 Both the stacked and V-beam systems determine the altitudes of all targets at the same constant rate. We have shown that there is a great disparity in the rates at which these data are needed for different categories of aircraft. The V-beam principle is, in addition, wasteful of the time of track-sorting machinery which works on a time-sharing basis. These reasons indicate strongly that the nodding-beam height-finder is likely to prove the most economical system when all points of view are considered.

4087 Some alternative possibilities are discussed in connection with system costs in Appendix IV-5.

4088 High-altitude cover must also be provided; but obtaining this poses no new problems, and is principally a matter of radar design along known principles.

2. The Centralized System

a. Organizational Structure

4089 It has been shown that requirements for resolution sufficient to put radar fire-control devices on-target, that the problems of detecting low-flying aircraft over land and of determining altitude, that a good solution to the MTI problem over land – all either demand the employment of relatively short-range radars or are more economically accomplished in that way.

4090 It seems clear that military air defense operations of a cooperative nature cannot be organized about a great number of small individual GCI stations and that, if many small radars are to be employed, means must be sought to combine these radars so that they operate as though they were but parts of one large radar.

4091 If this can be accomplished, an elaborate and complete offshore coverage provided by picket ships and aircraft can easily be handled as component radars of the same system.

4092 This implies that a way must be found of equipping a great many radar sets with a common presentation. A system that will achieve this goal is under active development under the sponsorship of the Air Defense Systems Engineering Committee (ADSEC) of the Scientific Advisory Board, USAF. This "centralized" system possesses many other valuable potentialties as well.

4093 It differs both in organizational structure and in detailed instrumentation from the present air defense system and from other proposed integrated systems.

4094 In order to show how this system differs from the present system and from those proposed systems mentioned in Para. 4010 et seq., it is first necessary to group the various functions of the system into broad categories. These are:

(1) Detection, or the gathering of position and other data from various sources, such as radar, flight planes, GCI, etc.;

(2) Pre-command functions, such as tracking identification, etc.;

(3) Command;

(4) Post-command functions, such as GCI.

4095 A schematic diagram showing the location of these functions in the present system and in the centralized system is shown in Fig. IV-3, in which the lines represent channels along which data, commands etc., must flow.

4096 The difference in organizational structure lies in the combining of all the GCI station functions in a single place which is also the ADCC. As a result, large numbers of small radars can be used to achieve low coverage over land, AEW and picket ships can be integrated into the land-based systems, and no military operations will be conducted at radar sites – the radars being regarded only as sources of information.

4097 The difference in detailed instrumentation lies in the exclusive use of time-sharing digital information-handling techniques in which no one component part performs any single military exclusively.

4098 The centralized system lays stress on automaticity of operation for two reasons: to achieve large traffic-handling capacity, and to enable it to respond quickly to unexpected situations.

4099 The machinery of the centralized system is flexible and can itself learn new operating procedures without requiring either structural changes or the delays inherent in training men.

4100 This system can, without special provision, handle all kinds of weapons: it can furnish mid-course guidance for interceptors; it can put AA weapons on-target; it can work with either BOMARC- or NIKE-like missiles; it can furnish tracks and identification of aircraft to civil agencies and send position data and, if necessary, commands to civil aircraft; it can handle interceptors and AA weapons in the same territory, and can automatically keep its interceptors out of the artillery fire zone or, alternatively, can prevent the artillery from firing at friendly aircraft.

4101 The centralized system naturally fits into a combined civil and military surveillance system. It can control, or furnish track data for others to control, civil air traffic. It can use any radar being operated by any service anywhere in the defense area, provided the radar in question has the required range and resolution.

b. The Information and Control Center

4102 The evolution of AC&W systems is led toward fully automatic operation by the advancing development of offensive weapons. Instead, therefore, of being a system operated by human beings with mechanical aids, an ultimate system might be looked upon as a fully automatic AC&W system inherently capably of operating by itself, but with suitable human monitoring. The stress is therefore placed on the machine with its ultimate capabilities for high speed and high traffic capacity, rather than on the human being with inherent limitations on both speed and capacity.

4103 A high potential for automatic operation is required to counter high-speed weapons and to enable the system to respond successfully to surprise attacks. Because of rapidly increasing weapon speeds, a control and warning system of the future should be inherently capable of much faster response than seems obtainable from a chain of human beings. The system should be fundamentally capable of fully automatic operation, including all phases of evaluation and weapon assignment. In actual operation, the degree of automaticity will be determined by the political and technical situation at the time. While slow aircraft speeds and a state of relative world peacefulness exist, a large degree of human monitoring, evaluation and control may be desirable in the interests of safety. On the other hand, during an actual military attack, especially with high-speed weapons, the only choice may become fully automatic data analysis and utilization. The system should be capable of providing these varying combinations of control.

4104 The Information and Control Center of a centralized AC&W system should be able to correlate information from all sources, of which the radar network is only one. It must keep track of all aircraft in the air space under its supervision. It should be able to put all defense weapons on-target.

4105 A single information center would exist in each air defense division. Parallel equipment might be used to assure reliability. Into this center would be

fed all the information obtained from radar sets, aircraft flight planes, airfield operations, ground observers, etc. These data would be processed and combined to get the total air situation, and, based on this situation and with the aid of any human monitoring employed, the defensive actions would be initiated and controlled.

4106 The information center should have capacity for tracking all traffic, including civilian aircraft, interceptors, other military traffic, and all enemy planes. In addition, it should be able to control interceptors and to direct other forms of weapons. The geographical area covered by a single center will depend on estimated traffic density. On the basis of presently foreseeable equipment, the center might handle an area between 50,000 and 500,000 square miles.

c. Automatic Data Processing

(1) General Features

4107 The primary objectives of an automatic data-processing system would be to increase performance and traffic capacity, rather than to reduce the number of men required by the system. It is to be expected that a fully automatic system will require approximately the same number of men as now employed, but will do a more complete job.

4108 An ADCC is primarily an organization for correlating and processing a large amount of simple information and for using that information to make routine decisions. The central piece of equipment in the data-processing center of this automatic air defense data system will be a computer. It is our view that a digital computer best meets the requirements for speed of operation and flexibility of setup to meet new and unforeseen developments. An analogue-type computer is, in general, circumscribed by its initial design to definite limits of accuracy and to the performance of a definite function. A digital computer can be quite thoroughly changed in function by the insertion of a new set of orders on a paper tape. A very-high-speed machine is indicated, since the size of the area covered and the adequacy of handling the problem are determine primarily by the machine capacity – higher speeds and greater storage capacities would permit the processing of information from a larger area or the more sophisticated handling of information in an area of a given size.

Preliminary estimates show that a digital computer capable of executing 20,000 single-address orders per second represents about the lower limit of satisfactory speeds. A high-speed internal storage capacity of 30,000 to 100,000 binary digits is indicated, together with several hundred thousand binary digits in a slower access memory, such as a magnetic drum. The machine and equipment should be kept as flexible as possible. In keeping with modern digital-computer practice, the instructions to the equipment should be retained in storage, thereby giving great flexibility in changing standard operating procedure and doctrine.

4109 The coordinating apparatus of a centralized system should be a general-purpose, high-speed electronic digital computer.

4110 The equipment can be expected to have special features unique to the air defense problem in addition to those found in existing digital computers. Among these will be special machine orders or equipment for trigonometric operations and coordinate conversion, and special orders to assist data correlation and sorting.

4111 Because of the programming flexibility, one can arrange for overloading to lead to gradual deterioration of performance rather than to total collapse. Under overload conditions, choices could be available, such as the less-accurate tracking of all aircraft or the exclusion from considerations of particular areas in which no enemy activity exists.

The following paragraphs discuss briefly several tasks of the automatic computing center.

(2) Automatic Track Initiation

4112 Track initiation – the initiation of new aircraft tracks – is the first step in data processing. Automatic track initiation, which seems essential to a high-speed information center, will require the storing of radar signals over a period of several radar scans until there is a basis for distinguishing noise from the beginning of a new aircraft track. This step will place a major burden on the digital-storage and processing-time requirements if the number of fictitious signals received from the radar sets is comparable to or greater

than the number of true aircraft signals. Every effort must be made, therefore, to furnish clean radar data. Automatic initiation presents no serious problem if noise-free radar information can be assumed. It will be necessary that ground and cloud clutter be rejected at the radar set before the digital data is encoded and transmitted. Full use must also be made of the fact that most tracks will start either on a perimeter or at an airport, or will be handed over from adjacent computer centers.

(3) Track Sorting

4113 The track-sorting operation is essentially that now performed on a plotting board. The continuous incoming flow of radar data is sorted according to aircraft tracks, and from this information, aircraft speed and heading are derived. This function is probably the most critical in the entire data-processing chain. At this step the radar information, including noise and the absence of signals from actual targets, must be properly composed into the tracks of aircraft. The track-sorting operation must cope with aircraft maneuvers, crossing tracks, and with any cloud and ground clutter that still remains in the radar information. It must likewise extrapolate aircraft tracks through areas in which no radar information is obtained. The flexibility of the programed digital computer should be especially significant in this function. Nonlinear smoothing formulas can be used, data from overlapping radar sets can be combined into a single aircraft track, the smoothing of quantized radar data can be done with respect to aircraft course and speed rather than with respect to X and Y or R and θ coordinates, and information from all sources, including radar direction finding, visual sighting, and the ground observer corps, can be combined into one total aircraft track picture. The data rate of the radar network is an important factor in the sorting operation. If the data rate is too high, an unnecessary burden is generated by the delivery of too much information for processing. On the other hand, too slow a data rate, combined with low resolution in the radar set, may lead to a confusion in areas of heavy aircraft traffic and may make the generation of unambiguous tracks impossible. A digital computer operating with such electronic techniques as have already been demonstrated should be able to correlate 1000 radar signals

with aircraft tracks in 3 to 10 seconds, including the required coordinate conversion on the radar data. With a computing cycle of 15 seconds, less than half the 15-second period would be used for correlation of data into tracks, and the balance of the computer time would be available for other data-processing functions (see Appendix IV-6).

(4) Identification

4114 Automatic data processing can aid the identification process by making possible the rapid searching and combination of all available information.

4115 The automatic phases of identification can include the comparison of aircraft tracks with previously filed flight plans, information obtained on aircraft take-off if the craft has been continuously tracked since it left the airport (see Appendix II-1), radar IFF (Identification, Friend or Foe) reports, information from ground observers, and pilot reports. Various predetermined probabilities of identification can be assigned to each of these sources of information, and any aircraft track falling below a specified probability threshold might be displayed for a command decision or might be recommended for interceptor inspection. Satisfactory operation of this system will require tightening up the reliability and promptness of reporting aircraft flight schedules. We may continue to require approach corridors, check points, and landing fields remote from important targets to reduce the hazard from inadequate identification information.

4116 As much as possible of the identification function should be performed automatically, leaving only the doubtful cases to be judged by a man. Future centralized AC&W systems in conjunction with improved operational procedures should permit identification by machine in most cases.

(5) Information Presentation

4117 The presentation of information for human interpretation and monitoring is a subject requiring much experimental study. A new system carrying on

automatically many of the data-processing functions will use men so differently from the way they are used in the present-day air defense system that present experience and prejudices are unlikely to be of great value. Information display should provide for the following:

(a) Verification that the system is operating as intended;

(b) The general status and situation display;

(c) Detailed data as a basis for those decisions that are the responsibility of the men in the system. These will include selective displays of various categories of aircraft, displays of new aircraft tracks, and displays of unidentified airplanes.

(6) Weapon Direction

4118 Weapon direction is a straightforward problem, once the information on aircraft has been correlated and the identification, threat evaluation and weapon assignment have been completed. Different weapons will require different types of information. The same machine that tracks and identifies can also compute train angles for putting AA weapons on-target and course orders for mid-course interceptor guidance, can direct BOMARC- and NIKE-like devices, and generally supervise all defensive weapons.

4119 For the interceptor aircraft, the central computer may calculate aircraft heading and altitude orders to cause an interception. This will probably be a collision-course computation, at least up to the final stages of closure. Information transmitted to the interceptor may include heading angle, time until interception, bearing of the target, orders for final maneuvers to place the interceptor in a favorable position, information on the number of targets that may be encountered, and the possibility of friendly aircraft in the area. The frequency with which the interceptor needs this information depends on the interceptor and target characteristics, and may vary during the progress of the interception. In general, the interceptor should be instructed at intervals of from ten seconds to two minutes. The calculation of weapon directions at the information center may represent a computing load comparable to that for data correlation. In other words, a few hundred bomber-interceptor combinations might require several seconds of computing time for a complete

solution. This can, nevertheless, be accomplished with a time lag not greater than 15 seconds.

d. General Problems

(1) Time Scale

4120 With good priority and support from the Air Force, a first full-scale air defense district operation with short-range multiple radars and an automatic information-processing center might be installed by the end of 1956. An all-out effort might achieve this sooner. Under ordinary non-emergency circumstances, the date might be considerably further in the future.

4121 A full-scale centralized system covering approximately the area of a present Air Division can be installed before the end of 1956.

(2) Reliability

4122 Along with the high efficiency and flexibility of the digital computer, there goes a vulnerability to electronic failure that is greater than in other systems. In the present state of the electronic art, it is probable that three electronic processing systems should operate in parallel to permit comparative checking of results and to allow for the required maintenance time of the equipment. The preceding comments on efficiency take account of this need for multiple equipment, and even with this paralleling it appears that the digital equipment does not lose its advantage in simplicity for a given magnitude of information processing that is to be done.

(3) Peacetime Operation

4123 Since the air defense system should be kept in top operating condition and ready for action at any time, the centralized AC&W system should be kept in continuous operation to observe and provide information on civilian air traffic.

(4) Two Crucial Points

4124 Success of this system requires answers to at least two problems: first, satisfactory automatic recognition of radar signals relatively free of ground and cloud clutter and jamming; second, demonstration that large interconnected electronic systems can, in fact, be constructed and maintained with adequate reliability and continuity of operation. Present military field experience with electronic equipment is not promising on the latter count, but recent research into electronic reliability and performance results from an existing digital computer at MIT are encouraging. The most powerful innovation has been extensive use of "marginal checking" for predicting component failure before trouble develops (see Appendix IV-7.)

C. IMPLEMENTATION OF THE LONG-TERM PROGRAM

1. Model System

4125 It is recommended that every effort be made to obtain an early operational evaluation of a centralized radar and digital computer network. We propose the establishment in Eastern Massachusetts of a model system nicknamed the "Cape Cod Air Defense System" (see Fig. IV-4), which would employ between 10 and 15 modified SCR-584, AN/CPN-18, or AN/ASR-2 radar sets, along with height-finder radars, all connected to the WHIRLWIND digital computer at MIT. This experiment should be so planned as to keep flexibility in the components and systems interconnections, in order that the flow of information can be modified on the basis of further research and experience. This model system may be installed in one and one-half years and be under test in two years. Tests have already been made with one radar set feeding data automatically to the WHIRLWIND digital computer. The computer has done automatic track sorting and data smoothing and prediction, and has successfully calculated magnetic compass headings for interceptions with actual aircraft. The Cape Cod air defense experiment will be a continuation and expansion of the tests already completed.

4126 For early operational evaluation of the centralized system concept, an experimental AC&W network of this type should

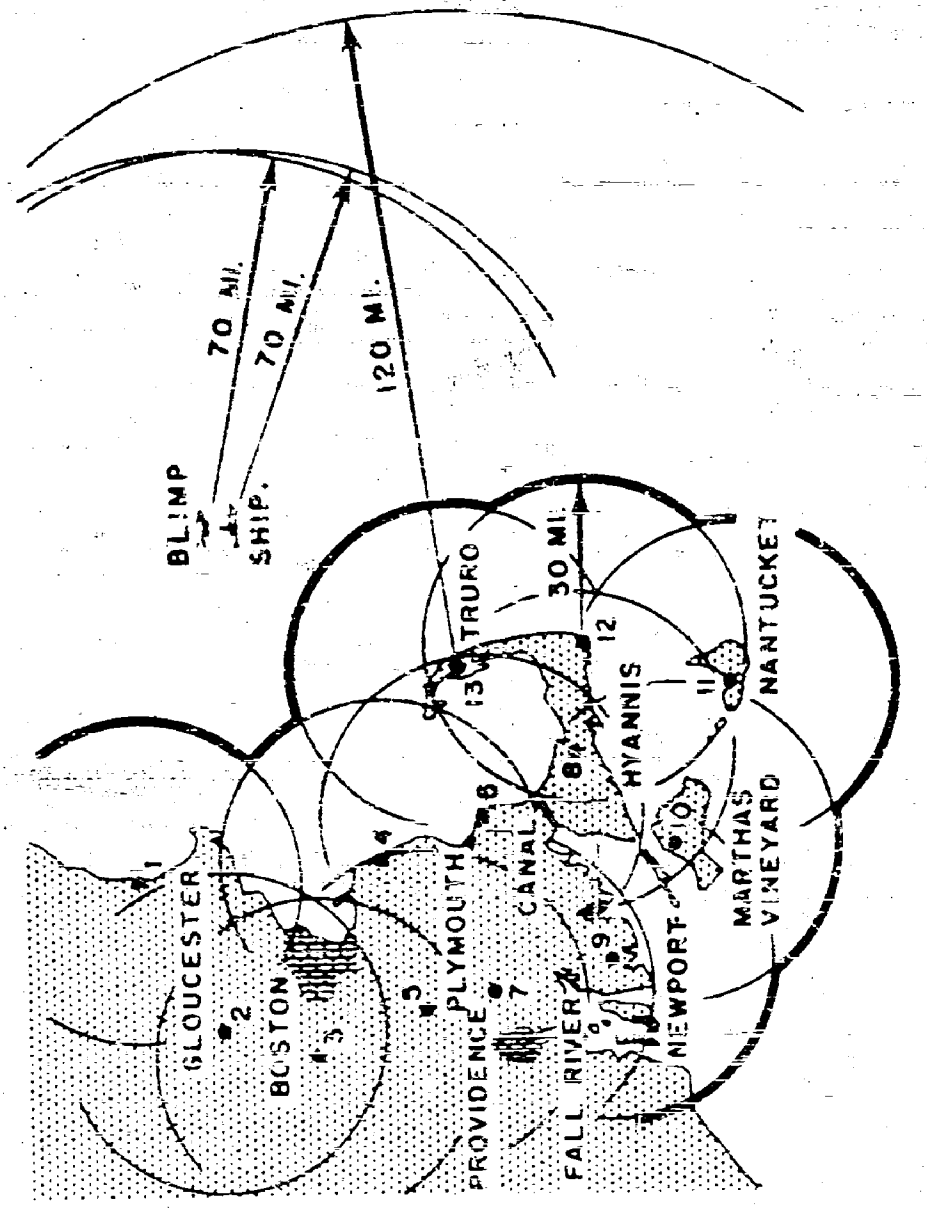


Fig. IV-4 Proposed "Cape Cod" system.

be established in Eastern Massachusetts by connecting between 10 and 15 radars and height finders to the WHIRLWIND digital computer at MIT.

2. Computer Design

4127 Several steps should be taken immediately to insure the availability of an improved computer design at the time that the above experiments are successfully proven.

(a) A revision and modification of present WHIRLWIND computer drawings should be done to take advantage of the experience obtained since construction of the machine was started.

This phase of the program should have always available a computer design that is being upgraded as rapidly as possible with respect to the air defense system requirements.

(b) In addition to the gradual upgrading of the WHIRLWIND computer design which will have continuously available drawings that can be called on when required, it is recommended that a new design be started which will take advantage of the best computer components and techniques that now show sufficient research promise.

Such a design might not be expected to materialize into final form in less than two or three years. It should take advantage of the design and operating experience with the WHIRLWIND computer, the experience with other operating electronic computers, the new digital computer components that have been developed in the last few years, and the operating experience and systems study going with the Cape Cod air defense system. The machine would include special features uniquely suited to the air defense problem, as determined by the applications and coding studies now in progress.

4128 Based on experience with WHIRLWIND and other electronic computers, and on the results of the Cape Cod experiments, a new digital computer should be designed with special features uniquely suited to the air defense problem.

3. Laboratory Program

a. Storage

4129 Since the high-speed internal storage of all existing computing machines is marginal with respect to the present problem, it is recommended that additional research in high-speed storage devices be encouraged. This should be aimed at both improved storage capacity, speed, and reliability of presently existing electrostatic tubes, and also at the development of new and fundamentally better types of high-speed storage. An example of the latter might be three-dimensional arrays of ferromagnetic or ferroelectric storage elements.

b. Computer Components

4130 Development of other computer components should be expended – transistors, crystals, reliable vacuum tubes, maintenance procedures, display equipment, etc.

c. Data Transmission

4131 Special attention must be given to the encoding and transmission of radar data and to the rejection of false radar signals.

d. Separated T-R Radar

4132 Because of the reduction in effect of ground clutter and coupled transmitter noise, and because of the absence of velocity blind zones which occur with pulsed Doppler equipments, it is recommended that the systems work on separated T-R continued.

e. Pulsed Doppler

4133 Because of the advantages of a self-contained system, the development of pulsed Doppler systems should be stressed. The use of two frequencies or two repetition rates to eliminate the effect of blind speeds should be studied.

f. Gap-Filler System

4134 Because of the slow scanning speed possible in this application and the consequent reduction in complexity of equipment, together with the use of

L-band with its freedom from velocity null zones and greatly reduced scatter from rain, the use of a gap-filler type system should receive serious consideration.

g. Radar Components

4135 Work should continue on the production of higher-power CW sources with low transmitter noise, and on the development of stable pulsed amplifiers that are free from frequency modulation.

4136 The development of methods of obtaining stable comparison frequencies (whether by modulation or delay lines) is essential.

4137 Continued investigation of multiple filters for analysis of the Doppler spectrum and the reduction of noise bandwidth is also recommended.

SECTION V

AIR DEFENSE WEAPONS

SECTION V

AIR DEFENSE WEAPONS

A. INTRODUCTION

5001 The purpose of a weapon is to destroy the enemy or prevent him from accomplishing his mission. Important phases of air defense such as target detection, acquisition, identification, communications, weapon assignment (gun, interceptor or missile), while essential to the success of a system, are but means to an end. None is of value unless the enemy is engaged by the weapon and destroyed, or at least prevented from the accomplishment of his mission. The tone of the following discussion, therefore, is to focus attention on the single problem of destroying enemy aircraft anywhere at any time.

5002 Present defense weapons and those under development have been considered to determine their capabilities and limitations. The interrelations of these weapons and the threat have suggested certain emphases in weapons and weapon-system developments and their employment.

B. INTERRELATION OF WEAPONS AND THREAT

5003 The development and employment of air defense weapons may be referenced to time and space parameters. As to time, the weapons art may be about to experience a major discontinuity with the appearance of guided missiles. The air-to-air missile (AAM) will serve principally to increase the effectiveness of our interceptors. The surface-to-air (SAM) type may ultimately have great influence on our whole weapons system. This latter type will greatly influence our thinking in terms of space parameters. In meeting the high- and low-altitude threats in time periods before and after the availability of guided SAM, certain broad conclusions are evident. The conclusions and recommendations stated in later paragraphs in greater detail may be briefly summarized as follows:

1. Time Period Prior to the Availability of SAM

a. High-Altitude Targets

5004 The interceptor is far superior to conventional antiaircraft artillery (AAA) or unguided rockets against high-altitude targets. While interceptor

developments should not ignore the low-altitude problem, they should be directed particularly against targets above the low altitudes during this time period.

b. Low-Altitude Targets

5005 Antiaircraft artillery, using predicted-fire guns or unguided rockets, appears to be the principal means to attack air targets at low to medium altitudes. Interceptors will effectively cover the low-altitude zone only with the aid of a ground system, discussed in Section IV. Development of predicted-fire surface-to-air weapons should concentrate on short-time-of-flight solutions to meet the low- to medium-altitude threat.

2. Time Period After Effective SAM Are Available

a. High-Altitude Targets

5006 Surface-to-air guided missiles will complement interceptors in an integrated composite defense. Continued emphasis will be required on longer range and higher altitude coverage by missiles and interceptors to match the changing nature of the threat. Predicted-fire weapons will not be competitive at high altitude, and development of guns and unguided rockets for this purpose should then terminate. Medium altitude predicted-fire weapons should be continued only to the prototype stage as an insurance for surface-to-air guided missiles.

b. Low-Altitude Targets

5007 Interceptors and guided SAM are expected to have serious limitations at low altitudes. Predicted-fire surface-to-air weapons with very high rates of fire, and rockets with appropriate fire control, appear to have high merit in this application.

C. INTERCEPTORS

1. Introduction

5008 Since manned interceptors can be employed, for the purpose of active air defense, only in the presence of some form of aircraft control and warning (AC&W) system, it follows that deficiencies in this system may have an overriding effect in limiting the scope of interceptor action. It is quite clear, for

example, that inadequate radar coverage, delays in filtering and transmitting data, limitations in the control-system capacity for handling many simultaneous tracks, and a number of other factors, may all restrict the circumstances under which it is possible for interceptors to engage in combat with enemy aircraft. Where an effective defense implies the destruction of enemy aircraft prior to bomb release, serious deficiencies in the AC&W system may paralyze the interceptor force, regardless of aircraft performance or potential combat capabilities.

5009 The technical possibilities and time scale involved in attempting to remedy this situation by the development of a much improved AC&W system have already been discussed elsewhere in this Report (see Sections III and IV). Certain limitations must be expected to remain until such a system has been developed. There is reason to suppose, however, that in the immediate future much may be gained by directing attention to those qualities of the manned interceptor that can be made to compensate in part for inherent deficiencies in present systems of aircraft control and warning.

5010 In particular, three promising fields for improvement in this interim period are apparent. These are:

(a) Reduction in scramble times on receipt of orders from the AC&W system;

(b) Increase in interceptor forward speed and rate of climb, particularly the latter;

(c) Greater utilization of the interpretive capabilities of the pilot prior to the combat phase of interception.

5011 Both (a) and (b) are quite obvious courses of action in compensating for insufficient depth of radar coverage and for time delays prior to the scramble order. Point (a) is nevertheless emphasized here because significant reductions in the time to scramble can be achieved by further attention to airfield arrangements and by constant practice of realistic operational scrambling procedures.

5012 The possibilities for improving the forward speed and the rate of climb of current aircraft are discussed in Para. 5033. The necessity for high rates of climb, or short times to altitude, under existing circumstances, have been amply demonstrated by air exercises in the United States and the United Kingdom in recent years. Although some newer aircraft are capable of comparatively short times to altitude, a continuing requirement for such further

improvement as can be achieved is considered to be justified.

5013 If some of the interpretive functions now performed by the AC&W system are delegated to the interceptor crew, the system automatically becomes capable of handling a greater number of tracks, and therefore is less subject to saturation than at present. In view of the possibility of a dense attack against the continental United States, overseas areas, or portions of the Fleet, the problem of saturation of the AC&W system cannot be ignored. In an earlier section (Para. 3141) we have therefore recommended that "broadcast control" should be planned as an emergency method of interceptor control. For this, the interceptor must be capable of navigating on the basis of target-position data supplied from the ground, and therefore must be able to determine its own position with reasonable accuracy. Although this can be done now under certain limited circumstances, it is generally recognized that a suitable navigational aid is necessary for satisfactory broadcast control. Development of such an aid has not yet been completed, and under the present program none will be available before 1954. The possibility of improving upon this date and of providing some form of interim equipment is considered in Para. 5147.

2. Aircraft

a. Technical Adequacy of Present and Future Programs

5014 The interceptors now in service with the United States Air Force (USAF) or intended to be in service within the next two years have, in nearly all cases, some margin of combat performance over that credited to the TU-4 or the submarine-launched guided missile of the LOON type. Exceptions occur with obsolescent propeller-driven interceptors which may have unsatisfactory characteristics for combat with the TU-4 at altitudes approaching 35,000 ft. Times to climb for these aircraft and for the F-80 are also excessive at the higher altitudes, and constitute a performance limitation in interceptor operations with present AC&W systems. This has been amply demonstrated during recent air defense exercises in the United States and the United Kingdom.

5015 Every attempt is being made to equip the Air Defense Command (ADC) and tactical forces as quickly as possible with the best available aircraft. Whenever possible, more powerful engines or afterburners are being incorporated into

later versions of current interceptors in order to reduce time to climb and to improve combat performance at altitude. Since the whole of this program appears to be aimed at developing the performance capabilities of these aircraft to the practical limit, no further comment on the performance of interceptors expected to be in service during the next two years is considered necessary.

5016 The selection of interceptor types for service in Air Defense Command and in the tactical air forces, and the program for improving their performance capabilities during the next two years, appear reasonable in view of present technical limitations.

5017 By Spring 1953 the USAF plans to have three types of interceptor operating within the ADC and three types with the tactical air forces. In the former case, all three types of aircraft are intended to be capable of all-weather operation and, of these, one type (F-86D) is single-place while the remaining two (F-94 and F-89) are two-place. The majority of the interceptors (fighter-bombers) scheduled for the tactical air forces are single-place day fighters (F-84F and F-86E) supported by a small number of single-place all-weather F-94 aircraft. Beyond Spring 1953, the CHARLES group has been informed of no firm plan for replacement aircraft other than the MX 1554 ("1954 interceptor").

5018 It seems appropriate, therefore, to discuss the possible limitations that may arise from continued retention of the above aircraft beyond the Spring of 1953 and the extent to which the MX 1554 program may be expected to prevent or remove technical inadequacies.

5019 It is evident that the process of performance improvement by changes in power plant, without major structural alterations, cannot be continued indefinitely. In the case of all aircraft scheduled for service in 1953, wing thickness and sweep (or lack of sweep) primarily determine the Mach number (M) at which large increases in drag and other compressibility effects occur, while body dimensions limit the space available for power plant and ducting. The nature and extent of proposed developments prior to 1953 indicate that relatively little further general improvement in the performance of these aircraft can be anticipated after that date and, in particular, it is highly unlikely that maximum level speeds greater by more than two or three per cent will be attainable.

5020 Reference to the estimated performance of enemy aircraft that may constitute a threat to the continental United States in future years, as we have been informed, shows that a first major change may be anticipated in 1954 when the enemy may be capable of launching 450-knot LOON-type missiles with a range of 100 miles from "improved" TU-4 type aircraft at an altitude of up to 35,000 ft. If these missiles are employed without evasive action, the performance of interceptors in service appears to be quite adequate. By 1956, however, 500-knot bombers flying at up to 50,000 ft. may be capable of reaching targets in this country. Against a threat of this description, it is clear that the performance of the interceptors planned for service before 1953 will be inadequate.

5021 Interceptors scheduled to be in service in Spring 1953 are not capable of much further major development and will be inadequate to counter the threat expected by 1956.

5022 In overseas areas, where distances from enemy bases will be considerably shorter, there is a strong probability that enemy aircraft having a higher performance will be encountered at an earlier date than in the continental United States.

5023 Experience in Korea has already indicated the need for the best available day fighter in situations in which fighter-fighter combat is anticipated.

5024 Defense against light or medium bombers or reconnaissance aircraft, with performance of the order of M = 0.9 at altitudes up to 50,000 ft., may be required as early as 1954 in overseas areas. At the same time, it may be expected that the enemy will be endeavoring to put into operation the most advanced day-fighter aircraft that he is capable of producing. It is clear that in these theaters the problems of developing improved defensive capabilities are more nearly comparable to the enemy's problems in developing offensive capabilities, and that the balance of performance superiority in favor of one side or the other will be extremely critical. In overseas theaters, it is therefore important to prepare for the introduction of new or radically improved interceptor-tactical fighter aircraft as soon as possible.

5025 In overseas areas, high-performance enemy aircraft will be encountered earlier than in the United States. For air defense overseas the USAF should plan forces that include the most advanced day-interceptor tactical fighter types.

b. The Single-Place All-Weather Concept

5026 At the present time, interceptor forces in the United States Air Force, the United States Navy (USN) and the Royal Air Force (RAF) comprise two classes of aircraft. These are:

(1) The day interceptor, intended to be capable of visual target acquisition and therefore useful for combat only under good conditions of weather and visibility. All these aircraft have a single crew member;

(2) Night and all-weather interceptors, intended to be capable of combat under nonvisual conditions and in the presence of icing or other weather hazards. Currently operational aircraft of this description all have a crew of two.

5027 For the defense of the continental United States, the USAF plans to provide an entirely all-weather first-line interceptor force by the middle of 1953. Of the three aircraft types to be in use, two have a crew of two, the other a single crew member. For operation in overseas theaters at this date, the USAF plans to provide a majority of single-place day interceptors supported by a few two-place all-weather aircraft, all having a capability for employment in offensive roles in addition to interception duties.

5028 For Fleet defense, the USN plans to have available single-place day interceptors in addition to single-place and two-place all-weather interceptors.

5029 Preoccupation with the problem of dealing with dense attacks, expected particularly under conditions of good visibility, has led to the opinion in the United Kingdom that a broadcast control system is most likely to result in a rapid improvement in air defense against this form of attack. While a single crew member is considered capable of meeting the demands of such a system under good visibility conditions, a single-place interceptor concept has not been accepted for defense against any form of attack under conditions of poor

visibility and bad weather. For an indefinite period, therefore, the RAF interceptor force is planned to consist of single-place day (good visibility) aircraft and two-place (all-weather) aircraft.

5030 The main difference in the courses of action adopted by the three air forces is the role assigned to the single-place all-weather interceptor. Arguments favoring or rejecting the single-place all-weather concept are influenced by the estimated nature of the threat of air attack in various theaters. The policy adopted in each case has depended upon the degree of concern felt in the light of the anticipated threat as to whether the incorporation of all-weather features into a single-place aircraft will result in a compromise that is much less satisfactory than an aircraft designed as a day interceptor under good visibility conditions and also less satisfactory than a two-place aircraft under poor visibility and weather conditions.

5031 Single-place all-weather interceptors play important roles in the USAF and USN aircraft programs. The operational soundness of the single-place all-weather concept should be evaluated by exhaustive trials at the earliest possible date.

5032 When conclusions are drawn from operational tests to be made in the near future, it must be recognized, of course, that later advances in the AC &W system and in the airborne electronic equipment will lessen the demands made on the pilot of a single-place interceptor.

c. Technical Possibilities for Higher Performance

5033 The military characteristics of rate of climb, speed, maneuverability and range can be improved by technical advances in power plants, leading to higher thrusts, in airframe design, leading to lower drags without sacrifice in the structural strength required for maneuvering, and in the aerodynamic configuration and controls required for stable flight at all speeds without sacrifice in speed of maneuvers. Comments on these three factors relating to high performance interceptors are given below, without reference to particular aircraft, but in an attempt to lead to subsequent general conclusions about the MX 1554 program and about other improvements in interceptor aircraft performance.

(1) Power Plants

5034 The use of turbojet power plants with afterburning for transonic or moderately supersonic aircraft appears to be the best solution to the propulsion problem for the next three or four years. A rocket or ramjet manned configuration must almost necessarily be equipped with a supplemental power plant of longer duration than the rocket and more suitable low-speed characteristics than the ramjet.

5035 U.S. engine manufacturers are at present engaged in the development of turbojets with basic sea level static thrust ratings ranging from 7000 to 12,000 pounds and comparable combat thrust ratings ranging from 11,000 to 25,000 pounds. One engine in the 10,000-pound basic thrust class has been test-flown from the bomb bay of a B-29, and production is scheduled for late 1951. The time scale for production of most of the other high-performance engines is not so promising. Engines of the intermediate-thrust range are scheduled for production by approximately 1953, and those of the high-thrust range by approximately 1955.

5036 The probability of obtaining these basic thrust ratings on their present time schedule appears very good. However, the technical problems of afterburner operation at altitudes above 35,000 ft. are far from being solved, and it is definitely unlikely that solutions will be forthcoming at a rate such as to keep afterburner development abreast of engine development. Such delays in the attainment of proposed combat thrust ratings will drastically alter the expected performance of the MX1554 interceptor and should be avoided if at all possible. For this reason, it is recommended that high priority be given to afterburner development, and that suitable transonic vehicles be placed at the disposal of engine manufacturers for research programs in high-altitude, high-speed afterburner operation.

5037 Turbojet power plants with afterburning are indicated for the propulsion of transonic or moderately supersonic aircraft in the future. High-altitude high-speed afterburner operation urgently requires further development work; this should be

supported by making suitable test facilities available to contractors.

(2) Airframe Design

5038 Higher-performance aircraft, such as those of the MX 1554 proposal, must of necessity depart radically from the familiar characteristics of the present-day high-subsonic fighter. It is yet to be proved conclusively which of the numerous possible configurations incorporating delta-, swept-, or straight-wing planforms, with or without horizontal tail surfaces, is superior.

5039 All these planforms will undoubtedly utilize extremely thin airfoil sections (3 or 4 per cent thick), some with sharp leading edges, others with conventional rounded leading edges. Such a phenomenal departure from current wing design most certainly should entail rigorous detail wing structural-design studies corroborated by structural testing of practical constructed test specimens. Some analytical investigations have already been carried out for missile configurations somewhat similar to those of interest here. However, substantiating structural tests, in sufficient numbers to be conclusive, are yet to be forthcoming.

5040 The importance of thin-wing structure design lies in the extreme sensitivity of aircraft performance to small changes in wing thickness.

5041 The problems in the design of fuselages and nacelles for higher performance aircraft appear much less formidable and, except for the higher air loads encountered, may very well be patterned after existing designs.

(3) Stability, Control and Maneuverability

5042 The problems of transonic stability, control and maneuverability have received very little attention compared to that given to transonic drag. Research programs utilizing the free-flight rocket facilities of the National Advisory Committee for Aeronautics (NACA) are now in progress. Similar programs for the new 8-ft. and 16-ft. transonic wind tunnels are being planned for late in 1951. To date, however, the best source of stability information may be found in the flight-test data of present-day high-subsonic airplanes, tactical fighters as well as research aircraft. Some general conclusions may be drawn from these data.

5043 It appears that most of the existing airplanes capable of near-sonic flight do not possess good flying qualities at transonic speeds. First, the tailed airplanes exhibit undesirable changes in longitudinal trim with increasing Mach number, which requires the use of adjustable stabilizers or all-moving tails. Second, the combination of high wing loading, low aspect ratio, and large sweepback seriously limits the maneuverability of typical high-subsonic airplanes at high altitudes because of buffeting and the loss of lateral and longitudinal stability at moderate lift coefficients. This state of affairs is aggravated by the high drag due to lift associated with wings of this type, and it is found that attempts to maneuver these airplanes at transonic velocities result in rapid deceleration to subsonic velocities – of the order of one-tenth Mach number per second. Presumably this situation may be improved by the adoption of lower wing loadings and thinner wing sections – 4 per cent or less in the streamwise directions. Third, it has been found that the currently favored high tail location contributes to longitudinal instability at high angles of attack (e.g., in maneuvering and landing), and that tail locations below the wing root chord line are more favorable. Fourth, the lateral characteristics at transonic velocities are as bad as the longitudinal characteristics of these airplanes, with wing dropping, loss of aileron effectiveness, and lightly damped lateral oscillations being the general rule. Except for aileron effectiveness, these phenomena have not yet been investigated in detail. Fifth, the lateral characteristics of highly swept airplanes are unfavorable at high lift coefficients at all air speeds; but these difficulties may be overcome, at least at low speeds, by the application of ingenious autopilots or automatic stabilization devices.

d. The MX 1554 Program

5044 The MX 1554 proposals, nine aircraft from six bidders, are designs for interception of a hypothetical bomber flying at M = 1.3 at an altitude up to 60,000 feet. The interceptor is to have a 375-nautical mile radius of action. The MX 1554 now occupies an important position in the plans for air defense.

5045 Because of the advanced nature of the threat contemplated in the MX 1554 program, it is not surprising to find that the interceptor proposals require considerable advances in the design of power plants, in airframe design and

structure, and in controllability. The technical problems in these designs are discussed in Para. 5033. These problems are being attacked in aerodynamic and instrumentation laboratories, on the free-flight model ranges, and by means of the research airplane programs. Rapid pursuit of the development of any of the MX 1554 proposals will require that much general research in the transonic- and supersonic-flight range be conducted with specific reference to these proposals. This will complicate some of the research problems because the solution must meet specific demands in range, maneuverability, rate of climb, and armament. Because of the many appreciable technical advances required, it should be expected that this program will meet delays, and that changes in design will be necessary; thus, reliance should not be placed on early success. Furthermore, there are so many unpredictable factors that choice is difficult, and the possibility of failure to develop a useful interceptor is present in all designs. For this reason, the proposal to pursue more than one of these designs is sound.

5046 The MX 1554 program depends on the successful accomplishment of major technical advances. Delays should be expected in this program, and at least two designs should be carried to the prototype stage and flown.

e. Improved Performance of Existing Types of Aircraft

5047 The need to improve existing interceptors in the next few years stems from an estimate of the bomber threat. Medium and even heavy bombers will soon fly at speeds comparable to those of our present interceptors. Combining these considerations with the present shortcomings in the rate of climb to altitude of many of our existing interceptors, the margin of superiority of interceptor over bomber will disappear in the absence of improved interceptor performance.

5048 The MX 1554 program represents one approach to the higher-performance interceptor, in which a rather large improvement is to be secured by attempting to advance many phases of the design simultaneously. The question then arises as to whether another approach should be used. One such approach is obvious and is being carried on continually. This is the evolutionary change of

existing designs by addition of improved power plants, alteration of aerodynamic configuration and control-surface arrangement, etc., as these developments become proven. With the expected delay in the realization of the MX 1554 proposals, it is certainly desirable to proceed with this type of program. Improvement in speed and rate of climb at all altitudes should be pursued.

5049 As indicated above, some of the existing high-subsonic speed interceptors have inherently poor configurations for transonic flight. Others have distinct possibilities. Existing interceptors should be carefully reviewed to select those that have the greatest possibilities for further improvement in performance. If these selections are such as to carry an interim MX 1179 or equivalent control and guidance system, so much the better.

5050 Improving the stability and controllability of existing interceptors would be well worth while. A small improvement here might realize sufficient difference to constitute a margin of superiority in combat.

5051 Most of the aircraft that can be improved markedly are single-place aircraft. As indicated in Para. 5083, there may be considerable advantage to a two-place aircraft with a trained radar and antijamming operator. For this as well as other reasons, improvement in the performance of two-place interceptors should be pursued.

5052 In view of the advanced character of the MX 1554 program, we recommend that the Air Force insure its interim interceptor program by obtaining the maximum possible improvements in the speed, rate of climb, and control characteristics of carefully selected existing interceptor types. These should include a two-place all-weather interceptor.

f. Air Refueling of Interceptors

5053 Because of the need for retaining high performance and for reducing the take-off requirements, high-performance interceptors are inherently limited in fuel capacity. Air refueling is a method of increasing the effective fuel capacity with only a very minor performance penalty; it offers the following benefits:

(1) Increase in operational radius of action, resulting in greater flexibility of the force, provided adequate early warning is available;

(2) Increase in range, making possible the ferrying of interceptors over longer distances where base facilities are not available en route;

(3) Increase in endurance, making the land equivalent of a naval Combat Air Patrol more practicable;

(4) Increase in safety of interceptor and crew by having refueling available above bad weather, thus making possible a return to an alternate base.

5054 The fleet of air tankers with its overhead will necessarily detract from the strength of the front line. Plans for such a fleet must be carefully considered; it may not be possible to incorporate air-refueling facilities in all interceptors.

5055 At least a proportion of the land-based interceptor force should be equipped to permit air refueling, and a suitable number of air tankers should be provided.

Wherever possible, future land-based interceptors should be planned from the outset to permit air refueling.

5056 A prompt assessment of the value of air refueling at sea should be undertaken by the Navy.

g. Unorthodox Interceptors

5057 Several proposals have been made for interceptors that differ radically from the generally accepted trend; the small rocket-powered aircraft and the ramming interceptor are examples. In both cases, an attempt is made to define one basic mission and to avoid penalizing the interceptor with requirements to perform other duties. The low single-pass kill probability of present interceptors is recognized, and the proposals are aimed specifically at providing a system in which the largest possible single-pass kill probability is incorporated into each interceptor. At the same time, by concentrating on a simple airframe and the minimum of equipment, it is intended to reduce initial and operating costs to the extent that very much larger numbers of aircraft can be made available to perform the basic mission. Special interceptor systems of this or some other kind may have merit in particular circumstances.

(1) Ramming

5058 While it begins to appear technically possible to build an interceptor from which the pilot might escape after ramming a bomber, it is important to examine both the military justification for such tactics and the operational feasibility. Sighting and control problems may be troublesome, and it will be difficult to achieve a 'ram' on a thin-skimmed part of the target. It must also be remembered that such a weapon is a daylight fine-weather interceptor, and is inherently inflexible in operation. Nevertheless, since the need to obtain a kill is vital, it is recommended that the ramming concept be studied objectively both by military to see if it is wanted and by the industry to see if it can be done.

(2) Rocket-Driven Interceptor

5059 As a local defense weapon, a manned interceptor powered by a rocket motor and armed with a rocket battery has been considered by the German, who used the Me.163 with some success, and by the RAF, who have ordered prototypes of such aircraft. The advantages appear to be a very high rate of climb, cheapness, and no runway requirement, as well as a simplified air-crew training requirement. The disadvantages are short range, day-only operation, and a necessity for special ground equipment. A special development effort in propulsion, aircraft, guidance and fire control would be needed. In locations likely to receive only short early warning, or where dense raids must be anticipated, such an aircraft could be very valuable. It is therefore recommended that the British development be closely examined. A parallel American effort on rocket-powered interceptors does not appear justified.

(3) Vertical Take-off

5060 The requirements for increased performance in Fleet fighters is leading to take-off and landing characteristics that place an unacceptable burden on ship constructions and that would necessitate larger and larger carriers. In the interests of limiting the size and expense of carriers, while at the same time making certain that interceptors of adequate performance are available for the air defense of the Fleet, it is important to reduce the landing and take-off requirements of naval interceptors. Development of vertical take-off and landing is of great importance, and should continue.

(4) Interceptors without Undercarriages

5061 It is generally accepted that the alighting gear of an aircraft amounts to 6 per cent of its weight and, because they must have such gear, aircraft are larger or more expensive than they need otherwise be to perform a particular function. Alternatively, more fuel or armament could be carried. Further, the increasing performance required of aircraft is leading to runway requirements that are increasingly difficult to meet because of long landing runs and high wheel loads. (The take-off problem is less difficult because of the availability of JATO or catapults.) Therefore, important advantages can be gained by designing interceptors without undercarriages. Studies and development work in this field should be initiated.

(5) Low-Altitude Interceptors

5062 Once an AC&W system with low-altitude cover becomes available, it may be possible for the interceptor to intercept and engage in combat at all heights. In spite of the difficulties that fire-control equipment and guided missiles may have at low altitudes, orthodox air armament consisting of cannon or rockets will be adequate, provided the interceptor can be vectored to its target. It is therefore desirable that interceptors that can exploit the low-altitude capability of the future AC&W system be made available, in spite of the fact that the increasing emphasis on speed and height militates more and more against good enough low-altitude performance by the same aircraft. Due consideration must be given to the role of predicted-fire weapons at low altitudes. (See Section IV.)

5063 Unconventional interceptor designs may offer important advantages in special situations. We recommend close attention to developments in rammers, rocket-driven interceptors, vertical take-off, and interceptors without undercarriages. Particular emphasis should be given to the development of low-altitude interceptors.

3. Airborne Fire-Control Equipment

a. Introduction

5064 After the defensive interceptor aircraft has been brought within the vicinity of its target and has been headed generally toward it, no further significant help from the ground-control system is available. The interceptor is thereafter dependent on its own resources for locating the target, for bringing itself to an appropriate position and altitude at the appropriate moment to release its ammunition, for firing the ammunition properly, for carrying out whatever post-firing operations the ammunition may require, and for breaking away safely from the target. Certain equipment is carried for these purposes; this equipment, together with the aircraft itself and (usually) the pilot, constitutes the airborne fire-control system.

b. Fire Control for Guns and Cannon

5065 All USAF and USN fighters are now armed with fixed forward-firing machine guns or cannon. Any one round that hits is unlikely to kill: the kill probability can be made high only by making a large number of hits. If the fire-control system is good enough to reduce nearly to zero the fraction of rounds that miss entirely and thus contribute nothing to the kill probability, while causing or allowing the hits to be distributed with approximate statistical uniformity over the silhouette, it is as good as it needs to be.

5066 Because many hits are needed, while only a few rounds per second can be fired, the fighter armed with cannon must maintain itself for several seconds in the firing position. The practical consequence of this requirement, when the kinematics of the situation, the limited effective range of the rounds, and the limited turning rate of the fighter are all considered, is that the firing must occur while the fighter is turning along a lead-pursuit course and is approaching from generally astern of the target.

5067 The development and introduction, in the latter part of World War II, of the optical gyro gun sight makes use of the fact that the proper lead angle, for a given bullet ballistics, can be computed to a fair degree of approximation from two data: (1) the turning rate of the fighter while tracking the target, and

(2) the range to the target. The turning rate is measured by a gyroscope in the fighter; the range is measured either stadiametrically, or, in postwar II improvements of the gyro sight, by a small range-only radar with its dish located in the nose of the fighter and with a forward-looking beam wide enough to encompass comfortably the full scope of expected lead angles. Thus the pilot is relieved both of measuring range and of estimating lead. Moreover, positive range information is available to him for judging the proper time for firing. It is still necessary, of course, for him to track the target visually, i.e., to fly his aircraft so as to keep the target centered on the pip furnished by the computing gunsight. Most present USAF and USN day fighters are equipped with gyro gun sights, either with or without radar ranging.

5068 Developments during World War II led to night fighters with airborne radar search installations which enabled the radar observer, with assistance from ground control, to locate the target crudely, but well enough so that he could instruct the pilot how to fly a course that would close the range. Eventually, in good weather, the pilot could discern the target visually and could then complete a normal run, as in daytime.

5069 If the gun-armed fighter is to have all-weather capability – to be useful when the actual target itself is not visible to the pilot for steering purposes – some other means must be provided for telling the pilot where the target is. A radar that tracks the target in angle as well as range is the straightforward solution for this need. It has certain shortcomings; for example, present-day radar is much inferior to human vision in angular acuity, and it cannot recognize from the shape and markings of the target whether it is friend or foe. However, it can do a passably good job of furnishing the basic data (range, bearing angles, and time derivatives of these quantities) needed to determine what course the fighter should fly and when its guns should be fired. The various all-weather radar gun fire-control systems now in early use or under development employ various methods for combining the radar data with data from flight-sensing instruments (gyroscopes, typically) aboard the fighter in order to compute and display to the pilot, or send to an autopilot, the information needed for steering.

c. Fire Control for Unguided Rockets

5070 The air-to-air rocket battery promises to free the attacking fighter from the necessity of spending a long time exposed to effective return fire from a bomber target by permitting a lethal salvo to be fired from longer range, at higher closing speed, and at any aspect of the bomber (including the forward hemisphere). Each warhead would contain enough high explosive (1.4 lb.) to give a fair chance of destroying an aircraft such as a TU-4 if the rocket strikes the target. The problem is to launch the salvo so that its centroid will come near colliding with the moving bomber.

5071 To achieve such a near-collision, the fire-control system must cause the fighter, when it arrives within effective range for fire, to have an appropriate heading, dependent on the speed and course of the bomber, and it must cause the rockets to be released at the appropriate time, with a tolerance of a small fraction of a second. Further, because the rockets (unlike bullets) are critically sensitive to cross-winds early in their trajectories, the fighter should be flying a straight and stable course while the rockets are being fired; mushing and side-slip are highly undesirable. Several computing systems for achieving this kind of directed fire of rockets have been under development.

d. Fire Control for Guided Missiles

5072 Air-to-air guided missiles, when they become available, will present problems somewhat different, though not necessarily more difficult, for the airborne fire-control system. Large lock-on ranges for the tracking radar will continue to be important in order that the fighter, while still at long range and with a minimum of burden on the ground control, may have time to position itself for launching the missile at a favorable aspect of the target. The missile may require certain prelaunch information and readying signals from the fire-control system. In the case of a beam-rider missile such as SPARROW I, the fire-control system must so launch the missile that, after burnout of its motor, it will be on a missile collision course with the target. The fire-control system must then quickly bring the fighter about to a fighter collision course, and must thereafter passably maintain this type course during the flight of the missile. Semiactive-homing missiles such as FALCON or METEOR will apparently

tolerate launching errors of several degrees, and after launch will require only that the radar continue to track the target in order to keep it illuminated for the missile. Active homing missiles would, of course, make no postlaunch demands other than assessment upon the fire-control system of the launching aircraft.

e. Airborne Intercept Radar Systems

5073 The airborne intercept (AI) radar set performs two principal functions. The first is that of search, the second that of fire control. The second of these two functions must be done in conjunction with a computer, and in some operations may involve the interrelation of radar, computer, gun sight and autopilot. If the key functions of search and fire control can be separated, and they well might be in large planes, the design problem of the radar becomes much simpler since there is then no need to compromise between design considerations for the two functions.

5074 Major system-design considerations for AI radar are well understood, and, in fact, one cannot expect any tremendous improvements in present radar performance by new system design. On the other hand, many improvements in components are quite possible in the near future.

5075 Assuming that the function of search can be divorced from the function of fire control, let us consider search alone and inquire as to the characteristics of a good search set. First of all, long range is required, a high scanning and search rate is desirable, and good receiver and indicating performance are desirable. For long range we require, primarily, high power, which in principle is limited by the weight that the aircraft can carry; secondly, we require a large antenna, which is limited by the airframe characteristics of the aircraft; and thirdly, of course, we require a quiet receiver, which is limited to about 10 db above thermal noise. A frequency in the neighborhood of 3000 Mc is near optimum for the AI search function.

5076 In the fire-control function of the AI radar, we still require long range and good receiver sensitivity, but the requirement for a rapidly scanning antenna covering a large volume of space can be relaxed. Generally speaking, a high frequency is desirable. Frequencies of the order of 10,000 Mc are probably adequate for most purposes and indeed very good components are available in

this range; but for special sets, higher frequencies may be more suitable. Use of higher frequencies will also make the enemy's jamming problem more difficult.

(1) AI Radar Development

(a) AI Components

5077 It is a truism that ranges that are theoretically possible with radar sets are seldom realized in the field. This is especially true of airborne sets, and, more especially, sets for small aircraft. In making equipment for small planes, one compromises reliability at every stage with long range and with light weight. Because of the small volumes and high powers, undue heating and difficulty of maintenance result. If one is to improve the performance of AI radar, it would seem worth while to review critically the reliability and the performance of the various components of the radar set, for only here can large improvements be made.

5078 The components and component functions of AI radar sets require a very strong program of investigation to insure that AI radar can perform adequately. This does not imply that important work in this field is not now under way, but more work is required.

(b) Development Program

5079 The radome and the fire-control indicator, especially the radome for supersonic interceptors and the indicator for single-place interceptors, have not received the attention they require, and are responsible for a great deal of poor performance.

5080 A major program is "matching" the mechanical properties of the radome to the airframe and its electrical properties to the antenna. It is essential that the pilot's indicator be matched to the pilot, keeping his other duties in mind. This does not imply only the improving of present indicators; new methods of indication should be investigated.

5081 A stronger program of research on target noise, jamming and ground clutter, and development of means for overcoming these, must be established. Research on novel means of performing the T-R (transmit-receive) and mixer functions is required.

5082 Development of components for frequencies higher than X-band, of filtering, correlation and integration techniques for improving receiver performance, and of transistor development relate to many fields besides AI radar. These developments should be followed by engineers in the AI program with an eye towards incorporation as needed. In particular, any means for producing less heat in the AI radar and computer will be of the greatest importance, and stress should therefore be placed on development of transistors and associated components.

5083 For two-place interceptors, the search and fire-control functions of the AI radar set should be separated as much as vehicle limitations will permit. This will optimize radar performance, help defeat jamming, and give the pilot fire control during combat while search continues independently.

5084 In single-place interceptors, set operation must be made as simple as possible, and the search and fire-control functions may have to be combined. The radio frequency should be chosen to enhance the firing accuracy at the expense of search coverage.

f. Fire-Control Problems in the Period 1951-1954

5085 The activities of the USAF and the USN to develop fire-control systems suitable for new tactical situations and new ammunitions appear to have been under continuous review, with due attention to questions of adequacy, emphasis and undesirable duplication. It is clear that certain problems will be especially severe during the next few years.

5086 The ground system for early warning and control of interception will be primitive, and the interceptor will therefore need to be highly self-reliant, able to search for targets over a wide angle and pick them up at great range. Self-reliance, unfortunately, will be most urgently needed during a period when means to achieve it are still not fully developed and tested.

5087 According to the present plans, the two-place night fighter will be giving way to the single-place all-weather interceptor, while the developments that promise to lighten the task of the single pilot (fully automatic flight with maneuvering autopilot, good display of the radar information, etc.) are still not thoroughly tested by experience (cf. Para. 5031).

5088 A new ammunition, the air-to-air rocket, will be introduced, calling for approach tactics quite different from the tactics for cannon armament, and requiring high precision of the whole airborne fire-control system. When air-to-air guided missiles are available, this requirement for precision will be relaxed; unfortunately, the more stringent demand comes earlier, while the means to meet it are less surely available.

5089 Aircraft that have higher performance and that are more difficult to control manually will be introduced while the art of automatic flight control is still young. There is thus a danger that the air defense system, at some stage in the next few years, will find itself seriously limited in effectiveness by the fact that the interceptor pilot has been saddled with too difficult a job. This danger should be clearly recognized in the planning. To lessen this danger, development of devices and systems that will relieve the pilot of routine duties, and will leave him free to monitor the situation and cope with unforseen happenings, should be pushed as rapidly as possible.

g. Operational Degradation

5090 A fighter with a speed advantage of 100 knots will take little more than 3 seconds to close in from 1200-foot range to 700-foot range along a lead pursuit course. In this time, it can fire from 6 0.50-cal M3 guns a total of about 400 rounds. Assuming a ballistic dispersion of 6 mils rms, the shot pattern about the point of aim should be only about 12 feet in diameter. A typical fighter target silhouette, from (say) 15° off the tail, if held at the point of aim, should intercept perhaps 100 rounds, while a typical bomber silhouette under the same conditions should intercept perhaps 200.

5091 The records of World War II and the fragmentary information presently available from Korea make it appear likely that in actual combat, with approximately this rate of fire, the average number of hits in a single firing pass is

much nearer 1 or 2 than 100 or 200. Why do the other rounds miss? If they are near misses, attributable dominantly to lack of precision in the electrical and mechanical parts of the fire-control system, further intensive work to improve these components would be rewarded. If the misses are dominantly due to uncontrollable small random motions of the fighter aircraft during the firing run, more precise instruction as to where the aircraft should point cannot be obeyed and would thus be of little use; if this is the case, it might be possible, as is suggested in Para. 5105, to give the battery a little freedom of motion relative to the aircraft and to stabilize it against side-slip, yaw, mushing, and flight roughness. On the other hand, if the misses are dominantly gross misses, occurring because the pilot has been unable to approach the effective firing range correctly, to judge it properly, and to fly the aircraft smoothly while he fires, then it is clear that realistic practice, and perhaps even reassignment of pilots who prove to be incorrigibly poor elements in the fire-control system, would pay off in effectiveness.

5092 Large-scale tests to sort out these various degradation factors, if tests of sufficient realism can be devised and performed, would be useful from several viewpoints. They would show which phases in the process of getting a round from the ammunition belt into contact with the target can most profitably be improved, and they would furnish an essential part of the data needed for estimating force requirements. For fighters armed with air-to-air rockets, as planned for the interceptors of the ADC over the next few years, the same sort of questions may be asked. As soon as the equipment is available for use, it will be highly desirable, especially in view of its novelty, to see how well the over-all system works, and to locate the important degradation factors, by large-scale tests of sufficient realism. Continuing practice, under conditions as realistic as possible, should be made for the three purposes of (1) identifying the major degradation factors; (2) assessing hit probabilities; (3) training pilots.

5093 At the present time, one of the major reasons for poor performance of both optical gunsights and radar fire-control systems in the field results from difficulties in properly bore-sighting the fire-control system, and from a lack of appreciation of the importance of this problem. One of the troublesome variables is fuselage deflection; the deflection in flight differs from the deflection when the interceptor is standing on the ground by a factor several times

greater than the maximum acceptable bore-sighting errors between gun line and radar axis. At the present time, the bore-sighting operation includes such steps as jacking up the airplane in an attempt to reproduce the fuselage deflection existing in flight, locking of the antenna shock mounts to hold them in place with respect to the airframe, adjusting the antenna dish with respect to its mounting, and so forth. Considerable effort has been put into solving this problem, but it is inherently a difficult problem of precision alignment, and is not in a satisfactory state.

4. Predicted Flight Ordnance For Interceptors

a. Introduction

5094 The primary duty of the interceptor aircraft is to kill. It does so only with the weapon it carries to the point of the air battle. No matter how aerodynamically exquisite the interceptor may be, or how fast it can fly, it is useless if it does not destroy enemy aircraft. The value of the interceptor is a direct function of the lethality of its weapon.

5095 Theoretical calculations, supported by evidence accumulated during World War II and in Korea, have demonstrated conclusively that currently operational interceptors armed with existing weapons are capable of achieving a kill in combat with enemy aircraft in only a small percentage of firing passes.

5096 Improvement in the over-all kill potential of an interceptor force can be accomplished in two ways: more interceptors can be built, or the kill potential of each interceptor can be increased. Both courses of action should be strenuously pursued. The necessity for increasing the production rate of the best available interceptors is generally recognized by the military and is being encouraged. The single-pass kill probability of the interceptor can, in our opinion, be improved at a greater rate than is at present contemplated.

b. Aircraft Guns

5097 There is overwhelming evidence of a qualitative kind, and some quantitative data, to the effect that guns now carried into battle do not measure up to the task. Data in support of this statement are difficult to present because of the extreme difficulty of numerical assessment in peacetime. Even in wartime,

conclusions must be carefully drawn, for, of all rounds fired, only a few hit the target, and nothing quantitative is ever known about the others except that they missed.

5098 Deductions that can be made from studies vary with the assumptions, such as (1) type of attack, (2) plane of attack, (3) relative speed of interceptor and bomber, (4) altitude, (5) allowance for operational degradation, (6) vulnerability of interceptor, (7) vulnerability of bomber – to cite merely the obvious. One estimate for tail attacks by existing weapons with allowance for operational degradation gives values between 0.1 and 0.15 for the probability of kill of the bomber.* This figure is much reduced if the bomber is armed with larger than 0.50-cal guns,** or if attacks at low altitude are considered.** The inflammability of the fuel in the bomber is a large factor in determining kill probability.***

5099 Exact comparison between present day 0.50-cal guns (M3) and 20-mm (M3 and M24) is difficult, due to scarcity of data, problems of stoppage, and differing operational factors. It is to be noted, however, that in World War II the USN, the RAF, the German Air Force, and the Soviet Air Force all used 20-mm cannon or larger and that, of the major contestants in the air battles in that war, only the USAF used 0.50-cal guns in its interceptors. The major air battles in which USAF fighters were involved in World War II were over Germany while they escorted bomber formations, and involved fighter-to-fighter battles at a time when fighters were vulnerable to 0.50-cal ammunition.

5100 The fact that the USAF had great success in World War II should not, however, be offered as evidence in support of the efficacy of 0.50-cal guns in defensive air battles nearly a decade later. In the first place, the TU-4 uses 20-mm cannon in the tail; hence, a USAF interceptor with 0.50-cal guns will be firing upwind at half the range at which the TU-4 can fire downwind with armament twice as heavy. This is a depressing situation in which to place any pilot. In

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*"Fighter Defense Forces," (WSEG).

**Report on Armament Evaluation, PROJECT CHORE, Univ. of Chicago, Ordnance Research No. 1 (May 2, 1949).

***"Armament Evaluation F-91 Interceptor AP-31J and AP-31K, Republic Aviation Corp., RAC Report Number AP31J-112 (Dec. 1, 1949); "Fighter Defense Forces," op. cit.

the second place, because we now require fighters to reach supersonic speeds, the structural design is such that a fighter or interceptor is physically tough and is not so vulnerable to 0.50-cal ammunition as were the German Air Force fighters of 1943-45.

5101 The only direct way to remedy this weakness is to increase greatly the fire power of interceptors. This might be done by

(1) Increasing the caliber and rate of fire of the guns;

(2) Adding rockets to the armament of interceptors;

(3) Introducing air-to-air guided missiles.

5102 An opinion to the effect that rockets and missiles can supersede the gun is widely held. At the present time, however, the gun has sufficiently different and valuable characteristics to make it superior to the rocket in certain tactical situations. Furthermore, missiles don't exist. Also, the armament of interceptors must be flexible enough to deal with the widest possible variety of tactical conditions.

5103 The use of a larger-caliber round with HE (high-explosive) filling increases the effectiveness of the round in causing damage. Tough aircraft of the B-47 type will probably show low vulnerability to exploding projectiles having less than 1-1/2 pounds of HE unless the fuel system is hit. Some of the surveys* show, that due to low rates of fire, poor muzzle velocities, and bad exterior ballistics, the effectiveness of the weapons investigated was poor. Many of these results are based on very few firings, so that considerable extrapolation is necessary. Some results have shown that, to achieve acceptable lethality against aircraft with noninflammable fuel systems, calibers have to be increased to 50-60-mm. A 30-mm gun firing 1200 rounds per minute is being manufactured in Britain (the Aden gun). The USAF is developing a gun (T-121) using the same projectile, based on the design of the 0.60-cal T-130.

5104 Continued development of aircraft guns is essential and should be concentrated on 20-mm and larger calibers. A fresh effort

*"Aircraft Guns and Ammunition" (PROJECT CHARLES Briefing), Col. Rene R. Studler (Ordnance Corps) 28 February 1951; Report on Armament Evaluation, op. cit.

should be made to equip current fighters with the best available 20-mm rapid-fire cannon. Future aircraft should permit interchangeable installation of guns, rockets, and guided missiles.

c. Gun-Line Control

5105 Sighting errors are a large factor in determining success in an air battle. Guns that can be moved automatically through about 5 degrees in elevation or azimuth offer a potentiality that is worth examining in relation to this problem, for by this means the control of the gun line can be freed from the poor dynamics of the aircraft. Hence, the sluggishness or unsteadiness of aircraft or the inaccuracies of its flight-path inaccuracies need not limit the accuracy of controlling the point of aim of the gun. While this is in no sense a new idea, it is a feature of an integrated automatic fire-control system that has attractive design possibilities for decreasing the effects of large errors inherent in a system in which the aircraft itself is disturbed by flight roughness, and, as a dynamic member, is limited by the technology of autopilot design, control-surface loading, etc. These factors presently degrade the gun-aiming capability of existing fire-control systems. If this technique could be exploited, a fighter on-course could probably take moderate evasive action during the firing run. It is not clear which of the many alternatives for accomplishing direct gun-line control will be best, and it is possible that the kind of fire-control system and the nature of the target will be decisive factors.

5106 Limited automatic vernier control of the gun line should be studied as a means of decreasing the large aiming errors in the present fire-control system.

d. Aircraft Rockets

5107 Increasing fire power by the use of rockets is a direct way of improving the kill probability per pass, provided the hit probability of rocket fire attains an adequate value. Attacks from the beam offer more vulnerable targets,* but

*"Attack of a Rocket-Bearing Interceptor on a Passive B-29 Type Bomber," Hughes Aircraft Co., Tech. Memo No. 243 (October 1950).

introduce a computer problem for which the solution is only in the test stage at present. Furthermore, present rocket ballistics require a fighter to fly a straight course with accurate control of elevation.

5108 Rockets of several sizes have been considered, and current policy will result in the installation of 2.75" FFAR (folding-fin aircraft rocket) in selected interceptors (24 in the F-86D and F-94C, and 108 in the F-89D). Comparisons between 2.75" and 5" VT (variable time) fused rockets* suggest that the 5" VT rocket has somewhat greater effectiveness especially for a nose attack.** However, at this date there is some uncertainty that this choice is optimum, taking into consideration the limits imposed by storage difficulties, flight performance penalties, etc., on the number of each size that can be carried. In view of this uncertainty and of the importance of the problem, systematic investigation of all factors that determine optimum rocket types should be accorded a high priority.

5109 Every possible support should be given to the accelerated development of air-to-air rockets. In particular the following items appear to be important:

(1) The ballistics, stowage and launching of 2.75" rockets;

(2) Provision for at least 48 rockets for the F-86D and F-94C types despite the reduction in performance entailed;

(3) A systematic exploration of the effects of varying the type and parameters of rockets. Tests should cover the complete system comprising aircraft, fire control, operator and ammunition, because of the interrelation between these factors.

5110 Rocket weapons show great promise of more lethal interceptor performance in the near future. Research, development, and evaluation of rocket systems should be intensified with particular stress on problems of ballistics and installation, and on the selection of optimum sizes.

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*"Air-to-Air Rockets – Preliminary Assessment," RAND Report RM-443 (Sept. 1, 1950); Report on Armament Evaluation, op. cit.

**"Future Requirements for Air Interception in Fleet Air Defense," OEG Report 61; Report on Armament Evaluation, op. cit.

e. Evaluation and Training

5111 The scale of effort in the evaluation and testing of weapons is inadequate. This is shown by the frequent comments in the various surveys to the effect that few firings have been made, that assumptions involving extrapolation of aircraft and armament characteristics into the future are essential, that aircraft vulnerability is very much affected by fuel inflammability. Disagreement on the relative merits of differing types and sizes of weapons is apparent. The accuracy of the fire-control system will affect conclusions on the relative effectiveness of differing weapons by altering the relationship between lethality per round and the number of rounds fired.

5112 There is little or no provision for realistic target drones for evaluation purposes. Many of the conclusions of the references and of other evaluations are, therefore, questionable. Some of this uncertainty can probably never be eliminated, but efforts should be directed towards reducing it. Various efforts are being made to provide airborne targets.* Low- and medium-speed target drones are due for service test shortly. Work on high-speed targets has suffered various delays. Requirements are not yet determined for high-altitude, large drones. Techniques of observing and recording test data require improvement. The development of "miss-measuring" equipment should be pursued.

5113 Realistic training is the quickest way of improving the skill and effectiveness of pilots in the use of air weapons. The problem suffers from the lack of availability of targets. Work on high-speed, high-altitude drones was too low a priority. Skill at shooting should be as important a qualification for a fighter pilot as skill at flying. Since this may be a natural deficiency in certain individuals, they should be assigned to other duty.

5114 Obtaining good assessment of the relative effectiveness of various weapons is an urgent problem. Greater attention should also be given to gunnery ability in the selection and training of pilots. Both for weapons evaluation and for pilot

*Panel on Target Drones, Program Guidance Report, RDB Report Series No. 42, MTD 7/8 (December 1950).

training, fast high-altitude targets should be provided that match existing and potential enemy aircraft.

f. Engineering Resources

5115 A survey of the airborne ordnance development program shows the following situation.

(1) The majority of gun design and ballistic experts have been or are centered in Czechoslovakia, Sweden, or Switzerland in firms such as Skoda, Bofors, or Oerlikon.

(2) No commercial firms in the United States (or, for that matter, the United Kingdom) devote a large proportion of their research or development to air ordnance. This is a serious flaw in the whole fabric of industrial support to the defense needs of this country.

5116 Air ordnance in the United States does not command a research, development, and design effort commensurate with its importance. More incentive should be given to civilian talent in American industry to work aggressively in this field.

5. Air-to-Air Guided Missiles

a. The Air-to-Air Guided Missile as a Weapon

5117 Air-to-air guided missiles (AAM) will be armament for aircraft, falling into the same category as machine guns, cannon and unguided rockets, discussed in Para. 5088. If the accuracy and reliability can be made sufficiently high, missiles will probably replace both guns and unguided rockets as the primary armament of interceptors. However, their use will alter only the terminal phases of air-to-air combat, leaving relatively unchanged all phases of the operation leading up to contact by radar or visual means.

5118 Since no AAM development has been completed, there are no firm data on which to compare missiles with guns or unguided rockets. The calculated estimates of the performance of missiles indicate that, when their development is completed, they will be more accurate than other air-to-air armament. In this subsection it will be assumed that the development of successful air-to-air missiles is possible.

5119 Air-to-air missiles now under development have one important characteristic in common with unguided fin-stabilized rockets: at the time of firing, the velocity of either missiles or rockets relative to the aircraft is small, and, since both have weathercock stability, they tend to align themselves with the aircraft's direction of flight. Consequently, the only immediately feasible direction for firing AAM or rockets is the forward direction. Many suggestions have been advanced for the design of rockets and missiles to be fired cross-wind, but none of these suggestions has yet gone beyond the paper-design stage. The forward-firing limitation of missiles and rockets makes them primarily usable by fighter aircraft.

5120 Because the problem of firing missiles or rockets from the side or from the rear of a moving bomber is relatively so difficult, it is to be expected that for some time after guided missiles are available for interceptor use the bomber under attack will be armed defensively only with guns. The long range of the missile will then permit the interceptor to remain completely out of range of return fire.

5121 With guided missiles, as with air-to-air rockets, the fighter will be able to fire effectively from any azimuth relative to the target, rather than being constrained to attacks in the tail cone, as is the case with fixed guns or cannon. With this added latitude, the fighter can more quickly complete an attack after the initial lock-on, or can, in some cases, select especially vulnerable aspects of the target for attack.

5122 Some of the guided missiles under development offer promise of completing a successful attack when the altitude difference between fighter and target at the moment of firing is several thousand feet, by making use of the transient climb or dive capabilities of the fighter and the ability of the missile to climb or dive. With guns or rockets, no such large altitude differential is tolerable, and the problem of positioning the fighter very near the same altitude as the target is, and threatens to remain, a difficult one for the ground control system. The availability of AAM may greatly ease this problem.

5123 Another advantage to the fighter using AAM will be a decrease in requirement for maneuverability. The missile rather than the fighter can do the maneuvering where the most strenuous maneuvers are required, namely, in the last

part of the attack where the range is close. The missile can incorporate greater maneuverability than the fighter because it can be designed for this one specific job, whereas the design of the fighter must be compromised to meet many other requirements.

5124 As still another advantage, the initial aim of the fighter firing AAM need not be nearly so accurate as the aim of the fighter firing rockets or guns. The maneuverability of the missiles may be used in part to correct for errors in the initial aim. With present designs, the inaccuracies of aim permitted for missile fire are not great – being of the order of a few degrees – but this is large compared with the inaccuracies permissible for rocket and gun fire. This greatly relaxes the performance required of the computer carried in the interceptor, and relaxes also the requirement for exceptional firing ability on the part of the pilot or autopilot.

5125 It is important to note, however, that these two last-mentioned potential advantages can be fully exploited only after AAM have been so successfully demonstrated that it is no longer necessary to design the aircraft for effective use of guns and rockets as well as guided missiles.

5126 Since guided missiles have not yet been developed to a point of combat testing, it is impossible to see definitely what disadvantages they may have. Because of their size only a few guided missiles can apparently be carried in each interceptor. If they have to be mounted externally, the aircraft performance will be reduced. It is hardly conceivable that they will not, at best, call for more delicate maintenance and have less certain reliability than rounds of more conventional ammunition.

5127 There is no reason to believe that AAM cannot eventually be used in fighter-fighter combat. However, it must be recognized that a fighter target will be more maneuverable, and hence will require greater maneuverability on the part of the missile than does a bomber target. Furthermore, the fighter target will give a smaller radar echo, and consequently the engagement with target will be made at a shorter range, thus giving a shorter time for the attacking fighter to align itself with the target and to release its missile. Finally, the fighter target will have a greater speed than the bomber target; thus, the missile-to-target speed ratio will not be so favorable as in combat against a bomber.

b. Development Program

5128 The missiles now under development fall into two classes as to size or weight. The FALCON missile, weighing slightly more than 100 pounds at launch, is in one class, while all the others, ranging in estimated weight from the 315-pound SPARROW to the 575-pound METEOR, are in the other class. The disparity in size between these two classes arises from a difference in size of warhead and fuze, and this in turn arises from a difference in general approach to the problem of killing a bomber with a guided missile fired from an interceptor. The FALCON program has elected to exploit the kill potential of only those missiles that actually hit the target, writing off as complete losses those that miss. This choice permits the FALCON to use a very small warhead and a simple contact fuze. All the other missiles, electing to exploit the kill potential of the near misses, carry much larger warheads with proximity fuzes. If the total weight of armament is the limiting consideration, each interceptor can carry and fire three or four times as many of the smaller FALCON missiles, thus multiplying by a factor of three or four the probability that the necessary hit is actually obtained.

5129 Which of these two essentially different approaches to the problem is preferable is not clear on the basis of present knowledge. It is not yet possible to predict, for example, what accuracy of guidance will be attainable in practice, nor how the relative effectiveness of the two kinds of fuze-warhead combinations will depend on guidance accuracy. Proximity fuzes for the missile application are not yet fully developed, and it is therefore not yet certain whether they will function reliably at a sufficiently precise distance from the center of the target. The vulnerability of a multiengine bomber for prompt kill by fragments is difficult to estimate. Data on the effectiveness of blast at high altitudes are scanty. In view of these interrelated uncertainties, it is advisable that both approaches be pursued vigorously.

5130 All the AAM developments use solid-propellant rocket motors. Development of liquid-propellant motors and ramjet motors, as possible alternatives, is also going forward in connection with some of the missile projects.

5131 Most of the missile vehicles have progressed through several aerodynamic design configurations. It is to be hoped that the primary aerodynamic problems

have been solved for each missile, but this can hardly be certain until more flight experience has been accumulated.

5132 A variety of guidance methods is planned. BLUE SKY (U.K.) uses the simplest system, and is correspondingly most limited in operational use; the target is attacked from the rear, and the missile rides a radar beam straight ahead of the parent aircraft, which uses a fixed optical sight to fly a pursuit course after the launching. For SPARROW I, also a beam rider, the radar beam tracks the target automatically, and the aircraft after launching must put itself upon a collision course with the target. Of the two semiactive-homing missiles, FALCON carries a small tracking radar receiver in its nose, while METEOR employs a fixed-antenna phase-comparison system. Several active-homing radar systems are under development, one using continuous wave or frequency modulation (CW or FM), two others using pulsed K-band radiation. The range of attractive possibilities in radar guidance appears well covered, but the operation of these systems at low altitudes has not been sufficiently explored.

5133 Infrared homing devices for terminal guidance of AAM should have careful consideration.* Their immunity to jamming, and the absence of the "glint" difficulty of reflected radar signals, are advantages of major importance.

5134 Air-to-air guided missiles are potentially the most effective armament for interceptors, and the development of both small and large missiles should be vigorously pursued. The operation of guidance and control systems at low altitudes demands close attention, and the possibilities of passive infrared terminal guidance should be explored.

6. Navigation Aids

a. Introduction

5135 Navigational aids to all-weather flying are devices that offer assistance in the process of determining the position of an aircraft in space and of directing

*The military use of passive infrared devices is discussed in Appendix V-1.

it to reach a desired destination as independently as possible of weather conditions. The navigation of an interceptor in close-control intercept operations, prior to AI contact, is generally accomplished by the determination of the interceptor's position relative to its target by ground-based radar and by giving such instructions over a ground-to-air communication link as to enable the pilot or autopilot to direct the aircraft to the vicinity of the target. In broadcast-control intercept operations, however, an all-weather requires navigational aids that permit derivation in the air of the interceptor's own position (see Para. 3141. Additional requirements for such aids are imposed by the problems of en-route navigation in ferrying and training operations and of return-to-base operations.

b. "Common System" Development

5136 In the peacetime period following World War II, the tendency in navigation development has been to emphasize the "common" aspects of civil and nontactical military requirements, and to be hopeful that any system of navigational aids developed to fulfill them would likewise meet military wartime tactical needs. This has resulted in the adoption, as interim "common system" aids, of the VOR-DME (very-high-frequency omnirange-direction measuring equipment) polar coordinate system comprising a very-high frequency (VHF) omnidirectional range to be in full use in 1953, and ultra-high-frequency (UHF) distance-measuring equipment available somewhat later.

5137 The charter of the Air Navigation Development Board (ANDB), set up to administer Common System development, stated that the development of navigation and traffic-control aids for a common system was to serve the needs of civilian and nontactical military aviation and to be capable of useful integration with any air defense system. It was recognized that some, but not all, the requirements of tactical military aviation would be satisfied by such a system.

c. Tactical Requirements

5138 There are many military tactical situations involving special navigation requirements that are not fulfilled by the present interim common system, nor are likely to be met by future common system developments. Special military aids have been or are being developed to meet these needs – for example, for

blind bombing, for air-to-air rendezvous, for airborne troop drop, and for close-support air operations with ground troops. The requirements for all-weather navigation of air defense interceptors likewise demand the development of special military navigational aids tailored to these particular requirements.

5139 The outstanding requirements for a navigational aid for interceptors seem to be:

(1) Accuracy should be at least equal to that of the GCI (ground control of interception) radar.

(2) Coverage should be at least equal to that of the GCI radar system, in both horizontal and vertical planes.

(3) It should be operable in all climates, over land and water, and at maximum interceptor altitude.

(4) It should be capable of pilot interpretation and of sending command signals to the autopilot.

(5) It should not be of assistance to the enemy in navigating.

(6) It should have a low susceptibility to jamming.

(7) It should be of such size and weight as to allow fitting in all interceptors.

(8) If it employs electromagnetic radiations, it should employ frequencies that are not otherwise allocated for tactical operations in probable war theaters.

5140 An examination of these requirements shows a number of items at variance with the civil requirements for short-range navigation aids:

(1) The military requirements for security vs. the civil requirements for international familiarity and use;

(2) The military requirement for non-jammability vs. the complete absence of any such civil requirements;

(3) VHF frequency allocation for communication purposes in the European theater is incompatible with employment of this part of the spectrum for a VHF-VOR civil navigation system.

5141 In addition, the tactical requirements for accuracy and the restrictions on size and weight of airborne components imposed by interceptor configurations are probably more stringent than civil requirements.

5142 There is nothing in the foregoing discussion that demands that all aircraft have the specific navigation aid that best meets civil requirements. All civil traffic will clearly use one specific system because of the economics of so doing.

Nontactical military aircraft also can use the same aid. On the other hand, the navigation aid for tactical military aircraft must meet different and more stringent technical requirements. The universal use of an aid meeting all tactical requirements would place an unreasonable economic burden on civil aircraft.

5143 An assessment of the problems of air traffic flow in areas occupied by both civil and military aircraft that may be using different navigational aids in accomplishing their flight plans makes it clear that, at any one time, the responsibility for the control of air traffic should rest in one agency. In peacetime, where civil and nontactical military flying predominates and the military traffic has no special priority, the Civil Aeronautics Authority (CAA) should be the single agency responsible for the control of air traffic in the continental United States. Under war conditions, the controlling agency should be military. Under conditions such as those at present, when tactical operation of interceptors is required at the same time that civil traffic is normal, then clearly there should be joint agreement between the CAA and the military. Interceptors can use their own navigation aids and still conform to necessary traffic control procedures, so long as the tactical aids provide accuracy of navigation equal to or exceeding that of the civil aids.

d. Choice of Tactical Navigation Aid for Interceptors

5144 The navigational aid chosen for interceptor use in broadcast-control and return-to-base operations must, so far as possible, meet the tactical requirements cited above. Table V-1 lists all navigational aids under discussion. As discussed in Appendix VI-1, it is planned, during an alert, to deprive hostile aircraft of any navigational assistance they might derive from our own transmitters. Specifically:

(1) No radio broadcasts will be available to facilitate the use of airborne radio compasses.

(2) Civil navigation aids presently installed for international usage, such as the VHF omniranges, will not be available.

5145 It would therefore appear unwise to plan for interceptor use of such equipment since, at the very time their usage is most needed by our interceptors, they may have to be shut down to prevent enemy use.

TABLE V-1

NAVIGATION AIDS

Navigation Facility	Date Available In Service	Remarks
LF MF ADF (ARN-6, ARN-7, ARN-15)	Now	No ground facilities available during war
LF ranges	Now	No ground facilities available during war
VAR(VHF Visual Aural Ranges)	Now	No ground facilities available during war
VOR(VHF Omnirange)	1951	No ground facilities available under alert
ARN-21/URN-3, Multichannel, Improved accuracy, 1000 Mc, Omni- and DME	1953-54	Limited security, susceptible to jamming, meets other requirements
VHF homing (ARA-8)	Now	No fitting program, homing only
UHF homing (ARA-25)	1952	General fitting under consideration, homing only
North American Aviation inertial system	1955?	Meets requirements
Fighter Doppler navigational system	1955?	Meets requirements
APN-66 (XA2) components	1953	Size and weight preclude fitting in all aircraft
APN-34 DME for VOR system	1952	Too large for fighter aircraft, no ground facilities under alert
Miniature DME for VOR system (CAA development)	1953	No ground facilities under alert

e. Interim Programs

5146 It is essential, therefore, to consider the use of other aids which, although they do not meet all the tactical requirements, could provide navigation facilities for broadcast control over both land and water prior to the advent of the self-contained equipments.

5147 The most suitable system in an advanced state of development is the ARN-21/URN-3 1000-Mc integrated omnidirectional range- and distance-measuring equipment under development by the Navy. Detailed discussion with contractor and service representatives has shown that the start of production will be between April and ptember, 1953. It is expected to take at least one year to install the ground- and ship-based equipment and to fit the aircraft. The only apparent possibility of improvement on the production dates for the ARN-21/URN-3 system would be a saving of up to six months by priority on component delivery, but it is doubted that this is practicable.

5148 Although this system does not fully meet the requirements for security nor that of freedom from jamming, present indications are that its accuracy and coverage over both land and water will be sufficient for broadcast-control operations, and that its airborne components are sufficiently compact to be usable by both land- and carrier-based interceptors.

5149 The development and production of this system should therefore proceed with all speed, to fulfill service requirements prior to widespread use of self-contained aids.

5150 The above discussion indicates that there will be no navigation aid suitable for broadcast-control combat operations until 1954. As an immediate measure, interceptors should therefore be fitted with a homing aid for return-to-base operations and for en-route flying between bases.

5151 The installation of the ARA-25 UHF homer should, if possible, be phased concurrently with the UHF communication program, since, in addition to providing facilities for homing to all military bases and GCI's, it will make possible the interception of communications-jamming aircraft when normal interception methods are impossible.

f. Self-Contained Systems

5152 The future aids that best fulfill USAF tactical requirements for interceptor navigation are "Doppler" and "inertial" navigation systems. These are "self-contained" systems that require no cooperating ground equipment.

5153 We recommend that the development and production of fighter Doppler and fighter inertial navigation systems be carried on at high priority.

5154 When such systems become available, the need for standardization on one particular aid, for use within all aircraft of like function, disappears. There is no reason why aircraft using different self-contained aids cannot operate within the same air space, and consequently the navigation aid used in any aircraft can be chosen specifically for the aircraft – because its configuration best suits the airframe, or because it integrates best with the electronics and control system of that aircraft, or because the tactical use of the aircraft is best served by a particular aid.

5155 The primary application of Doppler and inertial techniques has been to the problem of long-distance navigation of bomber aircraft. Fighter inertial systems are already under development for use in later versions of the F-86D, but fighter Doppler development needs increased emphasis.

5156 The XA-2 version of the APN-66 Doppler navigation system developed for bomber application will be in production in 1953. A portion of this system, without the elaborate computer and other components required for long-distance navigation, might possibly be used, if operationally suitable, to provide some types of interceptor aircraft with an interim navigation aid. Republic Aircraft is considering the problems of installation in F-84 aircraft. There seems no reason why this aid cannot be fitted in F-89 aircraft, and probably it could be fitted in F-94's. The F-86D aircraft may provide a more difficult installation problem, but this may be soluble by certain changes (such as a smaller antenna) in the equipment.

5157 A study should be made immediately to determine the feasibility of fitting APN-66 (XA-2) equipment in all-weather interceptors, and if this is found feasible, trials should be carried out to evaluate the operational performance.

5158 Some consideration has been given by the Air Force to a fighter version of the APN-66 which would be subminiaturized and specifically designed to operate

satisfactorily in an interceptor. Planning personnel anticipate that such a version could be available in 1954 or 1955. However, no funds are presently allocated to this project, and the availability data will be delayed as the funding is delayed.

5159 It must be emphasized that both the Doppler and inertial developments are applications of relatively new techniques, as yet untried, in fighter aircraft. There will undoubtedly be many detailed equipment problems that will have to be solved before satisfactory flight service equipment is obtained; hence present planning dates must be viewed with caution.

5160 Neither the Air Force nor the Navy has at present, or will have within three years, a navigation aid satisfying all the needs of all-weather interceptors in air defense operations.

5161 The future aids that best fulfill Air Force tactical requirements are "Doppler" and "inertial" navigation systems that require no ground equipment. Their development should be carried on with high priority, and their suitability for interceptors should be evaluated as soon as feasible.

5162 The ARN-21/URN-3 program should be given full support to fulfill service tactical requirements until self-contained aids are in full use.

5163 As an immediate expedient, all interceptor aircraft should be equipped with the ARA-25 UHF homing aid.

7. Return to Base

a. Introduction

5164 It is essential that an efficient return-to-base and approach-landing system be provided, since the range of interceptors is limited, and time wasted in returning to base means reduced operational range and increased turn-around time – which means reduced combat time. There is also a very real gain in morale if pilots are confident of a safe return even when fuel is low.

5165 After combat, navigation back toward the base area can be accomplished by use of the aids discussed in the preceding paragraphs, or, if sufficient traffic capacity is available in the AC&W system, by further application of close-control procedures.

5166 In considering the marshaling and scheduling of traffic back to base, the data-processing problem is such that the control of traffic should be handled at a single point (not necessarily the air base) to secure a coordinated time scheduling. Two general methods could be available for providing the traffic-control agency with the position of aircraft to be scheduled for return to base. One method is to measure the aircraft's position from the ground, usually by radar. The other is for the aircraft to establish its own position by means of a navigation aid and to communicate this position to the ground. The first method appears preferable; it reduces the likelihood of large instrumental errors in the positional measurement of several aircraft, is consistent with systems for finding positions already available to the AC&W system, and is not dependent on the operation of an air-to-ground communications link (as opposed to the ground-to-air link).

5167 The final step to complete the return-to-base control loop is the ability to communicate the instructions derived in data processing to the controlled interceptor. Again we have an element that is common to the interception control process.

5168 In the long view, the information required for return to base, and the manner in which it must be processed and transmitted, is allied so closely to that required for close control of interception that the two problems cannot be considered separately. A data-collecting, data-processing, and interceptor-control system that ignores the return-to-base problem is incomplete.

b. Traffic Control

5169 All the basic needs for the control of traffic in return-to-base operations can, in principle, be met by future AC&W systems if proper attention is given to integration. The present AC&W systems however, even with all contemplated improvements, will have a limited track capacity. It is unreasonable to use up their limited capacity to effect local traffic control for interceptors returning to their base.

5170 Until a high capacity AC&W system is in use, it will be necessary, therefore, to provide a traffic-control radar, such as AN/CPN-18, at every interceptor base. Such radars have limited range – of the order of 30 miles – and consequently will be capable of directing interceptors at longer ranges only with the aid of beacons. The installation of 3000-Mc beacons is now planned for all Air Force interceptors. Alternatively, the homing equipment, recommended in Para. 5163 will enable the interceptor, after combat, to fly into the traffic control area. Direction finding (DF) equipment, provided at bases, will effect identification of interceptors entering the control area.

5171 Traffic control and scheduling by a controller, using a traffic-control radar, will be adequate to deal with the limited number of interceptors that can be handled by close control in the present AC&W system with its short-term improvements.

5172 If the future AC&W system, with greater intercept and traffic-control capabilities, does not materialize for some years, and some sort of interim system is used, the intercept capacity may be high but traffic-control capacity insufficient. It may then be necessary to employ a more sophisticated traffic-control capacity system than that immediately required. There are under development a number of systems directed toward solving these problems, including Datac, Digitac and Lantrac by the Air Force, and Automatic Carrier-Controlled Approach by the Navy.

5173 The scheduling of return operations should become a function of the AC&W system as soon as adequate track capacity is available. Meanwhile, all interceptor bases should be equipped with a traffic-control radar.

c. Landing and Approach Aids

5174 Landing aids presently available to interceptors are lights and painted runways. No electronic landing aids are available, nor will be in the near future. Further, it is not clear that this lack will be a serious limitation. Landing rates that are necessary for efficient operation of interceptors do demand scheduling (as described under traffic control above), approach aids, and parallel (or, preferably, double-width) runways to permit handling of units comprising a number of aircraft at a rate compatible with take-off rate.

5175 There are two approach aids in current use ILS (instrument landing system) and GCA (ground-controlled approach); the former can be presently used for automatic approach. Automatic GCA (AGCA) equipment is under development. There is no doubt that automatic approach is superior to manual approach, requiring 40 to 50 per cent fewer go-arounds and very much less pilot skill. The present policy of fitting automatic ILS equipment in land-based interceptors is a good one, and should be continued until AGCA becomes available. GCA should, in addition, be provided at all bases for use of those aircraft not fitted with ILS or whose equipment is inoperative, and for monitoring.

5176 If the performance of AGCA, as anticipated, is equal to that of ILS, AGCA equipment should then be provided at bases, and the use of ILS equipment in aircraft discontinued. The AN/ARN-14 equipment, which provides both VOR and ILS localizer facilities, will be of no value as a navigation aid during operations, but will, in addition to the glide-path receiver and associated antennas, have to be carried for the sole purpose of ILS approach. Future interceptors will, however, be completely equipped with control systems, via data link and autopilot, to use AGCA with no additional airborne equipment.

5177 Until automatic GCA equipment becomes available, all interceptor bases should have ILS and GCA facilities.

D. PREDICTED-FIRE SURFACE-TO-AIR WEAPONS

1. Role of Predicted-Fire Weapons in U.S. Air Defense

5178 Numerous conventional AAA battalions are now allocated or projected for deployment in defense of vital areas of the United States. Studies of the effectiveness of such gun defenses against high- and medium-altitude aircraft have

been made by numerous agencies.* These studies all indicate that very large numbers of fire units of 90- and 120-mm guns are required to obtain fifty per cent or greater attrition rates against flights of up to 10 TU-4 type aircraft at high altitudes. At lower altitudes, reasonably good results can be achieved with more modest numbers of weapons.

5179 New predicted-fire weapons under development will apparently not alter these over-all trends. Even with LOKI and the new family of guns, the kill probabilities of predicted-fire weapons are small against high-altitude targets (whether maneuvering or not).** Large numbers of such weapons would be required for engagements at any ranges and altitudes at which times of flight are much in excess of 10 seconds (see Para. 5189). With standard guns and weapons in development, Fig. V-1, shows an estimate of effectiveness of such weapons on a basis that takes into consideration the logistic costs. Comparison of these effectiveness figures with the projectile times of flight of the same weapons shows that, although the projected guns and LOKI may be an order of magnitude better than present guns, all such predicted-fire weapons are really effective only in the lower altitudes, where times of flight are not much in excess of 10 seconds. At these lower altitudes – generally below 10,000 feet for present guns, and below 20,000 feet for LOKI or the new guns against maneuvering targets – predicted-fire weapons are shown by these studies to be highly effective against all targets they engage.

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*"Comparison of Anti-Aircraft Weapons for Defense of Continental U.S. Targets," C. F. Meyer, Applied Physics Laboratory, The Johns Hopkins University (CF-1591A), 25 April 1951.

"Air Defense Systems Analysis – A Presentation to Project CHARLES," E. J. Barlow, RAND, 23 March 1951.

"Special Air Defense Study," J. P. T. Pearman and O. T. Schultz, Project ANALAA, ORO Report T-96, 23 Feb. 1950.

"Construction of AAA Fire Unit Analyzers, M2," Tech. Report No. 13, Res. and Anal. Sect., Plans Op. Div., AA and GM Branch, The Artillery School.

**Ballistics Research Laboratories, APG Tech. Note No. 119 (Sept. 1949).

"Estimated Effectiveness of Some Standard Development and Proposed Antiaircraft Weapons," Ballistic Research Laboratories, APG Report No. 125, H. K. Weiss and F. G. King (July 1950).

5180 Against a typical defense with a deployment of 6 battalions (24 fire units), high-altitude aircraft could fly with comparatively small losses. An attrition rate of less than 20 per cent has been calculated* for such a defense against 10 TU-4's at 30,000 feet altitude without intentional maneuver. Similar or more pessimistic estimates would be obtained by extrapolation from the data in Fig. V-2.

5181 If such a 6-battalion defense is attacked at lower altitudes by the same aircraft, the enemy could expect to suffer large losses. Extrapolation indicates that engagement at 10-seconds time of flight would almost quadruple the single-shot kill probabilities and increase the attrition rate to about 70 per cent. Extrapolation of the data of Fig. V-2(A) to the 24-battery defense would show similar high effectiveness against low-altitude targets.

5182 A substitution of new predicted-fire weapons for 90-mm and 120-mm guns in the above example would alter the numbers, but not the trend. Furthermore, it must be expected that enemy capabilities in terms of numbers, maneuver and speed will improve during this period of transition in predicted-fire weapons.

5183 The less tangible benefits of defenses consisting of predicted-fire weapons include bolstering of civilian morale and degradation of enemy bombing accuracy. The units in being would also provide an organizational and training nucleus for field army AAA units and for guided missile units. The present low-altitude limitations of piloted interceptors (cf. Para. 5005 et seq.) and of surface-to-air guided missiles (cf. Para. 5206 et seq.) are such that they will offer no serious competition in the near future to any predicted-fire weapon successful against low-altitude targets.

5184 Because an attack may occur with very little warning, and because antiaircraft (AA) weapons cannot be deployed from distant points in a matter of minutes, the value of such weapons may be seriously limited or nullified if they are located off-site. Only on-site deployment will be effective if no intelligence warning is received.

5185 For defense against high-altitude attacks, emphasis should be directed toward improvements in interceptor aircraft and

*"Comparison of Anti-Aircraft Weapons," op. cit.

their control, rather than in predicted-fire surface-to-air weapons.

5186 Conventional AA units of all types allocated or projected for the defense of the United States should be sited primarily to meet the low- to medium-altitude threat. All AA units allocated for the defense of the United States should be placed on-site now to be of value against a surprise attack.

2. Effective-Range Limitations Due to Time of Flight

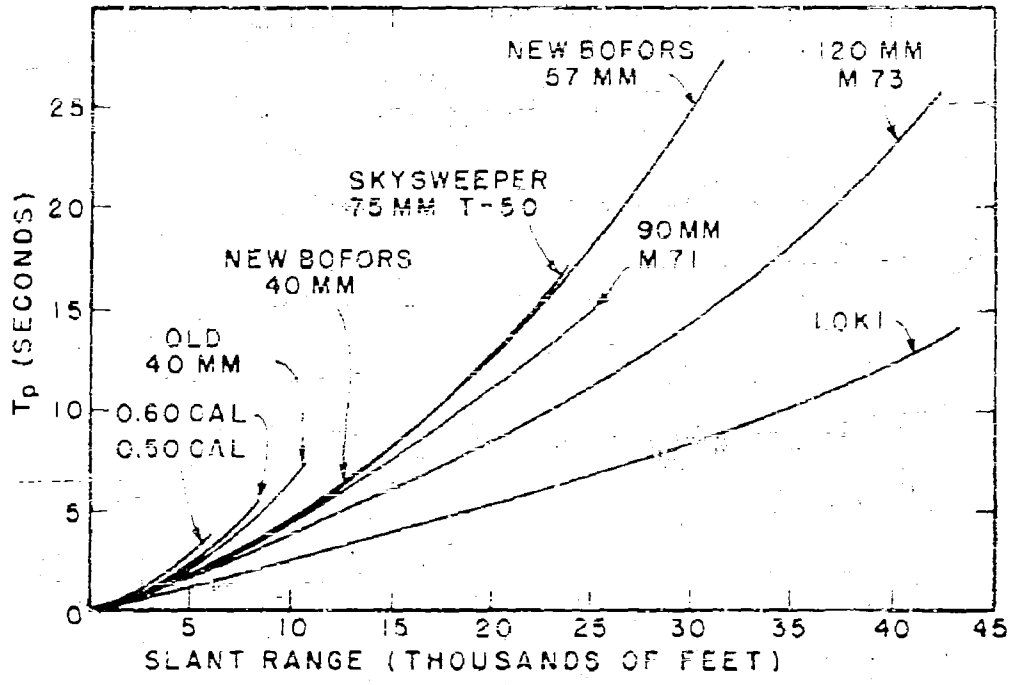
5187 The maximum range to which a weapon will fire is not an adequate description of its range capabilities. Far more descriptive, however defined, would be a maximum effective range, which connotes ability to perform its mission at the range stated. In the case of any predicted-fire weapon, the ability to perform its mission – killing airborne targets – is closely related to time of flight.

5188 Considerable effort has been devoted in recent years to analysis of the errors that contribute to inaccuracies in AA fire. Good agreement exists between test results and conclusions reported by several agencies.*

5189 Because prediction systems must estimate future target location (i.e., the location the target is predicted to occupy at the end of the predicted time of flight), certain errors result merely from this prediction process. These prediction errors are roughly directly proportional to the time of flight, and result from tracking errors, etc. Of even greater magnitude are the deviations of the target from the predicted points, due to inherent roughness of aircraft flight, particularly at longer times of flight (15 seconds) and even under the smoothest flight conditions (0.023 g). For conventional guns, ballistic and all other errors

*"A Study of Errors in AAA Fire Control Systems," BTL, 1 March 1949 (Project RAND Report R-185).

"Accuracy Data, 90- and 120-mm AA Batteries," Tech. Report 12, AA and GM Branch, TAS, Fort Bliss, Texas (June 1950).



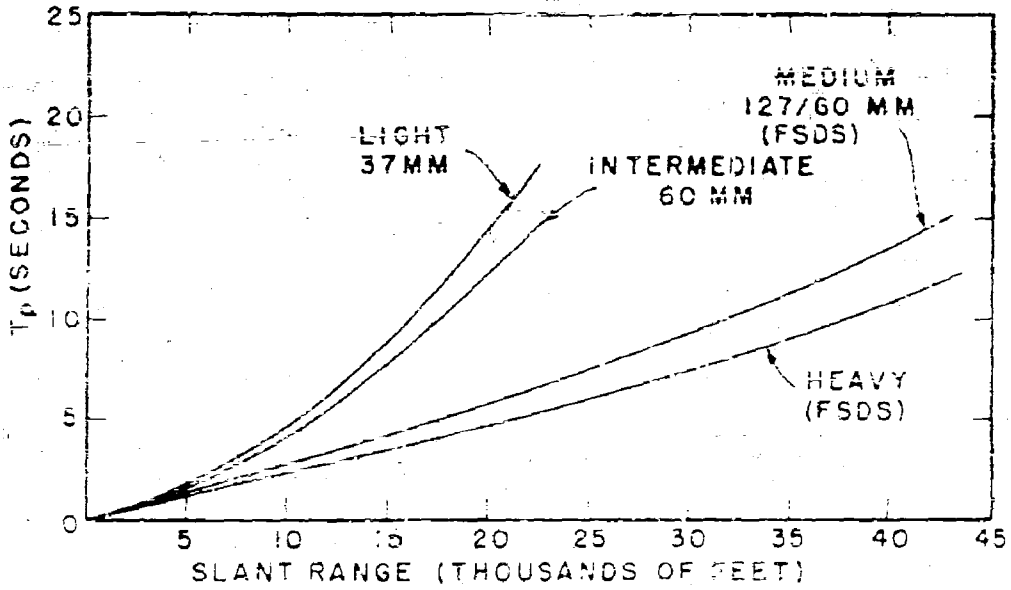


Fig. V-1 Time vs. slant range of standard and developmental antiaircraft weapons (Ballistic Research Laboratories, APG Report No. 725, July 1950).

(including gun dispersion) are overshadowed by flight roughness at times of flight much in excess of ten seconds.

5190 Curved-flight bomb sights, if perfected and used by the enemy, could seriously limit or nullify the effectiveness of AA gunfire at longer times of flight, irrespective of all other factors. Radar wander over multiple targets within the area of angular and range resolution of the tracking radar is an additional factor that tends to degrade the effectiveness of antiaircraft fire.

5191 Naval firing tests by 5-inch/38 guns with all types of existing fire-control systems against TD2C drones indicate that an effective range of approximately 5000 yards under normal conditions of flight roughness can be expected, and that the theoretical effectiveness of even the most advanced weapons and fire control is significantly degraded at longer ranges by flight roughness and maneuver.

5192 Firings of 90-mm and 120-mm guns at Fort Bliss, reported by the Artillery School, show that total firing errors may be correlated to exponential functions involving the time of flight. These data show a tenfold increase in the variance between 9 and 30 seconds time of flight.

5193 Times of flight as a function of slant range for typical standard guns and weapons under development are shown in Fig. V-1.

5194 These results clearly lead to a more conservative concept of the maximum effective ranges of predicted-fire weapons, even under the smoothest flight conditions, with no intentional maneuver, and in the absence of countermeasures. Such a concept, if accepted, would lead to changes in tactical doctrines as well as to revision of certain development programs.

5195 The maximum range of effective coverage of guns and rockets that are aimed at a predicted position of the target appears to be limited to a time of flight of about 10 seconds, even in the absence of intentional target maneuver.

5196 Development of predicted-fire weapons should be limited to low- and medium-altitude weapons for maximum times of-

flight of about 10 seconds.

5197 Tactical doctrine and employment of existing 90-mm and 120-mm guns should be based primarily on a maximum time of flight of about 10 seconds.

3. Broadening the Concept of the Family of AA Weapons

5198 Trends in aircraft design that indicate tougher and faster aircraft, together with the results of continuing postwar studies of AA weapons and aircraft vulnerability, culminated in a recent comprehensive study leading to the selection of a "Family of AA Weapons." This family was conceived as being capable of meeting the threat that might exist during the approximate time period 1955 to 1960. Various weapons were specified to cover the entire altitude zone from 0 to 60,000 feet, and to meet forward area as well as rear area requirements. It is contemplated that weapons of the family will ultimately replace all other predicted-fire Army weapons except LOKI. These weapons are characterized by high rates of fire, decreased times of flight to given slant ranges, and projectile total energies sufficient to damage "tough" aircraft such as the TU-4 and IL-10. The studies show that these characteristics should all lead to substantial improvement over previous predicted-fire weapons.

5199 The scope of the Army's current development program of predicted-fire surface-to-air weapons, which includes SKYSWEEPER, STINGER and LOKI, as well as the family of AA weapons, can best be outlined by reference to Table V-2.

5200 SKYSWEEPER was conceived near the end of World War II as a weapon that would overcome the major deficiencies of the existing 40-mm equipment – low range, low lethality, and inability to engage modern aircraft under night and all-weather conditions. Development of this weapon has been substantially completed, and large-scale procurement is now under way. Service testing and evaluation of the weapon is in progress and will continue to at least the end of the current year. In its present form, SKYSWEEPER suffers principally from comparatively low rate of fire and high cost. Planned replacement of the 75-mm

TABLE V-2. ARMY PREDICTED-FIRE

Project	Caliber of Projectile	Ammunition	HE (lb.)	Rate of Fire	Muzzle Velocity (ft./sec.)	Fire Control	Target
STINGER	0.60 (quad.)	Armor-piercing incendiary	None	750 rounds per gun per minute	3550	On-carriage automatic radar-gyro computer	800 mph Ground atta aircraft
LIGHT AA**	37-mm (twin)	Conventional HE shell with PD fuze	0.32	409 rounds per gun per minute	3000	STINGER-type fire control contemplated	
SKYSWEEPER	75-mm	Conventional HE shell with PD or VT fuze	1.64	45 rounds per minute	2825	On-carriage radar-computer	800 mph Ground atta aircraft
LIGHT INTERMEDIATE**	60-mm	Conventional HE shell with PD fuze	1.13	202 rounds per minute	3410	SKYSWEEPER-type fire control contemplated	1000 mph Tactical bomber
INTERMEDIATE** (Interim Version)	60-mm	Fin-stabilized discarding sabot round with PD fuze fired from 127-mm gun	1.5	120 rounds per minute	4075	T-33-type fire control developed for 90- and 120-mm guns	1000 mph Medium bomber
HEAVY**	60-mm	Same as intermediate round with a higher muzzle velocity	1.5	120 rounds per minute	4400	T-33-type fire control	1000 mph Heavy bomber
LOKI	Fin-stabilized 1-3/8" diam.	Projectile is second stage of liquid rocket-projectile assembly	2.0	Salvo of 64 rockets in 4 seconds.	4500 (at separation)	T-33-type fire control	1000 mph Heavy bomber

*Design specifications (except for SKYS
**Designated as a weapon of the "Famil
***Estimated date weapon will be in the

TABLE V-2. ARMY PREDICTED-FIRE SURFACE-TO-AIR WEAPONS SYSTEMS DEVELOPMENTS*

Muzzle Velocity (ft./sec.)	Fire Control	Target	Altitude Zone	Weight (trailed version)	Tactical Requirement	Ope Ava
550	On-carriage automatic radar-gyro computer	800 mph Ground attack aircraft	Radar horizon to 6,000 feet	2-1/2 tons	Divisional AA and to supplement coverage of larger-caliber weapons	Late 195
000	STINGER-type fire control contemplated		Radar horizon up to 15,000 feet (emphasis on zone below 10,000 feet)	2-1/2 tons	Primarily a divisional weapon	1954
25	On-carriage radar-computer	800 mph Ground attack aircraft	Radar horizon to 15,000 feet	10 tons	A nondivisional weapon for use in forward areas, and in other areas to meet low-altitude threat	Mid-1952
10	SKYSWEEPER-type fire control contemplated	1000 mph Tactical bomber	Up to 20,000 feet (slant range, 10,000 yds)	10 tons	Same as SKYSWEEPER	1954
15	T-33-type fire control developed for 90- and 120-mm guns	1000 mph Medium bomber	Primarily 10,000 to 35,000 feet	23 tons	A nondivisional weapon for use in rear areas of combat zone and in other areas requiring medium-altitude protection	Late 1954
0	T-33-type fire control	1000 mph Heavy bomber	35,000 to 60,000 feet (27,000-yd. range in 30-sec time of flight)	Not determined	Communication zone and zone of the interior weapon	See Remar
0 (at aration)	T-33-type fire control	1000 mph Heavy bomber	35,000 to 60,000 feet (28,000-yd. range in 30-sec time of flight)	Not determined	Same as heavy gun	1954

*Design specifications (except for SKYSWEEPER now undergoing service and evaluation tests)

**Designated as a weapon of the "Family of AA Weapons"

***Estimated date weapon will be in the hands of troops

-AIR WEAPONS SYSTEMS DEVELOPMENTS*

Altitude Zone	Weight (trailed version)	Tactical Requirement	Operational*** Availability	Remarks
horizon to eet	2-1/2 tons	Divisional AA and to supplement coverage of larger-caliber weapons	Late 1953	
horizon up to feet (emphasis below feet)	2-1/2 tons	Primarily a divisional weapon	1954	One version may be STINGER with 37-mm guns
horizon to feet	10 tons	A nondivisional weapon for use in forward areas, and in other areas to meet low-altitude threat	Mid-1952	(a) A rate of fire of 55 rounds per minute may be possible (b) Program directive contemplates procurement of 36 battalions in FY 52 (18 guns per battalion)
0,000 feet ange, yds)	10 tons	Same as SKYSWEEPER	1954	(a) VT fuze might be developed, if required. (b) Contemplated as a replacement for SKYSWEEPER
ily 10,000 to feet	23 tons	A nondivisional weapon for use in rear areas of combat zone and in other areas requiring medium-altitude protection	Late 1954	Contemplated as a replacement for the 90- and 120-mm guns
o 60,000 feet yd. range in ime of flight)	Not determined	Communication zone and zone of the interior weapon	See Remarks	Development deferred pending outcome o. LOKI and guided surface-to-air missile developments
o 60,000 feet yd. range in ime of flight)	Not determined	Same as heavy gun	1954	Contemplated as insurance for the heavy gun and for the guided surface-to-air missile

ndergoing service and evaluation tests)
s"

gun with a high-firing-rate 60-mm gun should largely correct the former deficiency.

5201 Requirements for and military characteristics of STINGER were established shortly after World War II to provide a weapon that would be more effective than existing quadruple 0.50-cal machine guns against modern aircraft under night and all-weather conditions. Design problems associated primarily with the 0.60-cal gun have resulted in repeated delays in completing this development. The earliest date for operational availability is now estimated to be late in 1953. It is understood that the Army contemplates no procurement of STINGER with 0.60-cal guns except in the imminence of war, but contemplates continuation of the development through the prototype stage.

5202 Vulnerability studies indicate that the threshold for damaging a tough aircraft is a total energy equivalent to about 0.2 pound TNT high explosive and that structural kills by HE shell as small as 20-mm are practically impossible.* On this basis, the 0.60-cal guns on STINGER with armor-piercing incendiary ammunition appear to be wholly inadequate against tough aircraft at all but extremely short ranges, particularly in view of the success in countering incendiary ammunition made possible by purging systems. On the other hand, the 37-mm light AA weapon of the family of AA weapons, with 0.32 pound explosive is calculated to be much more effective than the 0.60-cal STINGER under comparable conditions, and will be available only about one year later. Continuation of STINGER, as now conceived, appears unjustified, and increased emphasis should be placed on the 37-mm program.

5203 The unguided rocket weapon, LOKI, was initiated several years after current surface-to-air guided missile developments were under way. It was envisioned as insurance for the SAM program, and the same altitude capability (60,000 feet) was specified. It is of interest to note in connection with this weapon that, on the basis of its effectiveness, LOKI, under current specifications, is only a close competitor to guns of the AA family at all comparable ranges (see Fig. V-2). LOKI is, in effect, insurance for the medium and heavy guns

*"Results of Light AA Study," Ballistics Research Laboratories, APG, Tech. Note No. 393 (March 1951).

of the family rather than for the surface-to-air missiles, which apparently should be in a class by themselves. In order to meet the unrealistic performance requirements specified for LOKI, very stringent design problems have been posed for all components of the system, including the mount, booster and projectile. This has resulted in repeated delays in the development, and has raised some doubts about the ultimate success of the program as now conceived.

5204 From the published reports, it appears that specifications for the various weapons of the AA family* were compiled without due regard for the capabilities and limitations of other existing or projected air defense weapons – specifically, the interceptor and SAM. The family represents the optimum, provided the entire altitude zone from 0 to 60,000 feet were the sole responsibility of predicted-fire guns. It is not the optimum in terms of all air defense weapons likely to be available when the gun developments are to be completed. Subsequent to the determination of the design characteristics of the family of AA guns, several independent studies** have been made comparing the potentialities of guided missiles vs. predicted-fire weapons (including both guns and rockets) on the basis of the ratio of effectiveness to cost. The present status of such programs as NIKE and TERRIER, and the potentialities of these new weapons which are discussed in more detail below, suggest that the family concept be broadened to include at least all surface-to-air weapons. This concept should be one that considers predicted-fire weapons as members of the Air Defense Family – the others being the interceptors and the guided surface-to-air missiles.

5205 The Department of Defense should undertake a study to determine the ultimate "Family of Air Defense Weapons" with due consideration for the capabilities and limitations of interceptors, guided missiles, and predicted-fire weapons, with the

*Tech. Note No. 119, op. cit.

**"Summary of Preliminary Operations Cost Comparison, NIKE I Guided Missile vs. 120-mm AAA," ORO, Dept. of the Army, Staff Memo ORO-S-163, presentation at PROJECT CHARLES Briefing, 5 March, 1951; "Comparison of Anti-Aircraft Weapons," op. cit.; "Air Defense Systems Analysis," op. cit.

object of providing the maximum effective air defense at minimum cost.

4. The Low-Altitude Weapon Problem: Recommended Development

5206 The low-altitude threat (from a few hundred to several thousand feet), and the inadequacy of the present AC&W network in handling this threat, have already been discussed in previous sections. Apart from the inadequate low-altitude coverage of the present AC&W network, other current technical problems, such as the low-altitude limitations of the airborne radar, further restrict the use of interceptors at low altitude.

5207 The initial guided surface-to-air missiles offer little hope for improving the low-altitude defense. The initial air-to-air missiles will also have severe low-altitude limitations. Thus, at present and for some time in the future, there is and will continue to be a firm military requirement for a predicted-fire surface-to-air weapon designed primarily to meet the low-altitude attack.

5208 In the forward areas of the combat zone as compared to the continental United States, for example, there is an even greater need for the low-altitude predicted-fire AA weapon because low-level diving and strafing attacks will predominate, and because of tactical and logistical requirements.

5209 The low-altitude weapon should have the following principal characteristics.

(a) Automatic search, detection, and warning, and the ability to track and engage targets that are within range and have an unobstructed line of sight. Because of the speed of modern aircraft, automatic search, detection and warning are becoming essential for defense against low-altitude attacks.

(b) A high kill probability against targets engaged. In known predicted-fire weapons for this application, this implies an extremely high rate of fire in order to compensate for the short engagement time and the low single-shot kill probability.

(c) Cost and complexity considerably less than any low-altitude weapons now under development, particularly in view of the large numbers of such weapons required.

5210 Low-altitude weapons now under development – STINGER, SKYSWEEPER, and the 37-mm weapon of the AA family – are not adequate at low altitudes in these respects, even though these weapons represent significant advances in the state of the art. The light gun of the AA family, for example, which is

potentially the best by far of the group, suffers from the following deficiencies.

(a) The potential effectiveness of the weapon can be achieved only if target acquisition and tracking can be insured. The pulse-type K-band radar contemplated with this equipment cannot reliably detect low-flying aircraft through ground clutter.

(b) While the rate of fire is considerably greater than that of existing weapons, the number of rounds fired at the target may be inadequate, considering acquisition and track difficulties at very low angles of elevation.

(c) Costs and complexity of the weapon have risen to an alarming degree.

5211 Our present weapons are inadequate against aircraft at low altitudes. For the near future, new types of predicted-fire surface-to-air weapons offer the best hope for local defense against this threat.

5212 Advances in the field of CW radar make possible the development of a radar that provides essentially complete separation of moving targets (range rates of 150 mph or greater) from the ground echoes. This feature, in a short-range keyed CW radar, makes possible automatic warning and acquisition. The keyed CW radar may also be used to provide range and range-rate data.

5213 Optical sights in the daytime, and infrared* tracking equipment for either day or night operation, are capable of supplying the computer with the necessary precision angular data in both elevation and azimuth. The surveillance radar system could be used to find the target and point the sight or infrared tracker at the target. By use of the keyed CW radar to position the tracker, a time-consuming optical or infrared search period is obviated.

5214 In order to provide predicted-firing data to bring fire to bear with the accuracy necessary to achieve high kill probabilities, a computer would be necessary. The computer would require azimuth, elevation, range and range-rate data inputs.

*The military use of passive infrared devices is discussed in Appendix V-1.

5215 The fire power necessary to kill the target may be provided by either rockets or guns of extremely high firing rate. High firing rate makes possible the launching of all the projectiles in such a short time that the time of fire becomes a free variable. This is in contrast to present-day gunnery in which firing continues during the whole engagement. If the time of fire is a free variable, the projectiles may be launched at a time that will produce the maximum kill probability. The possibility of using rockets in this general application has been suggested by various agencies.*

5216 In view of these potentialities, PROJECT CHARLES has made a study of a proposed weapon system designed for low-altitude application. The system consists of a CW radar, an optical or infrared tracking mechanism, a computer including a time-to-fire circuit, rockets, and a multiple-tube rocket launcher. The system has been called PORCUPINE for purposes of identification. A detailed description of PORCUPINE is contained in Appendix V-2.

5217 It is estimated that PORCUPINE with 1.25-pound warhead could achieve an engagement hit probability of about 0.6 at a range of one mile and altitudes less than 1500 feet, against nonmaneuvering tactical aircraft, taking into consideration normal flight roughness and assuming a target frontal cross-sectional area of 150 square feet and side area of 750 square feet.

5218 Two weapon systems are described in Appendix V-2: PORCUPINE I and PORCUPINE II. PORCUPINE I consists of a keyed CW radar capable of searching for and detecting aircraft at ranges up to 4 miles. The antenna rotates at 3 revolutions per second, and a target may therefore be detected in less than one-third second. An audible warning and azimuth indication is supplied to a manually operated optical sight. The sight is used to track the target and point a rocket launcher. The CW radar provides range and range-rate signals to the computer. The time-of-fire computer triggers 100 rockets per engagement fired from a servo-controlled launching rack.

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*"A Presentation to PROJECT CHARLES and Informal Comments on Low-Altitude Weapons," Macon Fry, Operations Research Office, Dept. of the Army.

"Preliminary Design and Effectiveness of Low- to Medium-Altitude AA Rocket," Operations Research Office, Dept. of the Army, 27 March 1951, prepared by Columbia Research and Development Corp.

5219 The PORCUPINE II is similar to the PORCUPINE I, except that an infrared tracker is substituted for the optical sight. This makes possible night as well as day operation, and also eliminates the necessity of manual tracking.

5220 The automatic warning, acquisition and fire-control system described for PORCUPINE is not limited to use with rockets, since the same functions are just as necessary with guns. However, the choice between the gun and rocket is an important system decision, and must be made in such a way that difficulties of requiring too much range or accuracy from the rest of the system are not imposed. The important principle in the design of the system is to avoid excessively high performance requirements for any single component.

5221 The development of a new weapon called PORCUPINE is recommended for local defense against low-flying aircraft.

5222 In its simplified form, it will use a CW radar to alert the system, manually operated tracking, and a computer to select the optimum time to fire a salvo of about 100 rockets.

5223 In its advanced form, PORCUPINE is conceived as using a completely automatic fire-control system, comprising a keyed CW radar, an infrared tracker, a computer, and a multiple rocket mount. Selection of the time of firing for maximum kill probability will again be the key concept.

E. GUIDED SURFACE-TO-AIR MISSILES

1. The Present Development Program

5224 The development of surface-to-air guided missiles depends on progress in three fields of technology: jet propulsion, guidance, and supersonic airframe design. These fields are all comparatively new, and the advance in technology has been undertaken concurrently with projects for the development of operational

missiles. At the initiation of these projects, it was necessary to set up certain performance specifications as goals. In most cases, these goals, in the technical sense, were set quite high compared with the performance of the only devices resembling guided missiles that have so far been operational in war – the German V-1 and V-2. This circumstance has given scope and encouragement to the development, but the distinction between goal and achievement has not always been kept in mind. The realizable performance depends on the progress that can be made in the underlying fields of technology, and can be foreseen only in proportion as this progress is achieved. Thorough operational trials are also required.

5225 The present development program is also characterized by the fact that missiles with high technological performance specifications are being developed concurrently with others with far easier demands on technology. The missiles can be arranged roughly in a hierarchy with respect to their demands on technology and their corresponding chances of reaching their goals. For instance, for the guided SAM intended for air defense, this order seems to be (roughly) in order of increasing requirements:

(a) NIKE,
(b) Guided missile of the Swiss company Maschinenfabrik Oerlikon,
(c) TERRIER,
(d) TALOS,
(e) RED SHOES and RED DUSTER (U.K.),
(f) HAWK,
(g) GREEN WATER (U.K.),
(h) BOMARC.

The order of technological objectives corresponds in great measure with the order of the dates when the missiles can be realized, but not altogether, since these dates also depend on the development effort. For instance, the Swiss missile program, with relatively simple objectives, will not be completed early because the present development effort is inadequate. Based on the current status of the various SAM, NIKE I should be the first of those missiles to become operational in quantity, with TERRIER I following closely. If either NIKE I or TERRIER I perform substantially as specified at medium and high altitudes,

they will, on an effectiveness per unit cost basis, (a) outclass by at least an order of magnitude all existing medium and heavy AA weapons, and (b) outclass by a decisive margin weapons now under development to cover the medium- and high-altitude zones, including LOKI and medium and heavy guns of the Army's Family of AA Weapons.

5226 In planning defense systems based on the assumption that missiles will appear on specified dates with their ultimate performances, the distinction between goal and achievement has not always been recognized. It is remarkable that, in fields of technology of some standing (e.g., piloted aircraft, AI systems, fire-control systems), the difficulties facing innovations are immediately pointed out. But in new and little-explored fields, the most radical innovations are accepted as realizable. For the missiles with very high performance specifications, it should be questioned whether the goal can be met at all, or nearly enough to permit the missile to take the part assigned to it in air defense.

a. Interim Missiles

5227 The development programs in the past have been troubled with goal specifications that were increased as the expected performance of the target aircraft was increased. Aircraft development is proceeding rapidly. There is therefore a race between the improvement in performance of the aircraft and of the missile, and the missile has the handicap that it has not yet been born and gone to school. Fortunately, there has been some recognition of this in the planning of interim missiles in some programs – the TERRIER, interim BOMARC, and interim (1500-mile) NAVAHO being examples (the latter, of course, is not an AA missile, but illustrates the general point).

b. Tactical Application

5228 The question about initial goals is essentially one of the compatibility of certain specifications, of which the principal ones are the launching weight, operational kill probability, and range. As the progress of development clears the picture, it is found frequently that some readjustment is necessary, and to a certain extent it is a matter of choice as to which specification is relaxed. In most cases, it is possible to effect a compromise that will still leave some

over-all performance of the kind called for initially, but in a lesser degree. Even if it is found that the lesser performance brings in question the tactical application for which the missile originally was intended, the future of the project should not be wholly governed by this consideration.

5229 It is far more realistic to assume that technical and operational performance are dependent variables whose values can be fixed only after the missile has undergone thorough field trials. After the first full-scale operational tests, a considerable increase in tactical performance can be expected if the tests are continued and the results fed back to a renewed development. In other words; adopt the principle of "make-do," and let the guided missile find its role, however modest, when it has arrived. There is no doubt that this role can then be broadened.

c. Basic Types

5230 In this way of handling the guided missile program, a particular missile program is regarded as pursuing a particular design philosophy that seems promising in its military application, but with the degree of its tactical performance left undetermined. If we look at the present program from this point of view, we see that it is well selected and organized, with NIKE representing the command-guidance idea, TERRIER that of beam riding, TALOS that of beam riding with terminal homing, HAWK and the British missiles that of homing-all-the-way, and BOMARC that of a high-cruising, long-range missile with terminal homing in a dive.

d. Early and Late Designs

5231 Another characteristic feature of the present development program is that the realization of the missiles of the later and higher-performance types almost surely is dependent on the completion and trials of the earlier types. This is because the development of the earlier types promotes the general advance in technology required by the later types, and because the later missiles are faced with questions that can be answered only by the trials of the earlier types (e.g., target discrimination and logistic questions). The designers of missiles of later type should concentrate on fundamental problems, and resist pressure

for too early freezing of design. This is particularly true of the ultimate BOMARC which, at the present time, can be regarded only as a set of plausible design goals. The BOMARC program may require less elegant goals for an earlier and evolutionary stage, but this should not interfere with the fundamental work required for the ultimate BOMARC.

5232 Final decisions on tactical application of guided missiles should be made only on the basis of actual performance in full-scale operational tests.

2. Production Program

5233 The decision for production always has a stimulating effect on development. It is fortunate that limited production programs have been approved for three guided missiles, and those selected have been well chosen with regard to stage of development and distribution of types. This program should not jeopardize development work on other missiles that promise improved performance. The objective of the recommended production program should be to provide missiles for operational tests. The entire guided missile program will benefit if the results of such tests are fed back into development as completely as possible.

5234 It should be borne in mind that the time required for final engineering, successful production, "debugging," and proving-out to adequate operational performance can be nearly as long as the time of development to prototype. The dates assumed for full operational installation should be chosen accordingly; on the whole, the dates presently assumed appear to be optimistic by an amount of about one year in each case.

3. Initial Limitations

5235 All AA missile systems will have operational limitations in varying degree in performance against low-flying aircraft, and in target discrimination, and in traffic-handling capacity when used against dense formations. These limitations should be accepted initially and the missile rated accordingly in the scheme of defense. Again, there is no doubt that progress can be made in lifting these limitations once large-scale trials better define the problem. Another problem

that has been left by the wayside until recently is that of booster disposal or consumption. The work of the Glenn L. Martin Company in this field is to be welcomed, but the problem deserves more attention for land installations.

4. Common Bottleneck Problems

5236 Several missiles, both ground- and air-launched, are finding common bottleneck problems in such fields as radar resolution, radar glint, radar jitter, radomes, lack of systematic information in supersonic aerodynamics, and in nonrotating proximity fuzes. The last is also a problem for unguided rockets. Target discrimination by radar is a problem for guns as well as for guided missiles. Work is going on in these fields, but the whole guided missile development would be expedited if a more concerted and better coordinated attack on these problems were made.

5237 The objectives of the guided missile program are generally sound, but the chances of their realization would be greater if efforts were concentrated toward the solution of radar, fuze, and aerodynamics problems common to many missile programs.

5. Long-Range Surface-to-Air Guided Missiles

5238 The concept of a long-range surface-to-air guided missile intended to take over the functions of manned interceptors in area defense has a place in future military planning as a possible extension of present technological trends. The development of this type missile should be pursued.

5239 Assuming that satisfactory terminal guidance and target discrimination can ultimately be built into such a missile, it offers several advantages for area defense:

(a) An inherent possibility of homing on active jamming transmitters;

(b) An inherent possibility of using a pure CW homing head which might be useful for low-altitude attacks;

(c) Economy, as compared with an interceptor defense of equivalent lethality.

5240 The availability of long-range SAM would clearly permit a reduction in the size of the interceptor force, though it is extremely doubtful that it can ever

entirely replace the interceptor. No significant reliance should be placed on long-range missiles until it is possible for field commanders to have a choice between several alternative tactics and guidance systems, and until some of these tactics have been tried on as realistic a basis as possible in peacetime.

5241 The technical advances required for such a missile are much greater than for local defense SAM. Many of these problems, especially the homing radar and terminal-flight maneuvering, are similar to those of the MX 1554 interceptor concept. Because of the advanced technology required, early realization of such a missile should not be expected, and its development will be greatly accelerated by the technical and operational experience gained from both short-range SAM with terminal homing and manned interceptors of the MX 1554 type.

5242 The operational effectiveness of a long-range surface-to-air missile, such as BOMARC, will depend greatly on the capability of its ground-control system. Such a missile cannot be utilized until an operating AC&W system of greater capability than the present U.S. system is available. However, the chances of early realization of the ultimate guided missile for area defense do not appear sufficiently good to warrant the independent development of an AC&W system for it. We therefore recommend that the AC&W development effort be directed as outlined in Section IV, and that the BOMARC program be concentrated on the development of mid-course guidance for test vehicles and the solution of the target-acquisition problem.

5243 Research and development on long-range surface-to-air missiles such as BOMARC should be pursued. The problems are manifold and will require considerable research, but any large expansion of effort at this time must be weighed against its effect on shorter-term guided missile projects. In any case, the BOMARC program should be coordinated with long-term plans for the AC&W system.

SECTION VI

ELECTRONIC WARFARE

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ELECTRONIC WARFARE

A. ELECTRONIC COUNTERMEASURES

6001 In the limited time available to PROJECT CHARLES, a complete study of countermeasures has not been attempted. The discussion that follows is limited to a few points related to air defense; they represent a somewhat arbitrary selection from a large countermeasures program which, in its entirety, is under review by other groups.

1. Organization for Development

6002 The field of electronic countermeasures is one in which excellence is characterized largely by nimbleness. It is obviously uneconomical to build enough jammers in peacetime to be able to jam all conceivable equipments at all possible points of attack. Certain equipments should be developed and even produced in quantity if information from intelligence and ferret sources is definite enough to determine the required characteristics. In general, however, it seems wise to emphasize component development. For example, the current program of tube and receiver development, which will ultimately give coverage over all usable frequencies, seems to be a reasonable one and should be encouraged.

6003 A further requirement, however, is for rapid and effective use of these components once hostilities begin. We have heard of no adequate plans for making this possible. In the event of war, there is need for a sudden increase in countermeasures activities by highly qualified personnel. It is suggested that laboratory and limited production facilities for crash programs should be prepared now and kept in readiness by a skeleton staff. Additional personnel, highly qualified for work in this field and numerous enough to staff the facilities adequately, should be chosen now but left in their ordinary occupations until needed. They could be kept aware of possibilities and even do some preparatory work, so that the laboratory and crash production programs could be operating at full speed immediately after war begins.

6004 Success in the application of electronic countermeasures demands nimbleness and flexibility. A development laboratory and limited production shops for crash programs should be established now and maintained as stand-by facilities.

2. Information on Enemy Equipment

6005 Although versatile laboratory and production facilities of the type just outlined are necessary, they may not be sufficient. The critical period for the air defense of the continental United States may well be the first few weeks of a war. Consequently, the countermeasures that can be used effectively may be only those that are based on information obtained in peacetime. Intelligence and ferret operations are therefore of the utmost importance and may, indeed, be the factors that determine whether or not countermeasures can be employed during these critical first weeks. It is of particular importance to have definite, accurate information on enemy bombing radars and aids to navigation. Until such information is available, the production of large numbers of receivers or jammers is of doubtful value.

6006 In addition to the difficulty of obtaining information on enemy equipment, there seems to be considerable difficulty in getting to the proper persons what information we do have. It is recommended that an information center concerned with foreign military equipment should be established. This center would collect and catalogue equipment of possible enemies, and information concerning such equipments. It would maintain a laboratory where these equipments could be studied by authorized representatives of outside organizations, and from which such equipments could be borrowed.

6007 Information on enemy electronics equipment is scant and poorly disseminated. More data are needed, and an information center should be organized in this field.

3. Countering Enemy Navigation Aids

6008 The lack of information on bombing and navigational aids that an enemy

is likely to use makes the peacetime construction of jammers decidedly a gamble. There are, however, a few types of equipment that are clearly such powerful aids to a bombing force that it would indeed be surprising if an enemy did not attempt to take advantage of them. One of the chief examples of such equipment is the radar bombing aid. The excellence of modern forms of this equipment and the difficulty of conducting long-range missions without it makes its use by an enemy highly probable. Since it is fairly certain that microwaves will be used, versatile microwave jammers should be built in sufficient quantity to allow a few to be placed in the neighborhood of our most important targets. The current efforts along these lines should be encouraged. It is obvious that definite information on bombing radars that might be used against us would be of enormous value to this program.

6009 An enemy navigation aid that seems to us to be a likely possibility, and which is so difficult to counter that it deserves special mention, is the beacon, of transponder type, planted by enemy agents well in advance of an attack. Unless one can be discovered, or the required information (such as trigger and response codes) can be obtained from intelligence sources, it may be necessary to wait until an attacking plane is captured before effective countermeasures can be taken. Since the device is such an obvious one, little or no harm could be done by informing the public concerning its characteristics and appearance. Widespread public knowledge of beacons should make it more difficult for an enemy to plant them, and might result in the early discovery of such a beacon.

4. Control of Electromagnetic Radiations

6010 Countermeasures against aids to enemy navigation involve more than electromagnetic jamming. The vicinity of our important targets is flooded with electromagnetic radiations from various fixed antennas, and any one of these could be used by an enemy as a navigation aid. These sources include radio and television broadcasting stations and our own navigation aids.

6011 Some of these must be turned off during an alert; others, like the radio, are indispensable at that time for civil defense and must be prevented, by

confusion tactics, from serving as navigation aids. The problem of deciding just what should be done with regard to each source of radiation is a difficult and complicated one, and is discussed at length in Appendix VI-1. There is one point, however, that we wish to emphasize here: no "common" radio navigation system (i.e., one that is universally used) can be denied to an enemy by any method other than turning it off. This means that the military must have a navigation system of its own for tactical purposes. The features required in such a system are discussed in Para. 5135 et seq.

B. COUNTER-COUNTERMEASURES

6012 The development of electronic countermeasures is critically dependent on information regarding enemy equipment; in the absence of such information, the large-scale construction of jamming devices has been declared in Para. 6002 to be of questionable value. When we come to the protection of our own equipment against enemy jamming – counter-countermeasures – the situation is quite different. Here we have rather complete information, and the time to work on protecting the equipment against jamming is before the war starts.

1. Protection of Ground-to-Air Communications

6013 From the point of view of vulnerability to enemy jamming, our ground-to-air communications constitute a serious weakness in our air defense system. The experience of World War II and exercises in both the United States and the United Kingdom have shown that the whole intercept system can be made inoperative by the jamming of these links, and, furthermore, that they are relatively easy to jam. While ultra-high-frequency equipment should be an improvement, because of the wide range of frequencies available, we have no assurance that it will be wholly satisfactory in this respect. At present, our interceptors are virtually helpless without ground-to-air communications. The solution of the problem should therefore have the highest priority. An obvious improvement is the use of high-power transmitters on the ground. These should be provided immediately.

6014 Another possibility is the use of interceptors equipped with very-high or ultra-high frequency (VHF or UHF) direction-finding equipment to home on

communications jammers. Development and installation of such homing equipment has been recommended in Para. 5151 as an aid to navigation. The present suggestion supplies further reason for its adoption.

6015 These steps may not provide a complete solution. The problem is a difficult one and may not be solvable by standard communication methods; the solution may, indeed, require extensive modification of our air defense system. Meanwhile, it is most important that the controllers and pilots in the air defense system be given strenuous and realistic training in getting along with impaired or interrupted communications.

6016 The vulnerability of the present ground-to-air communication links is such that enemy airborne jammers could easily disable our intercept system. The maximum power of ground transmitters must be greatly increased.

2. Protection of AI Radars

6017 A second susceptible component of our air defense system is the airborne intercept (AI) radar. These radars are at present too easily unlocked by chaff. A velocity memory in the tracking mechanism should be of assistance, and this as well as other possibilities should be explored. It should also be kept in mind that a trained operator can often work through interference that confuses or paralyzes an automatic device. Since the pilot of an interceptor is already too busy, this function would require a second man in the interceptor. The need for effective operation in the presence of interference is thus a factor in favor of two-place all-weather interceptors (cf. Para. 5031).

3. Protection of Ground Radars

6018 The enemy may attempt to jam our ground-based air surveillance radars and thus prevent ground control of our interception (GCI). Quick change of frequency of the radar may be sufficient protection and would certainly require the jammers to be much more elaborate in order to be completely effective. Operators should be trained to make these changes in frequency quickly, and, if experience shows that it is necessary, the equipment should be modified to make quick tuning easier.

6019 Enemy interference with the radar warning and control network might take the form of attacks with radar-homing bombs released from enemy aircraft. Protective measures to be taken in anticipation of such attacks will depend on the military estimate of how serious and how imminent a threat this is. As a minimum program, the radar antennas might be placed in locations sufficiently distant from the control stations so that a bomb hit on an antenna would not destroy the station. Other protective measures consist of frequency-shifting schemes, and of multiple widely separated antenna installations with the possibility of shifting transmission from one to the other and of using some as decoys. These more difficult and costly techniques will go far toward defeating any foreseeable guidance system. However, they cannot be invoked at short notice; preparations for their use should be made as soon as intelligence indicates a major threat from radar-homing bombs.

4. Homing Interceptors

6020 The use of an interceptor equipped to home on VHF or UHF transmissions as a protection against jamming of the ground-to-air communications link has already been mentioned. There is a possibility that similar interceptors with homing equipment operating at other frequencies may be effective against enemy bombers carrying navigation and bombing radars or airborne jammers of GCI radars. Interceptors of this type should be provided as soon as possible and given thorough operational tests.

6021 Homing interceptors might be a powerful deterrent to the enemy's use of navigation and bombing radars, and should be provided for early operational tests.

5. Operator Training

6022 The importance of training operators to work through jamming or in spite of jamming can hardly be overemphasized. This may well be the most effective counter-countermeasure. Experience has shown repeatedly that jamming that confounds a novice may be virtually useless against an experienced operator.

6023 The training of operators to work through interference is one of the best available protective measures.

SECTION VII

PASSIVE DEFENSE AGAINST AIR ATTACK

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PASSIVE DEFENSE AGAINST AIR ATTACK

7001 PROJECT CHARLES undertook a consideration of passive air defense measures because it appeared likely that no foreseeable improvements in our active air defense system would achieve complete protection of our cities and industrial installations against enemy bombs. The full utilization of passive defense capabilities can reduce markedly the effect of any air attack that penetrates our active defenses, and can thus augment significantly the United States' air defense potential.

7002 Passive defense encompasses a broad sphere of noncombative activities, ranging from those actions that seek to weaken the enemy's will to fight, to plans for disaster relief after bombs fall. Neither of these fields seemed within the scope of PROJECT CHARLES, but between these two extremes is a wide area with two principal objectives: (1) to decrease the attractiveness to the enemy of his targets, and (2) to minimize the losses of both populations and resources that would be incurred if bombs are delivered on-target. A preliminary survey of these two aspects indicated that the first could be achieved by limited dispersal of population and industry, the second by protective measures such as shelter, by stockpiling, and by recuperation plans. Protection against air attack achieved by these means is not rapidly obsolescent and is relatively independent of enemy tactics.

7003 Because the staff of PROJECT CHARLES did not have sufficient technical competence in these fields, a group of economists was assembled (see Appendix P-1) to work actively with Committee C. The major proposals relating to dispersal, stockpiling, and recuperation are submitted in Appendices VII-1, VII-2, and VII-3 together with a discussion of the economic factors that are involved in any such policies. This Section of the Report will only summarize the principal conclusions and recommendations stemming from the economic study.

1. Dispersal

7004 The source of our vulnerability to any enemy bombing strategy is geographical concentration of industry and population. Thus, an obvious remedy

is dispersal. However, the locational patterns that now exist are the result of strong historical and economic factors; and it is not feasible, for both social and economic reasons, to disrupt drastically the status quo.

7005 We therefore advocate a long-term policy of limited dispersal of new industrial construction aimed at separation of strategic industrial facilities by distances of at least 10 miles. We recommend that residential construction be channeled into areas of low population concentration and away from the dense metropolitan areas.

7006 Fundamental to any dispersal policy is a thorough and general understanding of the circumstances that make necessary the deconcentration of population and industry. This educational process must be the responsibility of the highest levels of government, industry and public affairs. Means to implement a dispersal policy already exist in such mechanisms as the Certificates of Necessity issued by the Defense Production Administration, housing credit and construction controls, and materials allocations and priorities. The various forms of War Risk Insurance now under consideration by Congress offer additional means for introducing vulnerability considerations into locational decisions for industrial and residential construction. The Federal Government should itself set an example by locating its facilities with proper regard for a dispersal policy.

2. Stockpiling and New Capacity

7007 A study of three basic industries – steel, oil refining, and aluminum – indicates the need for stockpiling (particularly in aluminum), and for creating additional dispersed capacity for certain critical finished steel products.

7008 A program of stockpiling certain basic commodities, such as food and medical supplies, in peripheral locations, and duplication of essential community facilities are deemed necessary to preparedness against air attack.

3. Recuperation

7009 The effect of enemy bombs can be greatly alleviated if plans for restoration and reconstruction are existent before the emergency. The greatest value attaches to prearranged plans and equipment for rapid repair and

recuperation, for conversion of nonessential facilities to strategic production, and for substitution of curtailed resources by available supplies.

4. Protective Measures

7010 Present civil defense functions appear to be oriented more towards disaster relief after bombs fall than towards measures that will lessen the weight of the blow. We believe that more emphasis should be given to measures designed to prevent casualties. Shelters and other protective techniques, in conjunction with adequate warning, can reduce casualties from air attack by appreciable factors. The examples of Nagasaki and Hiroshima indicate that particular attention should be given prevention and control of fire hazards (See Appendix VII-3).

5. Support

7011 Passive defense activities should receive financial support commensurate with their capabilities, and from the national budget, probably in a fixed proportion to active defense costs.

6. Passive Defense Study

7012 The implementation of a dispersal policy and the maximum utilization of protective measures require broad and intensive studies of many facets of economic and social patterns in the United States. We endorse the program inaugurated by Associated Universities, Inc., to study the possibilities inherent in passive defense measures. We strongly urge that the National Military Establishment extend all possible support to this study program.

7. Summary

7013 We advocate a long-term policy of limited dispersal. New residential construction should be channeled into areas of low population density. New industrial construction should be so located that vital plants are separated by at least ten miles.

7014 A major factor in reducing urban casualties is the provision of shelters. With proper warning and other protective techniques, these will greatly reduce the loss of life in bombing raids.

7015 Plans, equipment, and training should be provided for recuperation from bomb damage, and for rapid conversion of nonessential facilities to strategic production.

SECTION VIII

MANPOWER IN AIR DEFENSE

SECTION VIII

MANPOWER IN AIR DEFENSE

A. USE OF NONCOMBAT MANPOWER IN DEFENSE

8001 The cost of air defense must be measured in manpower as well as dollars. Unless it is to make them better qualified for combat through training, any use in the air defense system of men qualified for combat is clearly a tax on our power for offense. With the paramount importance of offense in mind, we strongly recommend the use of noncombat personnel so far as possible throughout the air defense system.

8002 The residents of a locality are most directly interested in the success of its defense, and it is reasonable to give them a share in the responsibility for its defense. The principle, "defend your own home," is sound. The Armed Forces should welcome some relief from the responsibility of air defense, for it would enable them better to concentrate on their primary responsibility – offensive warfare.

8003 Possible types of organization for the home forces in air defense include:

(1) noncombat elements in the Armed Forces;

(2) reserve military corps like the National Guard and the Coast Guard;

(3) civilian agencies like the Civil Aeronautics Authority and the Federal Civil Defense Administration with its branches, particularly the Ground Observer Corps (see Para. 3148 et seq.);

(4) private citizens, particularly private contractors with their personnel.

8004 The training of combat personnel must be one of the functions of the air defense system of the continental United States. One way to provide for such training, and at the same time to make use of noncombat personnel, is to reserve one or more sectors of the air defense system for operation by potential combat personnel of the Services, leaving the rest to the home guard.

8005 Local defense is an especially fitting function for noncombat personnel. The experiments of the Army in the use of noncombat elements of the Armed Forces for local defense are to be welcomed. However, it appears desirable to go even further – to turn over, in so far as possible, the responsibility of

command to reserve groups such as the National Guard and Coast Guard. Independent responsibility is a major factor in building morale and efficiency in an organization. Coordination of local air defense with other activities can be effected at the command level.

8006 Consideration should be given to the qualifications of Coast Guard for operating offshore defense vessels such as picket ships (see Sections II and III). The Coast Guard is largely manned by men from the coastal states, who have been seafaring from childhood and are similar in training and outlook to fishermen and others who carry out arduous duties at sea in small boats. Such men are accustomed to life on a vessel that maintains station at sea for an extended period, accept it, and even like it. They are familiar with the topography of the coast, with the weather conditions, and with dealing with foul weather. The Coast Guard is probably the best source of information on station-keeping vessels and how to operate them. It is well qualified to take responsibility and to perform such operations.

8007 The function of maintenance of the aircraft control and warning system (AC&W) is one for which the use of civilian personnel is especially recommended. The military does not have the experience in maintenance (of the sort required by the AC&W net) that is possessed by our communication companies. It even seems possible to separate maintenance and operating responsibility and to induce a private company to assume the former.

8008 On the other hand, since the operation and command of interceptors involve combat responsibilities and are therefore essentially military in nature, these duties must remain with the United States Air Force and its regular service personnel. ("Operation and command" includes everything from the assessment of the air situation to the control of interceptors and guns.) It is not reasonable to assign separate responsibility and command, in certain sections of the area defense system, to reserve corps like the Air National Guard. The mobility required of interceptors in defense requires complete integration of such reserve corps with the Air Force

B. EFFECTIVENESS OF PERSONNEL

8009 It is clearly important to improve the operational efficiency of the

AC&W system by increasing the effectiveness of the personnel. Obvious areas for improvement are (1) training, (2) motivation, and (3) turnover rate.

8010 Improvements in all three areas can be obtained by introducing into the Air Force the practice of designating certain officers "for engineering duty only" (EDO). Corresponding designations of noncommissioned and warrant officers would round out the picture. The EDO officers should be given the opportunity to specialize in engineering and to develop much higher degrees of skill and proficiency than can be achieved in a short tour of duty. Selected officers could be trained in industry for the maintenance and operation of particular equipments, and then attached to GCI (ground control of interception), ADCC (Air Defense Control Center), and other stations of the air defense system. These officers would be particularly useful as instructors. They would have the three qualities needed to keep a radar station or an information center operating at peak efficiency: technical competence, motivation focused on the job, and stability of assignment.

1. Training

8011 The principal point that has impressed us in connection with training concerns the feedback of information about results. Men can improve their performances only if they have knowledge of the results of their actions. The feedback should be as direct and as immediate as possible. In air defense, however, there is usually no good criterion on the basis of which a man's performance can at each step be scored or rated. Only rarely does anyone have "criterion information," -i.e., information sufficiently good to serve as a basis for scoring--until so late that the details of the action are cold or forgotten. Without criterion information, it is difficult or impossible for any individual or group to develop high proficiency. We regard it as one of the most important steps toward improving the effectiveness of the AC&W operating personnel that better criterion information be obtained and better feedback be provided, both in prejob training and in on-the-job training.

8012 Clearly, there are two ways to obtain criterion information: (a) to increase the use of practice targets, flying very precisely on predetermined courses, and (b) to make use of extremely realistic simulators, introducing occasional

simulated targets into the radar presentations. In either case, the known target should enter the system and be processed exactly in the same way as any other target (i.e., without foreknowledge on the part of the operating personnel). Immediately after it has been acted upon, the action taken should be checked against the action known to be appropriate on the basis of the predetermined circumstances. Finally, each man should be informed whether or not his handling of the particular target was appropriate and, if it were not, what he should have done differently, and how. This procedure would allow personnel to correct errors and to improve efficiency. It would not be necessary to have a large number of practice or simulated targets. Even if there were knowledge of results in only two to five per cent of the cases, the improvment in performance would probably be marked.

2. Motivation

8013 Motivation should be focused on the actual job at hand by tying promotion, leave, and other rewards to the performance of that job. Forceful steps should be taken to convince personnel throughout the AC&W system that aircraft control and warning is a career, and that advancement and success depend upon performance of AC&W duties. Controllers, for example, should be promoted for excellence at controlling fighters, not for "hours in the air." A system similar to that based on "select crews" in the Strategic Air Command could be employed in the AC&W stations if there were sufficiently reliable indices of performance.

3. Turnover

8014 We recognize that it is sometimes necessary to have a high turnover rate in an expanding organization. However, because of the importance of stability to the efficient operation of such a complex system as the air defense system, we recommend that every possible step be taken to reduce the rate of turnover of personnel in the AC&W stations.

8015 The cost of defense in manpower may be a more important limitation than its cost in dollars. To release combat personnel for offensive warfare, we recommend extensive utilization of noncombat and civilian personnel in the air defense system.

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This document contains 240 pages. No. of 1500 copies 540

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROBLEMS OF AIR DEFENSE

Appendices

to

Final Report

of

PROJECT CHARLES

VOLUME II
of
Three Volumes

1 August 1951

Contract No. DA36-039sc-5450

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PROJECT CHARLES BRIEFING SCHEDULE

APPENDIX P-2

BRIEFING SCHEDULE FOR PROJECT CHARLES

(19 February – 12 March 1951)

(Note: The following program presents a list of names and topics of the formal presentations. The briefing was so active and informal that it was impossible to list the names of everyone who participated.)

19 February, 3E869, Pentagon Building, Washington, D.C.

Speaker	Subject
Gen. N. F. Twining, USAF Vice Adm. J. H. Cassady, USN Lt. Gen. John D. Hull, USA	Welcome and Remarks by Senior Service Representatives
Dr. F. W. Loomis, MIT	Genesis of the Project
	VULNERABILITY TO AIR ATTACK
Maj. Gen. Charles P. Cabell, USAF	The Continental United States
Col. B. E. Allen, USAF	The Strategic Vulnerability of the U.S. to Air Attack with Atomic Bombs
Rear Adm. M. E. Curts, USN	The Fleet
Col. C. G. Patterson, USA	Advanced Bases and Overseas Land Combat Forces

20 February, 4C1052, Pentagon Building, Washington, D.C.

Dr. C. L. Zimmerman, USAF	Capabilities of the U.S. Strategic Air Force
Col. E. H. Porter, USAF	Comments on Soviet Strategic Air Capabilities
Rear Adm. G. B. H. Hall, USN	Capabilities of Submarine-Launched Missiles
Brig. Gen. E. Moore, USAF	Capabilities of Soviet Tactical Air Arm.
Mr. Walter Williams, AEC Capt. A. McB. Jackson, USN	Problems Associated with the Production and Employment of Atomic Munitions

Speaker	Subject
Maj. W. W. Hurt, USAF Capt. C. H. Coggins, USN Col. J. R. Whisenand, USAF	Chemical, Biological and Radiological Agents

21 February, 4E442, Pentagon Building, Washington, D. C.

CURRENT AIR DEFENSE SYSTEMS

Maj. Gen. Joseph Smith, USAF	Organization and Command Relationships for Air Defense Based on Key West and Subsequent Agreements
Lt. Gen. E. C. Whitehead, USAF Brig. Gen. H. B. Thatcher, USAF	Current Air Force Organization and Material for Air Defense

CURRENT ARMY ORGANIZATION AND MATERIAL FOR AIR DEFENSE

Maj. Gen. W. W. Irvine, USA	Organization of the Army for Air Defense
Lt. Col. H. P. Van Ormer, USA	Antiaircraft Artillery Program
Dr. George H. Shortley, ORO	Evaluation of Army Organization and Equipment

22 February, 4C1052, Pentagon Building, Washington, D. C.

Capt. D. F. Krick, USN	Navy Organization for Air Defense
Col. W. L. J. Baylor, USMC	Air Defense in Amphibious Warfare
Comdr. P. L. Folsom, USN	Material for Air Defense by Navy
Mr. M. L. Ernst, OP NAV	Evaluation of Navy Organization and Equipment
Brig. Gen. R. R. Hendrix, USA	Actualities of Warfare (Army)
Capt. C. V. Laning, USN	Actualities of Warfare (Navy)
Dr. George E. Valley, MIT	Current Fixes: ADSEC
Dr. George C. Comstock, AIL	Current Fixes: Western Electric

23 February, 4E442, Pentagon Building, Washington, D. C.

DEVELOPMENT TRENDS AND PROGRAM OF THE SERVICES IN AIR DEFENSE

Maj. Gen. W. H. Maris, USA	Army
Rear Adm. C. M. Bolster, USN	Navy

Speaker	Subject
Maj. Gen. G. P. Saville, USAF	Air Force
Air Commo. G. W. Tuttle, RAF W/C D. C. Stapleton, RAF Mr. Stewart Scott-Hall, Min. Supply Capt. E. D. G. Lewin, RN Maj. Gen. H. Hounsell, Army	United Kingdom
Grp. Capt. W. R. MacBrien, RCAF	Canada

26 February, Sloan Building, MIT, Cambridge, Mass.

IMPROVED COMPONENTS THAT ARE NOT YET OPERATIONAL

Dr. H. G. Stever, MIT	Principles of Flight
Dr. R. Hage, Boeing	Trends in High-Speed Design
Dr. C. Stark Draper, MIT	Limitations of Exterior Ballistics
Dr. W. R. Hawthorne, MIT	Methods of Aircraft Propulsion

27 February, Sloan Building, MIT, Cambridge, Mass.

AIRBORNE SYSTEMS

Lt. Col. P. J. Schenk, USAF	USAF Aircraft and Aircraft Systems
Dr. R. F. Mettler	The MX 1179 Integrated Electronic and Control System
Lt. Col. H. E. Burns, USAF	1954 Interceptor Program
Lt. Col. J. R. Dempsey, USAF	BOMARC

SYSTEMS ANALYSIS

Capt. P. H. Ramsey, USN	U.S. Navy Aircraft and Aircraft Systems
Col. E. C. Best, USMC	Practical Aspects of Electronic Equipment
Lt. Comdr. E. W. Harrison, USN	Equipment under Development

28 February, Sloan Building, MIT, Cambridge, Mass.

AIRBORNE WEAPONS

Col. R. R. Studler, USA	Aircraft Cannon and Machine Guns
Dr. L. T. E. Thompson, NOTS	Unguided Rockets

Speaker	Subject
Dr. E. G. Schneider, MIT	General Description & Comparison of Air-to-Air Guided Missiles
Comdr. F. C. Cassidy, USN	Shipborne Radar Systems
Sq. Ldr. R. G. Enticknap, RCAF	USAF Developments in the Ground-Reporting System
Mr. Herbert Sherman, AMC	FPS-7 Radar Ground Equipment
Mr. John Marchetti, AFCRL	VOLIR and BILLBOARD

1 March, Sloan Building, MIT, Cambridge, Mass.

Comdr. W. C. Abhau, USN	Navy Fire Control Systems
	ARMY WEAPONS
Mr. Wilhelm Jorgensen, USA	T-33, SKYSWEEPER, STINGER
Mr. W. D. Teague, Jr.	Antiaircraft Missiles (LOKI)
Dr. W. C. Tinus, BTL Mr. E. E. Wheaton, BTL	NIKE Program
Mr. Aaron Coleman, SCEL	SYSNET
Mr. Macon Fry, ORO	Evaluation of Army Development
Mr. R. B. Kirshner	TERRIER
Mr. W. H. Goss, APL	TALOS

2 March, Norfolk, Virginia

	CONTROL AND COMMUNICATIONS CENTER
Vice Adm. R. B. Briscoe, USN	Amphibious Operations (USS Taconic)
Lt. Comdr. A. H. Magie, USN	Early Defense of AGC
Comdr. E. B. Rittenhouse, USN	Force Readiness – Defense of NOBS, Norfolk
Capt. C. C. Wood, USN	Importance of Air Defense
Capt. P. L. Dudley, USN	Visit to Aircraft Carrier USS Leyte

5 March, Bell Telephone Laboratories, Whippany, N. J.
Chairman: W. A. McNair

S. C. Hight, BTL	Project COSMOS
R. C. Newhouse, BTL	Navy Intercept Project

Speaker	Subject
A. C. Dickieson, BTL	Discrete Address Data System
A. A. Lundstrom, BTL	Gun Fire-Control System (Mk 65)
	Demonstrations:
W. H. MacWilliams, Jr., BTL T. W. Winternity, BTL N. C. Olmstead, BTL R. G. Stephenson, BTL	Mark 65 Laboratory
J. B. Bishop, BTL	AN/TSQ Data Transmission Set
R. R. Hough, BTL	AAFCS-T-33
M. J. Burger, BTL	NIKE System Tester
L. W. Morrison, BTL	NIKE Missile Guidance Section
6 March, Roslyn, N.Y.	
Col. L. J. Staub, USA	Visit to Fort Totten AAA Gun Battery
Lt. Col. Harley Sather, USAF	Visit to Mitchell Field AFB, GCI
Brig. Gen. R. J. Minty, USAF	Visit to Roslyn ADCC
7 March, Naval Air Test Center, Patuxent River, Md.	
Capt. M. E. Gouin, USN	Welcoming Address
Comdr. W. J. Widhelm, USN	Station Search Radars
Lt. Comdr. R. M. Elder, USN	Comparison of Banshee and Sabre
Comdr. J. H. Boyum, USN	Night Fighter Performance and Operations
Comdr. A. F. Fleming, USN	Operations Development Force
Lt. C. A. Brownell, USN	AEW
Capt. J. B. Bowen, USN	Electronic Testing
Lt. H. J. Kirkpatrick, USN	Electronic Countermeasures
Lt. J. H. Dick, USN	Omni-DME Equipment
Capt. J. B. Bowen, USN	History of the APQ-35

Speaker	Subject
8 March, Sloan Building, MIT, Cambridge, Mass.	
	COMMUNICATION SYSTEMS
Dr. T. Murrell, U. of Ill.	Data Transmission
Harry Davis, AMC	UHF
Carl Russell, NATC	UHF Program
	NAVIGATION
Dr. George Comstock, AIL	Electronic Means for Navigation
Dr. Walter Wrigley, MIT	Inertial and Autocelestial Navigation
Mr. Joseph Blatt, CAA	Corridor Flying
Mr. B. F. Green, AFCRL Col. Jack Taylor, USAF	Problems of Landing Fighters
Dr. C. E. Cleaton	IFF
9 March, Sloan Building, MIT, Cambridge, Mass.	
Mr. Walter E. Tolles, AIL	Effectiveness of Countermeasures on Air Strikes
Dr. John F. Byrne, AIL	Vulnerability of Aircraft Equipment to Countermeasures
Mr. W. G. Street, ORO	NIKE vs. 120-mm Gun for Local Defense of Army Advanced Bases
Brig. Gen. S. R. Mickelson, USA	Operational Aspects of the Army Surface-to-Air Guided Missiles Program
Dr. G. E. Valley, MIT	Review of the ADSEC Program
12 March, Sloan Building, MIT, Cambridge, Mass.	
	COMMENTS BY THE BRITISH DELEGATION
Mr. Stewart Scott-Hall, Brit. Min. Supply	
Maj. Gen. H. Hounsell, Brit. Army	
W/C D. C. Stapleton, RAF	
Air Commo. G. W. Tuttle, RAF	

APPENDIX II-1

IDENTIFICATION

APPENDIX II-1

IDENTIFICATION

The identification of an airplane that has been observed in a particular volume of space may take place in a variety of ways. If the original observation is visual, the procedures for identification are straightforward and need not be discussed. If, on the other hand, the plane has been sighted by radar, more complications arise. In the first place, various degrees of identification are required under various circumstances, ranging from a mere distinction between a friendly and an enemy plane through determination of the type of plane (i.e., fighter, bomber, noncombatant, etc.) to unique personal identification of the particular plane. This last degree of identification, if reliably performed for all friendly planes, satisfies any of the lesser requirements.

The distinction between friendly and enemy planes (Identification, Friend or Foe, or IFF) has been attacked by various electronic means that are, in principle, nothing but a mechanization of the ancient procedure of challenge by a sentry and reply with the proper password. So long as the password is known only to friends, the procedure is safe, whether it is accomplished by words or by electronics. Furthermore, the two parts of the procedure, a challenge and a reply, are common to both methods. The challenge may consist of the radar pulse by which the plane is seen, the reply then consisting either of some passive modification of the reflection (such as a rotating dipole, a vibrating corner reflector, etc.) or of some active reply (such as the radiation of an amplified version of the received radar pulse, or the emission of a characteristic signal upon receipt of a radar pulse). Alternatively, the challenge may consist of a special signal sent out in association with some of the radar pulses at such times as the identification function is required. The reply is then a characteristic signal that is radiated whenever the special challenge signal is received. Either or both the signals, challenge and reply, may be coded, and the code for either or both may be changed at prearranged times.

The Mk X system in its later proposed forms is an example of such a procedure. The challenge consists of a signal on a particular L-band frequency made up of two pulses radiated simultaneously with some of the radar

pulses when desired. The time spacing of the two pulses constitutes the challenge coding and is fixed at one of three definite values. There are then three distinct challenges that are not changed. The reply consists (in the proposed modification) of a train of pulses, five to seven in number, sent out on another frequency in L-band in response to the appropriate challenge. The number and spacing of the pulses then give the coding of the reply. It is proposed to change this coding at intervals ranging from one minute to a day or more. No agreement seems to have been reached until now as to the best time interval for code changing. Such agreement will almost certainly have to await trials of the system under conditions approaching actual use. If reliance is to be placed on the security of differentiation between friend and enemy, it must be made impossible or unprofitable for the enemy to obtain the code either by subversion or by a process of interrogating a friendly (to us) plane with his own equipment and finding out what sort of reply it gives. The requirements are similar to those placed on a cryptographic system where, first, the enemy must not be allowed to steal or capture a code book and, second, he must not be able to take a coded message and decode it in a way that allows him to read other messages quickly. The first type of compromise seems best avoided by strict limitation of the distribution of code material. As applied to Mk X, this principle would preclude any use of a military version of such equipment on civilian planes. It may be argued further that any system at all closely analogous to the military version should not be used on civilian planes unless under strict military control, in order that breaking of the code by the enemy is not facilitated.

An aircraft control and warning (AC&W) net for an area such as the continental United States must deal with situations in which air traffic controls both civilian and military planes. These situations will certainly arise during a period of tension or cold war, and may persist even into periods of open hostile action. The identification function for such a net cannot, therefore, be based on Mk X or any close relative. However, the net should be so designed as to make use of whatever information may be generated about military planes. The ground installations for Mk X or any successor would obviously be operated entirely by military personnel, whatever the arrangements

for the other data-gathering portions of the AC&W net, and would serve as an additional source of information similar to Civil Aeronautics Authority (CAA) flight plans, etc. The only requirement on the data-processing part of the AC&W system is that it be able to accept such information.

Since accurate identification is an important part of AC&W, and since IFF has been shown to be of definitely limited utility in a region such as the continental United States other means must be considered. The use of flight-plan information is one possibility. Here the pilot of the plane decides on his course, asks for an altitude, calculates the time of arrival at his first destination, and reports all this before take-off. It is then presumed that a plane arriving at a given location at prearranged time, heading, and altitude is the one for which the flight plan was filed. Since aircraft flight is subject to some unpredictable variables, a certain amount of tolerance must be allowed in predicted positions, both as to time and location. If very few planes are flying, this uncertainty in location does not interfere with identification; but as soon as the traffic density is high enough to make the average distance between planes comparable to the necessary tolerance allowed in the flight-plan position, identification becomes completely indefinite. If two-way radio communication with the plane in question is available, it may be possible for the pilot to report his exact location at a given instant, as determined either by visual observation or precise navigation means. In the absence of such information, it may still be possible for ground direction-finding (DF) stations to obtain bearings on the radio transmissions from the plane that will give sufficiently accurate location for unambiguous identification. This procedure obviously takes quite a bit of time, and fails completely in the absence of two-way radio communication.

It should be noted that, once identification has been established by any means whatever for a given plane, an unambiguous track of that plane retains the identification. For all domestic traffic, perfect identification is possible at take-off and landing. Therefore, if the AC&W net can keep tabs on all traffic at all altitudes, domestic flights can be followed from take-off to landing with perfect identification at all times. If this state of proficiency can be achieved, the problem is reduced to the identification of inbound traffic of

external origin. It seems possible to hope that IFF can take care of military planes in this category, leaving a residue that should be small enough to permit consideration of procedures requiring a moderate amount of time and attention by an operator. Furthermore, the identification required is special in that, for a given flight, it need be accomplished only once, at a particular place, at a definite time. These circumstances permit contemplation of some scheme such as the following, which seems to have good potential security, comparative simplicity, and adaptability to either the present system or proposed developments.

Suppose that under conditions of cryptographic security a set of, say, 50,000 random groups of, say, 10 figures and letters is generated in duplicate, sealed into opaque envelopes that are destroyed on opening, given serial numbers on the outside, and are then divided into the two sets. One set now goes to the Air Defense Command (ADC) where it is retained with proper security. The other set is parceled out as needed to military representatives at the foreign airports from which the inbound flights originate. Just before take-off of such a flight, the pilot of the plane is given an envelope bearing a serial number, for which he signs a receipt verifying the fact that it is unopened. The serial number is now transmitted by radio in clear to the point in the United States at which the flight should check in. This point then takes its envelope bearing the same serial number, verifies the fact that it is unopened, opens it and is prepared to compare the letter-number group contained with the group read over the radio by the plane purporting to be the one expected. The system is thus one-shot in nature. The method of operation can be fully know to the enemy without giving him more than the infinitesimal chance of 1 in 10^{15} of breaking the system by chance. If subversion is used to get the material to secure entry for one plane, it does not help the next one to get in. Furthermore, records are available to show where the security leak occurred.

The situation contemplated up to this point is one in which the air traffic is made up of both civilian and military planes. Where the traffic is almost purely military, some shift of emphasis is required. Quick, secure identification continues to be of utmost importance, but it must now be secured in a situation where advance flight plans are limited or nonexistent, where there

is no safety border of a perimeter to permit checking, and where failure is almost certain to result in casualties. In this situation, there is need for the most reliable and secure system that can be devised and operated. Nothing should be done to try to make the identification system serve other purposes if even a slight reduction in security is entailed.

One obvious place where secure identification is required is at weapons capable of firing at aircraft. These weapons may be ground-based (guns, NIKE, etc.) or airborne. The latter case, air-to-air identification, is probably the thorniest one in the whole field. It seems desirable that an interceptor equipped with airborne intercept (AI) radar should have an IFF interrogator of comparable angular resolution. The size of antenna for L-band that would give such resolution could not possibly be mounted in a small jet fighter. In situations of low traffic density, it might suffice to have omnidirectional IFF interrogation, the replies being correlated with the radar indication on the basis of range alone. Other possible solutions involve the so-called "Black Maria" system in which friendly planes are fitted with a crystal video receiver for the band used in the AI radar, plus the AN/APX-6 transponder. The transponder replies only when there is a coincidence of received radar pulse and IFF reply. The effective angular pattern of the IFF is then determined by that of the AI radar. From the discussions with representatives of the Navy and Air Force, it appears that the plan now in favor in the United States involves a separate X-band IFF system for air-to-air use. In this scheme, an X-band transponder would be required on every plane, in addition to the L-band AN/APX-6. The coding equipment might well be common to the two transponders, however.

The interceptor plane would carry the two transponders, its AI radar (X-band), and the X-band interrogator-responder (I-R) equipment. Presumably, only the transmitter and receiver would be required, the antenna being that of the AI radar. Such a procedure would involve a somewhat complicated duplexing arrangement, but it does not seem out of reason. The directivity would then be equivalent to that of the AI set automatically.

The British interceptors with their S-band AI could make no use of this X-band IFF. According to information from the United Kingdom, the British

propose an L-band development akin to SCR-729 or Lucero. British interceptors would then be able to interrogate U.S. planes, since these would carry APX-6 anyway. However, U.S. interceptors would be completely unable to interrogate any British planes unless the latter carry X-band transponders.

When the different requirements for the United States and the United Kingdom are borne in mind, the apparent divergence of programs for air-to-air IFF seems less significant. It seems certain that the X-band IFF development will take considerable time, whereas an airborne L-band I-R, apart from antenna-directivity problems, offers no difficulty whatever. Therefore, with the U.K. requirement of air-to-air IFF at the earliest possible time, their choice seems to be the proper one. On the other hand, the X-band system has definite advantages if the development problems can be solved; one such advantage, in a quite unrelated field, is the provision of GCA (ground controlled approach) assist by the use of the X-band transponder.

If the British program contemplates the mounting of an X-band transponder in its planes at whatever time the X-band system becomes operational in U.S. interceptors, even though the British interceptors are still using L-band at that time, there appears to be no difficulty whatever in the cooperation of any types of planes belonging to the two countries.

S. N. Van Voorhis

APPENDIX II-2

RADIO BEACONS LIST

APPENDIX II-2

RADIO BEACONS LIST

1. The list of recommended radio beacons is given in Table II-2-1. These are universally radio beacons operated by the Coast Guard as aids to maritime navigation.

In general, Coast Guard radio beacons do not operate continuously and are not suitable unless modified. Some of these beacons have already been modified so as to be useful, and it is contemplated that other beacons can be adapted.*

2. The modifications required of the various stations are given in the table.

Committee B
(J. C. Street, Chairman)

*"Should these radio beacons prove useful to aircraft, it is contemplated that other Coast Guard radio beacons will be modified. Comments, recommendations, and inquiries are, therefore, invited concerning these and other radio beacons operated by the Coast Guard. Communications should be addressed to the Commandant (GH6-1), U.S. Coast Guard, Washington 25, D. C." U.S. Department of Commerce, Flight Information Manual, Vol. 5, No. 1 (Aug. 1, 1950).

TABLE II-2-1

Recommended Radio Beacons

Location	Freq. (kc)	Present Operations			Modifications Required	
Latitude / Longitude		Type	Mode	Range (miles)	Mode	Range (miles)
1 Mt. Desert Light Station, Maine 43° 47' N 68° 51.3' W	288	– . . .	Int.	5-20	Cont.	200
2 Cape Cod Light Station, Mass. 42° 02.4' N 70° 03.7' W	302	– – . –	Cont.	400	Nil	
3 Nantucket Shoals Light Ship, Mass. 40° 37.0' N 69° 38.3' W	314	– – – –	Cont.	200	Nil	
4 Ambrose Channel Light Ship, N. Y. 40° 27.1' N 73° 49.4' W	286	.	Int.	100	Cont.	200
5 Winter Quarter Light Ship, N. Y. 37° 55.5' N 74° 56.4' W	298	– – – .	Int.	100	Cont.	200
6 Cape Henry Light Station, Va. 36° 55.6' N 76° 00.4' W	290	– . –	Cont.	200	Nil	400
7 Diamond Shoal Light Ship, N. C. 35° 05.3' N 75° 19.7' W	312	– – .	Int.	200	Cont.	
8 Cape Flattery, Wash. 48° 23.5' N 124° 44.1' W	288	. – – .	Int.	200	Cont.	400
9 Cape Disappointment Lt. Sta., Wash. 46° 16.6' N 124° 04.3' W	310	– – –	Int.	5-20	Cont.	400
10 Blunts Reef Light Ship, Calif. 40° 25.9' N 124° 30.3' W	292	. – . –	Int.	100	Cont.	400
11 Farallon Light Station, Calif. 37° 42.0' N 123° 00.0' W	314	. – .	Int.	200	Cont.	400
12 Point Arguello Lt. Sta., Calif. 34° 34.7' N 120° 39.0' W	302	– – –	Int.	200	Cont.	400
13 Long Beach Harbor Lt. Sta., Calif. 33° 42.5' N 118° 15.0' W	296	Spec.	Cont.	5-20	Cont.	200
14 Point Loma Light Station, Calif. 32° 39.9' N 117° 14.5' W	286	– . – .	Int.	200	Cont.	400

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APPENDIX II-3

PROBABILITY THAT AN INTERMITTENT AEW PATROL WILL BE IN A POSITION TO SIGHT A CROSSING STREAM OF BOMBERS

APPENDIX II-3

PROBABILITY THAT AN INTERMITTENT AEW PATROL WILL BE IN POSITION TO SIGHT A CROSSING STREAM OF BOMBERS

In considering the utility, for remote early warning, of an intermittent airborne early-warning (AEW) patrol from Iceland to the neighborhood of Spitsbergen and back, a calculation was necessary of the chance that such intermittent flights would be effective. The calculation assumes that neither the enemy nor our own force knows the timing of the flights scheduled by the other and changes his plans accordingly.

An unusual parameter entering into the present calculations is length of the bomber stream, to be designated by L. The major threat to the United States is not an attack by a single bomber, but one by a large number at approximately the same time. In the case of a very remote early-warning patrol, detection of the tail end of the bomber stream would provide the warning just as well as detection of the first bomber in the stream. This consideration makes one point of advantage on the side of a distant patrol as compared with one close to our shores.

So long as the separation between the bombers or bomber formations is less than several hundred miles (a condition defined more precisely below), the chances of detecting the different bombers are not independent, but the raid is equivalent for detection purposes to a continuous stream of length L equal to the distance between first and last bomber. For instance, if 50 planes fly in formations of five at six-minute intervals, the stream has a total length equal to the distance flown in one hour.

The factors affecting the likelihood that L will be large or small are:

(1) The Soviet Air Force is in range difficulty in attacking United States targets, and therefore cannot afford to have planes waste gas while large formations are assembling.

(2) It is to the enemy's advantage to have the planes that are going to different target areas arrive at their destinations at about the same time. To allow for different distances and wind conditions, take-offs might be scheduled over one or two hours to achieve this aim.

(3) Single planes or small groups that are sighted may not arouse so much suspicion as very large formations. This may contribute to success of a surprise attack.

(4) Opposing the above arguments is the fact that a compact group of bombers is more likely to slip through an intermittent patrol, such as we are discussing, than is a long stream.

Because there are arguments on both sides of the question, the calculation has been carried out for different values of L. In the special case of a raid by a single bomber, the result is obtained by setting L equal to zero.

Another parameter of importance in the calculation is the sweep width, designated by W. The airborne radar does not have an exactly defined range but instead the probability of detecting an enemy bomber is a smoothly varying function of distance. An exact calculation of the patrol efficiency, therefore, requires an integral over time and space, taking into account at each distance and as a function of time the appropriate probability of detection. The result is equivalent, however, to that which is obtained under the assumption that within a certain distance, W/2, the probability of detection is 100 per cent, and outside this distance the probability is zero, independently of the time during which the planes are this close to each other. The value of W must be determined by an integral like that described above. W is less than twice the maximum range at which detection is possible, and corresponds more nearly to twice the range within which detection is highly probable.

In order to maximize the efficiency of the air patrol, range of the radar should be maximized, which implies use of the largest antennas available. We are, therefore, thinking in terms of PO-2W search planes equipped with 17-foot antennas. Data with which to calculate W for these new, large antennas are not available, but we think 75 nautical miles is a conservative estimate of the range for high detection probability; this corresponds to W equal to 150 miles. This is particularly conservative if one thinks in terms of a raid team containing about 50 bombers, since these would either be grouped in formation, increasing the effective reflecting area, or spread out at such small distances that an AEW plane would have a chance to see several of them if any one came within 75 miles.

Other factors entering into the calculation are listed below, together with values assumed for them in the calculation.

v = velocity of AEW plane. Efficiency increases with v, for constant total of patrol planes in the air; hence a conservative value of 160 knots was assumed.

u = velocity of bombers. Efficacy of patrol decreases with u, hence a rather high cruising speed, 300 knots, was assumed so as to keep the calculation conservative.

θ = angle between path of patrol plane and that of bombers. For the Ireland-Spitsbergen run, θ was taken as 55°.

S_1 = velocity of AEW plane relative to bombers while AEW plane is outbound.

S_2 = velocity of AEW plane relative to bombers while AEW plane is inbound.

$$S_1 = \sqrt{u^2 + v^2 + 2uv \cos \theta}, \qquad S_2 = \sqrt{u^2 + v^2 - 2uv \cos \theta}$$

For the values of u, v and θ assumed above, S_1 = 413 knots and S_2 = 246 knots.

H = component of one-way length of patrol course that is perpendicular to the bomber paths. $H/\sin\theta$ = total one-way patrol length, which was taken as 1000 nautical miles, giving 820 miles for H.

N = number of patrol planes simultaneously in the air, equally spaced on the same patrol path (provided a continuous patrol is maintained).

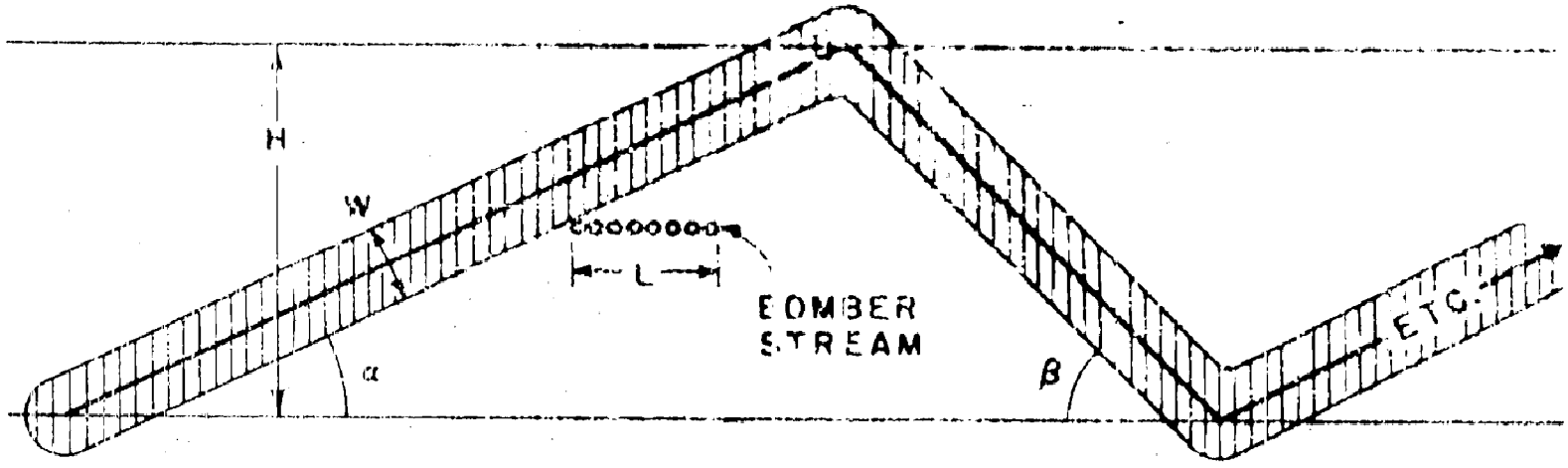
Calculations have been made for N = 1, 2, and 3.

T = number of hours between beginnings of patrols if they are discontinuous; calculations have been made for T = 16 hours and 24 hours.

E_c = calculated efficiency for continuous patrols.

E_d = calculated efficiency for discontinuous patrols.

In setting up the formula, it is easiest to make use of moving coordinates so chosen that the bomber stream is at rest. As illustrated by the shaded area in Fig. II-3-1, a patrol that goes back and forth over a straight line monitors a zig-zag area in such coordinates. The width of the shaded band is W. A



$$\tan\alpha = \frac{v\sin\theta}{u + v\cos\theta}$$

$$\tan\beta = \frac{v\sin\theta}{u - v\cos\theta}$$

Fig. II-3-1 Patrol area in moving coordinates.

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bomber stream would be undetected only if its total length lies outside the shaded area. By applying this principle, one obtains the following formulas for E_c and E_d.

$$E_c = \frac{N}{2Hu}\left[W(S_1 + S_2) + 2Lv \sin\theta\right] - \left(\frac{N}{2Hu}\right)^2 (WS_1 + Lv \sin\theta)(WS_2 + Lv \sin\theta).$$

$$E_d = \frac{W(S_1 + S_2)}{Tuv \sin\theta} + \frac{2L}{Tu} - \frac{(WS_1 + Lv \sin\theta)(WS_2 + Lv \sin\theta)}{2Hu^2 Tv \sin\theta}.$$

The condition for effective continuity of the bomber stream is that the separations be less than WS_1/v and WS_2/v. For single bombers, $L = 0$.

With the assumed values of the parameters described above, the calculated efficiencies, expressed in per cent, are as shown in the following table.

L	Continuous Patrol			Discontinuous Patrol	
(miles)	N = 1	N = 2	N = 3	T = 24 hr.	T = 16 hr.
0	19	36	52	10	15
300	33	59	79	17	26
600	45	77	96	24	36

For a squadron of nine AEW aircraft, we are told that a reasonable planning factor is one flight per aircraft every six days during routine operation (corresponding to T = 16 hr.), and that two aircraft continuously on-station is a reasonable maximum effort during short periods of stress. For L = 300 miles (a bomber stream one hour long), these conditions correspond respectively to efficiencies of 26 and 59 per cent.

K. Greisen

APPENDIX III-1

DEVICES CONSIDERED FOR EARLY IMPROVEMENT IN THE EFFICIENCY AND CAPACITY OF THE DATA-REPORTING SYSTEM

APPENDIX III-1

DEVICES CONSIDERED FOR EARLY IMPROVEMENT IN THE EFFICIENCY AND CAPACITY OF THE DATA-REPORTING SYSTEM

The Committee studying the means of achieving early improvements in the aircraft control and warning system gave brief consideration to a number of schemes or devices which are indicated in this Appendix.

One type consists of elaborate electronic schemes that would increase the data-handling capacity by providing markers on the displays as an aid to coordination, and some by providing information stores. Markers on the displays would:

(1) Allow separation of the functions of pickup and tracking;

(2) Allow division of the tracking job among numerous men;

(3) Facilitate allocation of targets to controllers.

The schemes considered were:

(1) The British Comprehensive Display System (CDS);

(2) A simplified CDS system for ground use, developed by the British Telecommunications Research Establishment (TRE), and the analogous American equipment developed by the Naval Electronics Laboratory (NEL);

(3) The photographic Target Position Indicator (TPI) with electronic insertion of information;

(4) Aided tracking (sometimes called American CDS);

(5) Use of electronic markers on B-scopes;

(6) The interim target designation system developed for the Navy by the Radio Corporation of America (RCA).

Although these devices appear capable of effecting considerable improvements over present data-handling methods, realistic appraisal indicates that they could not be operational soon enough to be considered as early improvements. Instead, they must be considered in comparison with other long-term developments, such as the centralized system scheme described in Section IV of this Report, or the Ground Reporting System and the BOMARC Test Program developments (Section IV).

Other devices of varying complexity were considered as aids in the production of an air-situation plot. These devices include the following:

(1) "Poor Man's TPI." Under this scheme the radar observers would be provided with thin transparent sheets to be placed over the face of the PPI (plan position indicator) tube, and on these sheets the radar observers would draw crayon lines to mark the tracks of aircraft in the sectors assigned. The sheets so prepared by a number of observers would be fed simultaneously into a single optical projector, which would display the entire air situation on a single board. The regular replacing of the sheets with new ones would keep the situation up-to-date. This extremely simple device has been tried and shown to result in an increase in tracking capacity.

(2) "Modified Poor Man's TPI." This utilizes pantograph system for entering data as perforations in opaque tape, which would be fed through multiple-colored optical projectors so that tracks would be shown for moving objects.

(3) The photographic TPI system itself. Further remarks on this system are given in Section III.

(4) The multiple-colored photographic scheme using the Land process, as described in detail in Section III.

(5) Conducting glass as an aid in transmitting coordinate information.

(6) Pantograph and directed light spot as an aid in transmitting coordinate information to a plotter behind a plotting board.

(7) The Naviscreen apparatus, which utilizes multiple directed light sources to project arrows representing tracks on a large plotting board.

(8) Direct PPI projection schemes.

(9) The automatic projection plotting board which has been developed for the Navy, and which provides for superposing information on the track picture by means of projectors.

(10) The graphicon display system developed by RCA.

(11) The digital radar relay scheme (DRR), which involves a device for taking information directly off a PPI scope in encoded form immediately ready for transmission over telephone lines.

The Committee does not wish to discourage the development of any one of these devices, all of which seem capable of effecting an improvement over current methods of data plotting. Nevertheless, the Committee has chosen to recommend particularly only one of the schemes for rapid exploitation. The schemes numbered (7) through (11) seemed to require considerable complexity

in utilization or further development extending over such a time that they could not be regarded as early improvements. Of the simpler devices, (1) through (6) in the above list, and the Land-process photographic scheme seemed to offer the most hope in terms of magnitude of improvement and simplicity of application.

K. Greisen

APPENDIX III-2

MECHANICS OF THE PRODUCTION OF A CLEAN AIR-SITUATION PICTURE USING THE PROPOSED PHOTOGRAPHIC APPARATUS

operator who uses a special height-indicating display. Raid size can probably best be obtained by an A-scope operator, using an expanded display gated in range and azimuth. Electronic IFF interrogation is performed on request by an IFF operator. Identification by correlation with flight plans is attempted, on request, by an identification clerk. These information-gathering personnel are located on the raised platform commanding a view of the track board.

Since the collection of all this information takes time, it is important that new tracks do not appear too frequently and that the ancillary information does not usually need repetition. If 60 tracks are being followed and each one is in view for 30 minutes, for instance, the average rate of appearance of new tracks is 2 per minute. Under such conditions, fluctuations will give rise to occasional delays in getting the desired information. If the traffic density is very high, the number of height finders, etc., must be increased.

After the height, speed, raid size, and IFF information has appeared and flight plan correlation has been attempted, the responsible filter officer must make a decision on the identification of the aircraft as to category – routine friendly, friendly fighter, bogey or hostile. If there is doubt at this stage, direct contacting of the plane with VHF or UHF direction-finding radio may be tried, as recommended in Section II, and identification may result from the ensuing conversation. In any case, the decision as to category must be made within about two minutes of the first appearance of the track.

This decision is entered on the tote board by means of a keyset, and also communicated to the appropriate track marker who thereupon changes the track from the neutral color to a different type of crayon that indicates the category, one color being used for routine friendly planes and another for those planes that should appear in the filtered air-situation picture – hostiles, bogies and friendly fighters.

If the track belongs to the latter category, a keyset is used to enter the tote-board data about the track on the tote boards visable to the interceptor, and antiaircraft controllers.

As mentioned in the Report, selective photographs are to be made of the track board at regular intervals, and by color selection or other means these photographs will contain only the crayon lines and the numbers pertaining to

the hostile, bogey and friendly fighter tracks. These photographs are projected on a screen visible to the controllers, who use the filtered air-situation picture for target-acquisition purposes; they are transmitted to the ADCC in order to contribute to the total air situation being evaluated there.

Two details have been skipped in the above description. One is the visual distinction in the one-color clear air-situation picture between tracks of friendly fighters and those of enemies or bogies. This may be done by a distinctive marking (for instance, crosses or dashed lines) on one of the classes of tracks. The other detail is the plotting of cross-told information and the cross-telling of locally derived information. This is described in Section III. Cross-told information on tracks not yet visible with the local radar must carry with them the necessary ancillary information and identification, since these cannot be locally derived. The personnel for receiving the cross-told data should be equipped with keysets for entering the ancillary data on the tote boards; and they should plot the tracks in the crayon colors appropriate to the categories of the tracks.

Because of the need for carrying cross-told information, it is apparent that track numbers used by different GCI stations should not be identical. Three digit numbers may be used, or a letter followed by two digits, in which the first number or letter indicates the station reporting the track.

Several elements of awkwardness remain in the tentative procedures described above, and we offer an additional tentative suggestion for removing them. One objectionable feature is the assignment of the track number, which requires that a man on the dais communicate with a track marker and indicate a specific track before a number has been assigned to it. Another is the need for writing track numbers, and erasing and rewriting the numbers as the track moves. A third is the need for putting arrowheads on the tracks to indicate direction of motion – and erasing and redrawing the arrowheads as the track advances. Fourth is the need for repeatedly erasing the tail of the track. Furthermore, the crayon lines will partly obscure the optically projected blips from the track marker. Finally, the distinction between different categories of tracks in the filtered air situation is awkward.

These objectionable features can be largely overcome by the use of short

plastic arrows instead of crayon lines. Each track marker may have at his disposal a number of arrows of several types, differing in color or transparency, in order to indicate the different categories of aircraft. As new blips appear on an established track, he would need only to move the arrow a short distance across the board. The arrows can be made to adhere slightly to the board so as to prevent slipping. Each arrow may have inscribed on it a number which will reappear in the selective photograph, or may have a plastic number attached to its tail. The assignment of number to the track may be done by the track-marking personnel, with duplication prevented by the initial allocation of the plastic arrows. Arrows for friendly fighters may be similar to those for bogies and hostiles in color or transmission properties, but may have a distinctive shape.

K. Greisen

APPENDIX III-3

TECHNICAL SHORTCOMINGS OF GCI EQUIPMENT CURRENTLY BEING INSTALLED

APPENDIX III-3

TECHNICAL SHORTCOMINGS OF GCI EQUIPMENT CURRENTLY BEING INSTALLED

Through operation during field trials and by inspection of the equipment, the following technical difficulties have been found concerning the AN/CPS-6(B), the AN/FPS-3, and the AN/FPS-6 radars.

1. AN/CPS-6(B)

(a) The Stalo "runs away" at frequent intervals. This has been reduced from once every two hours to once a day at the McChord Air Force Base site.

(b) MTI operation is poor unless the antenna rotation is slow and the repetition rate is high. This contrasts with the needs of GCI operations.

(c) The advantage of adding a long-range dish will be offset by:

(1) The requirement for separate presentation at ranges greater than 100 miles.

(2) The requirement of a basically different radar system from the rest of the set, including 400-cycle power, complicating supply and servicing.

(3) The fact that the extra range provided will not be at low altitudes. Other means will be necessary for obtaining low cover at long ranges which could give the high cover as well.

(4) The requirement of another IFF system for the separate sail to insure coordinated displays. This will tend to compound maintenance problems.

2. AN/FPS-3

(a) The receiver noise figure is expected to be on the order of 18 to 20 db in the field.

(b) The design of the RF section is such that maintenance will be difficult. Not only is the worker exposed to weather, but many parts must be removed to service others. Poor servicing will probably be the result.

(c) The T-R system provides inadequate crystal protection.

(d) Ground clutter was obtained on the upper-beam side lobes, and it is suggested MTI be used on both beams.

(e) The multispeed drive system will lead to difficulties in maintenance and confusion in operation. A two-speed drive is probably all that is necessary.

(f) The present antenna feed system gives a severe gap between the lower and upper lob which can easily be flown over by jets or even bombers. This gap is even more serious because of the high noise figure mentioned in (a). Work should be initiated to correct this gap by redesign of the feed system. This might be achieved by splitting and overlapping alternate feeders.

3. AN/FPS-6

(a) The FPS-6 height finder has been placed in production prior to the completion of the development. As a result, one may expect a series of uncertainties which will arise as the development is completed and which cannot be predicted.

(b) The RF power source and duplexer (which is along new lines) has yet to be completely life-tested.

The foregoing statements are supported by no reports, at present. The information was obtained by consultation with individuals from Service laboratories who have been making evaluations of the sets. Since the difficulties are recognized by the Service laboratories, some action is being taken but apparently at low priority. No remedies are likely to be available to the field within a year, and some will require a major redesign.

Committee B
(J. C. Street, Chairman)

APPENDIX III-4
DEPENDABILITY

APPENDIX III-4

DEPENDABILITY

The following suggestions of the problem of dependability are not the result of detailed studies by PROJECT CHARLES. It is understood that work directed towards the improvement of reliability of certain components – for example, vacuum tubes – is now in progress (see reports of the Panel on Electron Tubes of the Research and Development Board). Specifically, we suggest:

(1) The most important improvement is obtainable by increasing conservatism in the design of electronic components. It seems to us essential that a means of penalizing bad designs be established so that, in selecting between two competing designs of equipment, one does not have the visible factors of weight, size, range and performance to be balanced against an invisible and unmeasured factor of reliability or its life expectation. A method must be devised to weigh the reliability of equipment, and thus to set limits that must be met in exactly the same way that specifications set limits in size, weight, and range. It would be desirable if a set of standards analogous to Underwriters Laboratory approval in the electrical field could be established for the performance standards to be met by any piece of electronic equipment. Among other things, this will necessitate education of the designers and of those writing specifications.

(2) It is essential that troubles should be promptly reported and analyzed on a sampling basis, if necessary, so that some understanding of defective equipment or defective designs may be obtained. It is essential to encourage maximum speed in reporting trouble on new equipments so that a serious maintenance condition will not develop after large numbers are in service. Statistical methods used in sampling should enable one to point unquestionably at the weak elements in electronic equipments.

(3) It is highly desirable, where possible, to select personnel so that the officer in charge of installation of electronic equipment has sufficient knowledge and appreciation of his equipment to distinguish between mediocre and excellent maintenance. Even good maintenance technicians require the morale boost of support and appreciation by their superiors. Poor technicians will never be weeded out nor moderately good technicians improved without such knowledge at higher levels.

(4) It is important to teach the maintenance technicians to report, or, where possible, to remedy themselves a cause of recurrent defects rather than to learn to recognize and repair a trouble speedily. A surprising number of clever maintenance men and even

engineers take pride in becoming familiar with the weaknesses and pecularities of a particular system and of being able to fix it quickly rather than taking steps to eliminate the whole source of the trouble.

(5) It is essential to remove all unnecessary complexities and restrictions in the supply of replacement parts to the maintenance technicians.

(6) There exists a panel on test and training equipment for guided missiles within the Research and Development Board. It seems reasonable that a similar activity should take cognizance of all test and training equipment.

Of the above six suggestions it is our feeling that items (1), (2), and (3) are perhaps the most important.

M. M. Hubbard

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APPENDIX III-5

REPORT TO PROJECT CHARLES

ON THE

GROUND OBSERVER CORPS

CONTROL SYSTEMS LABORATORY

UNIVERSITY OF ILLINOIS

June 13, 1951

SECRET

APPENDIX III-5

REPORT ON THE GROUND OBSERVER CORPS

Control Systems Laboratory
University of Illinois

A. INTRODUCTION

The following remarks are the result of a brief study of the contribution that the Ground Observer Corps (GOC) can make to our present air defense system. The study was made by five members of the Control Systems Laboratory of the University of Illinois at the request of PROJECT CHARLES.

In its present state, the Air Defense Command (ADC) includes in its organization a volunteer corps of some 300,000 civilians, manning 7700 observer posts. Future plans call for enlarging this corps to over half a million volunteers, manning 20,000 observer posts. The questions of interest in this study are whether it is possible for a ground observer corps to make a significant contribution to the raid-reporting system, what are the costs of such an effort, and whether the present organization of the ground observers is capable of achieving results obtained by other such organizations.

That there is information available to the observers which is of value in air defense for warning, traffic control, and interception is without question. The present radar net does not provide low-altitude coverage over large areas, does not offer any coverage in some areas, can scarcely identify type, identity, and formation strength of planes, and has only limited height-finding capacity. In addition, many radars are susceptible to window and to electronic jamming. The ground observers have much of this vital information and are not easily jammed. Records of our World War II observers and of the recent British Royal Observer Corps (ROC) exercises show that ground observer information can be filtered and relayed to direction centers with sufficient speed to be useful, if the reporting and filtering is properly organized. Our present system of ground observers, without modification, is not capable of supplying useful information for intercepting high-speed raiders.

Since no other means exist at present for tracking low-flying bombers and interceptors, it is our recommendation that the ground observer corps be used now and that it be modified to bring its performance up to those standards proved realizable by our own World War II experience and by the remobilized Royal Observer Corps. It is further recommended:

(1) That the optimal distribution of filter centers for our extended geography be studied;

(2) That the optimal methods of using the GOC data be investigated carefully;

(3) That automatic aids for spotting, reporting, plotting and filtering be investigated;

(4) That, as a system of closely-spaced radars is developed to provide low-altitude coverage, ground observing be continued in a form that will supplement the radar with identification information and will provide an emergency jamproof source of plots.

B. PRESENT GROUND OBSERVER CORPS

The organization of operations of the present GOC is described in Annex A. A summary of Annex A and some comments are included here. Members of the corps are recruited by local civil defense supervisors in cooperation with ADC. Training and notification of impending exercises are furnished by direct mail from ADC to the civilian volunteers. Mobile Air Force teams will start soon to do this work. Some 2,000,000 man-hours per week would be required to man the 7700 observer posts and the filter centers on a 24-hour basis.

The process of reporting an aircraft by ground observer to the plotter at the filter center has been studied recently. The following summarizes 3000 measurements made by a telephone company representative in the last exercise.

Average time to establish a telephone connection: 32.6 sec
(Range 8 to 67 seconds)

Average time to give a report on an aircraft: 53.7 sec
(Range 31 to 95 seconds)

An additional delay of about one minute now occurs in plotting on the filter board the information reported by a ground observer.

It is to be noted that no explicit data concerning the accuracy of plots or tracks were found, but that few tracks are sufficiently unambiguous to persist on the filter board for five minutes.

The above numbers are to be compared with wartime GOC and ROC performance.

C. POTENTIALITIES OF AN EFFICIENT GROUND OBSERVER CORPS

The principal contributions that a ground observer corps might make to a raid-reporting system under conditions of good as well as poor visibility would be:

(1) Low-flying coverage;

(2) Identification (type, identity, unusual circumstances);

(3) Estimates of height;

(4) Early suppression of nontactical aircraft tracks during heavy traffic conditions;

(5) Relative freedom from countermeasures.

The major question discussed here is how well an efficient ground observer corps meets the above desiderata. If the American GOC of World War II, and the present-day ROC can be considered as efficient units, their performance data and organization are pertinent. It should be noted that the ROC has complete responsibility for providing overland coverage in the United Kingdom for the Royal Air Force, both for warning and interception; the total defensible area of the United Kingdom should be borne in mind, however, in making a comparison with our problem.

The spacing of observers, which determines the time between independent reports, is the same in the United States and in the United Kingdom. To our knowledge, observer reports in the United States are utilized only as supplementary to radar plots through GCI filter boards. In the United Kingdom, normal operation calls for control from either radar or ROC plots;* for the special problem of intercepting high-speed raiders, broadcast control to the interceptors directly from the ROC filter board was arranged.**

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*"Suggested Scheme for Future Fighter Command Reporting System," Ministry of Supply, Telecommunications Research Establishment Memorandum Number 211 (1951). "The Utilisation of Information from Stage I Ground Radars," Ministry of Supply, Telecommunications Research Establishment Memorandum Number 385, January 4, 1951.

**"Low Level Interception (Irland Targets)," Central Fighter Establishment (CFE) Report No. 155 on Trial No. 94 (1950).

The ROC contains a large number of well-trained Home Guard civilian volunteers who work closely with the armed forces both in wartime and in realistic peacetime exercises; the ROC personnel training practices are described in the Royal Observer Corps Training Manual (Air Ministry Booklet AP3215, 1949).

Accuracy of tracking by the ROC has been analyzed in Research Branch, Fighter Command Report No. 672. Under "non-busy" conditions, the following were estimated:

(1) Average lateral error in position: visual one mile; aural one mile;

(2) Average height error: visual 10 per cent, aural ~20 per cent. (Height is less reliable above 20,000 ft.) Reliability of aural observations varies sharply between ROC Groups.

(3) Number of aircraft: visual, exact; aural, "good estimate."

(4) Type of aircraft: visual, usually excellent; aural, "good idea."

The time delays of the World War II GOC in the United States were studied by Quarrier of Bell Telephone Laboratories. He obtained the following data at the N.Y. Filter Center and the N.Y. Operations Board (1943). These data do not include the time taken for the telephone company to route the call from the observer to the filter center.

		Average Time Delay for a Typical 100 Calls (seconds)
	FILTER CENTER	
1.	Appearance of signal at plotter's box to answer by plotter	1.43
2.	Time of reporting (answer to disconnect)	8.65
3.	Disconnect to pip plot	4.52
4.	Pip to stand or arrow (by filterer)	4.36
	Total Filter Room	18.96
	OPERATIONS BOARD	
1.	Arrow or stand to start of tell	1.93
2.	Start of tell to completion of plot on operations board	10.95
	Total Operations Room	12.88
	TOTAL	31.84

This number compares favorably with ROC estimates of an average time of 30 seconds consumed in plotting and filtering reports in the TERRIER III exercises,* and of 25 seconds for visual reports and 40 seconds for aural reports in the previous postwar exercises.**

The accuracies and time delays of ROC and GOC have been given above. Some remarks on the over-all effectiveness of these two units, particularly ROC which have been subjected to realistic exercises recently, may be useful.

The British Central Fighter Establishment experimented in exercise TERRIER II with the effect of the time delays in reporting plots of enemy raider positions.*** An "enemy raider force" of low-flying (less than 500 feet) Vampires attacked cities inland from the east coast, broadcasting their own position over VHF radio with various delays. Interceptors were scrambled on the basis of simulated early warning, after which the pilots calculated their own interception courses from the broadcast plots. Sixty-second delays in the data were too large to give reasonable chances of interception. With 30-second delays, 65 out of 80 raids were intercepted.

In a second exercise, TERRIER III, 30-second time delays in transmission of data to RAF interceptors were achieved by direct transmission of plots over VHF from the ROC filter center, bypassing further filtering at higher command levels. The interceptors, using these plots and visual signals furnished by Very lights fired directly from observer posts,**** were then able to intercept 57 per cent of the low-flying raiders; 40 per cent of the raiders being intercepted before they penetrated 40 miles from the coast. Coastal radars were able to give early warning on only 46 per cent of the raiders; those on which radar early warning was given were intercepted sooner, as

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*CFE Report No. 155, op. cit.

**"The Capacity, Delays and Errors of the Fighter Command Raid Reporting System," Research Branch, Fighter Command (RAF), Report No. 699, 14 October 1950.

***CFE Report No. 155, op. cit.

****Very lights were fired only if the raider was within one-half mile of the post.

would be expected. (Note that the coastal radars were closely spaced, looking over water.)

It is not clear that broadcast control is the most effective way to use the ground observer plots, nor that longer time delays might not be tolerable if a ground controller were using the data to calculate vectors for the pilot. It is safe to say, however, that if the plots reach the person calculating the interception course within 30 seconds of the time of observation, effective interception is realizable. Incidentally, in the above exercise, 70 per cent of the raiders were intercepted by fighters using the ROC plots, although only 57 per cent were made by planes specifically scrambled by the ROC plots.

It seems possible that continuous tracks existed for distances as great as 75 miles, since some of the interceptions were made after penetrations of such depth. It is not known whether this is the maximum track that can be attained; this point should be investigated, since sustained tracking over hundreds of miles would allow repeated attempts at interception.

D. DEFICIENCIES OF PRESENT AMERICAN GOC AND RECOMMENDATIONS FOR QUICK FIX

The ground observer corps in this country, as presently organized, falls far short of realizing the potential capabilities of such systems, as exemplified by the experience described in the previous paragraphs. Some specific difficulties and possible cures are enumerated below.

1. The observers are almost completely untrained in aircraft identification. This should be remedied by an immediate program of instruction, using, for example, movies and flash cards.

2. The morale of the civilian volunteers who comprise the bulk of the GOC is exceedingly low. If it is to be useful, the corps must be imbued with a morale based on the realization that it is a vital link in the air defense network. This can be implemented only by constant coordination with the military and by realistic exercises.

3. No convenient mechanism exists for communication from the filter center to the observer posts, or between adjacent observers. The long delays involved in early warning could be alleviated to a considerable extent if the

observers could be notified in advance where and when to expect incoming targets. Such a system would require a network of full-period talking lines, perhaps in a cluster arrangement similar to that used by the British. Because of the enormous area coverage required in the American defense zone, the intimate communication between a single plotter and a small number of observers employed in the British system may not be applicable to this country. However, the inter-observer link, in itself, would aid greatly in the solution of this problem. This link might well be obtained by equipping each cluster of posts with radio transceivers tuned to a common frequency with a full-period telephone line from each cluster to the filter center.

4. Use of voice communication hampered by conversational amenities at all stages along the line results in excessive delays. Tracks finally reaching GCI are at least two minutes old. With present aircraft speeds, this represents an error so great that interceptions might be impossible on the basis of this cause alone. In the absence of further instrumentation, a considerable saving in time could be effected by the use of a well-chosen voice-coding system such as used by the British ROC.

5. The plotting tables are often too large to be handled efficiently. Aids must be provided to the plotters and filters to assist in manipulation of the plotting and tracking markers.

6. The number of tellers per filter center is too small at some centers. The two GCI tellers at Chicago are expected to transmit all the information furnished by the several hundred observers reporting to the two boards. This limitation, combined with the general confusion in the filter center, limits to one per minute the number of tracks told from an entire board. There should be at least one teller per filterer provided at the filter center.

7. Even when aircraft leaving established airfields file flight plans and are identified on take-off by the control tower, this information is not available to the observer corps, and track designation must be obtained in complete ignorance of this information. This defect can be remedied by location of observer posts near airfields or by communication links between airport control towers and filter centers.

8. The plotter has no way of indicating the quality of a received plot, e.g., whether the report is visual or aural, etc. Following the British system, either different plotting markers should be used to distinguish quality or some indication should be provided on a more versatile marker described below.

9. The present order of reporting information by the observer does not permit plotting while the information is being passed. Instead, it is necessary for the plotter to write the information received on the back of his plotting slip or on a scrap of paper and later to transcribe it. This difficulty, in itself, introduces a delay of about one minute in the total data-transmission time. The following sequence of reporting used in the World War II system would enable a plotter to set the appropriate information into a multiwheel plot marker and to place his plot in coincidence with receipt of the observer's information: number of aircraft, type, height, time delay in report to center, post code, location of aircraft, heading of aircraft.

10. The observer's clock is often not properly synchronized with the clock at the filter center. Since time reports serve as the basis for estimating velocities of the observed reports, this leads to considerable confusion at the GCI. This difficulty is easily remedied by instituting a periodic synchronizing procedure, or by reporting only the time delay in making a report.

11. The plotter's writing is often not legible to the filterers and tellers. Plot cards should be replaced with plotting markers on which the information pertinent to the flight may be inserted, using legible printed characters. The type of marker pip proposed in ADC's experiment at the White Plains Filter Center, which is similar to that used by the GOC during the last war, is well suited for this purpose.

12. In order to read the information on the plotting table, the filterers can operate only from one side of the board. In addition, the geometry of the plotting card is such that in a region of heavy traffic the cards in front mask those behind. Both these deficiencies are overcome by use of the White Plains plotting markers.

13. Since both individual plots and filtered tracks are displayed on the same cards and with identical marker arrows, filterers and tellers have difficulty distinguishing between plots and tracks. The ADC proposal to rectify

this difficulty involves the filterer's replacing the plotting markers with track arrows, and displaying the track information pertinent to the flight on a special simple display stand with printed cards.

14. The GCI teller has no way of knowing which tracks have been told to GCI, nor any orderly sequence for telling tracks. No communication link exists between the teller and the filterer other than a combination of hand and voice signals which are often lost in the general uproar. This situation will be eased considerably by the assignment of one teller to a particular filterer as described in (6). In addition, light or voice signals should be arranged so that the teller can quickly determine which tracks represent untold data.

It is felt to be essential that, in any realistic utilization of GOC data, the time delay between observer and plotter must be reduced by the use of continuous communication. Inter-observer and center-to-observer communication should be provided. The filter center personnel should be increased at least to the point of providing one GCI teller per filterer. Observers must be trained in aircraft identification and in the use of mechanical aids which should be furnished. The delays presently involved in plotting and filtering of tracks at the filter center should be reduced by the use of markers of the White Plains variety, or the equivalent. It is vital that good liaison be established between the military and the civilian volunteers of the GOC.

E. AUTOMATIC AIDS

It seems that the most promising direction for long-term improvements of the ground observer reporting system lies in automatization.

It is clear that automatic aids are possible along every line of GOC organization, starting with the observer posts. What is not known, and should be investigated carefully, are questions relating to cost, number, optimal distribution of equipment, etc. It is assumed here that automatic aids are desirable.

1. Aids to the Observer Reporting System

Aside from simple mechanical and optical aids to observation (such as a sighter or good binoculars) that might help the present American GOC, it is conceivable that an electromechanical device could be developed that would

speed up the process of reporting observations. The device might consist of a set of buttons corresponding to the set of possible choices an observer makes when reporting a plane, which, when depressed, would send out a coded signal along the telephone line to the filter center. This device will be called the transmitter. Similarly, a receiver might be developed that allows the filter center or other observers to communicate with a given observer post in a coded form – for example, by flashing lights at the observer post.

The functions of the receiver are important in alerting observers, in anticipating tracks, and as an aid in developing morale. ROC experience has indicated the great desirability of high morale.

Some further elucidation of receiver and transmitter functions is in order. The process of speeding up communication has been emphasized above. This is not the sole advantage, since receiver and transmitter may reduce the telephone line costs of an efficient observer system by using such well-developed teletypewriter techniques as "simplexing" and "compositing." These teletypewriter techniques are described in various training manuals of the American Telephone and Telegraph system. The point deserves careful study.

Once a coded signal gets into the telephone line, the problems of transmission of this information, of storage and of selection seem to be, in principle, the same as those of any radar net. There are a number of distinctions to be made, however, between radar and GOC data which may have decisive effects on future apparatus. One is that the rate of flow of information can be several orders of magnitude greater for the radar than for the GOC net, firstly because of the finer space quantization, and, secondly, because of the shorter "reaction time" of the radar set as compared with the human. A second point is that some data are obtained by GOC that are not available to the radar, particularly type of aircraft and (possibly) altitude.

The two considerations above may make the transmission, storage, and selection problems easier for GOC than for radar, but may at times complicate the presentation problem.

2. Aids to Filtering

The functions of filtering and of establishing tracks may be thought of as

problems in correlation. If rules for the correlations can be stated explicitly and quantitatively, the functions are amenable to computer treatment. (Note that filtering is one of the major bottlenecks of the GOC system, and that any methods for increasing the speed and accuracy of filtering would be of considerable value.)

It was mentioned earlier that the rates of information flow may differ vastly in the GOC and the radar nets. This difference in rates may make a relatively slow-speed digital or analogue computer a desirable instrument in establishing tracks, as in filtering out inconsistent data.

Storage of information may pose different requirements in the GOC and in radar nets. Thus, serial memories having relatively long access time may prove satisfactory for the GOC data.

One final point may be made in connection with automatization of a GOC system, particularly with respect to its applicability to a future radar net with low coverage. GOC and radar data are overlapping and supplementary to each other. If automatic aids exist for processing GOC information, these may be integrated with the radar information in a manner that might increase considerably the over-all effectiveness of the system (GOC plus radar), and to a degree that each scheme (GOC or radar) would be incapable of achieving readily alone. If this be true, then it is important that an efficient automatized GOC system be developed.

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APPENDIX III-5

ANNEX A

PRESENT U.S. GROUND OBSERVER CORPS ORGANIZATION

APPENDIX III-5

ANNEX A

PRESENT U.S. GROUND OBSERVER CORPS ORGANIZATION

The procedures vary between filter centers. The following description may be considered to be representative.

1. Personnel

The filter center receives information from some 300 observer posts over 27 trunk lines. A typical plotting board is manned by 12 plotters and two filterers. In addition, there is one GCI teller per board and a floor supervisor. Each board overlaps one or more adjacent filter center areas and employs one overlap teller per overlapping zone. In addition, there is a telephone traffic man on hand during exercises. Further overload facilities are provided by idle trunks answered away from the board from which plots are forwarded by runners. Observer posts, located preferably on roofs of buildings or on towers constructed at local expense, but often in doorways, are set up at distances of about eight miles between posts. During exercises, the posts are manned by two observers at a time, working three- to four-hour shifts. Normally, one of the observers acts as a spotter and the second as a telephone reporter. The communication link between the observer post and the filter center is an ordinary telephone connection into the commercial telephone system lines. At the GCI, there is a plotter for each of the three or four filter centers reporting. Total man-hours for the national organization of 7700 observer posts with two observers per post is over 2,000,000 man-hours per week. In addition, some 80,000 man-hours per week are required to man the filter centers. These numbers assume 24-hour service; if early warning were reliable, a smaller crew might be organized to man the posts only when alerted. At present, the filter centers are set up on an interim training basis, and are manned only during bi-monthly exercises. In the event of an emergency, an SOP exists for alerting the observer corps and filter center personnel in three or more hours.

2. Process of Reporting

The observer is provided with a polar diagram on which to represent local landmarks as an aid in estimating distance and direction of aircraft. On spotting a plane, the observer jots down pertinent information on a report sheet. The sheet is handed to the second observer who contacts the local telephone operator and announces "aircraft flash." On receipt of the "aircraft flash" message, the telephone operator checks to see if the call originates from an authorized phone. If so, the reporter is connected to the correct plotter's position at the filter center. On receipt of the message "Air Defense, go ahead please" from the filter center plotter, the reporter transmits the data in the following order.

(a) Station location and identification – e.g., able-baker-zero-four-red,

(b) Direction of plane from observer post (8 points),

(c) Distance of plane from post to one-mile accuracy,

(d) Direction in which plane is going (8 points),

(e) Number of aircraft observed, if possible, or "few," "many," "unknown."

(f) Type of aircraft if identification known, or general class of airplane (fighter, bomber, transport, etc., number of engines, type of engines, motor, jets, etc.),

(g) Identity of aircraft (military U.S., military foreign, civilian U.S., civilian foreign, N.C. number if readable, unknown),

(h) Height (very low, low, medium, high, very high, unknown),

(i) Time observation was made (minutes after last hour),

(j) Unwarranted action (firing guns, bomb bay doors open, etc.).

On completion of the message, the plotter signifies reception by saying "Check, thank you." The average time to transmit this message is 53.7 seconds (3000 observations by a telephone company representative), with a range of 31 to 95 seconds. It is also of interest to mention the time taken to establish a telephone connection: average time is 32.6 seconds; range is 8 to 67 seconds (3000 observations).

The observer is generally instructed to report only certain classes of aircraft, and only aircraft closer than four or five miles to the observation post.

The plotter usually writes items (a) through (d) on the back of his plotting card and items (e) through (i) on the front in the provided space while the message is being received. After disconnection, the plotter inserts the plot card in a small plastic stand and places it on the board together with an arrow indicating the position and direction of the flight relative to the reporting observer post. Apparently, additional delays of about one minute are involved in placing the reported information on the board. The plotter repeats this entire procedure on each plot.

The plotting board is divided into large areas about one degree by one degree which are designated by a two-letter code. Each major area is further subdivided into squares ten minutes on a side. The total georef grid covered in a single plotting board may represent an area of 30,000 square miles.

It is the function of the filterer to observe all plots on the board and to determine when a series of these plots can be tied together and identified as a definite track. When a track has been identified, the filterer assigns it a track number. The filterer then removes all but the last three arrows representing the most recent information on the track. The filterer is also responsible for keeping the board cleared of old tracks and plots. Unless otherwise indicated, a plot is removed from the board after it becomes five minutes old, if no further action has transpired. Before removing old tracks from the board, the filterer must signal the GCI teller so that this information will be relayed to GCI. There is no provision for the filterer to communicate with the observer.

The GCI teller (one per plotting board) is connected to the GCI station over government full-period talking service. The teller delivers a running report on all tracks on the board in the following manner: track number, four-number grid position, direction of track, and time of plot. On the initial call to GCI on any track, the teller also relays all the information noted on the track card. In the event that GCI already has the track under proper radar control, it will advise the radar teller to direct the filterer to place a blue "no tell" marker on the track card. Under this procedure, the plotter and filterer maintain continuity of information on the track, but the track is no longer reported by the GCI teller unless he is specifically requested for information.

The overlap tellers are provided with government full-period talking service telephone lines to adjacent filter centers. The overlap teller has the responsibility of giving all the information indicated on the track card to the adjacent filter center operator so that the track can be properly transferred from one area to the next. The telling sequence is: four-number grid location, direction of track, track number, number of aircraft, type of aircraft, identity, altitude, and time of plot.

The floor supervisor has the general responsibility for maintaining proper flow of information to and from the plotting board. He has facilities for monitoring incoming calls so that he can spot-check to see that proper procedures are being followed. He is responsible for distributing the load in congested areas of the board by rotating plotters and by bringing in relief from the overflow positions. Supervisors also write down information on calls coming in to incorrect plotting positions; these are given to one of the filterers or a runner to be relayed to the correct plotter. Supervisors are notified to come in on the line in any case of trouble or whenever action indicated in item (j) above is reported. In the latter event, the supervisor places a red "action indicator" label on the track card. Upon seeing this label, the GCI teller reports this action and all pertinent details directly to the supervisor at the GCI center, if necessary neglecting other areas of the board. The supervisor has the general responsibility of assigning personnel to specific plotting, filtering, or telling positions at his discretion.

APPENDIX III-6

USE OF MICROPHONES TO OBTAIN AIRCRAFT WARNING

APPENDIX III-6

USE OF MICROPHONES TO OBTAIN AIRCRAFT WARNING

This is to record some considerations given to the use of microphones in aircraft detection. Microphones differ substantially from radar installations in their capabilities. They have points of similarity with ground observers and may be of interest as a substitute for ground observers in special cases.

1. Description

One specific type of installation will be described, but it will be obvious that large modifications may be introduced in various places. There is no attempt to show that the type described approaches closely to the optimum.

One hundred microphones are placed on a rectangular grid at a separation of about 2 miles so that the whole covers an area of about 400 miles. These microphones are connected by means of wire lines to a central station. The microphones are of good quality and have associated with them individual amplifiers, which are powered over the lines.

At the central station, matters are so arranged that when the signal from a microphone exceeds a certain value, which happens when an aircraft approaches sufficiently close, a relay operates. The ultimate prupose of this is to light a lamp on a large-scale map of the territory. The position of the lamp corresponds to the position of the microphone in the territory covered. Thus an observer of the map can form an idea from the lamps as to where the aircraft is and in what direction it is traveling. However, the relay does not operate the lamp directly but causes the sound to be submitted to an operator, who listens to it and causes the lamp to light if the sound is judged to be due to an aircraft. This intermediacy of a human is thought necessary to avoid the possibility that miscellaneous noises will be received as signals and will cause confusion.

2. Limitations

The fundamental limitation on this mode of detection arises from the facts that the signal is attenuated and that there are various noises present, so that

the noise may at times override the signal. Important sources of noise are wind, precipitation, thunder, machines and animals, both large and small.

The noise from a reciprocating engine aircraft is largely confined to the range below 0.3 kc. The dissipation in the atmosphere tends to vary as the square of the frequency and it happens that in clear air the dissipation below 0.3 kc is substantially negligible; thus, noise from such aircraft does not lose its characteristic nature due to this effect. Jet engines have a much wider frequency range, and it is to be expected that when such noise travels over long distances it will lose its characteristic nature and become low-pitched. Fog may cause large attenuation at 300 cycles, and it is to be expected that both reciprocating engine noise and jet engine noise will change in nature in traveling long distances through fog or clouds. Wind gives rise to velocity gradients and thus interferes with the propagation of sound waves, particularly upwind.

The results may be summed up by saying that there are various conditions of storm, fog or cloud when noises may be expected to drown out the signal.

3. Comparison with Ground Observers

It is of particular interest to compare microphones with ground observers because many of the factors are effective in both cases. The outstanding advantage of microphones is that it is possible to cover a large territory with relatively few personnel. The outstanding advantage of ground observers is that they can make use of the sense of sight and that their sense of hearing is binaural. The former is inherent; the latter could probably be obtained with microphones by going to sufficient complication.

The visual sense is limited first to daylight and second to those days that are reasonably clear. It is likely to fail under the conditions when aural observation also fails. Thus it may be doubted whether the visual sense adds to the number of occasions when aircraft are detected. It does, however, have the advantage that when seeing is good it is possible to add important details as to identification and formation size.

Binaural listening is an important aid in discriminating against noise. It is possible to reject much stronger interfering noises with binaural than with

monaural listening, provided the interference comes from a different direction. In order to be comparable in discrimination, monaural microphones would have to be spaced closer than binaural observers. Perhaps it is reasonable to assume that the microphone system described with its 2-mile spacing is equivalent in detection possibilities to ground observers spaced 2.5 or 3 miles apart.

H. Nyquist

APPENDIX IV-1

COMMUNICATIONS

APPENDIX IV-1

COMMUNICATIONS

This appendix records the principal matters that were considered by the group working on communications.

A. UHF vs. VHF RANGE

Very-high frequency (VHF) refers to the range 108 to 152 Mc, which lies entirely within the VHF. Ultra-high frequency (UHF) refers to the range 225 to 400 Mc, which lies partly in the VHF and partly in the UHF. This whole range, however, is customarily referred to as UHF.

The change from VHF to UHF produces two kinds of problems, which we shall call transmission problems and procurement problems. The transmission problems are those of propagation, antenna effectiveness, noise, cross-talk, sensitivity to jamming, and related matters. The procurement problems include the design of suitable equipment which will be available in time, as well as numerous supply problems that will arise in the transition period. It should be pointed out that procurement and transmission questions are not practically separable. The task of gathering the necessary information, particularly that related to procurement problems, seemed too great for PROJECT CHARLES to undertake in the time available.

On the transmission questions, some tentative conclusions, which may be helpful in the meantime, are listed below. Neither unanimity nor certainty was attained on these conclusions, and, they should not be accepted as final until confirmed, but they do represent a consensus of opinion.

1. Tentative Conclusions

(a) In order to receive a signal that will override a given amount of thermal noise with omnidirectional transmission and reception, the required radiated power varies as the square of the frequency.

(b) Furthermore, the cut-off effects due to the curvature of the earth enter somewhat sooner with high frequencies.

(c) The lobe structure is finer at higher frequencies. This is disadvantageous in some respects and advantageous in others, but it probably is not of controlling importance.

(d) For interfering signals, jamming, or radiated noise, identical conditions to those given in (1) apply. The competition between desired

and undesired signals is independent of frequency if power thus radiated in each is held constant. If the power radiated in the desired signal is increased with increasing frequency, to maintain a fixed ratio to internal thermal noise, the power required for jamming rises with increasing frequency.

(e) The wider band available in UHF can be used to advantage in combating jamming.

B. SURFACE-TO-SURFACE LINKS FOR AN IMPROVED AC&W NET

Surface-to-surface links are those that join surface generators and receivers of data in the AC&W net. The term does not include the surface-to-air links. The links normally included are wire lines, but radio links will be required for communication with offshore stations, and perhaps in other locations. The current proposals will, of course, be subject to change as new developments arise.

1. Radar-Computer Links

The radars are assumed to have associated with them certain processing and storing devices such that, when a target is detected, its coordinates will be determined, placed in storage, and held until needed.

The functioning of the whole system depends on the functioning of these links. In order to be made sufficiently reliable, they should be provided with a reasonable number of alternate routes. Since the cost of the links will be an important item, the lines must be utilized effectively. Any processes for determining and storing the coordinates are an advancement in this direction. In addition, a number of radars should be arranged to share a party line, which will apparently necessitate a discrete address system for these links.

2. Computer-Weapons Links

Computer-weapon links fall into two classes, those to short-range weapons and those to interceptor control points. For short-range weapons, there is a single control point, and the essential data to be transmitted are the coordinates of the target and a start signal. Beyond this, the local equipment at the weapons center is assumed to furnish any required information. In the case of interceptor control links, it is necessary to furnish vectoring information to the

aircraft for a prolonged period, and only toward the end of the operation is the interceptor left partly on its own. This difference is essentially due to the fact that the interceptor range is long in comparison with the radar range, whereas the gun range is short. Missiles whose range is long in comparison with radar ranges probably fall in the same class as interceptors.

The information that must be transmitted to a short-range weapons center is less than that transmitted from a single radar. Consequently, there is the same incentive for party-line operation as for a discrete address system. Therefore, such centers and radars might advantageously share the same party line. The weapons centers would thus be part of the same discrete address system as the radars.

3. Other Surface Links

In addition to these two main classes of links, there may or may not be need for special links, depending on the final form of the radar system. One such link may be from computers to height finders. (It may be necessary to have separate devices to act as height finders, which are requested, by the computer, to measure the height of a target of specified azimuth and range.) Another special link may be required for IFF (Identification, Friend or Foe) operations. In both cases, the ring party line appears suitable, and the only requirement is that the terminals be so arranged that these operations can be carried out.

The height finders would be separate devices that might be located at radar stations. The IFF operations would doubtless be performed by radars or height finders, or both.

It is not clear whether all these links need to transmit in both directions, but it seems simplest to assume so at the present time. When the requirements are better understood it may be found possible to omit the demands on some links.

Figure IV-1-1 represents ten stations which may be scanning radars, height finders, interceptor control stations, gun control stations, or combinations connected by a ring of two-way links; it shows an interruption at some

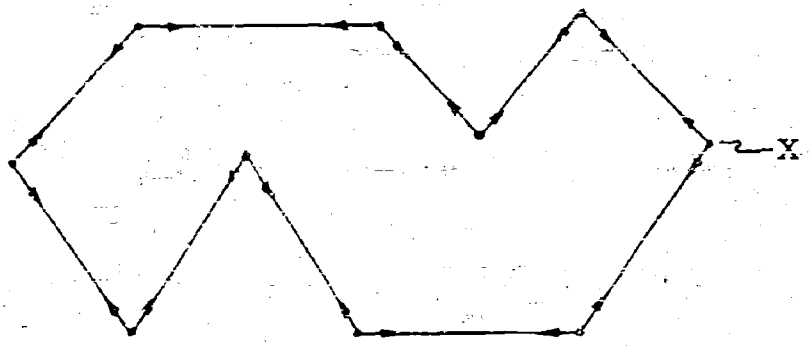


Fig. IV-1-1.
Ten-station system with interruption at point X.

one point, such as X. Matters can be so arranged that any station, A, can transmit the address of any other station, B, plus any stored information, and this information will be received by B. Station B can follow by transmitting any information that it has in storage at the time. If information is to be transmitted in this manner without confusion, the medium should be assigned to only one station at a time. This might be done by assigning the task of calling the roll to one of the stations, or to an added station.

Since this circuit functions with an interruption at X, which may occur at any point, it follows that any link may be interrupted and the circuit will continue to function if the break at X is arranged to close. Furthermore, any one of the links shown may be interrupted without serious reaction, and, likewise, any one station may be destroyed without preventing the operation of the others. This would seem a reasonable degree of precaution, unless further studies indicate that destruction of stations is fairly likely, in which case further complications may be warranted.

It is next necessary to consider how computers may be connected to the network. It seems reasonable to assume that three computers should be connected to the ring and should perform their work in parallel. If two out of the three agree, they should be assumed correct. The most obvious procedure is to connect a triad of computers to each ring, much as the other stations are

connected. The computer cost can probably be greatly decreased, however, by connecting a number of rings to the same set of computers. Such connection will be assumed herein. The consequent length of the computer links makes it undesirable to insert them in series in the ring. The arrangement shown in Fig. IV-1-2 is simpler, and should be satisfactory. Here, the closed curve represents the ring shown in Fig. IV-1-1, and two additional stations, denoted by the circles S, are added in series. These may be called the supervisory stations; only one of them is in control at any time, while the other stands by for emergencies. The three computers, indicated by C, are connected to the supervisory station, one of whose functions it is to relay to all three computers any messages that arrive for them.

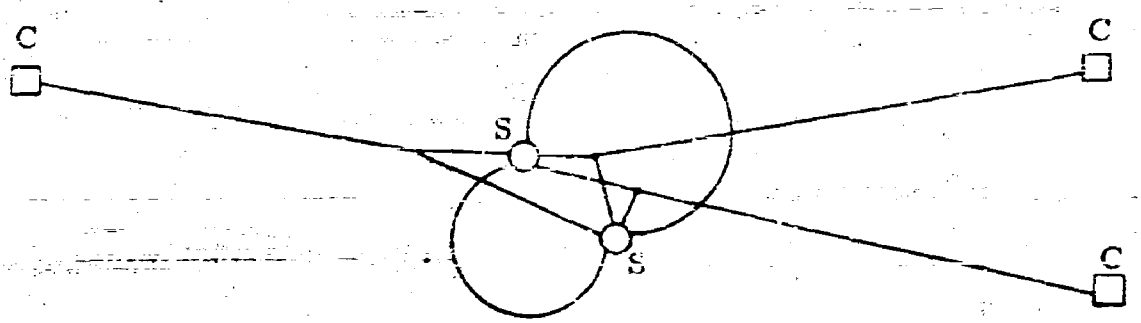


Fig. IV-1-2.
Addition of computer equipment to network shown in Fig. IV-1-1.

Another function of the station is to compare simultaneous messages from the computers with one another and, if two agree, to forward this message to its address. It was stated above that a station is needed that will call the addresses of the stations, in order to give them opportunity to transmit information in storage. The supervisory station is a logical choice to fill this need. Further, these stations are the natural points of contact between human beings and the automatism, i.e., points for display, monitoring and intervention. The form that the instrumentation should take is not known, but one such point per ring would apparently be sufficient.

The ring itself is half-duplex, that is, information can flow in either

direction, but in only one direction at any one time. The links between the supervisory centers and the computers may be full-duplex, in which case information can flow in both directions simultaneously.

Figure IV-1-3 indicates qualitatively how the various stations associated with one triad of computers may be organized. Each of the three closed curves represents a ring such as is shown in Fig. IV-1-1. The territory served by a

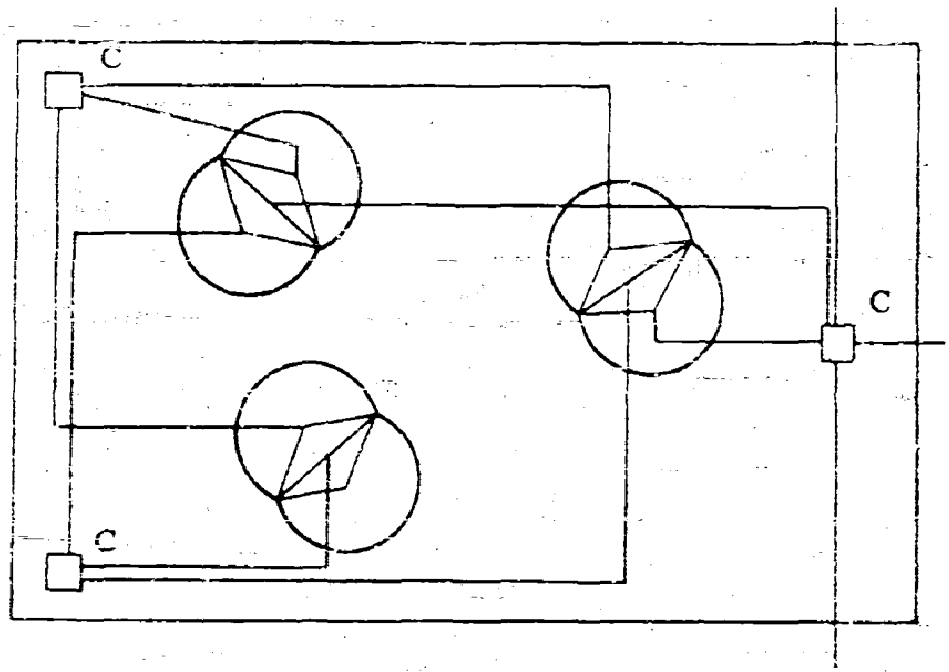


Fig. IV-1-3.
Organization of stations in one triad of computers.

triad of computers may, for present purposes, be called a computer district. Such a district is indicated by the rectangular boundary of Fig. IV-1-3. The blank areas in the rectangle are to indicate that there may be more, or possibly fewer, than three rings of stations. In addition to the links discussed so far, links are also required from each computer to its opposite numbers in nearby districts.

No attempt is made to estimate the best size for a district, but the following remarks have some bearing on the question. There is apparently no strong reason why a computer district should be of the same size as the subdivisions

created for military purposes. Small districts result in shorter computer links within the districts, and should therefore lead to greater reliability and lower link cost. The links between districts would also be shorter, but more numerous, so that, in this respect, the costs should not be far different. Large districts result in greater vulnerability, due to link failures. With respect to vulnerability from enemy action, fewer and larger computers may be preferred, because it is simpler to provide good shelters for them.

Figure IV-1-4 shows some possible connections between computer districts.

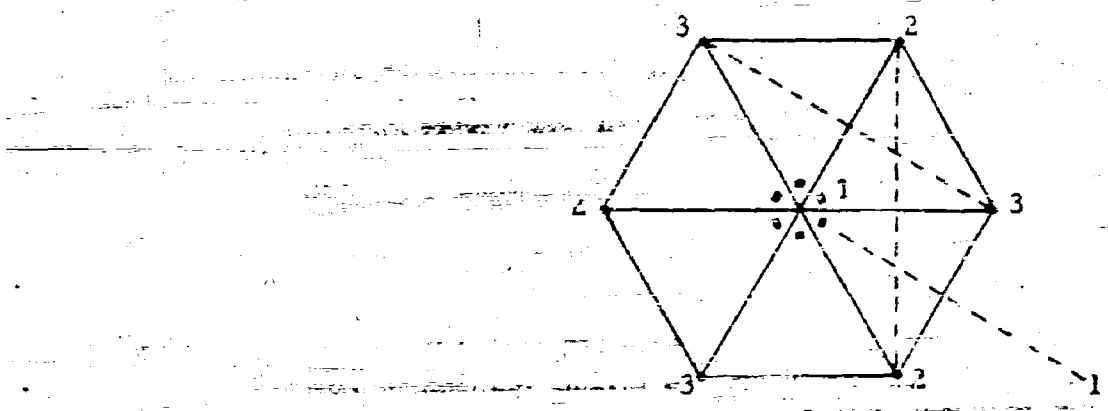


Fig. IV-1-4.
Possible connections between computer districts.

The computer districts are represented by the solid triangles, and the computers are situated near the corners. This results in the grouping of six computers in close proximity.

If the three computers in each district are numbered 1, 2, and 3, it is necessary that the 1's communicate with each other, and likewise the 2's and the 3's. Communication between unlike numbers is not necessary, and the assignment of members is left to arbitrary choice.

Consequently, the group of six stations in close proximity can be given the same number, can be housed under one roof, and connected by local links. Groups of links from one group of six to another group of the same number would run as indicated by the dashed lines.

The grouping of six computers under one roof has the same advantage mentioned above for large computers, namely, it is possible to put them in strong shelters. Such grouping also has advantages with respect to operation and maintenance of spare parts, e.g., one spare part might be a seventh computer.

The degree of duplication shown should be sufficient to take care of disconnected accidents. In the event of ice storms, however, or an exceptional windstorm, there is correlation between the various areas. In such storms, open-wire circuits may be disabled in several places at once, but cable circuits may be expected to continue to function. For this reason, at least a selected portion of the links should be placed in cables.

Providing microwave radio for some of the links must be considered. They are particularly attractive when wide bands must be transmitted. They may also be found desirable as insurance against storm damage to open wire lines. The sites, and many other items needed for radio relays, are acquired in any case, hence the cost is small. But the average distance between radar stations may be great enough to require an intermediate repeater for the relay. In some cases it may be worth while to provide the repeater or practicable to bridge long spans.

A need exists for communication between separate display centers, and for the flow of information from centers of lower to centers of higher rank, but this will introduce no particularly difficult communications problem.

Since a low-altitude AC&W system such as is envisaged here must be one of gradual growth, special care must be taken to make such a transition possible. It is important that the new system fit into existing systems in various stages of evolution; this is largely a communications problem. Present methods of transmitting data by telephone are generally not completely satisfactory, so that some form of telegraphic data transmission will have to be provided in all systems. Fitting the various systems together will require close cooperation and painstaking attention to detail.

C. GROUND-TO-AIR LINKS

Ground-to-air links are required for transmitting information from the aircraft control center to the aircraft, and provide for the following functions:

(1) Take-off;

(2) Reaching the target;

(3) AI operation during engagement;

(4) Return to base;

(5) Landing.

Take-off will presumably be accomplished without help from the communication links. Return to base and landing may require their full functioning until a late stage in the landing process.

An important question is whether the links should be one-way or two-way. The latter system, while more costly, is useful in the following respects.

(1) It permits prompt acknowledgment of orders;

(2) It permits transmission of the statement that an order has been executed;

(3) It permits retransmission to the ground of certain numerical information, such as: altitude; airspeed; heading; position as given by navigation aids; prompt indication of the time of occurrence of certain steps, in cases where it is important that there be a minimum of delay; other occasional information that is not particularly urgent;

(4) It permits the prompt return of information in case the airborne radar is jammed by other than the assigned target. This may require change of plans, which should originate on the ground or at least be known there.

It is generally agreed that the data links, whether one-way or two-way, cannot be made to take the place of telephone circuits to the pilot. While certain types of information can probably be transmitted most simply by telephone, other types are more suitable for data transmission links, partly because the telephone may not be available when needed, and partly because the transmission of such items requires much effort on the part of the pilot. However, these items lend themselves well to automatic transmission.

It would be helpful if altitude information could be obtained from the aircraft itself because it is difficult to obtain by radar operation. Obtaining it in this way would not obviate the need for radar measurements, since there would be enemy planes that would have to be located, but the height-finding job would be much eased.

The aircraft speed can be determined by radar observations and is largely

a by-product. The air speed is an additional datum which would furnish information about the wind; in a future control system, particularly one dealing with civil aircraft, this knowledge might be helpful.

Heading appears to bear the same relation to course that air speed does to speed. All four quantities taken together should furnish vector information about the wind.

Position information as given by navigation aids may be of utility in landing operations. Such information is expected to play an important role in carrier landing aircraft. Airfield landing may be considerably different from carrier landing; however, the landing of interceptors is a critical operation, and every means to facilitate it should be given careful consideration.

If an aircraft could furnish its own coordinates, together with an identifying address, the problem of tracking would be straightforward, and there would be no confusion of tracks. However, since enemy aircraft would obviously not furnish this information, radars would be required in any event.

At this time, it seems safest to assume that a return link will be necessary. PROJECT CHARLES considers it desirable to provide a return channel, but feels that great care should be exercised to restrict weight and bulk in the equipment.

The provision of return links brings with it, as a corollary, the necessity for time division. Practically, it seems to require a discrete address system, although there are other possibilities, for the most part not very different. A discrete address system will be assumed herein.

The detection of low-altitude bombers makes it imperative that the radar links reach low altitudes, which implies close spacing of the data transmitters. Simple geometrical considerations indicate that, if the target and the interceptor are at the same altitude and the same is true of the radar and the data transmitter, there should be about as many transmitters as there are radars.

This brings up the question of interference among the transmitters. While some interceptors are at 500 feet, others may be 100 times as high and see 100 times as many transmitters. Moreover, a low-flying aircraft may see three transmitters at once, and may receive the same signal strength from all.

The interference seems to be avoided most simply by arranging matters

so that only one transmitter is transmitting at the same carrier frequency at any one time. In addition, it would be desirable to have an interval of at least one millisecond between the end of transmission from one station and the beginning of transmission from another. This ensures that interfering waves must originate at least 186 miles away. This method apparently would not introduce any special problems, because the computer knows which transmitters are in the vicinity of the interceptor; in fact, it seems to result in some simplifications.

For the air-to-ground transmission, the power that can be transmitted from the aircraft is limited, but it is desirable to avoid interference from jamming or other sources. The other interceptors are not sources of interference, since use of a discrete address system ensures that they do not emit simultaneously. The natural way to minimize other interference is to have three to five times as many receivers as transmitters, spaced fairly uniformly over the terrain. If a source of interference is near one of the ground receivers receiving from one interceptor, it is not likely to be near all the others, unless it is near the interceptor and emits comparable power. This procedure is not entirely effective, and may run into considerable cost for links and receiving stations. The statement about costs may perhaps require modification. One can picture UHF receiving stations atop telephone poles, powered over cable pairs and transmitting the received signals over these pairs.

In any event, it is of interest to consider the alternative case – where there is a single receiver for each transmitter located near it. One alternative would be to require every receiver that receives a self-checked message to store it until another message is sent out. If the home receiver received a self-checked message, it would forward it. If it received a garbled message, some routine should be established for questioning the other receivers. A simpler, but less effective, procedure would be to ignore a garbled message received by the home station.

While this discussion is concerned primarily with data links, it is also necessary to consider telephone links with respect to the new problems brought in by low-altitude operation. The same possibility of interference from a plurality of ground transmitting stations exists, and the same remedy appears

suitable: to ensure that only one ground transmitter is in use, and that it is usable. It appears that the data-transmission circuit, in addition to its proper function, should undertake to see that the right ground transmitter is used. It should also perform similar functions for the ground receivers. The exact nature of these functions depends on the mode of operation selected. (If there is to be a choice between reception by one of several ground receivers on a telephone link, this selection cannot be made by self-checking, but should be done by a "voting circuit" that selects the ground receiver with the best signal-to-noise ratio (S/N).

In a discrete address data system, the aircraft does not speak until it is spoken to. Data that accumulate in the meantime are returned immediately after a message has been received. It is expected, however, that this opportunity will occur frequently, perhaps not less than once a minute. Thus, the data link might be used as a means by which the pilot can request the use of the telephone line. This is one opportunity offered by a data system; however, the possibility of jamming the data links must be given consideration in this connection.

The question arises as to whether the surface-to-air links should be duplex or simplex. Duplex links appear to offer many advantages, but this subject should probably be reviewed in connection with telephone links. There are apparently no stronger reasons for duplexing with data links than with telephone. Data links using the discrete address system can be made to transmit in one direction at a time.

The most obvious method of transmission is by the use of binary digits, and in discrete address systems the address, at least, should be of this type. It is assumed herein that digital transmission is used, but PROJECT CHARLES does not make any recommendation at this time. For data transmission, frequency modulation appears preferable to amplitude modulation. If there should be difficulty with echoes, it could probably be minimized by the use of frequency modulation. The Project is not in a position to make any corresponding recommendation with respect to telephone links; there are advantages in having the two alike.

D. OFFSHORE LINKS

The offshore installations may be either shipborne or airborne. Provision of the links is more difficult with shipborne installations, however, and these will therefore be considered first.

Maximum radar coverage should be obtained with a minimum number of ships. This implies that distances will be stretched to the utmost, and frequencies having surface-wave propagation may have to be employed. In addition, it may be desirable to have two lines of ships in places where particularly great depth of coverage is desired.

It does not seem reasonable to use anything but UHF for the surface-to-air links, which implies that there will be zones where interceptors cannot be vectored at low altitudes. This situation must be accepted; it may not be serious, because the interceptors may not have time to proceed very far.

The shore-to-ship links can be arranged in a group corresponding to a ring, but with no ring relation among the points. If a frequency can be found that spans the greatest distances involved, a number of ships – perhaps up to ten – can be worked on a single channel. Such a frequency might be just above or below broadcast range. The signals at the most distant ships would be fairly weak, and it would not take too much power to jam them. On the other hand, at these frequencies it would be difficult to radiate much power from airborne jamming transmitters. The level relations could be improved by using some of the centrally located ships as relays for more distant ones.

With airborne equipment, the problem of communicating with interceptors is eased. Presumably, UHF with a suitable selection of relaying points could be used for the circuit interconnecting the group. The power in the airborne equipment (other than the interceptors) should preferably be comparable to that used in ground stations.

E. BANDWIDTH IN SURFACE DATA LINKS

Although it would be of considerable interest to know the bandwidths required in the surface data links, this is not possible at the present time; the manner of functioning is not well understood and the numerical values that

determine the answer are not well known. Nevertheless, it is thought desirable to carry out a computation with assumed values. It may be reasonably expected that the assumed values are not so far in error, hence, that the result obtained is a fair approximation. Moreover, it should not be difficult to substitute better figures when they become available and thus obtain a better answer. Consideration will be limited to ring circuits because they appear to be the critical parts.

1. Assumptions

There are 200 aircraft over the ring, of which 100 are interceptors that must be tracked and vectored, 50 are friendly civil craft that must be tracked and vectored, and 50 are enemy bombers that must be tracked and height-found.

No allowance is made for weapon control other than that for interceptors. Guns or ground-to-air missiles, if employed, would also require data-handling capacity, but it is assumed that a correspondingly smaller number of interceptors would be needed in that case.

No allowance is made for jamming. Repetitions and other procedures may result in the need for more pulses. The increase would come in the time allotted to messages to interceptors. This, as will appear, is the lesser part of the total.

The address of a computer, radar, ground transmitter, height finder, and the like consists of 5 information pulses, plus an additional pulse for self-check.

The address of an aircraft consists of 10 information pulses, plus 2 pulses for self-check.

The radar scan cycle is 5 seconds; but targets are, at times, reported more than once per scan cycle. A factor of 2 will be allowed for this. The number of pulses required to specify the coordinates of a target will be taken as 15, with 3 added for self-check.

Height finding will be required once per minute per enemy bomber, and the number of pulses required to specify the height is 5 plus one added for self-check.

No identification by radio is required at this stage. There is little need for it with the exhaustive tracking contemplated, and any that might be required would take place at an earlier stage.

The rate of sending messages to interceptors varies in accordance with the phase of the interception. The average assumed is once per 10 seconds. The length of the message is taken as 35 pulses (exclusive of address), plus 7 pulses for self-check. The return messages are assumed to consist of 25 pulses, plus 5 for self-check. For vectored civil aircraft, the same message lengths are assumed, and the average rate is assumed to be once per 30 seconds.

In half-duplex telegraph circuits, there is an inevitable interval between the instant the message in one direction ends and the earliest instant the message in the other direction can begin – namely, the time it takes the message to travel from one end to the other. For convenience in the present discussion, the term for the corresponding interval will be called the clearing time. It will be assumed that it is one millisecond, on the average.

Strictly speaking, the number of targets that must be tracked is less than the number of aircraft, because some of them – particularly enemy bombers – fly in formations that are unresolved. Similarly, the vectoring is sometimes done in terms of squadrons and larger aggregates, rather than in terms of individual planes. These effects are neglected herein.

2. Azimuth and Range

The number of messages of this kind that must be transmitted in a 5-second period is 200 x 2 = 400. Each of these requires 18 pulses for information and check. In addition, there must be time allotted for the address of the reporting radar. When there is little business, an address will usually be called with no message forthcoming. On the other hand, when business is heavy, a plurality of messages may follow the calling of one radar address. We are concerned with a rather heavy load where there are occasional delays; we shall accordingly assume that the average number of messages is one per address. Thus, the number of pulses required per second is 80 x 24 = 1920. In addition, there is the accumulated clearing time, which amounts to 80 x 2 = 160 milliseconds per second.

3. Height

In one minute there must be 50 pairs of messages, each pair consisting of an inquiry and a response. The inquiry requires 18 pulses for the message and 6 pulses for the address, and the response requires 6 pulses for the message and 6 for the address. The total number of pulses is 36 per message pair, or 30 per second.

In addition, there is the clearing time, which amounts to 3 milliseconds per message pair, or 3 milliseconds per second.

4. Vectoring Information

There are 100 messages to interceptors in 10 seconds, or 10 per second. There are also 50 messages to civil aircraft in 30 seconds, or 5/3 per second - making a total of 11.7. Each message is made up of 54 pulses, 42 for the message proper with check, and 12 for the aircraft's address. Each message is, moreover, preceded by the transmitter's address (6 pulses). Thus, the total number of pulses is 60 per message and 680 per second.

There is also the return message, which contains 30 pulses of message. It probably should also have the aircraft's address and perhaps the computer's address, making a total of 30 + 12 + 6 = 48 pulses per message, or 560 pulses per second.

The clearing time is 4 milliseconds per message pair, or 47 milliseconds per second.

5. Total

For the total, we find that 1920 + 30 + 680 + 560 = 3190 pulses that must be transmitted in one second and that, moreover, 160 + 3 + 47 = 210 milliseconds of every second is used as clearing time. The rate at which pulses are sent cannot be less than 3190/0.790 $\simeq$4000 per second. This corresponds to a base band of 2 kc in the ideal limit.

Under the assumptions made, a system built to just meet the requirements would be busy all the time, and, once it fell behind, there would be no opportunity to catch up; furthermore, if the data were lumped, there might be some lost messages. Actually, conditions are more favorable because, as the

storage devices fill up there will be more and more occasions when several messages from radars will be sent in succession, thus saving address time and clearing time.

F. JAMMING OF SURFACE-TO-AIR LINKS

It seems impossible to build a system of links so secure that it cannot be jammed to some degree if the enemy wishes. On the other hand, it seems impossible to jam completely a well-built system. We must count on a partially jammed system so that at some times, in some places, and in some frequency ranges there is jamming. A reasonable aim is to make the probability of jamming so small that it does not seriously impair operations. In achieving this objective, we may be able to go so far that the enemy does not find it worthwhile to attempt jamming.

A quantitative treatment would require knowledge of how much power the enemy has at his disposal (as well as the powers we are to use), and also what methods he elects to pursue. It is nevertheless of some interest to consider the laws that govern under specific circumstances. Assume that our signals are binary digital with the current on and off. Then any interfering signal whose amplitude is greater than one-half the on-current will cause errors in reception, because it may be at times in such phase as to subtract from the on-signal, in which case the resultant is less than the interference with the off-current. Thus, the critical limit is a 6-db differential. It is not possible to have all receiving instruments in perfect adjustment; therefore it is reasonable to say that the differential must be 10 db when the magnitude of one of the signals is known. When both the wanted signal and the interference are intermittent, there may be additional problems of adjusting the sensitivity with great rapidity, but these problems will be bypassed.

If the enemy elects to jam with a signal of variable amplitude, it is the maximum amplitude during one message spurt that counts and a counter-countermeasure would be to send the messages in short pieces and perhaps with repetition. But if the last stage in the jamming transmitter is a vacuum tube amplifier, the enemy gains little by varying the amplitude from the maximum that such a tube can handle. It may be that he will use a device that does

not require an amplifier. Such a device might be a spark plug coupled directly to an antenna, or perhaps a magnetron designed for this purpose. The former results in a very short pulse that can, in large measure, be countered by clipping in the radio stage (provided the receivers are suitably designed). A magnetron-like radiator could presumably be designed to give the best possible duty cycle from the jammer's standpoint. If the pulse were made equal in duration to an elementary signal pulse, and if the pulse frequency were such that two would occur in each message, this would be a bad situation to cope with – almost as bad as if the maximum occurred continuously.

The two principal conventional methods available to the communications engineer for combating jamming are:

(1) Radiating a strong enough field so that it is more than 10 db stronger than the jamming signal;

(2) Keeping the enemy ignorant about when, where, and in what frequency range he should concentrate.

Under the first of these categories, we can help the surface-to-air transmission by placing the stations close together, by radiating much power from the ground stations, and by employing directivity. In the system described above, we are already forced to put the transmitters close together to obtain low-altitude coverage. This is an incidental benefit with respect to jamming, but it is hardly practical to decrease the separation still further as an anti-jamming measure.

Consider now the effect of increasing the radiated power by, say, 6 db. This is equivalent, for present purposes, to keeping the radiated power constant and decreasing the jamming power by 6 db, i.e., halving the interfering field intensity. Under the conditions we are assuming, this means that the area in which jamming may take place is divided by 4. We can express this somewhat loosely by saying that multiplying the power by 4 results in dividing the probability of jamming by 4.

In some respects, the conditions for directivity are suitable for ground-to-air transmission. The transmitter knows the azimuth of the aircraft to be addressed, and a beam can concentrate the available power in that direction. It would be a very difficult matter, however, to build an antenna of substantial directivity and to turn it with the speed required. Electrical turning of the

beam may be somewhat less difficult, but here, too, the problems are great and it is not believed that a solution has been found.

Turning now to the air-to-ground direction, we have the possibility of increasing the power of the airborne transmitter and of providing a plurality of spaced ground receivers for each ground transmitter. For power increase, the same rule holds – that the interfering area is inversely proportional to power. Without making assumptions about configuration, it is not clear that the same can be said about probability, but it is perhaps nearly true. This means of combating jamming is limited by the fact that the power is limited by weight, which is limited in interceptors. It seems clear that an interceptor will always remain at a disadvantage with a jammer who specializes in this function and can therefore make jamming equipment his whole payload.

The use of a plurality of receiving stations seems to be very effective if the jamming area of any one jammer is small. If, on the other hand, the effectively jammed area is as large as the range of the airborne transmitter, there is nothing to be gained when the interceptor and the jammer are close to each other. If they are far apart, there may be a gain, provided the receiving stations are also far apart.

We now come to the measures available under category (2) above – namely, those that are designed to keep the jammer ignorant as to frequency, time, and place most suitable for jamming. With respect to time, the advantage is that the messages are short and occur irregularly. This forces the enemy to the use of continuous emission if he does not want to miss anything. It is true that, as described above, the messages occur in pairs and, if he is content with jamming the return link, he might start jamming each time we have begun sending. If this became serious, some other routine might have to be worked out. We probably have not accomplished much, communicationswise, by forcing the jamming signal to be continuous. Once a jamming device has been provided, it probably costs little more to run it continuously. This point should be remembered when homing on the jammer is considered.

With respect to the place where jamming is best done, the irregularity in the emissions makes this choice difficult also. Add to this the high velocity of travel, and it seems clear that there is little opportunity to make use of preferred locations.

With respect to frequency uncertainty, we start out with the advantages that the band is wide, thus making many channels available, and that the successive messages at any station are usually of different frequency, so that, if the enemy determines the frequency for one message, it may be something different for the next. To utilize the former advantage, care should be taken to ensure that wide frequency ranges are possibilities. If certain narrow ranges are assigned for special purposes, the enemy is in less uncertainty. Some effort should also be made to have various aircraft differ with respect to frequency. In addition, we have the following, in increasing order of complexity:

(1) Send out fake messages between the genuine ones.

(2) Change carrier frequencies in accordance with a predetermined random sequence.

(3) Change carrier frequencies in accordance with what the enemy does.

It is clear that, if all possibilities were used, the enemy would be forced to cover all the bands uniformly or in some kind of random sequence.

If the jammer has a given amount of power and divides it between two channels, the probability of jamming (being proportional to the power) is reduced to one-half in each channel. Thus, the total probability is not altered; therefore it may be expected that there would be little choice between the two alternatives open to the jammer. Consequently, if we make use of all the possibilities, we may expect that the jammer will jam uniformly over the band. Unless the power available were very great, this might not seem worth while.

Beyond the measures considered so far, which lie in the field of communications engineering, there is the totally different one of homing on the jammer with a missile or with an interceptor. It seems clear that, if jamming is to be effective, large powers must be radiated, and this favors homing. The homing might draw the reply of intermittency, but this in itself would be a great help under these conditions, provided the on-period could be made short.

G. FREQUENCY UTILIZATION WITHIN THE UHF

There are two problems of importance in this connection. One is to arrange matters so that a large number of channels can be obtained. This may

not be a serious problem for some time, but, with the numbers and densities of aircraft that are considered future possibilities, this problem may well become critical.

The second problem relates to jamming. As pointed out above, the surface-to-air links are vulnerable to serious efforts on the part of the enemy, and this is especially true of the air-to-surface direction. To efficiently combat this difficulty, we must utilize the potential advantage of the wide frequency range available to make the choice of jamming frequency as difficult as possible.

The substitution of duplex (cross-band) working can be substituted for simplex working to increase by a large factor the number of channels available for surface-air-links. There are, however, numerous problems that must be disposed of before this step is taken. The substitution also helps on the jamming problem because, if the simplex method is used, the jammer can tell – by observing the emitted frequency – how he can jam an airborne receiver.

However, for maximum effectiveness against jamming, it is necessary to keep the jammer completely in the dark as to where the frequency is located. This seems to require that the frequencies used be made to rotate through the whole band in some unpredictable manner with time. It probably will not be practicable to work this out in ideal detail, but it seems necessary to go far in this direction if jamming is to be minimized.

It is our feeling that some group should undertake the task of proposing an optimum utilization of the band 225 to 400 Mc.

H. Nyquist

APPENDIX IV-2

THE GROUND-WAVE RADAR

APPENDIX IV-2

THE GROUND-WAVE RADAR

The coverage of microwave systems is limited by the horizon because the earth produces an electromagnetic shadow. Careful examination of the shadow region below the horizon shows that there is some energy in the region, but that microwave frequencies the amount of energy would be extremely small. If the frequency under investigation is reduced, an increasing amount of energy would be found in the shadow zone. In fact, it can be shown that a surface wave exists that follows the surface of the earth. This wave is essentially propagated by the currents induced in the earth by the electromagnetic fields set up by the radiating system. The physical reality of this surface or ground wave has been presented both experimentally and theoretically in the literature; the existence of this surface wave makes possible the detection of targets below the line of sight.

A. GROUND-WAVE PROPAGATION

Unlike the microwave radar, where the signal strength of echoes is determined primarily by geometric considerations as the distance to a target is varied, the ground-wave system suffers from the additional loss due to the dissipation loss of the conducting earth. In most instances, the losses due to the ground currents will greatly exceed the geometric losses of the conventional radar equation. It is well known that the attenuation of a ground-wave signal per unit distance is much greater when horizontal polarization is employed than when the energy is radiated with vertical polarization, and therefore the latter is employed in the system under discussion.

The greatest single factor that must be taken into account in the design of this system is the relationship between ground-wave field strength, distance, altitude and frequency. The most important fact is that, for a given set of conditions, the field strength falls off very rapidly with increasing frequency. This can be seen in Fig. IV-2-1, where the relationship between received field strength (for one-way propagation) and distance is plotted for frequencies between 5 Mc and 3000 Mc. It is immediately obvious that the use of frequencies

above 30 Mc would result in extreme losses. For this reason, the investigation of the ground-wave radar has been restricted to frequencies below 30 Mc.

The field strength at a point distant from the radiator is also affected greatly by the conductivity of the surface between the two points. Only with a medium such as salt water is the conductivity sufficiently high that losses are low enough to permit successful operation of a ground-wave system. Over most terrain, the losses would be so great that no useful results could be obtained.

B. GENERAL CONSIDERATIONS

The ground-wave radar as planned would operate in the frequency region from 15 to 25 Mc, with the optimum apparently at about 20 Mc. This optimum point is governed by considerations of ground attenuation (as discussed previously), antenna gain, cosmic and atmospheric noise, and the frequency at which the ionosphere becomes conducting at a given time. The effect of these parameters has been studied in considerable detail by the Raytheon Manufacturing Company. Detailed information can be found in their quarterly progress reports to the Air Material Command.

The curves of Fig. IV-2-2 show the power required to detect a one-square meter target for the contemplated experimental system operating at 20 Mc. This system will have the following characteristics.

Antenna: 23 db gain; 600 x 150 feet.
Receiver bandwidth: 10 and 100 kc.
Transmitter power: 2 Mw peak.
Repetition frequency: 100 to 300 pulses per second.
Integration improvement: 10 to 20 db, depending upon system.
Scanning: ±30 degrees.

The curves of Fig. IV-2-2 are computed for the 10-kc bandwidth, and assume that both cosmic and excess receiver noise are zero. Also shown on this drawing are the data obtained by Sir Robert Watson-Watt and his associates, operating an experimental system at Hill Head in Scotland. The work undertaken by Sir Watson-Watt is being done for the Air Defense Systems Engineering Committee (ADSEC), to provide some preliminary design data. The target

cross-section data indicated on Fig. IV-2-2, ranging from 2 square meters for an F-84 jet fighter to 80 square meters for a B-29, were obtained by the Hill Head group. The performance of the Hill Head system is estimated to correspond to the 0-db curve in Fig. IV-2-2.

It is believed that the system now planned will perform along the 80-db curve on a plane like the B-45, and will do somewhat better on a B-29 type aircraft. Operation along the 80-db contour can be maintained in practice.

C. ALTITUDE DETERMINATION

An examination of the curves of Fig. IV-2-2 shows that the pickup range of an aircraft is a strong function of the height at which the aircraft is flying. This fact can be used to get an approximate indication of the height determinations to within ± 1500 feet, which should be possible if the system is properly maintained.

D. VULNERABILITY TO COUNTERMEASURES

This system has greater vulnerability to jamming by the enemy than would a microwave set of comparable maximum range, since it can be compromised by a shipborne jammer located beyond the detection range of the system, whereas an airborne jamming set would be needed to effectively jam the microwave system. To provide greater security against countermeasures, it is proposed that noise-modulated continuous-wave (CW) transmission be employed in the final system. The techniques that would permit this are currently being investigated in the Research Laboratory of Electronics at the Massachusetts Institute of Technology.

E. RESOLUTION

The extremely long wavelength that must be employed limits the resolution of such a radar to about 10 miles at its maximum range of 125 miles. Thus, it is mainly suitable for shore-based early-warning sites where the traffic density is so low that the identification problem is easy.

Committee A
(G. E. Valley, Chairman)

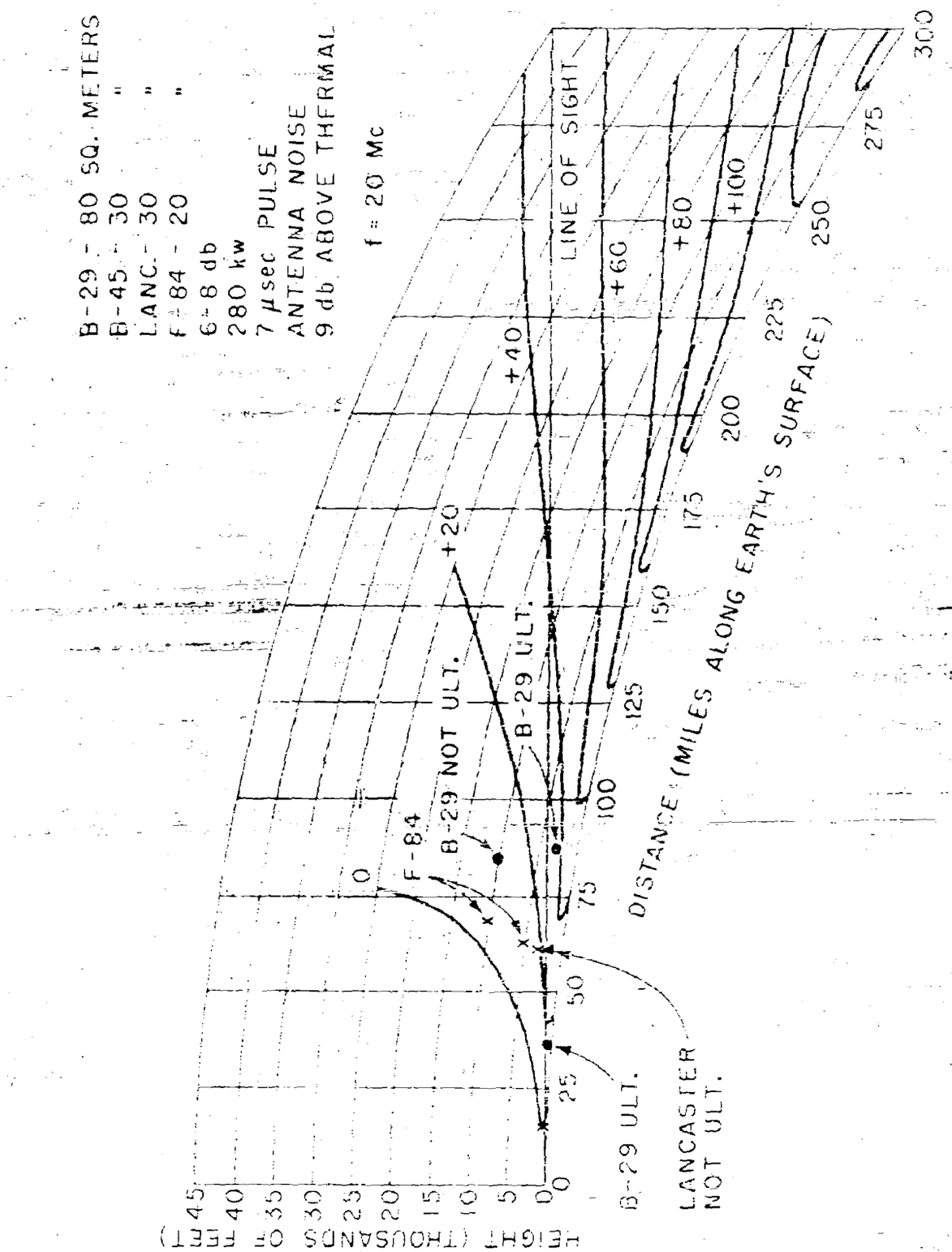


Fig. IV-2-1 Decibel contours, required transmitter power, to detect a one-square-meter target, vertical polarization.

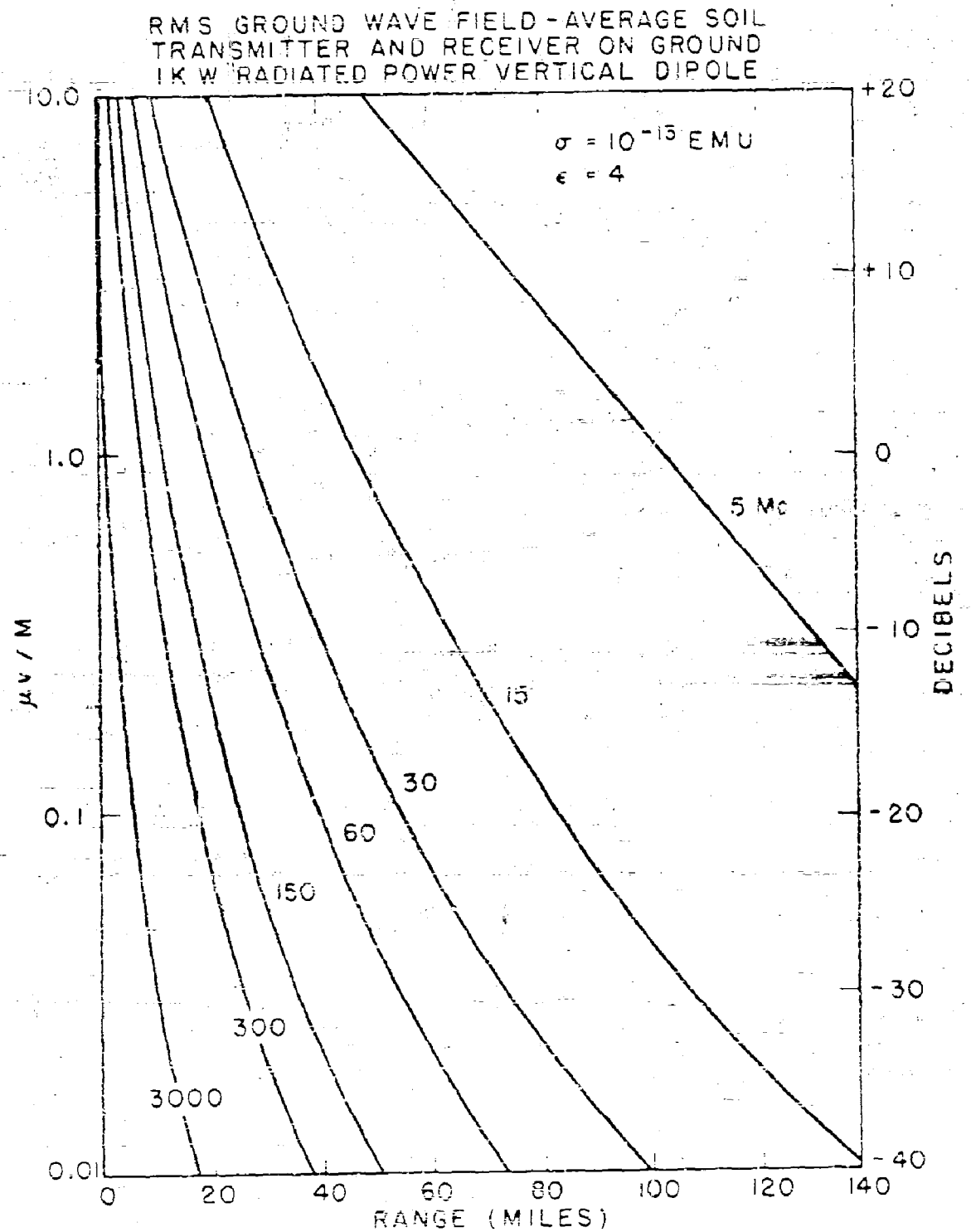


Fig. IV-2-2 RMS ground-wave field.

APPENDIX IV-3

DEAD VELOCITIES IN PULSE MTI SYSTEMS

APPENDIX IV-3

DEAD VELOCITIES IN PULSE MTI SYSTEMS

Pulse radar schemes for giving MTI (moving-target-indication) information by use of the Doppler effect are ordinarily characterized by so-called "dead velocities," that is, radial velocities of a moving target at which no information is obtained. These velocities are those for which the Doppler frequency is some multiple of the pulse-repetition frequency, and are given by the relation

$$v_d = 11.2 f_p \lambda k \quad (k = 1,2,3\ldots),$$

where f_p is the pulse-repetition frequency in kc/sec, λ is the wavelength in centimeters and v_d is the radial velocity in miles per hour. Schemes have been proposed for eliminating these dead zones by the simultaneous use of two radar systems operating with different wavelengths, so chosen that the least common multiple corresponds to a velocity higher than the range of interest. Two radar sets operating at different pulse rates, chosen by a similar rule, would be equally effective. The following scheme, involving only one radar set, is an outgrowth of a suggestion by Dr. Nyquist of PROJECT CHARLES. It is applicable to the system of indication in which a band-pass filter separates signals from moving targets from the signals due to ground clutter, etc.

For the purposes of discussion, the radar set may be simplified as follows. Assume that an oscillator is running steadily at the radio frequency. Let the output of this oscillator be split, one part going to a pulse-modulated amplifier, the output of which is radiated. Let the received echo signals, after amplification at the radio frequency, be applied to a mixer circuit, together with the other branch of the oscillator output. The resulting signal will be, for a single reflecting target, a copy of the modulating pulse applied to the transmitter, multiplied in amplitude by the cosine of the difference in phase angle of the two paths from the oscillator to the mixer. The frequency spectrum of the resulting signal will be just the frequency spectrum of the modulating pulse. If, on the other hand, the reflecting object is moving, the frequency spectrum of the signal out of the mixer will be shifted by an amount equal to the Doppler frequency.

If a train of evenly spaced pulses is sent out, the frequency spectrum of the echo from stationary objects will approach a line spectrum, the spacing of the individual components being equal to the repetition frequency. If the reflecting object is moving, the frequency spectrum of the received signal will again approach the character of a line spectrum with the same spacing. However, the modulation and demodulation process has, in effect, brought the region of negative frequencies into the picture in such a way as to introduce another set of lines into the spectrum of the moving object. The over-all result is the same as would be obtained by putting a spectrum line on each side of the location of each line of a stationary target, the spacing being equal to the Doppler frequency. As the speed of the reflecting object increases from zero, the spectrum lines may be pictured as splitting and moving apart.

If the echo signal arises from many objects, the frequency spectrum will retain its line character. If one of the objects is moving, the spectrum of its echo signal will consist of lines that will lie between the lines of the signal from stationary objects, unless the radial velocity is equal to one of the previously given dead velocities, in which case the lines of the two spectra will be superimposed. A band-pass filter occupying the region between any adjacent pair of lines in the ground-clutter spectrum will pass only signals from moving targets, but will, of course, miss those targets with speeds in the dead zones.

Suppose now that the pulses that are sent out are not spaced evenly, but are separated alternately by times t_1 and t_2 ($t_1 < t_2$). The resulting signal is then periodic, with the period $T = t_1 + t_2$. The frequency spectrum will be made up of lines spaced by a frequency $f = 1/T$. For a very long train of pulses, the frequency spectrum will be given by

$$F(\omega) = 2 \cos \frac{\omega t}{2} \, \delta(\omega = \frac{2\pi n}{T}) \, f(\omega) \qquad (n = 0,1,2,3\ldots),$$

where $F(\omega)$ is the spectrum of the train of pulses, $f(\omega)$ is the spectrum of a single pulse and

$$\delta(x) \begin{matrix} = \infty & x = 0 \\ = 0 & x \neq 0 \end{matrix}.$$

$F(\omega)$ is then different from zero only if $\omega = 2\pi n/T$.

Suppose now that

$$\cos \frac{\pi n t_1}{T} = 0,$$

or

$$\frac{\pi n t_1}{T} = (2l + 1) \frac{\pi}{2} \quad (l = 0, 1, 2, 3 \ldots).$$

Then

$$\frac{t_1}{T} = \frac{2l + 1}{2n}.$$

The nth line of the spectrum (at frequency n/T) will be missing, as will the lines at odd integral multiples of n. A band-pass filter may now be used over the range

$$\frac{n - 1}{T} + \epsilon < f < \frac{n + 1}{T} - \epsilon.$$

(The quantity ϵ is related to the departure of the spectrum of ground targets from a pure line character, and lumps the effects of noise and scanning.) Signals from a moving target will now be passed by this filter, unless the radial velocity lies in the range

$$\frac{22.4 \lambda n}{T} - \epsilon < v < \frac{22.4 \lambda n}{T} + \epsilon.$$

For the ordinary case, the pulse-repetition frequency must be less than a maximum value determined by the maximum range of reflecting targets. For the case considered here, $1/t_1$ must be less than this same maximum value, so that 1/T is somewhat less than half the usual maximum frequency. The procedure has therefore multiplied the first dead velocity by a factor nearly equal to n. (The exact value of the multiplying factor is $(2l + 1)$, which may be set equal to (n-1) if n is even.) Thus, if n = 10 and $l = 4$, the lowest dead velocity is nine times as great as in the usual case. If t_1 is taken as 500 μsec, giving a range of 47 miles, and λ = 3.1 cm, the lowest dead velocity is 625 mph.

If the frequency spectrum of the echo signal from stationary targets is not a line spectrum, but has a width arising from noise, finite time of illumination, or similar factors, the term in $F(\omega)$, (which is supposed to eliminate the stationary target signals from the range covered by the filter) will not be completely

effective. In fact, since that term, $\cos(\omega t_1/2)$ is effectively the same as the one governing cancellation in the normal delay-line MTI, one may conclude that there are identical limits on subclutter visibility for the system discussed here and for the delay-line system.

There is some experimental evidence in a Bell Telephone Laboratories' memo* describing thorough tests of a delay-line MTI fitted to an AN/TPS-1B radar, which points to the practical unimportance of theoretical dead-velocity effects. In these experiments, a plane flew a radial course, at differing values of speed, covering one of the supposed dead zones. Careful measurements were made of the sensitivity of the system as a function of the plane's velocity. The poorest observed sensitivity was only about 6 db below that measured for the optimum velocity. In the same memo, it is suggested that the noise on the echo signal from the airplane is responsible for the behavior observed. In terms of the frequency spectra of the various signals, the situation would be one in which the width of the distribution for the airplane signal is enough greater than the width of the ground signals that the delay line cancellation affects the two quite differently. A distribution whose half-width corresponds to a velocity of about ten miles per hour would suffice to explain the observed effects.

In the schemes proposed recently by Barlow** and others for replacing the delay line by an electrical filter whose frequency characteristics are more flexible, it seems quite possible that the dead-velocity effects might become much more important. The wider and steeper-sided notch in the frequency characteristic of the filter might well eliminate rather thoroughly an airplane signal of the greater width suggested above. While the importance of such dead velocities in any over-all system operation cannot be assayed, it seems rather likely the effects will be present.

S. N. Van Voorhis

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*"Final Report on the Flight Tests of the Moving Target Indicator Kit as Applied to the AN/TPS - 1B Radar Set," E. K. Van Tass and R. D. Fracassi, Bell Telephone Laboratories, Memo for File MM-46-3500-98, 28 August, 1946.

**"The Capabilities and Limitations of Some MTI Radar Systems," RAND Corp., Research Memorandum RM-527, 1 February 1951.

APPENDIX IV-4

CW SYSTEMS

APPENDIX IV-4

CW SYSTEMS

A. INTRODUCTION

One of the most important requirements at the present time of an adequate aircraft control and warning (AC&W) network is adequate low-altitude coverage. This implies coverage in altitude from, say, 200 feet upward, and the detection and tracking of aircraft moving in the presence of clutter.* Low-altitude coverage also implies stations that are placed not further than 50 miles apart to overcome the effect of the earth's curvature. These two requirements – close spacing and clutter rejection – have led to the concept of small, short-range continuous-wave (CW) radars. It is the purpose of this Appendix to outline the proposals, with their advantages and disadvantages, and to point up some of the problems that will be encountered.

The close spacing of the radars means that there will be large numbers of data sources in any reasonable area. The problem of handling and coordinating the data from many sets is therefore of major concern. It is most desirable that the processing and transmission of the data be automatic. Consequently the rejection of all false targets such as ground clutter, chaff, rain, etc. must be accomplished to a much higher degree than is presently obtained on existing moving-target-indication (MTI) equipments. Therefore, the major problem in the design of the individual sets is the almost complete rejection of unwanted signals.

In addition to clutter elimination, it is desirable that the output of the radars be in a form suitable for automatic transmission, and that sufficient data processing be accomplished at the radar in order to make this transmission possible. Furthermore, the equipments should be simple and cheap – simple in the sense that they require only periodic maintenance, and cheap in the sense that the production as well as operation be economically feasible even with the use of large numbers.

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*Requirements for an Ideal Aircraft Detection Network for AC&W, G. E. Valley, PROJECT CHARLES Memo 6845-186C, 4 June 1951.

The accuracy and data rate necessary are those to give a target position once every ten seconds on each target within plus or minus one-half mile in range, azimuth and elevation.*

Although there are two types of system possible so far as altitude coverage is concerned – low altitude only and all altitudes – the possibilities of complete altitude coverage have been given main consideration. A network that had complete altitude coverage could replace the present pulse radar networks, while a network that covered to an altitude of one or two miles would be only a gap-filler network to be used in conjunction with the present networks. The gap-filler equipments with their restricted altitude coverage would be simpler in form, and there is much to be said for the use of an equipment that is designed specifically to do one job – that is, the detection of moving targets in the presence of rain or ground clutter. However, there are the disadvantages concurrent with the use of two different systems, and it was felt desirable to investigate the possibilities of a network that could do the complete job.

In a radar set that is designed to eliminate the echoes from stationary or slow-moving targets, use is made of the Doppler frequency shift of the echo from a moving target. The signals from fixed objects or slowly moving objects are filtered off, and the echoes with shifted frequencies are detected. There are, therefore, two important considerations in the design of any equipment to detect moving targets only:

(1) The frequency stability of the transmitter and other reference oscillators used in the receiver;

(2) The type and degree of filter rejection that is employed to eliminate the unwanted echoes.

For example, in a pulse MTI equipment, the phase of the received frequency is compared with a reference oscillator and this phase difference is compared with the phase difference from the preceding pulse. For stationary targets, there is no change in this phase difference, and they are therefore canceled out. On the other hand, moving targets do result in a change in the phase,

*Requirements for an Ideal Aircraft Detection Network for AC&W, G.E. Valley, PROJECT CHARLES Memo 6845-186C, 4 June 1951.

difference, and they are detected. This change in phase difference is due to the motion of the target during the time between successive pulses, and is equivalent to a Doppler frequency shift. Since one pulse is compared with the next, the time of frequency stability is the time from one pulse to the next. In a CW radar set, it is the Doppler shifts that are detected, and the time of frequency stability that is important is the reciprocal of the smallest frequency shift that it is desired to resolve plus the transmission time (actually, time from transmission to reception of one pulse). These times during which the frequency must be held to certain limits may be different for a pulsed equipment than for a CW equipment.

The filtering or rejection of unwanted signals may be accomplished in a variety of ways. With present MTI equipment, it is obtained by the means of a supersonic delay line. Unfortunately, the nature of the transmission characteristic of a delay line as a function of frequency – that is, considering the delay line as a filter – is not the required characteristic that is wanted for the proper rejection of ground clutter or slowly moving target return. It is extremely difficult to build a delay line or combination of delay lines that will have a satisfactory rejection characteristic for very slow-moving targets, such as ground targets modified by the scanning of the antenna, rain and chaff.* On the other hand, by building filters using lumped circuit components, it is easy to obtain almost any desired transmission characteristic. The operating frequencies for such filters are in the neighborhood of 10 to 100 kc, and therefore any ranging information is lost. Continuous-wave radars use these lumped-circuit filters, and can obtain very good ground-target rejection. They do, however, lack the ability to provide range information directly.

B. SINGLE FAN-BEAM CW RADAR

One of the simplest systems proposed uses a single vertical beam that rotates in azimuth. The azimuth beam width is of the order of 2° and the rotation rate is of the order of one rps. The target is detected if it has a radial

* "Radar Systems Analysis: (Comparative Performance Study of Pulse, FM, and Doppler CW Techniques for Ground-Based Long-Range Search and MTI Radar Systems"), Sperry Gyroscope Co., Report No. 5223-1109 (June, 1948).

velocity that is higher than the cut-off velocity of the filter, which rejects stationary targets. The information that this equipment would provide would be radial range rate, $\dot{r}$, azimuth angle, θ, and time, t. If it is assumed that a target is flying in a straight line at constant altitude and at constant speed, it is theoretically possible to determine from $\dot{r}$, θ and t, for three observations, the range as well as the height, speed, and direction of motion of the plane. However, the errors in measuring $\dot{r}$ result in such large errors of height and range that this method is not practical. A slight weaving motion in either the horizontal or vertical plane, would result in prohibitively large errors in the calculated altitude.

The equations for the determination of position and course from three observations from a simple Doppler station were given by Franklin.* An analysis of the uncertainties in such a Doppler system and a study of the errors was made by Stabler.** In brief, the calculation of range and altitude depends upon the first and second difference of the observed values of $\dot{r}$, θ and t; and very inaccurate results can be expected unless both the azimuth and frequency readings change by significant amounts between observations. Even with widely spaced observations, the height determinations for low-elevation-angle planes are likely to be so uncertain as to be of little, if any, value.

It may be possible to determine range by a suitable smoothing of the observed range rates over a considerable period of time, even in the presence of weaving that might have a period of two minutes during which the plane undergoes a horizontal turn at the rate of one-half degree per second, first to the right for one minute and then to the left for one minute. For a 600-mph plane, this is only a 1/4 g turn, and the additional distance traveled (compared with a straight-line course) is only one per cent; the maximum sidewise

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*"Single Doppler Station," Servomechanisms Laboratory, MIT, Engineering Notes E-330, February 27, 1950; E-339, April 7, 1950.

**"Doppler System Uncertainties," H. P. Stabler, 12 July 1950; "Doppler System Uncertainties, Evaluation of Differential Coefficients," H. P. Stabler, 9 August 1950; "Doppler System Uncertainties, Height Values When the Percentage Height Error is Large," H. P. Stabler, 22 August 1950; (Memoranda to S. B. Welles of Air Defense Office, A. F. Cambridge Research Laboratories).

displacement is 0.6 mile. Such a slow weave would result in completely unusable information on the basis of calculations using three observations, but smoothing over a considerable portion of the weave might result in useful range information. However, the amount of calculation necessary is large. Once range information is known, it is possible to keep track of the range by the summation of range rate observed every second from the equipment. Therefore, both range and azimuth are known continuously.

By using several stations in depth and using the time at which the plane passes through the crossover point of the first station – that is, the time and direction the Doppler frequency shift goes through zero – it would be possible to keep track of the later changes in range merely by using the range rates. In a system such as this, the time lag is of the order of the time it takes the plane to fly half-way across the area of the first radar set. A range-rate gate and an azimuth gate must be employed in order to keep track of each target. By using antenna rotation rates of the order of one per second, it would be possible to keep track of a target.

C. MULTIPLE-STATION CW RADARS

Since a single station provides only azimuth and range rate and since it is difficult to determine range by the change of the range rate, particularly in the presence of weaving, the determination of range by triangulation from two or more stations may seem attractive. It will be apparent, however, that when more than one target is in the field of view the possibility of improper correlation is high, and it is necessary to distinguish the fake targets or "ghosts" from the real targets. One method would be to use a third CW radar so placed that the three sets are located, say, at the three corners of an equilateral triangle. In this case, the condition for correlation is that the intersection of three beams must be within a small area if a target is to be considered a real one. If, however, the three radars do not look at the target simultaneously, allowance must be made for the possible motion of the target between the time of detection by the different sets. To cut this area down to a reasonable size demands high rotation rates of the individual sets. In addition, when the number of targets within the triangle is of the order of five or more,

the possibility of triple intersection corresponding to fictitious targets becomes rather high; furthermore, the courses of these fictitious targets will be very similar to those of the real targets, and there is no way of differentiating between the real and ghost targets. A comprehensive study of the ghost problem in CW radar triangulation has been made by RAND.*

D. FREQUENCY- AND AMPLITUDE-MODULATED SYSTEMS

Although many FM systems have been considered, none of them has been able to meet the range resolution requirements, nor the satisfactory elimination of ground clutter that is required. The allowable time on-target is also much too short for some of the FM systems proposed. The possibility of the presence of more than one target per beam width at different ranges is a further difficulty in the use of FM techniques.

Similar remarks may be made about AM for determining range. In this case, the Doppler shifted echoes associated with the sidebands produced by amplitude modulation of the carrier are compared in phase. The basic difficulty is that, if there is more than one target per beam width, the measurement of phase difference results in a range that is somewhere between the ranges of the two targets. In addition, the AM frequency must be higher than any expected Doppler shifted frequencies and yet be low enough so that phase shifts of greater than 360° are not obtained for ranges that are to be expected with this system. In order to fulfill this requirement with ranges of 20 or 25 miles, the carrier frequency must be much smaller than microwave frequencies, and this means that it is impractical to get the required narrow beam widths.

E. SEPARATED TRANSMITTER AND RECEIVER SYSTEMS

In a system of this kind, the receiver is separated from the transmitter by nearly the maximum detection range that a combined system with the same operating parameters would have. As the transmitter beam scans at some

*"The Capabilities and Limitations of some MTI Radar Systems," Research Memorandum RM-527, February 1, 1951, RAND Corporation.

particular time, it illuminates a target, and some of the signal received from the target will be detected by the receiving beam. At this time, a unique measurement of target position can be obtained, since it is only a target at the intersection of the two beams that can give rise to a signal at the receiving station. It is this uniqueness of position that characterizes the separated system in contrast to the systems mentioned above, where range is accomplished by triangulation using two or more systems (with the consequent possibility of ghosts). A further technical advantage of the separated T and R systems is the elimination of the coupling problem between receiving and transmitting antennas and the difficulty of the transmitter noise in decreasing the effective sensitivity of the receiver. With a common T and R system, the receiver sees the integrated effect of all ground clutter within the beam for all the ranges. On the other hand, for a separated system, the receiver sees the ground clutter from only that portion of its beam that is intersected by the transmitting beam. Consequently, the problem of the elimination of clutter is greatly reduced.

A particular pair of stations, one transmitter and one receiver, must cover a certain region of space, the shape of which will depend on the sort of matrix in which the stations are laid out (square, hexagonal, etc.). Each resolution element in this region must be searched jointly by both stations in the data period of 10 seconds. If a single beam were to be used at both stations, one would have to scan rapidly, the other slowly, in such a way that the slow beam moves less than a beam width while the fast beam is covering the entire region. Requirements of time-on-target and data rate cannot possibly be met simultaneously in this way. If a single beam is retained for the transmitter, but several beams and several receivers are put at one receiving site, the uniqueness of position measurement is retained and the data rate is increased. The transmitter beam would ordinarily be the rapid scan (less gear to move fast for one beam) while the plurality of receiver beams would scan slowly. An obvious extension of this concept would bring in enough receiver beams to cover the region without scanning.

For reasons of sensitivity as well as range rate resolution it is desirable to maintain a beam-on-target time of at least one or two milliseconds. During

this relatively long dwelling time per target, all the necessary geometrical calculations for range and elevation can be made, possibly without the need for storage (or with at least a relatively noncomplex type of storage) in the data-handling system. This promises some appreciable economy in data-handling components.

1. Errors in the Calculation of Position

A simplified treatment has been given of the errors in the determination of position from such a system – say, one that consists of a transmitter pencil beam which gives elevation and azimuth angles, and a receiving system at a distance D from the transmitter which can measure only azimuth angles.* If the three angles measured are each correct to $\pm \theta$, then the resulting errors in the positions $\pm\Delta X$, $\pm\Delta Y$, and $\pm\Delta Z$, are each less than $\pm 3D\Delta\theta$. Within the square D on a side (maximum off-baseline distance equal to D) and up to a height of D/2, the errors of the distance along the baseline and of height become infinite along the baseline, and hence the off-baseline ground distance must be greater than about D/10 to limit these errors to $\pm 3D\Delta\theta$. For example, if D is 20 miles and the angles can be measured to $\pm 1°$, then the Cartesian coordinates of positions are always accurate to ± 1 mile, and to $\pm 1/2$ mile for the greater portion of the time.

2. Calculation of Velocity

It is theoretically possible to determine the velocity of a target by measuring the Doppler frequency shift at both the transmitting station and the receiving station. However, the errors in computed velocity are rather large, and the amount of equipment necessary is considerably more complicated than that necessary for measuring position only; it is felt that the advantages to be gained from measuring and computing velocity are more than offset by the difficulty of measuring Doppler velocity shift at the transmitter and the additional computing equipment necessary.**

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*"Position Accuracy of a CW Radar System," S. B. Welles, Air Defense Office, Air Force Cambridge Research Labs., 3 Jan. 1951.

**"Errors in Velocity Determination of a CW Radar System," S. B. Welles, Air Defense Office, Air Force Cambridge Research Labs., 31 Jan. 1951.

3. Coverage

The loci of constant received signal power for a common TR combination alone are the usual circles in the XY plane or actual hemispheres in three-dimensional space. For a separated T and R system, if received power is plotted in the Z direction, the surface that is obtained is one that has peaks over the transmitter and receiver stations with a saddle point halfway between and degenerating into circular symmetry at points far distant from the transmitter-receiver. As a first approximation, the received power as a target goes out along a line from either transmitter or receiver and will vary inversely as the square of the range to the point in question. This is in contrast to a common T and R system, where the received power decreases inversely as the fourth power of the range. The resultant smaller dynamic range of the received signal is useful particularly because sensitivity time control cannot be used on a CW system.

4. Scattering Cross-Sectional Area

It has been theoretically shown by R. Spencer that, for a closed convex surface illuminated from one angle, the mean power reflected from this surface at any other angle is constant. Thus, to a first approximation, there is little difference in the strength of the received signal due to a difference between the angle of illumination and the angle of reception. This fact has been borne out by model studies made at X- and K-band by the Antenna Laboratory of AFCRL. Also, when the target is flying along the perpendicular bisector to the baseline between transmitter and receiver, the received signals are higher than normal, due to specular reflection.

5. Null Courses

In an ordinary Doppler radar, there is no received signal when the target is moving perpendicular to the line of sight – that is, when the aircraft follows circular paths about the station. In the separated case, however, since the Doppler is proportional to the time rate of change of the distance from transmitter to the aircraft plus the distance from aircraft to receiver, this is zero when the distance is a constant, and null paths will be a family of confocal

elipses with the transmitter station and receiver station as the foci. In three dimensions, these will be elipsoids of revolution. It will be noted that, in the region between the stations, the courses that the airplane must fly to be invisible are predominantly parallel to the baseline, whereas outside of this region the null contours are compressed about the foci and the probability of the plane's being in a null is increased. For this reason, it seems expedient to exclude these end zones and to depend upon adjacent cells to give data in these regions. The null patterns indicate that the TR baseline should be situated so as to be normal to any bomber flight path through the cell area toward the target area. The region near the baseline is also quite likely to be insensitive, since the null surfaces here are small elipsoids of revolution and the airplane is likely to be flying tangential to one of these null surfaces. This region, however, must also be excluded on the basis that the triangulation errors are very poor.

6. Information Rate

A simple CW radar system measures azimuth and elevation angles as well as Doppler frequency shift. The Doppler frequency shift in cycles per second, due to a moving target, is proportional to the product of the velocity of the target and the carrier frequency. The minimum Doppler shift resolvable will be inversely proportional to the time the beam remains on the target. Hence, there is a definite relation between the measurement accuracies of these two angles and the frequency shift, the total angles covered, the maximum Doppler shift that is to be expected, and the time that the scanning system must take to scan through these angles.* This relation states that the time to scan through the total solid angle multiplied by the maximum Doppler frequency is equal to the product of three ratios: the ratio of the maximum velocity to be measured to the minimum resolvable velocity difference, the ratio of the maximum azimuth angle to the minimum angular resolution in azimuth, and the ratio of the maximum elevation angle to the minimum resolvable elevation angle. It is

*"Notes on a CW Radar System," J. V. Harrington and T. F. Rogers, Air Defense Office, AFCRL, 9 Feb. 1951.

seen, therefore, that, for large angles of coverage to obtain small angular and velocity-measuring errors, the time necessary is increased; one way to decrease this time is to use high Doppler frequencies (this means high carrier frequencies). For this reason, X-band is considered to be of great advantage. The other way to decrease the total time necessary for scanning is to use multiple beams – both transmitter and receiver beams, but in such a way as to have no ambiguity of target position. As an example, consider the case of X-band with a maximum target velocity of 600 mph, a range-rate resolution of 13 mph, which corresponds to a Doppler shift of 400 cycles, covering 360° in azimuth with a 2° wide beam and 60° in elevation with a 2° elevation beam width. Data period for such a system of parameters is 14 seconds. The position accuracy with such beam widths would be of the order of one to one and one-half miles.

7. Side-Lobe Response

One of the difficulties to be experienced with a separated receiver and transmitter system is the side-lobe response. In a common TR system that is used with pulsed radar, the side-lobe response is due to the two-way side-lobe pattern of the antenna, which is of the order of some 30 db below the main lobe. For the separated system, however, the one-way side-lobe response is the important quantity, and targets that are in the main lobe of the transmitter beam may be picked up on a side lobe of a receiving beam if they are stronger than the one-way side-lobe reduction factor of the receiving antenna pattern. For example, if the range from 20 miles to 2 miles is considered, and a plane comes in along a radius to one of the stations, the received power will increase by a factor of about 10^2 or 20 db. If at the extreme range, it was just visible on the main lobe, at the close-in range it would begin to be apparent on the side lobes if the one-way side-lobe reduction was only 20 db. Of course, a similar situation would occur with the common T and R system; here the received power would be some 40 db greater, while the side-lobe response would be down some 30 to 40 db also. However, with the pulsed case, it is possible to use sensitivity time control and to reduce the strength of the main echoes, thus eliminating the appearance of side lobes. With a separated T and R

system, it would be difficult to adjust the gains of the receivers as a function of the transmitter angle and receiver angle, and it is therefore advantageous to use antennas with greater side-lobe reduction.

In any practical separated system, multiple beams must be used – either stationary vertical fan beams or rotating stacked pencil beams. In either case, there will be the difficulty of coupling between the receiver antenna feeds; this should be kept at a minimum to prevent the obtaining of false angular information. One of the main ways of preventing this interfeed coupling would be to use multiple antennas with staggered lobes.

8. Three Types of Separated T and R CW Systems at X-Band

In Table V-1-1 are listed three variations of the separated CW radar systems that would satisfy the basic requirements of accuracy and data rate. Possible antenna types that would give the required beams are mentioned, as well as the difficulty in obtaining side-lobe reduction and small coupling. From this point of view, the use of linear arrays is advantageous, because one-way side-lobe reduction may be as great as 30 db.

One of the advantages of the "V-beam system" is the smaller number of receivers necessary. Only 8 are needed, as compared with 30 and 45 in the other two cases. It should be noted that, in all cases where a system is to be used in a net of systems, the receivers must be able to work on two frequencies – the frequency of the transmitter on one side and the frequency of the transmitter on the other side. The main disadvantage of the V-beam system is the requirement that much higher powers be used. This is mainly because the time-on-targets is considerably less, and that two fan beams are used, rather than a fan beam and a pencil beam. The range-rate resolution of the V-beam is some 50 mph, and this may be considered excessive. In order to obtain the required accuracies, the azimuth beam width of the V-beam should be at least one-half that of the other systems. The main advantage of the V-beam is the possibility of using linear arrays with the low side lobes possible, and also the use of a smaller number of receivers.

The advantage of the fan-beam, stacked-pencil-beam combination is that it requires less power and has better range-rate resolution than the V-beam

Table V-1-1 Separated CW Radar System

Type	Multiple Fan Beams Scanning Pencil Beam	Fan Beam – Stacked Pencil Beams	Fan Beam – Fan Beam V-Beam
Transmitter			
Beam pattern	Pencil 2° x 2°	Vertical fan 2° x 60°	Vertical fan 1° x 60°
Antenna type	Foster scanner, fed by linear array	Linear array	Linear array
Rate of scan	18 scans/sec (60° in elev.)	2-1/4 rps	3 rpm
Total power	50 w	150 w	2-1/4 kw
Number	1	4 grouped	2 back-to-back
Side lobes (one-way)	~30 db in azimuth	~30 db	~30 db
Receiver			
Beam pattern	Vertical fans 2° x 60°	Pencil 2° x 2° 30 stacked in elev.	V-fans, each 1° x 60° 4 horiz. and 4 slant
Type of antenna	Lunberg	Constrained waveguide lens	Linear arrays
Rate of rotation	Stationary	3 rpm	4-1/2 rps
Number	45, plus switch between quadrants	2 stacks back-to-back; switched between two freq.	8, each operation on 2 freq. Slant beams capable of operating on 2 freq. simult.
Time-on-target	1/540 sec	1/405 sec	1/1620 sec
Range-rate resolution	18 mph	13 mph	54 mph
Coupling diff.	Yes	Yes	No
Side Lobe (one-way)	~20 db	~20 db	~30 db

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system, as well as giving the elevation angle directly. If the side-lobe difficulty could be eliminated in the case of a stack of 30 2° x 2° pencil beams for receiving, then the fan-beam, stacked-pencil-beam combination would show the greatest promise.

One of the important technical difficulties with any equipment that depends for its operation on the detection of small frequency shifts is the elimination of all mechanical vibrations and sources of field modulation that would give rise to microphonics or hum. High-speed rotating structures must be extremely well balanced. The multiple-fan-beam, scanning-pencil-beam system is attractive because it uses stationary receiving antennas and because the rotating portion of the Foster scanner can be kept small and can be accurately balanced. Preliminary consideration of this type of scanner shows much promise of being built at relatively low cost.*

The total power necessary for the transmitter, given in Table V-1-1, is only relative. Experimental data are necessary to justify the assumption that 50 watts is sufficient for satisfactory operation of, say, the scanning transmitter pencil beam and the stationary multiple fan beam. If 50 watts is sufficient for this system, then 3 times this is sufficient as the total power needed for the fan-beam, stacked-pencil-beam system, and 2-1/4 kw is necessary for the V-beam system.

9. Experimental Work

An experimental CW radar system is now being tested at AFCRL. This equipment employs common T and R with two fan beams of 1° azimuth beam width and about 20° in elevation. The set operates at X-band with an output power of some 50 watts. IF amplification is used with a local oscillator that holds the signals roughly within the IF band pass of the receiver. After detection, the signal is beat up to the neighborhood of 70 kc and passed through a bank of filters. These filters are a set of magnetostriction rods which are driven magnetically, and the output is detected acoustically. The filters are

*"3 cm 60° Vertical Scanner," J. S. Foster, Radiation Laboratory, McGill University, 22 March 1951.

sampled by a rotating tube leading to a crystal detector. The data are presented on a PPI type display, with radial deflections being proportional to velocity. Ranges of approximately 10 miles have been consistently obtained with this equipment on medium-size targets. The theoretical range of this equipment should be about twice that obtained so far, and considerable further work must be done to obtain this performance.

It is planned to place a transmitter on the Blue Hills (Massachusetts) that will have a 1° beam width in azimuth and about 45° coverage in elevation. A power of about 50 watts at X-band will be used. A receiving fan beam (1° x 45°) antenna is installed on top of the Laboratories of AFCRL. This will give range data using a separated system, and will furnish data on the problem of side-lobe response. A sample of the transmitted power for reference will be relayed from the transmitter to the receiver by the use of 2 small dishes. This has already been accomplished and no difficulties were experienced. The problem of suitable filtering for ground-clutter and rain-storm rejection will also be studied.

The initial display will be a distorted B-type scan. Coordinate position will be calculated by the use of diode matrices.

F. CONCLUSIONS AND RECOMMENDATIONS

1. Systems

a. Separated T and R

Because of the reduction in effect of ground clutter and coupled transmitter noise, and because of the absence of velocity blind zones which occur with pulsed Doppler equipments, it is recommended that the systems work on separated T and R be continued.

b. Gap-Filler System

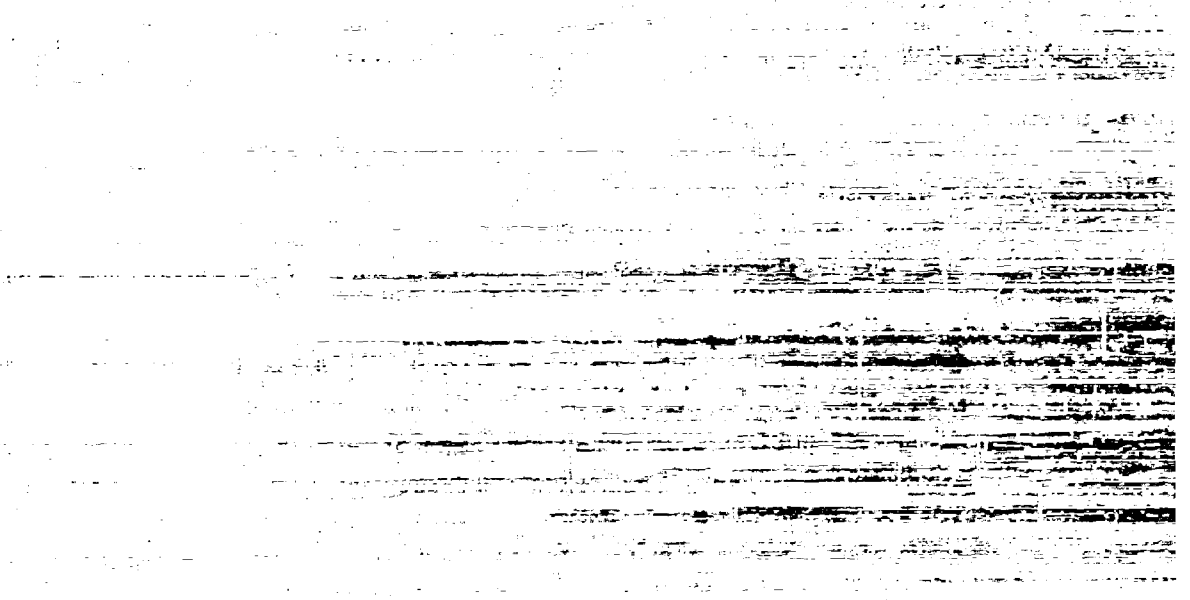
Because of the slow scanning speeds possible in this application, and the consequent reduction in complexity of equipment, together with the use of L-band with its freedom from velocity null zones and greatly reduced scatter from rain, the use of a type of gap-filler system should receive serious consideration.

2. Components

a. Work should continue on the production of higher power CW sources with low transmitter noise, and on the development of stable pulsed amplifiers that are free from frequency modulation.

b. Continued investigation of the multiple filters for analysis of the Doppler spectrum and the reduction of noise bandwidth is also recommended.

Committee A
(G. E. Valley, Chairman)



APPENDIX IV-5

COST ESTIMATES FOR A CENTRALIZED AC&W SYSTEM

APPENDIX IV-5
COST ESTIMATES FOR A CENTRALIZED AC & W SYSTEM

The following estimates cover those parts of the data-gathering, data-processing, and data-using portions of the proposed ideal system for management of the air situation that seem to correspond to the existing radar network, thus permitting a reasonable comparison of the probable cost of the two systems. The data-gathering system is assumed to consist of a fairly large number of small radars. Measurements of plan position and of height are regarded as requiring separate radar sets. These sets may be tied together fairly intimately, or, on the other hand, there may be fewer height-measuring sets than position-measuring sets. For estimating purposes the two types of radars are assumed to be present in equal numbers, to cost equal amounts, and to be located in pairs, one of each type at a given site.

The required distribution of sites may be calculated on the basis of the low coverage required of the position-measuring set. An aircraft flying at an altitude of 500 feet may be seen out to a distance of 30 miles over a smooth earth. If the sites are arranged in a hexagonal lattice, an area of 2300 square miles may be covered by each set without exceeding the 30-mile range anywhere. If the area per set is reduced to 1500 square miles, the maximum range required is reduced to 24 miles and the spacing between nearest neighbors becomes 42 miles. Over a smooth earth, aircraft 900 feet above one radar site would be visible from the six nearest neighbors.

The area corresponding to an average Air Division as now set up is assumed to be 150,000 square miles. On the basis of the above assumptions, 100 sites or 200 radar sets would be required for this area. The data processing for the entire area is assumed to be done by electronic digital computation, using three computers in parallel to insure reliability. A radio transmitter, VHF or UHF according to requirements at the time, is assumed to be put at every fourth site to permit sending command and other information to aircraft anywhere in the area.

A. ESTIMATE OF CAPITAL EXPENSE

1. Radar and Radio

It is assumed that the ASR-3, which is the current airport surveillance pulse radar, is similar in general characteristics to what we want. This set has a 2° beam in azimuth by 45° in elevation. It is equipped with delay-line-type MTI, and all its electronic components have standby duplicates. In small lots as presently made by Bendix, the installed cost, including tower and spare parts is $90,000. We allow $60,000 extra at each site for a watchman's shanty, a rough road suitable for a jeep up to 1/2 mile long, a latrine and other facilities needed by a now-resident watchman. It is assumed that special terminal equipment needed will be compensated by the lack of presentation scopes.

We then have a capital expenditure for radar stations of

$$100 \times \$240,000 = \$24,000,000.$$

In addition, at every fourth station* we shall install a powerful radio transmitter in order to talk to the fighters at low altitude. These sets are estimated to cost $25,000 each. We then have $25 \times \$25,000 = \$625,000$ for radio. Then the total cost of the radar and radio is $24,625,000.

For comparison, a 9-radar air division at present costs $9 \times \$3.5 \times 10^6$ per radar station, or $31,500,000. This includes GCI and living quarters which we don't need for the centralized system.

2. Command Center

We assume 3 computers running in parallel in separate bomb shelters for safety. These are taken to cost $3,000,000 each. In addition, we assume facilities for 600 men at $5,000,000. Total for Command Center: $14,000,000.

For comparison, the present ADCC installations cost about $3,000,000.

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*The arrangement of radio transmitters would provide solid line-of-sight coverage for aircraft at any altitude above about 1200 feet. It is assumed that an interceptor would not need to fly below this altitude for long periods, even when seeking a very low-flying target. Provision of a radio transmitter at every site, instead of at every fourth, would increase the total cost only slightly, and would add only a modest amount of complication to the operation of the system.

TABLE IV-5-1 Costs of Present vs. Proposed Systems

PRESENT SYSTEM		PROPOSED CENTRALIZED SYSTEM	
CAPITAL COSTS	Millions	CAPITAL COSTS	Millions
Radar and radio	$31.500	Radar and radio	$24.625
Command Center	3.000	Command Center	14.000
Total	$34.500	Total	$38.625
OPERATING COSTS		OPERATING COSTS	
Yearly cost (9-station air division):		Yearly cost (4 yr. amortization):	
9 radars and facilities ($31.5 \times 10^6/4$)	$ 8.000	Capital costs/4	$ 9.700
Plus spares at 10	.800	Replacement and parts at 10%	1.000
1 ADCC at $3 \times 10^6/4$	.750		
Total	$ 9.550	Total	$10.700
Personnel:		Personnel:	
200 officers at $12,000	$ 3.000	One civilian watchman 24 hr./day at $5,000 plus one civilian technician 8 hr./day, per radar station:	
2000 enlisted men at $4,000	8.000	100 sta. × 4 watchmen × $5,000	$ 2.000
		100 sta. × 1 technician × $10,000	1.000
		Overhead at 100%	3.000
		600 milit. at $7,000, incl. overhead	4.200
		Tech. staff, incl. overhead	.500
Total Salaries	$11.000	Total salaries plus overhead	$10.700
Communications:		Communications:	
		200 prog. channels $120/mi./yr. mean length 200 mi.; 200 · 120 · 200	$ 4.800
		25 2-way voice channels for radio at 120/mi./yr. of average length 200 mi. 25 × 120 × 200	.600
		For each ADCC, 1600 mi. approx. 10 kc channels at $1,000/mi./yr.	1.600
Total Communications Facilities	$ 1.000	Total Communications Facilities	$ 7.000
Total Present Air Division Cost	$21.550	Total Recurring Cost Incl. Amortiz.	$28.400

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Thus it is seen that within the limits of estimate error there is no difference in costs of the two systems (see Table IV-5-1). In addition, the centralized system estimate is regarded as pessimistic with regard to ultimate radar cost and number of radar technicians needed.

The height-finding function should perhaps be discussed in somewhat more detail in order to justify the estimating procedure used above. The following factors must be considered.

(a) It must be possible to measure height by means not involving the cooperation of the aircraft.

(b) It may be desirable in some cases to utilize information furnished by the aircraft (e.g., interceptors under close control may send down their altitude on the return data link that seems to be wanted for monitoring the whole control process).

(c) In general, aircraft do not change altitude nearly so rapidly as they do position.

(d) It may be possible to establish a boundary at some medium-low altitude, say 5000 feet, below which height is not measured, by radar at least. Such a division seems reasonable for weapons control when the types likely to be used at various altitudes are considered.

Over and above these factors is the fundamental condition that data-rate and time-on-target requirements cannot be met by a single radar set attempting to measure both plan position and height. Two types of radar are therefore needed, although the two types may look much alike, as in the V-beam. Because of possible ambiguity in data output, the V-beam principle seems less attractive than the use of a nodding-beam or beaver-tail height-finder. The height-finder may be arranged to slew to a particular azimuth on command from the central data-processing unit and to send back the signals so gathered, permitting the computer to calculate the altitude of some one aircraft that is momentarily of particular interest. For such operation, there is no apparent reason why the height finders should be any closer together than the position-measuring radars; in fact, they might be spaced somewhat further apart if the measurement of low altitudes is minimized. Therefore, the assumption made at the beginning that the two types of radar are equally numerous is a conservative assumption for this type of operation. On the other hand, it may be possible to have a separate height finder continuously rotating at each site, arranged somewhat as follows.

Suppose one is designing a radar to be built especially for the centralized system, with all the freedom to pick characteristics that is so implied. Suppose, furthermore, that a pulse-type radar is contemplated. Pickup of aircraft at low altitudes, perhaps below 5000 feet, will require a good MTI scheme. Any MTI system requires the radar beam to stay on the target for at least a definitely calculable time; for usual pulse radars, this time corresponds to about 15 or 20 pulses hitting the target. The radar antenna must then scan the low-altitude region slowly. The information-rate requirements of the whole system set an upper limit to the whole scan time of perhaps fifteen seconds. These two requirements can be harmonized if one beam of the radar scans only this low-altitude region and takes the full 15 seconds for one revolution of 360° in azimuth. The region of space above 5000 feet altitude must now be covered in some other way. Suppose that a height-finder akin to the one used on the SX radar be mounted on the same antenna structure, and that it be arranged to cover the region from 5° to 40° in elevation angle, with a beam width of 4°. It can then cover this entire region of space with two pulses per target if the azimuth scan is such as to put 18 pulses on the target from the horizontal beam. For a random flight, an aircraft is within 12 miles horizontal range from some one of the radars for one-third of the time. At this range, the elevation angle of 5° corresponds to an altitude of 5500 feet. Therefore, the combination of the horizontal beam with MTI and the nodding beam should detect aircraft at all altitudes and should measure altitude on the average at least one-third of the time for all aircraft above 5000 feet.

This characteristic altitude of 5000 feet has emerged as a natural result of the spacing postulated for the radar stations. The requirements of MTI, and the parameters assumed for beam width of the height finder; thus it may be taken as illustrative of what such a system can do. It now becomes of interest to inquire whether such performance is useful. For the maintenance of tracks on aircraft, it seems intuitively that it should suffice, though this question should be examined in more detail. For use in directing weapons to intercept hostile planes, it again seems intuitively that such performance might well do, since there is a natural division between weapons effective at low altitude and at high altitude, and it is the high-altitude weapons that require the height information.

Finally, we must ask what effect the use of height information sent down from the aircraft will have on the rest of the system. The requirement that the data-processing unit be able to accept information from any available source ensures that this type of operation is possible without any significant change in computer design. Therefore, the only effect is to reduce the burden on the height-finder radars, and thus make more practical the scheme of measuring height only on demand.

Committee A
(G. E. Valley, Chairman)

APPENDIX IV-6

CAPACITY OF A DIGITAL COMPUTER FOR PROCESSING AIR DEFENSE DATA

APPENDIX IV-6

CAPACITY OF A DIGITAL COMPUTER FOR PROCESSING AIR DEFENSE DATA

SUMMARY

A rough analysis is given of the problem of processing, by digital computer, reports on 1000 targets received from 70 radars. As a basis for discussion, the capacity and machine design are given on the basis of the present WHIRLWIND computer at MIT, with changes that might be made in such a design. It appears that, by the addition of auxiliary drums and special operations to facilitate sorting and coordinate conversion, a WHIRLWIND-type computer should be able to handle the problem, including interception calculation, within a 15-second scan time.

The following comments are based on a brief analysis made in May, 1951, by Forrester and Everett at the MIT Servomechanisms Laboratory. A memorandum by von Neumann has also shown a similar ultimate capacity, but using different assumptions and techniques.

If a general-purpose computer, such as WHIRLWIND, is to correlate many reports with many targets (about 1000 each), the comparisons should not be made brute force but should be done on a presort basis. An area basis seems most reasonable.

The incoming data are already on an area basis (by radars). The targets must be kept on an area basis by some form of sorting procedure.

Considering a problem of 1000 targets, 70 radars with overlapping coverage, and a 15-second scan rate, we get roughly:

2000 reports due to overlapping coverage;

+ 25 per cent for height finding;

+ an unestimable amount of clutter;

+ a small amount of other noise;

or, say, perhaps 2500 reports in 15 seconds, or about 6 milliseconds per report. This report must be:

a. Converted to x, y with a fixed reference;

b. Correlated with 1000 targets;

c. In about one-half the cases, a smoothing prediction made;

d. A possible resorting made;

e. In 20 per cent of the cases, an interception prediction made;

f. New targets and missed targets cared for;

g. Various displays generated.

Assuming automatic acquisition, a large amount of clutter rejection must be made at the radar. The remaining clutter must be tracked, and is therefore part of the target complement.

At present WHIRLWIND speeds, 6 milliseconds allows for 120 single-address machine operations and, at the ultimate design speed, 300 operations. Either would be inadequate if the machine were restricted to presently defined orders, but this need not be done.

An interpolation converter which would be a modification in the present type of arithmetic element would permit direct polar-to-rectangular coordinate conversion at considerable time saving.

Another operation, basic to handling radar information, is comparison of the proximity or closeness of two sets of x,y positions. A special computing order, combining some arithmetic and logical steps, would be valuable in this frequent operation.

Preliminary sorting of radar and target information by strip or area according to one of the alternatives given by Everett* would reduce the amount of correlation time in the computer. His rough analysis leads to the following time estimates for a computer with the above special operations, using a magnetic drum for storing most information while it is not being processed by the computer.

*"Air Intercept Using a Whirlwind-Type Computer," Robert R. Everett, MIT Servomechanisms Laboratory, Report E-2022, May 25, 1951.

(1) Time per target being tracked:		
(a) To remove from the drum	500 μsec	
(b) To return to the drum	500 μsec	
(c) To correlate	2000 μsec	
(d) To predict (may be more)	3000 μsec	
	6 milliseconds	
Time for 100 targets		6.0 sec
(2) Time for radar data:		
(a) To transfer and convert (per report, 50 μsec) 2500 reports		0.125 sec
(b) Drum waiting time		0.375 sec
(3) Time for interception calculations:		
(a) Scan drum for 500 interceptors (50 milliseconds per 100 interceptors)		0.250 sec
(b) Scan the tabulation to convert target numbers to drum numbers		0.250 sec
(c) Scan the drum for targets		0.500 sec
(d) Compute 500 interceptions		2.5 sec
Total		10.0 sec

This is two-thirds of the 15-second radar scan interval that is assumed.

Nothing has been said yet about height information. The correlation should be roughly the same – maybe in x, y and z, with a larger x,y box. The smoothing prediction, etc., will be in z only. The time consumed should be negligible.

The above are estimates that should be correct within a factor of two for the operations indicated. Additional machine time will be needed for other information-processing tasks and for displaying information. The estimates show that the capacity of presently existing machines is the right order of magnitude. Only a detailed study will show precisely what compromises in formulating the problem and what other special machine features will be needed to create an exact match between the job and the equipment.

Jay W. Forrester

APPENDIX IV-7

MARGINAL CHECKING AND DIGITAL COMPUTER RELIABILITY

APPENDIX IV-7

MARGINAL CHECKING AND DIGITAL COMPUTER RELIABILITY

Recent results from operation of digital computers are overcoming a general impression of unreliability that has existed for the last few years. Very encouraging reliability has been shown by recent records of the WHIRLWIND computer at MIT and the SEAC computer at the Bureau of Standards in Washington.

Recent research into methods of obtaining electronic reliability – especially the "marginal checking" procedures used with the WHIRLWIND machine at MIT – show that powerful tools are available for improving reliability of electronic equipment. Still better performance than already demonstrated should be realizable.

Marginal checking is a technique for detecting the deterioration in the performance of electronic circuitry before the failure threshold is reached. In the WHIRLWIND computer, it has permitted the replacement of approximately 75 per cent of the aging and deteriorating components before they have reached the point of causing their first failures. It is a technique that can be applied to most electronic equipment. It is effective against those electronic failures that result from gradual changes in component performance – changing vacuum tube characteristics, decreasing crystal diode back resistance, changes in resistor value, etc.

About 75 per cent of the electronic faults in WHIRLWIND computer have been in this category. The remaining 25 per cent are mechanical intermittents, such as open and short circuits, and defects which do not lend themselves to marginal checking.

Marginal checking consists of placing a few circuits of the machine at a time under unfavorable operating conditions while at the same time running check problems to verify satisfactory performances. The test thereby demonstrates that the circuit has a safety margin between its operating point and the point where failure would occur.*

*Norman H. Taylor, "Marginal Checking as an Aid to Computer Reliability," Proc. IRE, Vol. 38, No. 12 (Dec. 1950).

The WHIRLWIND computer during the summer of 1951, approximately six months after it was put in operation, is being assigned for 35 hours per week to application groups who wish to use it as a tool. The time is scheduled a week ahead and assigned hour by hour to various activities. Approximately 90 per cent of this time has represented trouble-free operation of the machine. This is in spite of the fact that 20 hours per week of new installation work keeps the computer in a constant state of change, which is in itself a hazard to trouble-free operation.

Jay W. Forrester

APPENDIX V-1

MILITARY USE OF PASSIVE INFRARED
(Wavelengths Larger Than 2μ)

APPENDIX V-1

MILITARY USE OF PASSIVE INFRARED
(Wavelengths Larger Than 2μ)

A. INTRODUCTION

The evolution of useful military infrared equipment in this country is far behind the stage where it could be; and the evolution of military infrared equipment is probably much further advanced in the Soviet Union than it is in this country. Our failure to exploit infrared equipment to best advantage has lost to us an important military advantage which the Soviets can and probably do have.* Moreover, our failure to realize the capability of infrared has led us to neglect consideration of infrared output in the design of such military vehicles as tanks, aircraft, etc., which makes it all the easier for the Soviets to exploit their probable superiority in infrared equipment.

A major criticism of our present infrared program is that formulas concerning signal-to-noise ratio are not paid their due attention. This remark applies to the design of equipment, to the writing of performance specifications, to the applications chosen for infrared, and to our data-gathering programs.

Rather good progress has been made during the past decade in the development of infrared components. Resistance bolometers, thermocouples, the pneumatic heat detector, and the lead sulfide cell are available in quantity and with consistent performance. The properties of these cells are well understood and mathematically classified. Infrared transmitting materials are available, and methods of forming them into optical components have been developed. High-performance optical systems using these materials and concave mirrors have been designed and constructed. In general, we have electronic circuits well adapted to amplifying the output of the infrared-sensitive elements.

The separate components – detector, optical system, amplifying circuit – must be assembled to form an infrared detecting system. The characteristics of the separate components must be chosen not independently but with a view to

*Many of the best German infrared scientists have been "captured" by the Soviet Union.

how they combine with each other to give the over-all performance characteristic of the complete system. Perhaps even more important, the over-all system must be specifically fitted in detail to the job to be done. Finally, no performance specification that is not absolutely essential must be permitted to interfere with good system design.

The preceding paragraph appears obvious to the point of triviality, but its contents cannot be too heavily emphasized. Failure to pay intimate attention to the details of system design and specification may degrade performance 50 db, or even nearly 100 db in some cases.

It is believed that no comprehensive theoretical treatment of signal-to-noise ratios in infrared scanning systems is commonly in use, or even available in the literature. The following several sections present such a treatment in some detail.

B. THE SIGNAL-TO-NOISE RATIO OF AN INFRARED SCANNING SYSTEM

The problem of extracting a function $f(x)$ from the function $f(x)+g(x)$, where f and g are respectively "signal" and "noise" functions of the unidimensional variable x, has received thorough treatment. This is the problem of filter design in communication theory.

A similar problem exists in the design of an infrared scanning system. However, the problem is more complex for several reasons. Particular among these are the following.

(1) There are two types of noise -- dark noise and background noise; in general, reduction of the one is incompatible with reduction of the other.

(2) The signal and the background noise are functions of multidimensional variables.

Filter design in the unidimensional problem is simplified by the use of Fourier integral theory. The Fourier integral theory simplifies filter design by substituting the multiplication of characteristic functions for multiple integration. Similar simplification is possible to the multidimensional case. In outline, the procedure is as follows.

The signal f, a function of the m-dimensional variable $\vec{x}$ where $\vec{x}=(x_1,\ldots,x_m)$ is represented by its characteristic function F, a function of the m-dimensional "frequency" $\vec{\omega}$, where $\vec{\omega}=(\omega_1,\ldots,\omega_m)$.

The noise function g has an m-dimensional correlation function ϕ, a function of $\vec{p}=(p_1,\ldots,p_m)$. The function $\phi(\vec{p})$ has a frequency spectrum $n(\vec{\omega})$.

The scanning process, the defects of the image-forming system, the electronic filter that operates upon the output of the infrared-sensitive element, and the frequency response of the sensitive element – all are expressible as filter functions of the m-dimensional variable $\vec{x}$, which have characteristic functions of the m-dimensional frequency $\vec{\omega}$. Thereafter, the usual unidimensional treatment is applicable.

There remains the complication that maximization of the signal-to-dark noise and maximization of signal-to-background noise are incompatible. For any particular type of scanning system, and of target and background frequency spectra, there result two equations, one for $(S/N)_i$, the signal-to-dark-noise ratio, and one for $(S/N)_b$, the signal-to-background-noise ratio. The manner of choosing parameters that are incompatible to maximization of both $(S/N)_i$ and $(S/N)_b$ will be discussed in further paragraphs.

The theorems and equations used in unidimensional filter design are given below. The corresponding m-dimensional equations follow the unidimensional equations, with equation number primed.

$$F(\omega) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(i\omega x)\, f(x)\, dx. \qquad (1)$$

$$F(\vec{\omega}) = (2\pi)^{-\frac{m}{2}} \int_{-\infty}^{\infty} \exp(i\vec{\omega}\cdot\vec{x})\, f(\vec{x})\, d\vec{x}, \qquad (1')$$

where

$$\vec{\omega}\cdot\vec{x} = \omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_m x_m;$$

and

$$d\vec{x} = dx_1\, dx_2 \cdots dx_m.$$

$$f(x) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(-i\omega x)\, F(\omega)\, d\omega. \qquad (2)$$

$$f(\vec{x}) = (2\pi)^{-\frac{m}{2}} \int_{-\infty}^{\infty} \exp(-i\vec{\omega}\cdot\vec{x}) F(\vec{\omega})\, d\vec{\omega}. \tag{2'}$$

$$\varphi_g(\rho) = \lim_{a\to\infty} \frac{1}{a} \int_{-\frac{a}{2}}^{\frac{a}{2}} g(x) g(x+\rho)\, dx. \tag{3}$$

$$\varphi_g(\vec{\rho}) = \lim_{a\to\infty} \left(\frac{1}{a}\right)^m \int_{-\frac{a}{2}}^{\frac{a}{2}} \cdots \int_{-\frac{a}{2}}^{\frac{a}{2}} g(\vec{x})\, g(\vec{x}+\vec{\rho})\, d\vec{x}. \tag{3'}$$

$$\eta_g(\omega) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(i\omega\rho)\, \varphi_g(\rho)\, d\rho. \tag{4}$$

$$\eta_g(\vec{\omega}) = (2\pi)^{-\frac{m}{2}} \int_{-\infty}^{\infty} \exp(i\vec{\omega}\cdot\vec{\rho})\, \varphi_g(\vec{\rho})\, d\vec{\rho}. \tag{4'}$$

$$\varphi_g(\rho) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(-i\omega\rho)\, \eta_g(\omega)\, d\omega. \tag{5}$$

$$\varphi_g(\vec{\rho}) = (2\pi)^{-\frac{m}{2}} \int_{-\infty}^{\infty} \exp(-i\vec{\omega}\cdot\vec{\rho})\, \eta_g(\vec{\omega})\, d\vec{\omega} \tag{5'}$$

$$(2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \eta_g(\omega)\, d\omega = \lim_{a\to\infty} \frac{1}{a} \int_{-\frac{a}{2}}^{\frac{a}{2}} [g(x)]^2\, dx. \tag{6}$$

$$(2\pi)^{-\frac{m}{2}} \int_{-\infty}^{\infty} \eta_g(\vec{\omega})\, d\vec{\omega} = \lim_{a\to\infty} \left(\frac{1}{a}\right)^m \int_{-\frac{a}{2}}^{\frac{a}{2}} \cdots \int_{-\frac{a}{2}}^{\frac{a}{2}} [g(\vec{x})]^2\, d\vec{x}. \tag{6'}$$

A filter function b(y) is defined as an operator on f such that b is real-valued and obeys Eq. (7).

$$b \oplus f(x) = \int_{-\infty}^{\infty} f(x-y)\, b(y)\, dy. \tag{7}$$

$$b \oplus f(\vec{x}) = \int_{-\infty}^{\infty} f(\vec{x} - \vec{y})\, b(\vec{y})\, d\vec{y}. \tag{7'}$$

Define $B(\omega)$ and $B(\vec{\omega})$ by Eqs. (8) and (8').

$$B(\omega) = \int_{-\infty}^{\infty} \exp(i\omega y)\, b(y)\, d(y). \tag{8}$$

$$B(\vec{\omega}) = \int_{-\infty}^{\infty} \exp(i\,\vec{\omega}\cdot\vec{y})\, b(\vec{y})\, d\vec{y}. \tag{8'}$$

Then

$$\eta_{b\oplus g}(\omega) = B(\omega)\,\bar{B}(\omega)\,\eta_g(\omega). \tag{9}$$

$$\eta_{b\oplus g}(\vec{\omega}) = B(\vec{\omega})\,\bar{B}(\vec{\omega})\,\eta_g(\vec{\omega}). \tag{9'}$$

$$\varphi_{b\oplus g}(\omega) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \eta_{b\oplus g}(\omega)\, d\omega. \tag{10}$$

$$\varphi_{b\oplus g}(\vec{\omega}) = (2\pi)^{-\frac{n}{2}} \int_{-\infty}^{\infty} \eta_{b\oplus g}(\vec{\omega})\, d\vec{\omega}. \tag{10'}$$

$$b\oplus f(x) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(-i\omega x)\, B(\omega)\, F(\omega)\, d\omega. \tag{11}$$

$$b\oplus f(\vec{x}) = (2\pi)^{-\frac{n}{2}} \int_{-\infty}^{\infty} \exp(-i\,\vec{\omega}\cdot\vec{x})\, B(\vec{\omega})\, F(\vec{\omega})\, d\vec{\omega}. \tag{11'}$$

From Eqs. (1') through (10'), it follows that the best mean-square filter for detecting $f(\vec{x})$ in the presence of $f(\vec{x})+g(\vec{x})$ is $b(\vec{y})$, such that

$$B(\vec{\omega}) = \frac{\bar{F}(\vec{\omega})}{\eta_g(\vec{\omega})}. \tag{12}$$

If Eq. (12) is satisfied, the ratio of peak "signal power" divided by the mean "noise power" is equal to

$$\max\left(\frac{S}{N}\right)_b = \int_{-\infty}^{\infty} \frac{F(\vec{\omega})\,\overline{F(\vec{\omega})}}{\eta_g(\vec{\omega})}\,d\omega \,. \qquad (13)$$

The value of max $(S/N)_b$ determines whether or not f is detectable in the presence of g. In addition to the question of whether or not f is detectable, there is the problem of how nearly the prescribed function b may be realized in practice.

C. TWO-DIMENSIONAL FILTERS

The simplest form of two-dimensional filter is generated by scanning a plane (x_1, x_2) with a transmission function $b_t(y_1, y_2)$. At any time t, the filter point (y_1, y_2) is superposed on the point $(a_1 + d_1 t, a_2 + d_2 t)$ in the (x_1, x_2) plane. The transmission function b may assume any value between plus and minus unity. (Negative values may be realized by using two sensitive elements whose outputs are combined in opposition).

It is seen that $b_t(y_1, y_2)$ satisfies the condition expressed by Eq. (7') for a filter, and that

$$B_t(\omega_1, \omega_2) = \int_{-\infty}^{\infty} \exp[i(\omega_1 y_1 + \omega_2 y_2)]\, b_t(y_1, y_2)\, dy_1\, dy_2 \,.$$

It is also seen that such a scanning process examines, in the manner expressed by Eq. (7), only those points in the (x, y) plane upon which the point $\vec{y} = (0, 0)$ is at some time superposed. This presents a third general difference between unidimensional and m-dimensional filters. In the unidimensional case, there is no problem of examining the entire interval $x_\omega \leqq x \leqq x_b$. In the m-dimensional case, we can examine only those points of the function $b_t \circledast f(\vec{x})$ which lie on some line drawn through m-space. Thus the filter must not only distinguish between signal and noise, it must also "smear out" the function f into the function $b \circledast f(\vec{x})$; the degree of "smearing out" that is necessary depends upon how close successive scanning traces may lie. This imposes a restriction upon choice of b_t. We now have $f(x_1, x_2)$ filtered to the function $b_t \circledast f(x_1, x_2)$. The output of the sensitive element is operated upon by the function $b(\tau)$ where $b(\tau)$ is derived from the response characteristics of the sensitive element and of the amplifier. For simplicity of notation, suppose that scanning motion is

expressible as a-motion parallel to the x_2 axis – that is, d_2 above is zero. The sensitive element and amplifier have b(τ) such that

$$B(\omega) = \int_{-\infty}^{\infty} \exp(i\omega t)\, b(\tau)\, d(\tau) \qquad (14)$$

But

$$y = a_1 + a_1' \tau,$$

hence $b(\tau)$ transforms $b_t \otimes f(\vec{x})$ into $b_a \otimes b_t \otimes f(\vec{x})$ where

$$B_a(\omega_1, \omega_2) = B_a(\omega_1) = B(\omega_1, a_1'), \qquad (15)$$

and

$$b_a \otimes b_t \otimes f(\vec{x}) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{\infty} \exp(-i\vec{\omega}\cdot\vec{x})\, B_a(\vec{\omega})\, E_t(\vec{\omega})\, F(\vec{\omega})\, d\vec{\omega}. \qquad (16)$$

D. DARK NOISE

The infrared-sensitive element may be considered to be followed by an equalizing circuit such that the spectrum of the noise generated within the sensitive element is flat after passage through the equalizing circuit. We shall find it convenient to speak of the sensitive element plus equalizing circuit; when sensitive-element response is treated below, the response of sensitive element plus equalizing circuit is to be understood.

We shall find it convenient to assume that the amplifier that follows the equalized sensitive element may adequately be described as having a peak response at frequency ω, with noise-equivalent passband of width $\Delta\omega$ centered on ω. Many types of circuits may be so treated with essentially no loss of accuracy. It is quite possible that scanning procedures may be invented which will require electronic circuits that cannot be so treated; if so, these scanning procedures are not embraced by the treatment that follows.

Resistance bolometers, thermocouples, and lead sulfide cells are characterized by the general property that, given a frequency ω, and given the width h and length ℓ of the sensitive element, the response R of the equalized sensitive element in volts per watt to radiations modulated at frequency ω, divided by the rms noise per unit bandwidth $\sqrt{N_1}$ may be made equal to

$$\frac{R}{\sqrt{N_i}} = \frac{D}{\sqrt{lh}} \frac{1}{\sqrt{\omega}} \qquad (17)$$

The constant K depends upon the type of sensitive element considered. Equation (17) represents the maximum value of $R/\sqrt{N_i}$ that can be attained. There are certain regions of l, h and ω for which the value of $R/\sqrt{N_i}$ given by Eq. (17) is too large. These are:

(1) $$\frac{R}{\sqrt{N_i}} = \frac{K}{\sqrt{lh}} \frac{\sqrt{\omega}}{\sqrt{\omega_p}}$$

for PbS cells, when $\omega<\omega_p$. The value of ω_p is about 2500 radians per second.

(2) $$\frac{R}{\sqrt{N_i}} = \frac{K}{\sqrt{lh}} \frac{1}{\sqrt{\omega}} \frac{\sqrt{\omega_b}}{\sqrt{\omega}}$$

for resistance bolometers and thermocouples when $\omega>\omega_b$. The value of ω_b is about 500 radians per second.

(3) $$\frac{R}{\sqrt{N_i}} = \frac{K}{\sqrt{l_o}\sqrt{h}} \frac{1}{\sqrt{\omega}}$$

for resistance bolometers and thermocouples when $l<l_o$. The value of l_o is a millimeter or two.

Equation (17), together with the three exceptions listed above, permits evaluation of signal to dark noise. It should be noted, furthermore, that resistance bolometers and thermocouples must be constructed (time constant selected) in accordance with ω, otherwise $R/\sqrt{N_i}$ will be less than given by Eq. (17). On the other hand, a given PbS cell serves for any value of ω.

E. SIMPLE RECTILINEAR SCANNING PROCESS

Signal to background noise and signal to internal noise will now be treated for simple rectilinear scanning systems. A simple rectilinear scanning system is defined as follows. The sensitive element array forms a rectangular pattern of dimension $l \times h$ as shown in Fig. 1. The field is scanned by moving the pattern parallel to one of the sides of the rectangle, presumably parallel to the short side. If the long dimension of the pattern is less than the parallel dimension of the field to be scanned, progressive sweeps are necessary to scan the

field. The rectangle may give unit response over its entire area, or it may "cut up", as in either Fig. 2 or Fig. 3.

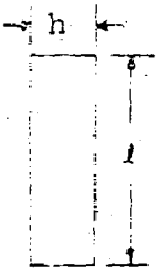


Fig. 1

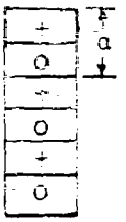


Fig. 2

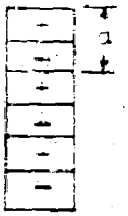


Fig. 3

Areas designated "+", "0", or "-" indicate the sign of the electronic response to radiation falling on the area indicated. Negative response may be realized by using two elements whose outputs are combined in opposition. The effect of a dividing line crossing the target image must be removed by causing the pattern indicated in Figs. 2 and 3 to progress with time, as indicated in Fig. 4. At least one complete cycle of the chop indicated in Fig. 4 must

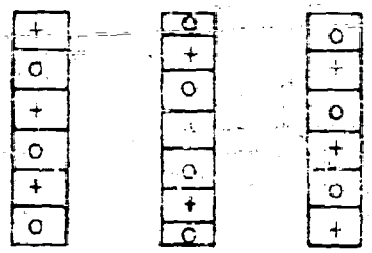


Fig. 4

transpire while the pattern is moved laterally by a distance h. The pattern of Fig. 2 may be chopped as indicated in Fig. 4 merely by placing a "squirrel cage" chopper in front of the sensitive element. The pattern of Fig. 3 may be chopped by using a squirrel cage chopper whose bars are reflecting surfaces; the reflected light is collected and focused into a sensitive element whose output is combined in opposition to that of the cell that receives transmitted radiation. The sensitive-element pattern forms the two-dimensional filter $b_t(\vec{x})$. The "bandwidth" of this filter in the (ω_1, ω_2) plane is inversely proportional to the area *hl*. The position in the plane at which the band pass occurs depends upon whether the rectangle has constant response over its entire area, or is chopped as in Fig. 2 or Fig. 3.

If the sensitive element gives constant response over its entire area, the frequency area passed in the (ω_1, ω_2) plane is rectangular in shape, centered at the point (0, 0) and of dimensions proportional to $1/h$ and $1/\ell$. If the Fig. 3 chop is used, this rectangle is split at the point (0, 0) and the two halves moved outward from the origin, along the ω_2 axis, until the centers of the separate halves are at the points $\omega_2 = \pm(1/2\pi a)$. In the case of a Fig. 2 chop, the frequency area passed is one-half the sum of those for Figs. 1 and 2. See Figs. 5, 6, 7.

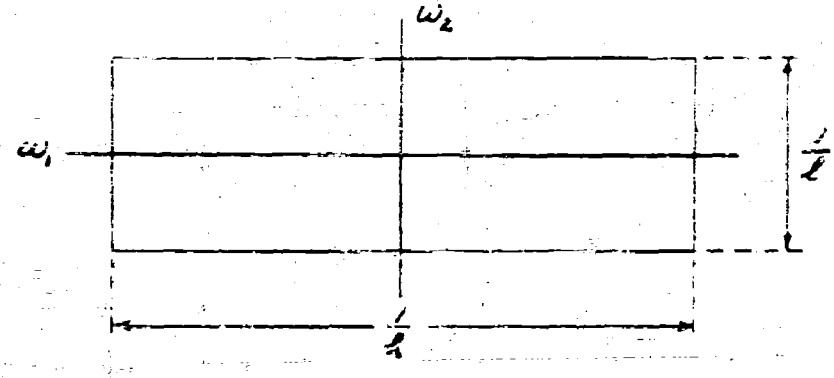


Fig. 5 - Corresponds to constant response over entire sensitive element. Frequencies passed in the (ω_1, ω_2) plane.

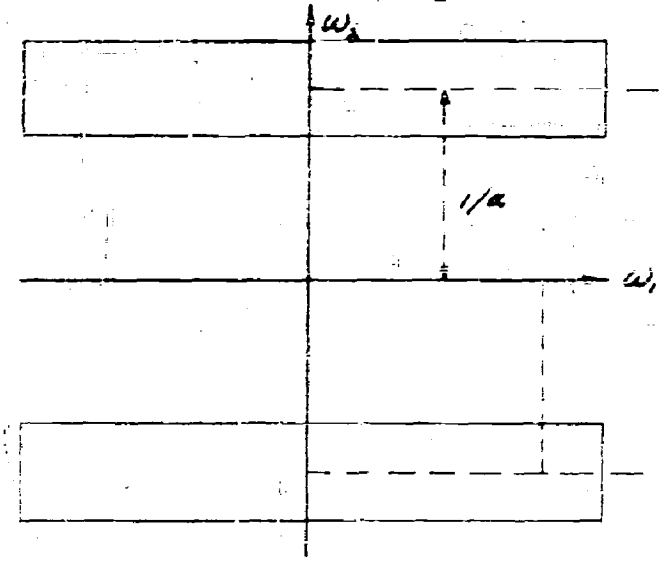


Fig. 6 - Corresponds to chop shown in Fig. 3. Frequencies passed in (ω_1, ω_2) plane.

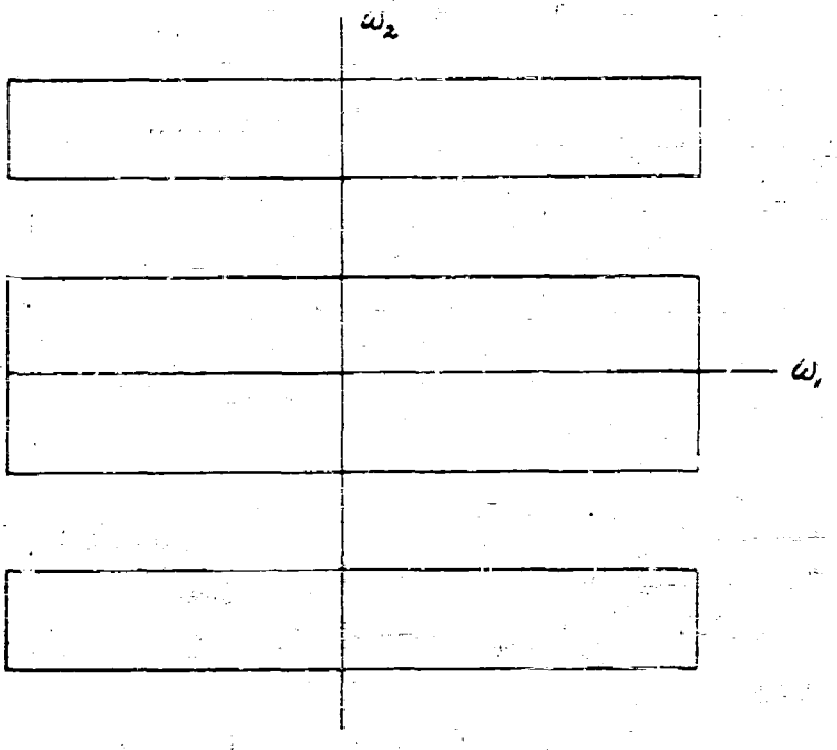


Fig. 7 - Corresponds to chop shown in Fig. 2. Frequencies passed in (ω_1, ω_2) plane.

The rectangle centered on (0, 0) in Fig. 7 may be rejected by the electronic circuit if the time for one chop cycle, τ_c, is short compared with the time τ_h to move the pattern the distance h. This is done by tuning the electronic circuit to the frequency of chop. The rejection factor for the central rectangle is τ_h/τ_c.

Suppose now that the target image is small compared with h, l and a. Suppose further that the background noise is due to large blobs, such as clouds, gradients, horizon, etc. Then the target will give amplitude vs. frequency distributions in the (ω_1, ω_2) plane that are flat throughout the areas depicted in Figs. 5, 6, 7. The noise spectrum will not be flat, but will have amplitude in the (ω_1, ω_2) plane which essentially is inversely proportional to distance from the (ω_1, ω_2) origin. Then we have:

(1) Signal to background noise ratio is proportional to l/h for Fig. 1 scan;

(2) Signal to background noise is proportional to $l/a\sqrt{lk}$ for Fig. 3 scan;

(3) Signal to background noise is proportional to $1/\alpha\sqrt{\ell k}$ for Fig. 2 scan, provided $\tau_k/\tau_c \geq k/\alpha$

Thus we see that to obtain good signal-to-background noise ratio, we desire small values of ℓ, h and α. If ℓ and h (and, in the case of Fig. 6, α) are made small, then the frequency ω at which the sensitive element must respond becomes high. We now assume that Eq. (17) holds; then, if time to scan a given area is given as T, we find that

$$\frac{S}{N_i} \sim T\sqrt{\ell k}, \text{ for Fig. 1 scan.}$$

$$\frac{S}{N_i} \sim \frac{2\sqrt{2}}{\pi} T\sqrt{\ell k}, \text{ for Fig. 3 scan.}$$

$$\frac{S}{N_i} \sim \frac{\sqrt{2}}{\pi} T\sqrt{k\alpha}, \text{ for Fig. 2 scan, when } \tau_k/\tau_c = k/\alpha.$$

F. EFFECT OF SYSTEM SPECIFICATIONS ON S/N RATIOS

Suppose we let

P_t = power radiated by target,

R = range at which target is to be detected,

Q_R = transmissivity of atmosphere through distance R,

D_t = the constant of Eq. (17), for response to target radiation,

P_b = rms level of background fluctuations,

D_b = the constant of Eq. (17), for response to background radiation; target and background may radiate at different wavelengths, hence D_t need not necessarily equal D_b,

Ω = solid angle to be scanned,

d = diameter of optical system that concentrates energy into the sensitive element,

f = focal length of optical system,

T = time allowed to scan Ω once,

N = number of independent detector amplifier systems allowed,

ℓ, b and a are as used above (see Figs. 1 through 3).

Let

$$A = \frac{a}{f},$$

$$\Omega_i = \frac{\ell b}{f^2}$$

Then for a Fig. 1 scan:

$$\frac{S}{N_i} = P_t D_t \frac{Q_R}{R^2} \frac{TN}{\Omega} f A^2 \sqrt{\Omega_i}, \tag{18}$$

$$\frac{S}{N_b} = \frac{P_t D_t}{P_t D_t} \frac{Q_R}{R^2 \Omega_i} \tag{19}$$

We wish to maximize $S/\sqrt{N_i^2 + N_b^2}$; that is, to minimize $(N_b^2/S^2) + (N_i^2/S^2)$. The only quantity whose choice is doubtful is Ω_i .

$$\frac{N_b^2}{S^2} + \frac{N_i^2}{S^2} = \alpha \Omega_i^2 + \frac{\beta}{\Omega_i}$$

where

$$\alpha = \left(\frac{P_b D_b}{P_t D_t} \frac{R^2}{Q_R}\right)^2$$

$$\beta = \left(\frac{R^2 \Omega}{P_t D_t Q_R T N f A^2}\right)^2$$

$$\alpha \Omega_i^2 + \frac{\beta}{\Omega_i} = \text{a minimum},$$

whence

$$2 \alpha \Omega_i - \frac{\beta}{\Omega_i^2} = 0,$$

$$\Omega_i^3 = \frac{\beta}{2\alpha},$$

$$\Omega_i = \left(\frac{\beta}{2\alpha}\right)^{\frac{1}{3}},$$

$$2\left(\frac{\beta}{2\alpha}\right)^{\frac{1}{3}} + \frac{\beta}{\beta^{\frac{1}{3}}}(2\alpha)^{\frac{1}{3}} = \frac{N_0^2 + N_1^2}{S^2} \quad .$$

Now let H^2 be the minimum acceptable value of $S^2/(N_0^2 + N_1^2)$. Then we have the requirement

$$(\alpha^{\frac{1}{3}}\beta^{\frac{1}{3}})(2^{-\frac{1}{3}} + 2^{\frac{1}{3}}) < \frac{1}{H^2} \quad . \tag{20}$$

Substituting the values of α and β into Eq. (20),

$$\frac{R^2}{P_t D_t Q_R}(P_b D_b)^{\frac{1}{3}}\left(\frac{\Omega}{\tau N f A^2}\right)^{\frac{2}{3}}\left(\frac{1}{2^{\frac{1}{3}}} + 2^{\frac{1}{3}}\right)^{\frac{1}{2}} < \frac{1}{H} \quad . \tag{21}$$

It is perhaps more meaningful if the volume V of the optical system is used instead of the focal length f. The volume is given approximately by

$$V = d^2 f = A^2 f .$$

Then, Eq. (21) becomes

$$\frac{R^2}{P_t D_t Q_R}(P_b D_b)^{\frac{1}{3}}\left(\frac{\Omega}{\tau N}\right)^{\frac{2}{3}}\left(\frac{1}{V^2 A^4}\right)^{\frac{1}{3}}\left(\frac{1}{2^{\frac{1}{3}}} + 2^{\frac{1}{3}}\right) < \frac{1}{H} \quad . \tag{22}$$

The inequality Eq. (22) states when the target signal is, in principle, detectable. Some exceedingly startling conclusions may be drawn from Eq. (22). For example, suppose all but two of the variables in Eq. (22) are fixed. Then how does one of the free variables depend upon the other? Typical results of this sort are listed in Table V-1-1.

The constants C_1 through C_5 in the table below are as indicated by the inequality Eq. (22). This table illustrates that the maximum rms background power fluctuation that leaves the target in principle detectable is a very strong function of such specification parameters as the range at which the target must be detected, the rate of scan of solid angle, and the number of independent detecting circuits. Moreover, V is a very strong function of the range at which detection is required.

The inequalities derived for the Fig. 2- and 3-type of scan in the manner in which Eq. (22) is derived for the Fig. 1 scan are respectively 23 and 24 below.

Table V-1-1

Free variables	Mutual dependence of free variables
$R,\ P_b$	$P_b < C_1 \frac{Q_m^3}{R^6}$
$\left(\frac{\Omega_x}{TN}\right),\ P_b$	$P_b < C_2 \frac{T^2 N^2}{\Omega_x^2}$
$V,\ P_b$	$P_b < C_3 V^3$
$\left(\frac{P_t D_t Q_R}{R^2}\right),\ (P_b D_b)$	$(P_b D_b) < C_4 \left(\frac{P_t D_t Q_R}{R^2}\right)^3$
V, R	$V > C_5 R^4$

$$\left(\frac{R^2}{P_t D_t Q_R}\right)^2 \frac{P_b D_b \Omega_x \Omega_y}{TN\sqrt{2}\, A^{\frac{1}{2}} V^{\frac{1}{2}}} < \frac{1}{N^2} \qquad (23)$$

$$\left(\frac{R^2}{P_t D_t Q_R}\right)^2 \frac{P_b D_b \sqrt{\Omega_x \Omega_y}\, \Omega_y \pi\sqrt{2}}{TNA^{\frac{1}{2}} V^{\frac{1}{2}}} < \frac{1}{N^2} \qquad (24)$$

$$\Omega_x = \frac{\alpha}{f}$$

$$\Omega_y = \frac{b}{f}$$

The "double strip" scan illustrated by Fig. 8 yields an inequality similar to that given in Eq. (22) but with a smaller numerical coefficient as the left hand side of the inequality.

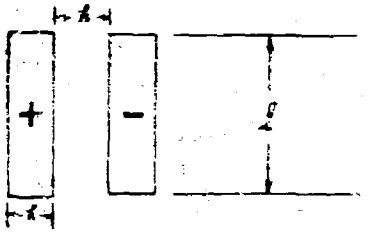


Fig. 8

The scanning systems most often employed are the Fig. 1 and Fig. 8 systems, or basically similar systems degraded somewhat for mechanical convenience. We may conclude, therefore, that Table V-1-1 is generally applicable to scanning systems conventionally employed. We note further, from a comparison of inequalities (22), (23), (24), that the Fig. 2 and Fig. 3 scanning systems are generally far superior to the Fig. 1 system.

G. RECOMMENDATIONS

1. Data-Gathering Programs

It is not possible to effect completely optimum system design, to set forth optimum system specifications, or to state with complete assurance what problems may or may not be solved by infrared, unless we have and could digest complete data on target radiations and on background radiations. It would be impossible either to acquire such data, or to digest it completely if it could be obtained. But as we progressively acquire more data and tabulate it intelligibly, we are more nearly able to realize optimum system design; and we are more nearly able to state with complete assurance what are fruitful applications of infrared (i.e., when an inequality such as Eq. (22), (23), or (24) may be satisfied).

At present, we encounter a considerable realm of uncertainty if we attempt to tabulate the infrared output of military targets and the nonuniformity of the background against which they are to be detected. We have, nonetheless, sufficient data to indicate that, at very short ranges, we can certainly detect aircraft by infrared. As the range becomes greater, we become progressively less certain as to what percentage of the time the conditions might be sufficiently favorable to permit detection. Also we have, as detection range increases, progressively less data of the sort necessary for optimum system design.

The meagerness of data usually results in attempts to develop systems that (it is hoped) will operate in the region of uncertainty – that is, at very long range. Moreover, the designers of the equipment, not having satisfactorily complete data on background fluctuations, are apt to neglect the background problem almost entirely, rather than to attempt to use what data we have.

Paradoxically, detection equipment designed for use at the short range of comparatively certain target detection is not the vogue. Reliable short-range detection is by no means void of useful military application, but is less glamorous than (occasional) long-range detection.

It is recommended that infrared equipment be designed for applications that are almost certainly feasible according to our present data. As we acquire

more data on target and background radiations, we can with a reasonable certainty of success accept more difficult problems. But the more difficult problems cannot be well solved until we have the data. Table V-1-1 points out the tremendous gain in discrimination against background that can be realized by not requiring a larger maximum detection range than is necessary. Similar tremendous gains can be realized, not by sacrificing the maximum detection range, but instead by knowing certain general properties of the background fluctuations to be expected, and by designing the detection system specifically to discriminate against the most troublesome expected background fluctuations.

Background fluctuations will certainly pose a severe problem to aircraft detection at long range. Equipment not designed in relation to the necessary data will certainly give results far inferior to those that could be realized when appropriate data become available. It cannot be emphasized too strongly that proper design of infrared equipment for the problem at hand is not a question of factors of two in signal-to-noise ratio – it is a question of a few factors of ten in signal-to-noise ratio.

It is recommended that data compilation of the sort being conducted at Wright Field be continued with all possible support.

It is further recommended that a study of background radiations be initiated. The pertinent data are the autocorrelation function of numerous typical backgrounds – the autocorrelation function is $\varphi_g(\vec{P})$ of Eq. (3) – and the variation of the autocorrelation function with wavelength. The autocorrelation function should be evaluated by scanning the background with sensitive elements that subtend a small solid angle, of the order of $0.1^\circ \times 0.1^\circ$ of arc and less.

2. Passive Defense against Infrared Devices

Our own military equipment, in particular tanks and airplanes, apparently is not designed with any consideration of how easily their infrared radiation can be detected. It is not possible to completely camouflage the infrared radiation from such vehicles, but it is possible in many cases to reduce detectability without degrading military performance.

For example, the F-80 jet has a few inches of hot tail pipe which is readily visible from the side. This tail pipe is a tremendous source of infrared radiation. But it can easily be withdrawn inside the fuselage (as is the case with most

jet aircraft) so that the radiation from the side view is reduced.

Dr. Overbo detected American tanks at ranges of from 1 to 3 miles; with the same equipment he could detect the Soviet T-4 tank at only one-half mile. Thus, it would be easy to search at night for American tanks by detecting their infrared radiation; it would be rather difficult to detect the T-4 tank. Perhaps more important, it would be simple to devise air-to-ground or ground-to-ground homing missiles that could function against American tanks; the same problem would be far more difficult against the T-4.

The Soviet tanks achieve reduction of infrared output by appropriately positioning and directing the exhaust pipes. This may have been an accident of design; but, if it was done specifically to avoid infrared detection, it would probably indicate that the Soviet Union has or is developing infrared-dependent anti-tank weapon systems.

3. Component Development

Emphasis has been placed above on system analysis and on target and background surveys. Development of components should be continued, but it is noted that system design has not yet caught up with component development. It is all too common for system designers to wish for a factor-of-ten improvement in sensitive element characteristics, when in fact several factors of ten are sacrificed through improper system design.

There are two phases of component development. One is the process of tailoring existing components to meet the specific requirements of particular system designs. This important phase cannot be performed until system design comes of age. The other phase is research on basic improvements to existing components and research on new types of components. Components particularly in need of development are the sensitive elements.

Electronic circuits will develop quite independently of infrared research, and the circuit requirements for infrared are generally similar to those of other electronic devices.

There are a few requirements on infrared transmitting optical media for specific applications that are not yet satisfactorily met. In general, however, the lack of completely satisfactory optical media does not pose a fundamental

limitation. Hence there is need for research on optical media and methods of fabrication, but this need is not at present a general outstanding obstacle to system design.

Infrared-transmitting filters are, of all the components, those most nearly capable of meeting all present requirements, but sharp cut-off filters are lacking for many particular wavelength intervals.

4. Engineering Techniques

Signal-to-noise ratio is often sacrificed merely to effect a mechanical scanning process, which is simple to perform, and electronic circuits which are of simple construction. It does not, however, always follow that the compromise systems are optimum either in simplicity or in performance.

Optimum specification of how a system should in theory perform is possible if the target and background characteristics are known. Such optimum performance cannot be realized in a system of finite complexity – mechanical, optical, or electronic. The question of how a finite degree of complexity should best be distributed among the various components of the system cannot be answered without a composite of knowledge and ingenuity in all the component fields.

5. Infrared Homing

Infrared homing systems are not fundamentally limited by glint* as are radar homing devices. Furthermore, infrared is capable of high resolution, and consequently can be freed of the multiple-target difficulty of radar homing.

The above-described advantages of infrared homing devices are capabilities that are in practice difficult to realize, and the difficulty increases as the specified range of initial detection increases. There is, furthermore, the disadvantage that the "thermal center" of the radiation pattern from a jet aircraft may lie within the tail gases, thus perhaps complicating the problem of side approach for an infrared homing missile.

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*"Glint" is the change of apparent target position with time. This phenomenon superposes a false apparent velocity component upon the true velocity of the target, and introduces a serious error into lead-computing devices.

The counterpart of radar glint, in an infrared homing system, is the possibility that the scanning system can change its choice of "target center" when the range closes (although the target radiation itself does not change). This is a possible consequence of capability of high resolution. When the missile has approached sufficiently close to the target, the target becomes larger than the resolution capability of the homing system. Then the "apparent center" of the target might shift – for example, from the center of gravity of the four engines of a four-motored bomber to one of the outboard motors. If this distance is 50 feet, and the shift occurs during the next to last half-second of flight, then during this interval the missile acceleration called for will be full acceleration in a direction along the wingspan. This misguidance could not be undone in the last half-second of control. This difficulty can, in principle, be overcome through proper seeker design; the system complexity required to do so increases as initial detection range increases.

The ability to achieve multiple-target discrimination requires high resolution and a process for selecting one of a few possible targets within a field to be scanned. This is to some extent incompatible with preventing a change in apparent target center as the target is approached. This incompatibility may be removed if the scanning process is changed as the missile approaches the target. Moreover, if the initial detection range is short, there is only a small chance that two or more targets ever appear within the field of view.

In general, both the above difficulties are more readily resolved if the initial detection range is short, for then system complexity may be directed more toward solving these problems than to solving signal-to-noise problems.

6. System Specification

Table V-1-1 indicates that it is most important that the specified detection range be no greater than absolutely necessary, and that the rate of scan of solid angle be as low as is absolutely practical. By observing these principles, the degree of background nonuniformity against which the target can be detected is enormously increased. The most fruitful immediate applications of infrared are therefore those that require a detection range of only a few thousand yards, and a rate of scan of only a few square degrees per second.

7. Infrared and CW Radar

An ideal combination of detection devices is CW radar and infrared. If a target is initially located by CW radar, infrared may come into play to give precise target bearing. The coupling with radar can shorten the detection range required of the infrared system, and can reduce the necessary rate of scan of solid angle necessary to the infrared systems.

A weapon that uses CW radar coupled to infrared is described in Appendix V-2.

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APPENDIX V-2

ATTACKS AGAINST AIRCRAFT FLYING IN THE ALTITUDE RANGE 50 TO 1500 FEET

APPENDIX V-2

ATTACKS AGAINST AIRCRAFT FLYING IN THE ALTITUDE RANGE 50 TO 1500 FEET

A. NATURE OF THE PROBLEM

At the present time, it is difficult for an interceptor to attack enemy aircraft at low altitudes. In addition, the detection and control of interceptors at low altitudes is a major problem. As a result, it is thought that a natural outcome of a successful effort in controlling interceptors against enemy aircraft at the higher altitudes will be to cause these aircraft to hide in the low-altitude region. It is therefore of the utmost importance to have available a weapon having a high kill probability against low-flying aircraft.

One of the reasons for using antiaircraft equipment for this purpose is that the warning interval that must be given to the AA equipment is very short (in the neighborhood of 20 seconds) if an automatic system is used. As a result, it is unnecessary to track the enemy craft over large distances -- a sufficient warning range being about 4 miles for the fastest aircraft. However, some form of search and automatic acquisition is a necessity because human observers cannot be depended upon to pick up high-speed aircraft approaching at low altitude. The usual acoustical warning from the noise of the aircraft is of no value. Therefore it is proposed here, as the first part of this program, to develop a new weapon having automatic search and acquisition, so that the attacking plane may be detected in time to permit firing on the plane. This weapon must have sufficient fire power so that the kill probability will be high when the enemy aircraft flies within range of the weapon.

B. THE FIRING GEOMETRY

Among the decisions to be made in connection with any automatic AA weapon is the range at which the enemy aircraft will be intercepted. This range may be a variable that depends on the flight path, but there will always be a maximum value beyond which interception will not be attempted or, at least, beyond which the probability of interception will be too small. In the case in

question, it is thought that the maximum firing range should be in the neighborhood of 4500 feet, or 1500 yards. The principal reason for choosing this range is that it results in about the maximum permissable time of flight. If the time of flight becomes long, normal maneuvers of the aircraft, flight roughness, or the decision of the pilot to fly away if he should see the rocket flash, will result in a very low hit probability. For example, it appears possible for a pilot, upon observing the flash of the rocket at launching, to pull completely out of the rocket firing pattern if the time of flight is in the neighborhood of 5 seconds. For purposes of discussion here, it is assumed that it would take approximately 2/5 second for a pilot to decide to pull upward out of the rocket flight path, and an additional 3/5 second for the aircraft to assume such an altitude as to result in a 2-g acceleration. The displacement of the aircraft from the rocket flight path may be computed by the simple formula $D = \frac{1}{2} at^2$. If the flight time of the rocket is 3 seconds, and one second is consumed by the pilot and the aircraft in preparing to accelerate, there are 2 seconds in which the aircraft can pull out of the rocket flight pattern. If the maximum acceleration is 2 g's, the aircraft displacement will be 128 feet from the straight-line path in this period of time.

Other considerations in choosing the maximum firing range are the dispersion of the rockets, the firing errors resulting from detection, computing and launcher inaccuracies, and the rocket density required to give the necessary kill probability. These considerations will determine the number of rockets that must be fired. It can be said, other things being equal, that the number of rockets required will increase as the square, and sometimes as the cube, of the maximum firing range. For the case where 100 rockets having a dispersion of 15 mils are fired, it is thought that the maximum range of 4500 feet is the best compromise.

It is also thought advisable to limit all firing to those cases where the enemy craft is approaching, in order to have a minimum rocket flight time and in order to take advantage of the kinetic energy of the rocket resulting from the high closing rates. In addition, firing at aircraft at such angles that the rocket flight path is perpendicular to the aircraft flight path will result in the requirement of relatively large lead angles and precise timing. For the

purpose of discussion, an angle called the approach angle is defined as the angle between the flight path of the aircraft and a radial line from the weapon to the point of interception. By limiting this angle to some figure such as 45°, large lead angles may be avoided. This in no way limits the azimuth angle around the weapon from which a target may approach and be fired upon, but the consideration does define a circle, smaller than the circle of maximum firing range, such that the weapon will fire on any aircraft having a flight path that will cross this inner circle. By spacing weapons so that these inner circles overlap, complete coverage may be obtained. Figure V-2-1 is a diagram indicating these geometrical considerations.

When an aircraft approaches the interception point at an angle of 45°, a large part of the presented area will be the side area of the aircraft, and the presented area will be approximately three times larger than the minimum presented area for the case of head-on approach. This is based on the concept that the side area of the aircraft is approximately five times the frontal area. In the case of flight paths having approach angles less than 45°, it appears advisable to delay the firing so that the point of interception is less than 4500 feet. By this means, the hit probability may be maintained high for all permitted courses.*

C. THE PORCUPINE I

It is suggested that a new weapon, called the PORCUPINE, be developed to shoot down low-flying aircraft. It is thought that this weapon should be developed in two stages: PORCUPINE I, a semiautomatic weapon; and PORCUPINE II, a completely automatic weapon. In order to reduce the development time to a minimum, it is proposed to use existent components, such as the Mark 15 gun sight and the 40-mm gun mount.

The PORCUPINE I (see Figs. V-2-2 and V-2-3) will consist of a search and acquisition radar, an optical sight, a computer, and a rocket launcher (see Figs. V-2-4 and V-2-5). The system will search an area 4 miles in

*The probability of hitting an aircraft with a salvo of rockets is further discussed in Annex A.

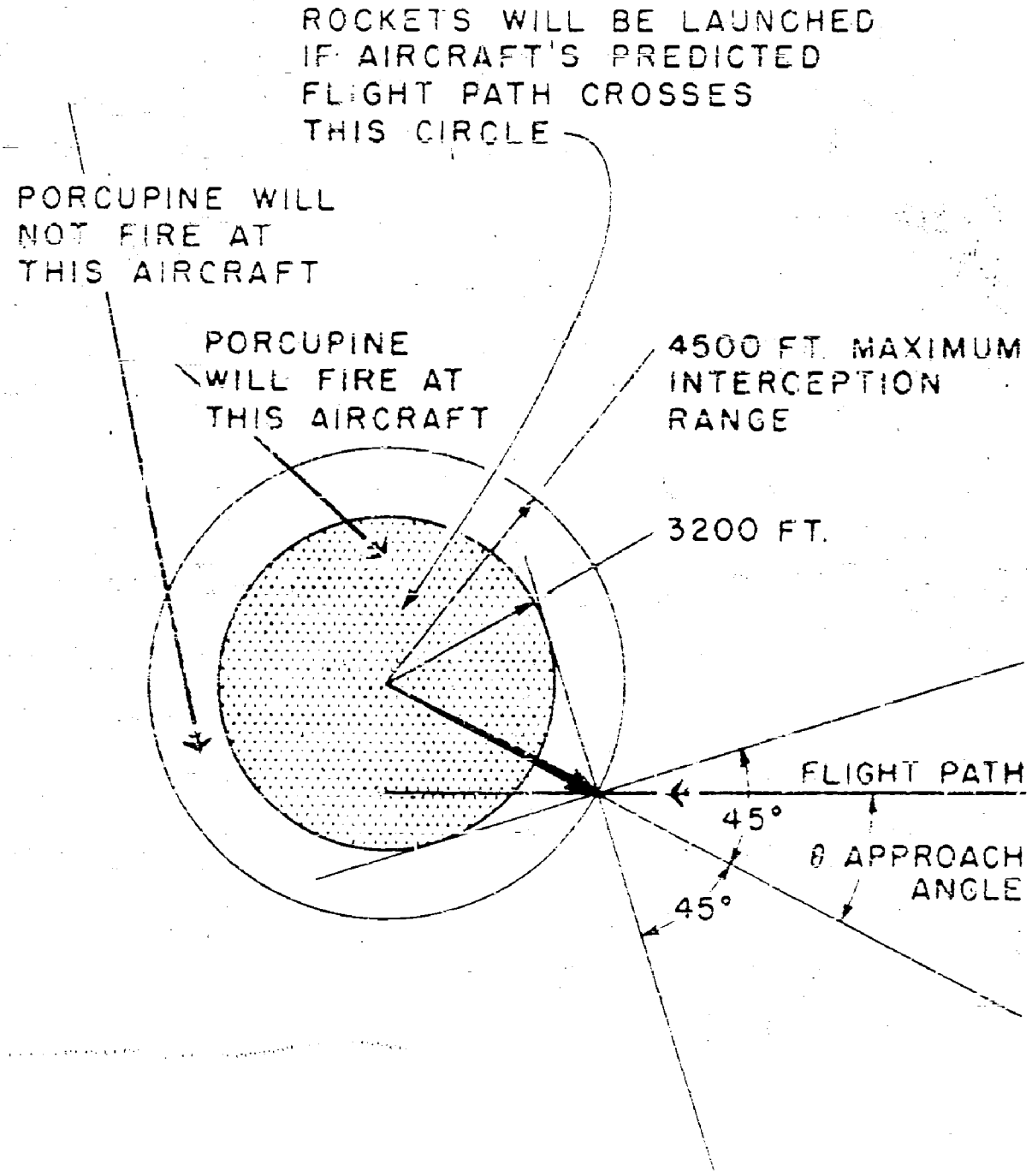


Fig. V-2-1 Firing geometry for rocket weapon.

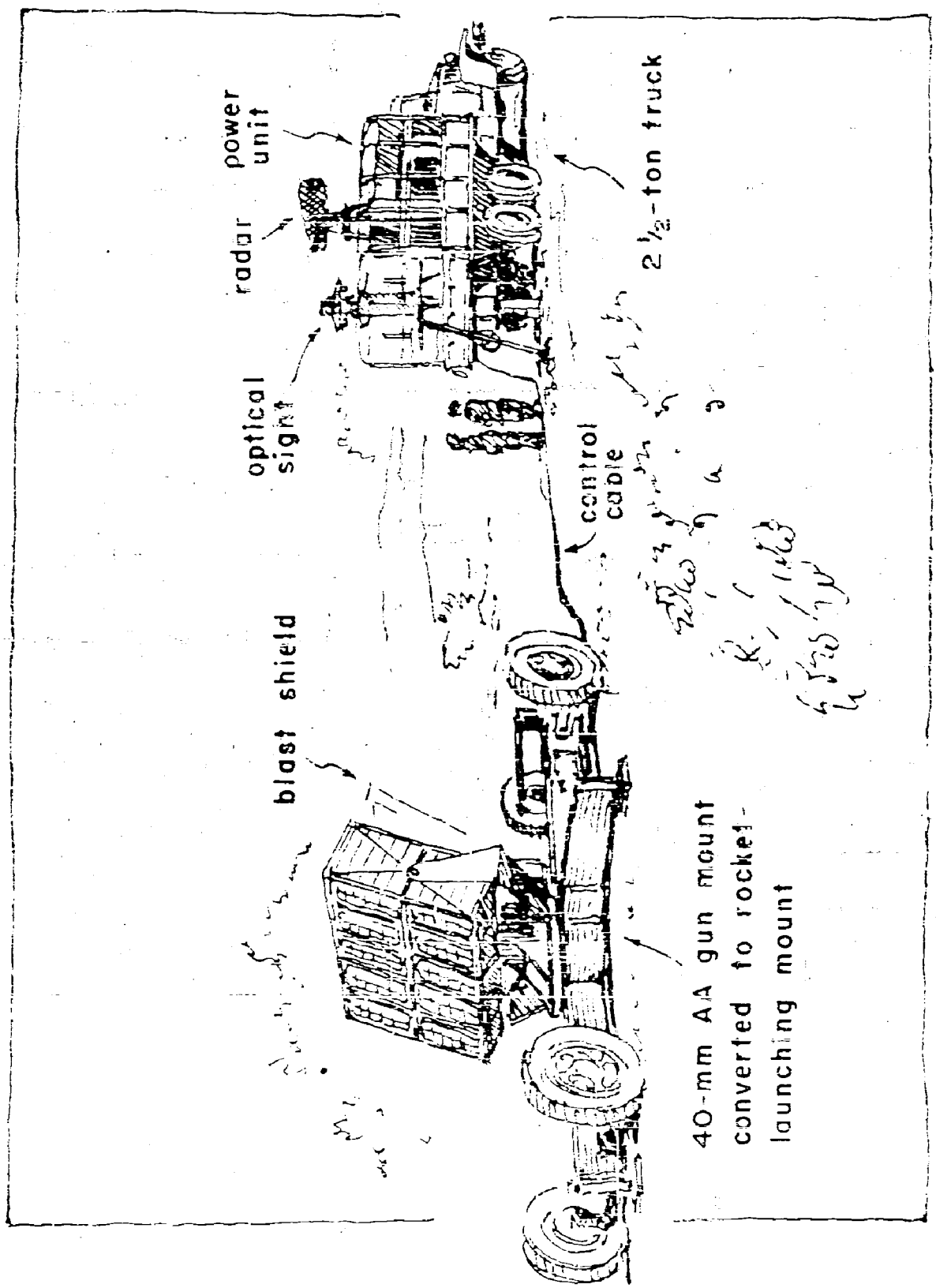


Fig. V-2-2 Suggested assembly of PORCUPINE I.

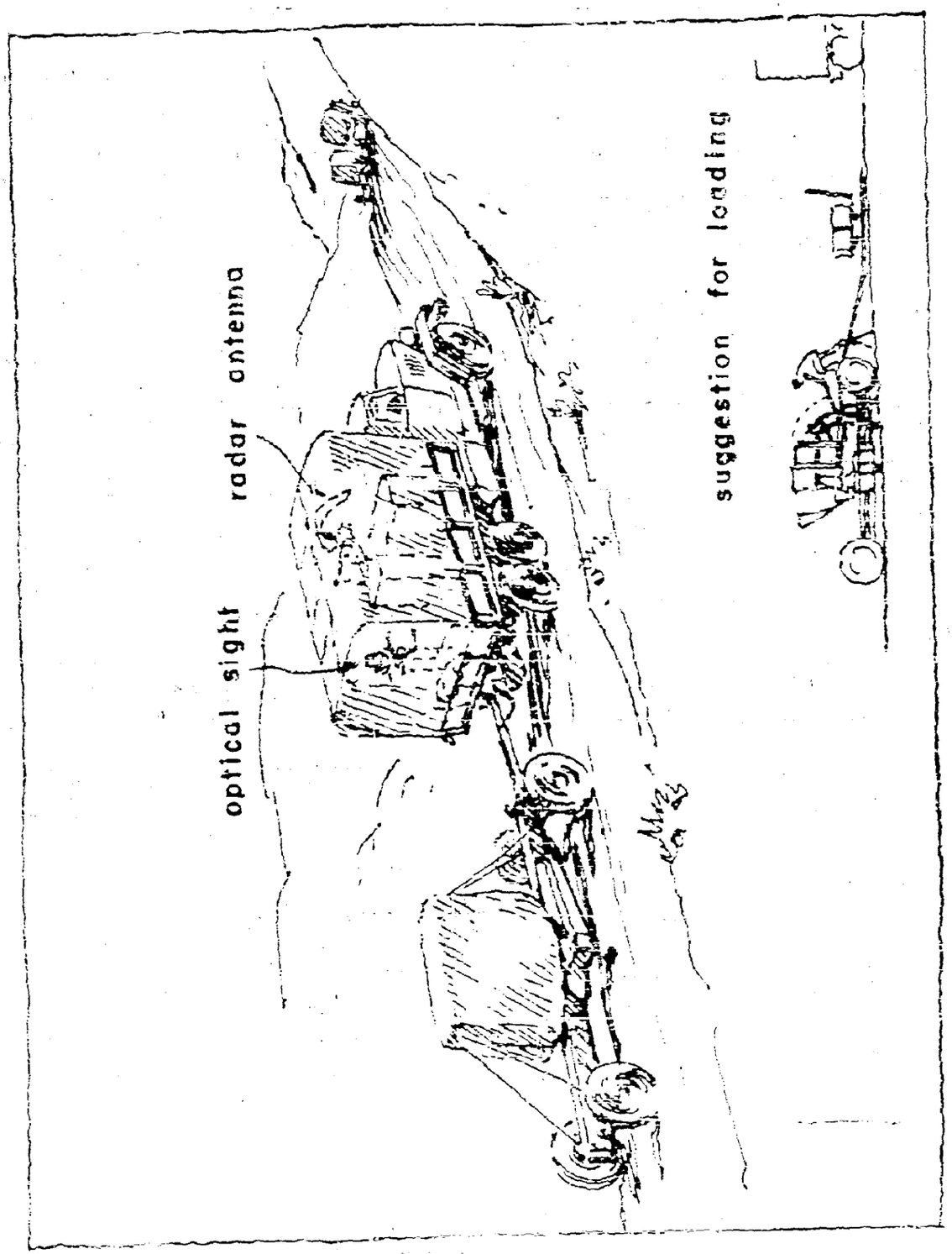
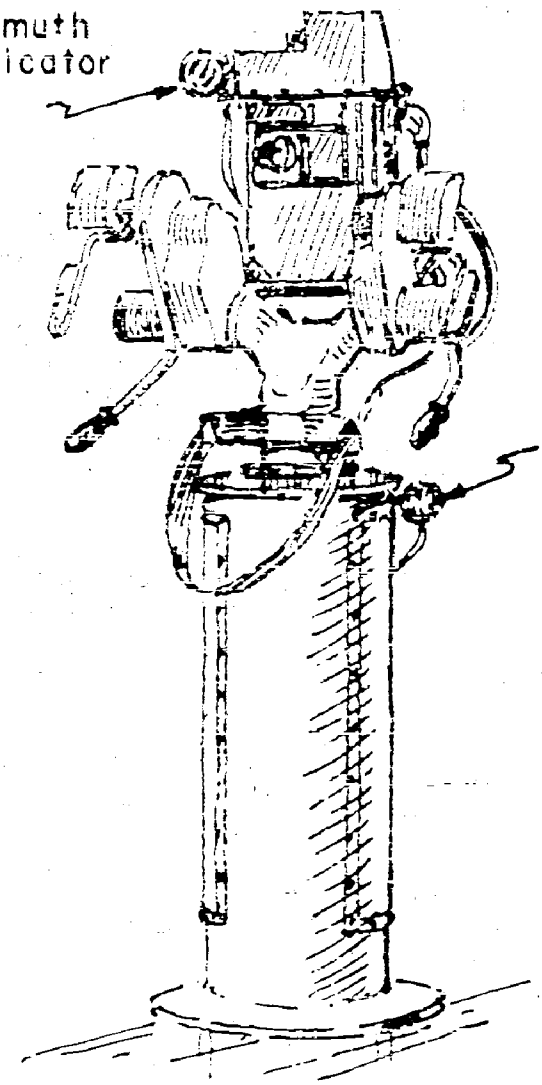
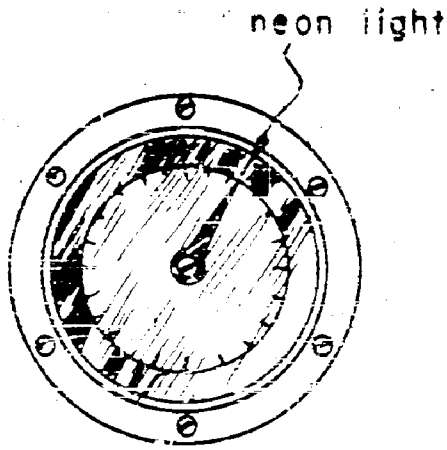


Fig. V-2-3 PORCUPINE I in transit.





detail of
azimuth indicator

Fig. V-2-4 PORCUPINE I optical sight, with loudspeaker and azimuth warning.

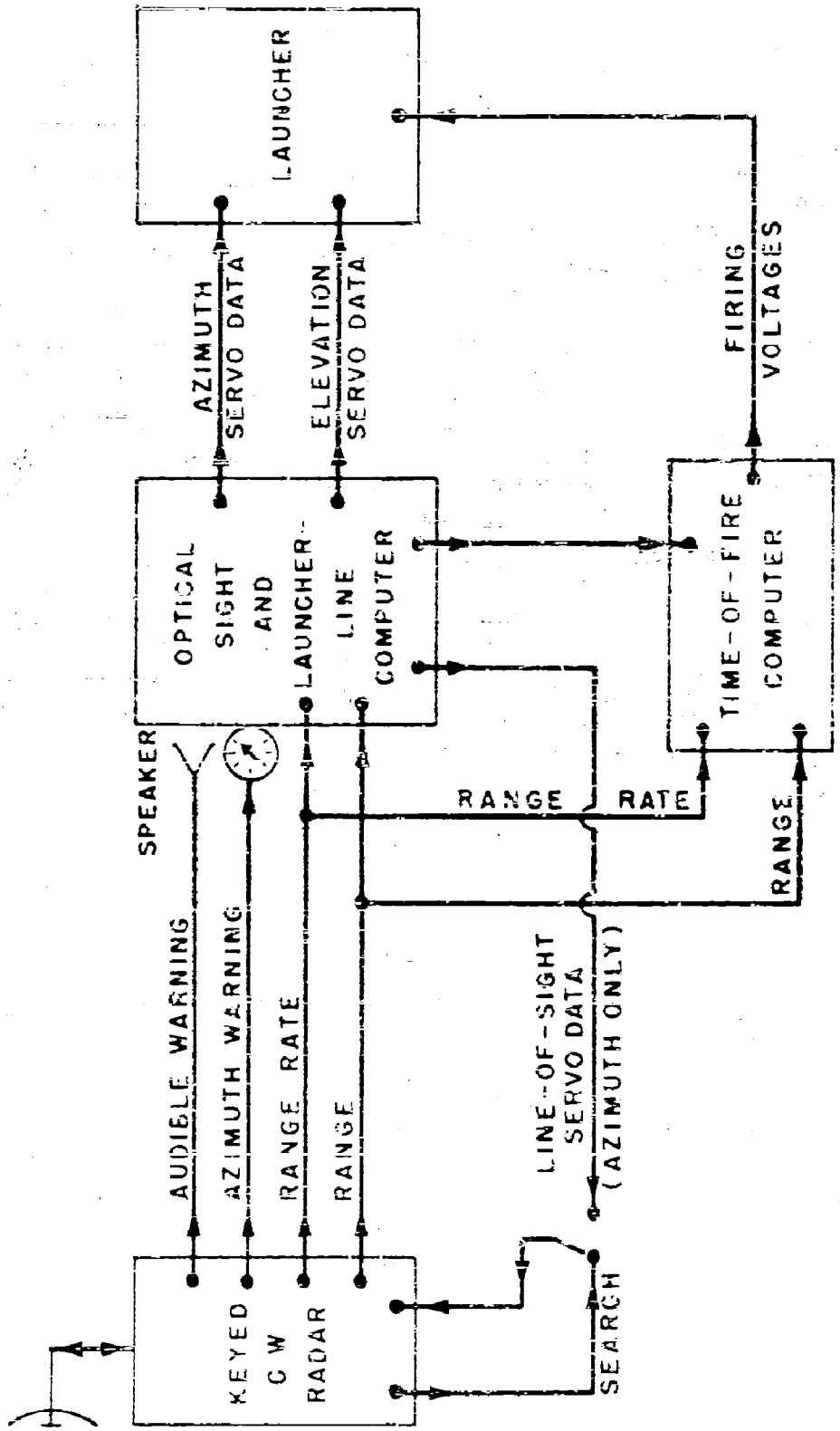


Fig. V-2-5 PORCUPINE I, functional block diagram.

radius for enemy aircraft, will track the aircraft at a range of 2 miles, and will intercept the target at a maximum range of slightly less than one mile.

A keyed continuous-wave radar is employed to scan the horizon 3 times per second, a rate of 180 rpm. This radar will be provided with a fan-beam antenna pattern having an azimuthal width of 5° and an elevation of from 0 to 10° at the 3-db points. This radar will be capable of detecting aircraft that have a closing velocity or range rate greater than 150 mph anywhere within a region having a radius of 20,000 feet, or approximately 4 miles. Filters are provided so that ground-clutter signals are ignored. When an aircraft flies into the search region of the CW radar, a Doppler signal of the order of 1500 to 6000 cycles per second will be generated (based on 3000-Mc carrier frequency).

This Doppler signal is amplified in the Doppler selector amplifier and placed on a loudspeaker located near the optical sight. The Doppler serves to warn the operator of the existence of an aircraft within 4 miles, and will by its tone give a rough estimate of the rate of approach of the aircraft to the weapon sight. In addition to the audible warning, an azimuth dial is located on the optical director (see Fig. V-2-4), which will show a red light or mark at the azimuth from which the radar echo having Doppler is received. The sight operator immediately slews the sight to the azimuth indicated by the red mark. The operator must then scan an area 10° in elevation by 2° wide, in order to locate the attacking aircraft. This may be done without moving the sight, since the operator's eye may scan this area at once. When the operator sees the attacking craft, he will adjust the sight to place the craft on the reticle, and, in addition, will flick a switch located on his handle bar so as to switch the radar servo system from search to track. The radar will track the position of the optical sight, with the exception that the lead angles will be subtracted from the sight's synchro data so that the radar will point in the direction of the target. This is required since the optical sight, being of the displaced reticle type, points to predicted positions rather than to the present position of the aircraft. The lead-angle subtraction may be accomplished by installing microsyn pickoffs on the sight's rate gyro.

At the same time, predicted-angle data are fed to the rocket launcher. The rocket launcher is a modified 40-mm (Bofors) gun mount on which

rocket-launching tubes are installed. The launcher will follow the optical sight and will point in the predicted position as the aircraft is tracked. A time-of-fire computer will judge the optimum time of fire based on the angle of approach, and will set off the rockets at the time that will result in optimum hit probability.

One hundred rockets will be launched in 0.1 to 0.2 second from the launcher upon receipt of the firing signal. In order to minimize torque on the launcher, the rockets will be launched in symmetrical groups spaced by intervals of approximately 50 milliseconds.

1. The Radar

This description of the radar system (see Fig. V-2-6) is not intended to be a detailed design of the radar, but is a means of presenting one method by which the end may be accomplished. The use of a klystron radio-frequency amplifier is implied in this description. However, consideration should be given to the possibility of using locket or otherwise controlled magnetrons for this purpose.

The radar system proposed will be identical for both PORCUPINE I and PORCUPINE II. In order to realize a system that provides rejection of ground clutter, it is proposed to use a keyed CW radar system. In this system, the transmitter is energized for a period of time equal to the time required for echoes to be returned from the most distant targets. The receiver is gated on during the periods when the transmitter is turned off. The transmitter signal consists of a series of RF pulses lasting 43 microseconds, interposed with offperiods of the same duration. The repetition rate is therefore 11.6 kc. Referring to Fig. V-2-7, the transmitter signal consists of a carrier f_c and sidebands at $f_c \pm f_m$, $f_c \pm 3f_m$, etc., where f_m is the modulating frequency. Most of the energy is confined to the components f_c and $f_c \pm f_m$.

Returned echoes consist of bands of energy centered about f_c, $f_c \pm f_m$, etc. These components are echoes from ground clutter and stationary objects. A band rather than a line is received because of modulation arising from the antenna rotation, movements of trees, etc.

In addition, signals are received on other frequencies $f_c + f_d$, $f_c + f_m + f_d$, $f_c - f_m + f_d$, etc. The Doppler frequency, f_d, adds directly to the frequencies

of each component. The shaded areas (Fig. V-2-7) indicate the places on the frequency diagram where the echoes from an approaching aircraft will be received.

Referring to Fig. V-2-6, the transmitter consists of a master oscillator and an RF power amplifier. The power amplifier is modulated by a square-wave oscillator at 11.6 kc. During the time that the transmitter is on, the receiver is disabled by voltage from the square-wave modulator.

Received echoes pass through a TR box to the first mixer. The local oscillator signal is generated by modulating in a balanced modulator the RF voltage from the master RF oscillator with power from the IF intermediate-frequency oscillator. The upper sideband $f_c + f_{IF}$ is selected by an RF filter and sent to the first mixer.

The resulting IF signals are amplified in the IF amplifier. Because of the manner in which the local-oscillator signal is obtained, signals returned at the carrier frequency f_c will appear in the IF amplifier at exactly f_{IF}. Voltage from the IF oscillator is heterodyned against the echo signals in the second mixer. The result is a series of frequencies f_d, $f_m - f_d$, f_m, $f_m + f_d$, etc. The moving-target separator passes f_d and $f_m - f_d$ and rejects all other components. This unit is an amplifier having a passband of approximately 1500 to 10,000 cycles per second (based on S-band). The output of the Doppler separator passes signals from 1500 to 6000 cycles per second. These signals provide the computer with range-rate data and warning of an approaching aircraft. In addition, the output of the moving-target separator is fed to a summing amplifier, where f_d and $f_m - f_d$ are added to obtain f_m. Three signals appear in the output of this amplifier (f_d, $f_m - f_d$, and f_m). The regenerated range signal at f_m contains information as to the range of the target by its phase. The range signal is amplified in the range-signal separator which is an amplifier having a passband centered around 11.6 kc. The resulting range signal of f_m is compared with the reference phase f_m (sinusoidal form) in order to obtain target range.

2. The Computer

The computer has the general function of converting line-of-sight and range information into signals for positioning the launcher and for firing the

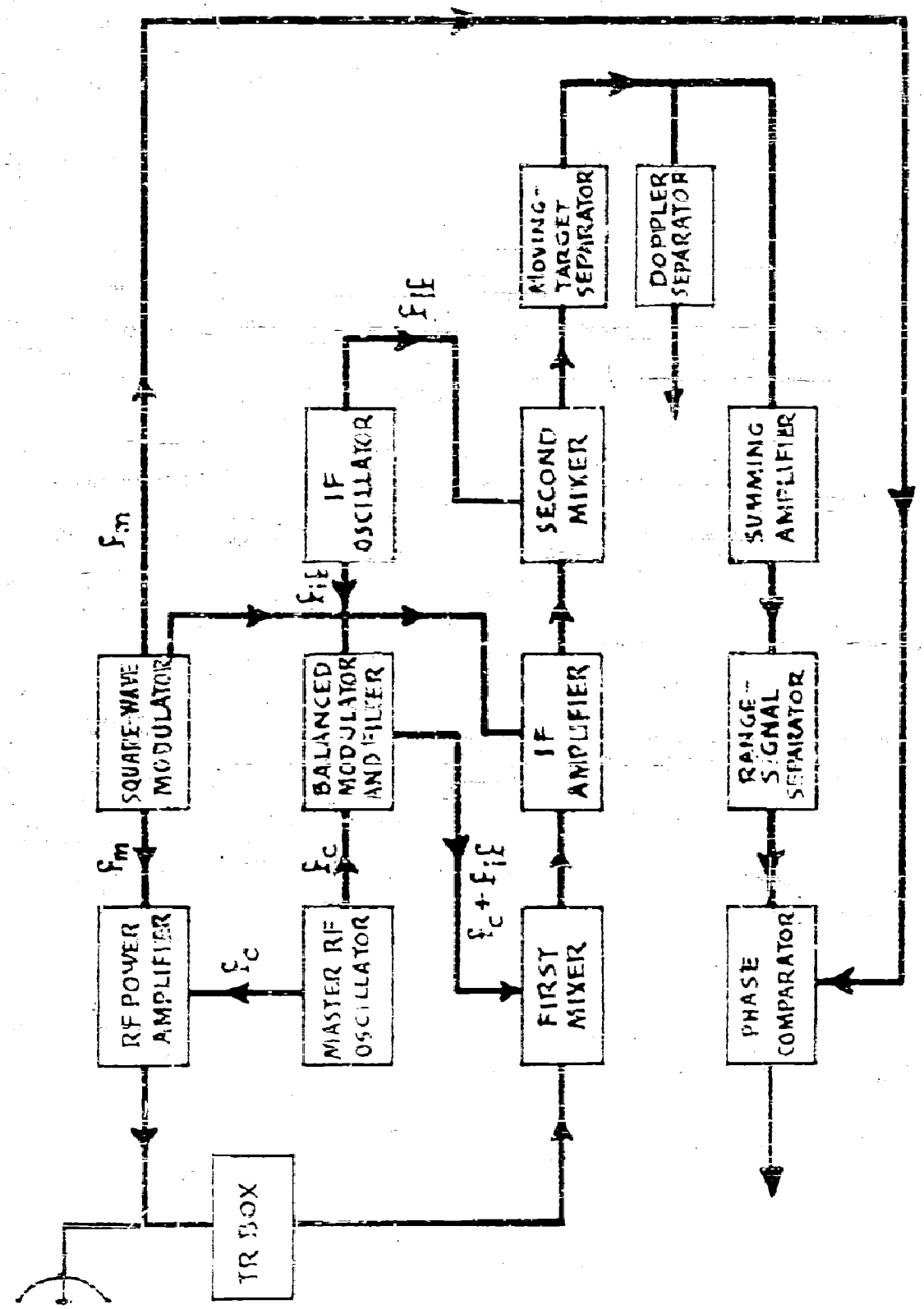


Fig. V-2-6 Keyed CW radar.

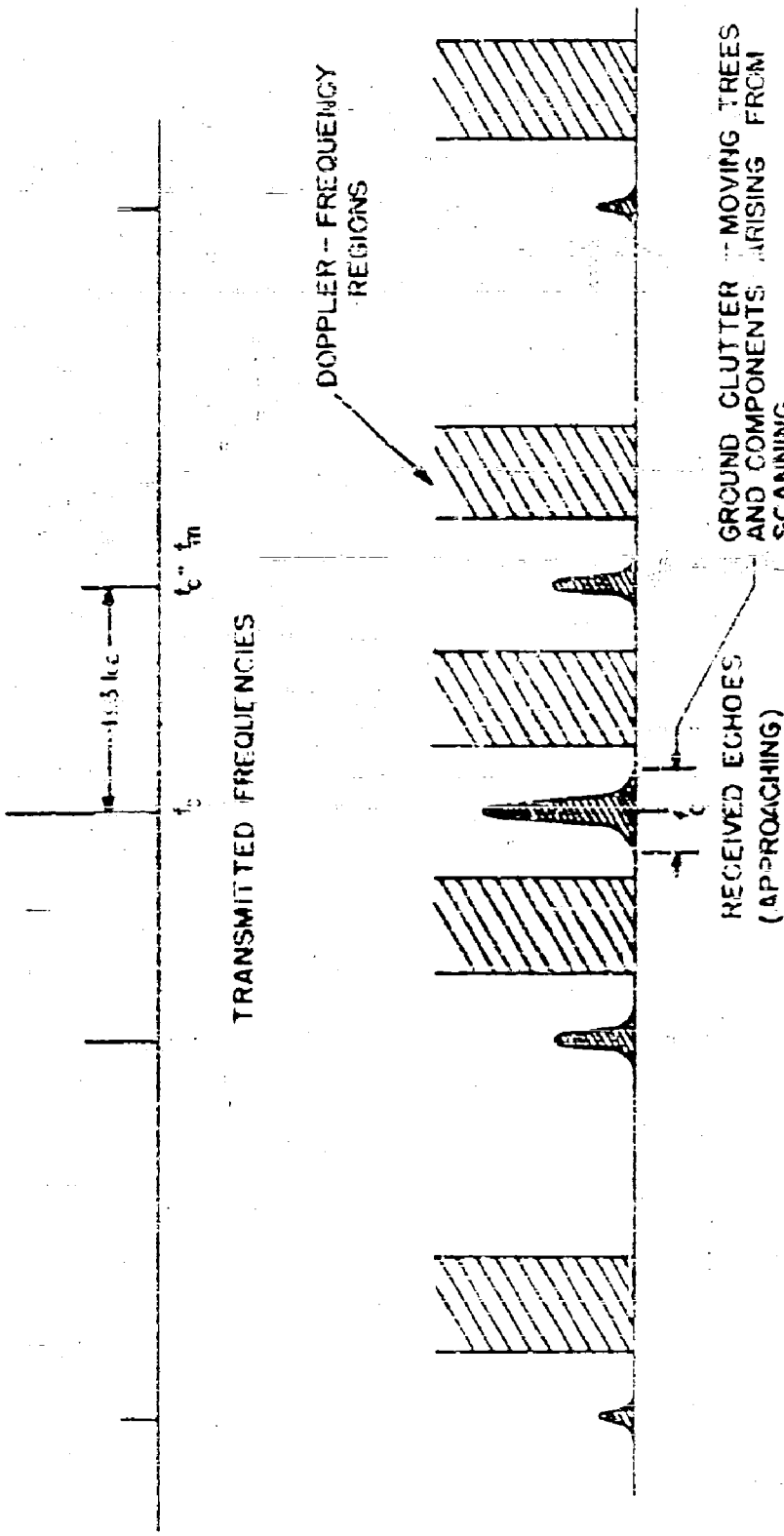


Fig. V-2-7 Spectrum diagrams.

rockets. The computer may be classified as a 3-second time-of-flight instrument with an accuracy of ± 5 mils for launcher position data. This means the computer problem fundamentally is not a difficult one, since the PORCUPINE accuracy requirements are considerably less severe than those for typical fire-control systems as used in World War II.

Two versions of the computer will be discussed. For PORCUPINE I, the manual system, an attempt will be made to use existing equipment with minor modifications only. For the automatic version of PORCUPINE, known as PORCUPINE II, a specially developed computer may be used (see Fig. V-2-8). The manual computer is discussed first.

a. Computer

It is proposed that consideration be given to the Navy Mark 15 computer. The Mark 15 mounted on a Navy Mark 51 or similar band-stand director, and, provided with radar range and range rate should represent an adequate tracking system. The sight consists of a telescope through which the operator sights the target. The operator holds the target on the reticle of the sight during the tracking time. Rate gyros are used to displace the reticle as a function of the angular rates. As a result, the axes of the sight point in the predicted direction. These data are repeated by synchros to the rocket launcher which follows the sight. A special indicator will be added to the director to give the operator initial heading information from the radar set.

It is interesting to note, for a typical problem, what time is available for acquisition tracking and launcher positioning. For a 1000-fps target, we may assume acquisition data are available to the operator at a range of 20,000 feet. 1500-fps rockets would be fired at a range of 7500 feet to cause impact at 4500 feet. The range between 20,000 feet and 7500 feet at the above target velocity gives the tracker 12.5 seconds in which to make final acquisition and to track the target. The conditions of the problem will permit computer-solution time to be less than one second. Hence, practically all this time the computer is operating in the equilibrium condition.

In order to use an existing computer for this application, certain modifications must be made. First, the computer must be calibrated for the rocket

ballistics. Second, the computer must be provided with the means for effecting an ambient temperature correction, since rocket ballistics will vary widely with temperature.

b. Firing-Time Computer

Since only one rocket barrage is to be fired at each target tracked, consideration must be given to the best time to fire. An early thought was to provide firing at a fixed slant range. More recent opinion suggests that a variable firing time would be advantageous and worth the cost. A computer to furnish firing-time information must be designed. The optimum firing time is, broadly speaking, the time at which the kill probability is a maximum for the particular problem being considered. If a target is coming head-on, the firing range should be short. If a target is on a passing course for which a larger area is presented, the firing range should be somewhat longer in order to avoid large azimuth rates. A detailed study of this problem must be undertaken before the best relationship is selected. However, as a suggestion, the following equations for the firing-time computer are offered.

$$x = R - R_i - \frac{\dot{R}_i}{V_p} \dot{R},$$

in which

$R \triangleq$ present range of target (available from radar);
$R_i \triangleq$ range at which impact is to occur,
$\dot{R} \triangleq$ present range rate (available from radar),
$V_p \triangleq$ average velocity of rockets to impact point;
$x \triangleq$ difference quantity.

When $x = 0$, the firing order is given.

The impact range R_i may be made a function of lead angle as follows.

$$R_i = R_{i(\min)} + \frac{R_{i(\max)} - R_{i(\min)}}{|L|_{\max}} |L| ,$$

in which $L \triangleq$ azimuth lead angle (available from computer).

These equations, though not exact, would be relatively simple to implement. A suggested circuit is shown in Fig. V-2-8.

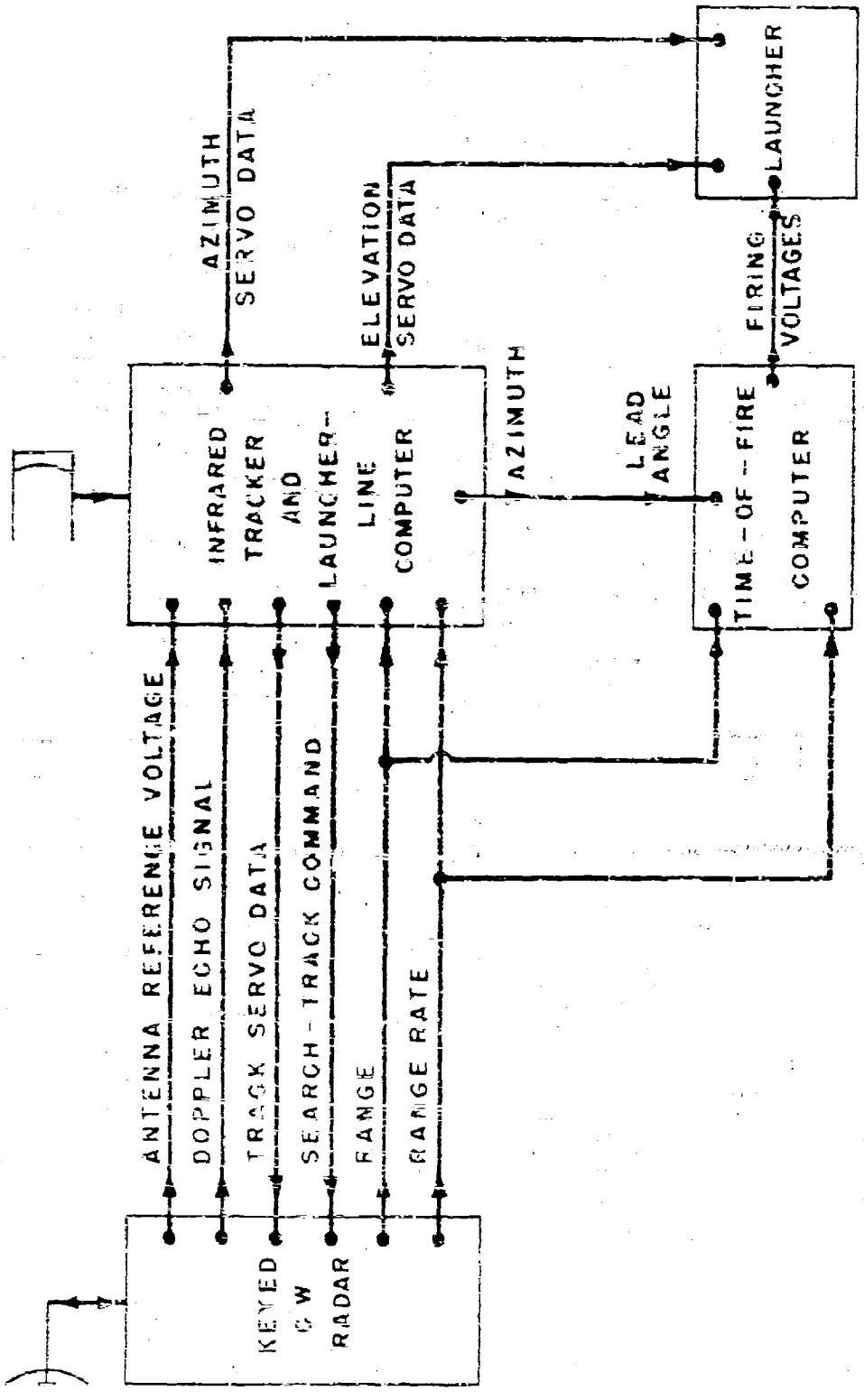
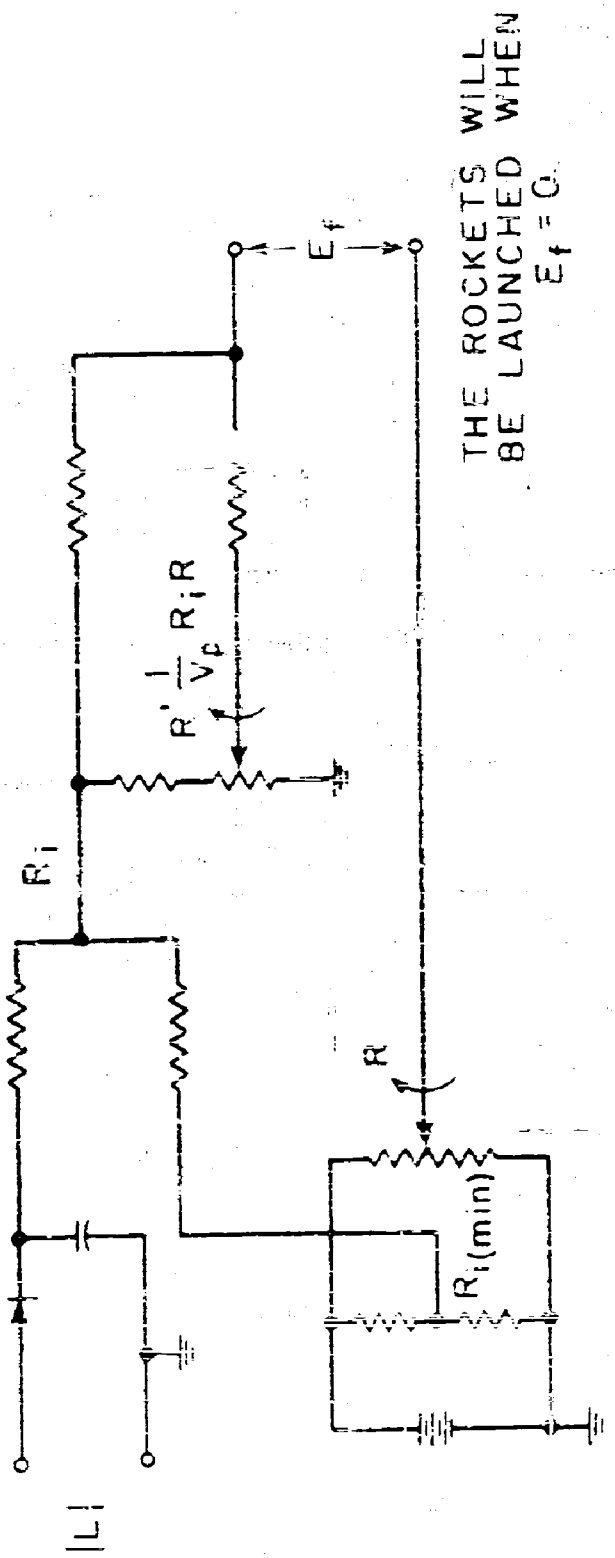


Fig. V-2-8 PORCUPINE II, functional block diagram.



$$E_f = R - R_i - \frac{1}{V_p} R_i R$$

$$R_i = R_{i(min)} + \frac{R_{i(max)} - R_{L(min)}}{L_{(max)}} |L|$$

Fig. V-2-9 Time-to-fire circuit.

c. Computer for Automatic System

For the completely automatic weapon, the use of an existing modified computer is unlikely. The equivalent of a complete on-carriage system is desired. While a computer similar to any of the current on-carriage may be suitable, this one must be built to less severe specifications. Also, as in the case of an optical tracking system, special consideration must be given to the difference between gun and rocket fire.

It is proposed that, concurrent with any program to develop the optical tracking system, a study of the automatic tracking system should be undertaken.

In summary, Table V-2-1 suggests typical specifications for the computer for either the optical-tracking or the automatic-tracking model. The data in the table should be considered tenative, since they were compiled largely from estimates of the performance of nonexistent detection equipment and nonexistent rockets.

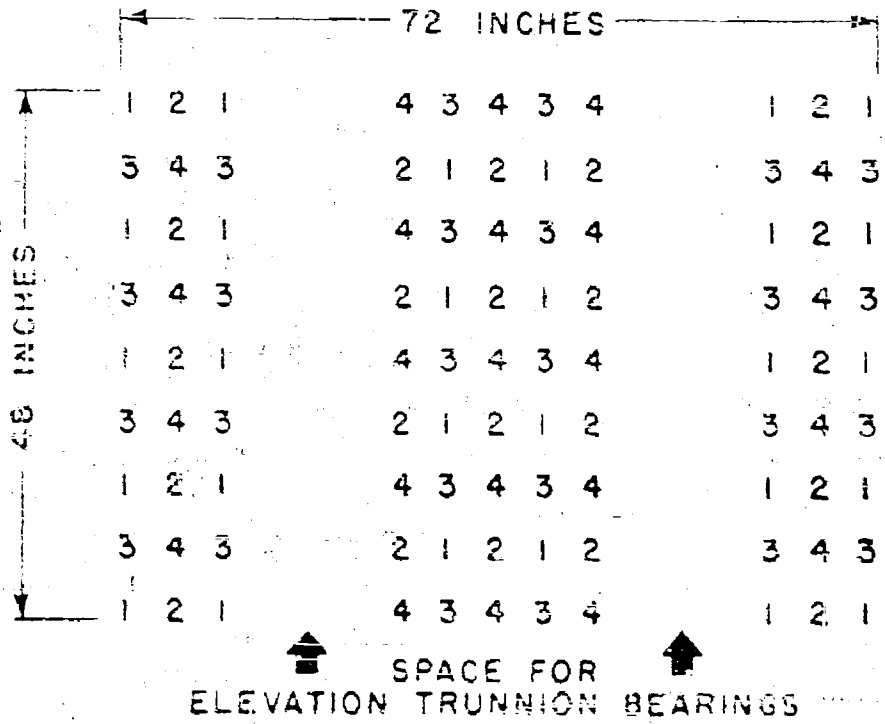
Table V-2-1

Tentative Computer Requirements

Maximum azimuth rate of target	100 mils/sec
Maximum elevation rate of target	100 mils/sec
Maximum range of target	20,000 ft.
Minimum range of target prior to firing	5000 ft.
Maximum range rate of target	1000 ft./sec
Maximum time of flight	3-1/4 sec
Maximum lead angle (composite)	25°
Wind correction	2 mils/ft./sec
Angular accuracy of launcher-line data	5 mils

Assumed Target Conditions

Maximum velocity	1000 ft./sec
Maximum altitude	1500 ft.
Maximum attack angle	45°
Course	straight line, horizontal



SALVO	NO. FIRED
1	28
2	22
3	26
4	23

Fig. V-2-10 Tube array and firing order.

TABLE V-2-2

Launcher Data (Estimated)

Weight of 99 rockets (estimated at 10 lb. each)	990 lb.
Weight of 99-tube launching assembly (estimated)	1000 lb.
Steel	1000
Aluminum	400
Moment of inertia, 99-tube launching assembly (estimated 9 × 11 array on 6-inch centers fully loaded)	
Azimuth	
Steel	10,000 lb. ft.^{2}
Aluminum	8,000
Elevation	
Steel	5,000 lb. ft.^{2}
Aluminum	4,000
Unbalanced moments (elevation only)*	
With launcher fully loaded	0 lb. ft.
28 rockets fired	187
50 rockets fired	334
76 rockets fired	510
99 rockets fired	660
Maximum required tracking rate*	
Azimuth	150 mils sec^{-1}
Elevation	150
Maximum required slewing rate*	
Azimuth	30 deg sec^{-1}
Elevation	20
Maximum required acceleration*	
Azimuth	15 mils sec^{-2}
Elevation	15

*Figures based upon steel launching-tube assembly

TABLE V-2-3

Launcher Power-Drive Data

Army designation of drive	M3 Oil Gear	
Type of drive	Electrohydraulic	
	Azimuth	Elevation
Gear ratio* of drive coupling	90	116
Gear ratio* of fine synchro	18	18
Estimated** maximum permissible moment of inertia of tube assembly	13,000 lb. ft.^{2}	12,000 lb. ft.^{2}
Load torque*** on tube assembly for 1-mil error	900 lb. ft.	1200 lb. ft.
Max. slewing speed	30 deg sec^{-1}	23 deg sec^{-1}
Max. error at 150 mils sec^{-1}	1 mil	1 mil
Error for 25 mils sec^{-2} acceleration	1 mil	1 mil
Probable synchro error	0.25 mil	0.25 mil
Max. synchro error	2 mils	2 mils

*Speed of item relative to mount

**Does not include deflection of mount structure

***Based upon 25 per cent of direct coupled inertia used in testing power drive

3. The Launcher

The possibility of using the major portion of the Army 40-mm antiaircraft gun carriage M2 to carry the launching-tube assembly should be considered. Preliminary estimates indicate that the present M3 oil gear power-drive units are capable of driving a launching-tube assembly accommodating 99 rockets.

Figure V-2-10 shows the tube array and firing order contemplated for the launcher. The principal problem here is to fire approximately 100 rockets in the least possible time and with the least unbalancing effect caused by back blast. Back-blast force is minimized by separating the tubes (6-inch centers). Interaction of rockets after leaving one launcher is made negligible (hopefully) by using a 12-inch or greater center distance between simultaneously fired rockets. This means that the rockets must be fired in four salvos; and it is expected that the total firing period will be of the order of 200 milliseconds. By firing the rockets in patterns that are symmetrical about the elevation and azimuth axes, no difficulty should occur with unbalanced moments caused by blast.

Table V-2-2 presents basic data for the launcher. These data are estimates only. The weight and inertia estimates are based on a rocket weight of 10 pounds, and on launching tubes that have the dimensions: length, 42 inches; inside diameter, 2.80 inches; wall thickness, 0.062 inch. It is impossible to arrange the elevation trunnion axis of the launching-tube assembly so that gravitational moments are balanced for all conditions of loading. It is felt that these moments should be approximately balanced when the launcher is fully loaded, and thus gravity will tend to depress the tube assembly when empty.

Table V-2-3 gives data for the M3 oil gear power drives coupled to the launching-tube assembly with gearing of the same ratio as that now used on the M2 gun carriage. These data indicate that the power drives will probably be satisfactory for operating the launching-tube assembly. It is difficult to estimate the effects of the elasticity of the complete mount, and some question exists as to the capability of the azimuth power drive for handling the relatively large azimuth inertia of the launching-tube assembly through the inevitable elasticity of the gearing, bearings and structure intervening between the power drive and launching-tube assembly. However, at worst, only a slight reduction in the performance should result on this account.

V. C. Westcott

APPENDIX V-2

Annex A

THE PROBABILITY THAT AN AIRCRAFT WILL BE HIT BY A SALVO OF ROCKETS

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THE PROBABILITY THAT AN AIRCRAFT WILL BE HIT BY A SALVO OF ROCKETS

SUMMARY

An expression is derived for the probability of at least one hit on a target with a salvo of rockets. A discussion is given of the allowable errors in the determination of the motion of the target and of the bore-sight errors of the rocket launcher. The advantage of "holding fire" for head-on approach targets is pointed out.

It is assumed that there is a sufficient number of rockets in the salvo and that there is close enough spacing between rockets such that a "continuous" distribution has some meaning. It is further assumed that the distribution of rockets in space is Gaussian. Then rather simple relations follow that express the probability of a hit as a function of the velocity of the rockets, the velocity of the aircraft, and the distance of closest approach of the aircraft to the center of gravity of the salvo. The most important feature of such a relation is that it expresses the variation in the probability of a hit with angle of approach of the salvo.

In Fig. V-2A-1, V_p represents the vector velocity of the target aircraft, V_r represents the vector velocity of the rocket salvo. The angle of approach θ is the supplement of the angle between these two vectors; it should be noted that θ is measured in the plane that contains the two velocity vectors. Relative to the rockets, the target moves through the rocket distribution at an angle γ from the line of flight of the rockets. The area of the target aircraft that is presented to the rocket is one area that is seen at an angle $\theta - \gamma$ from the axis of flight of the target aircraft. Tan γ is given by the following expression.

$$\tan \gamma = \frac{V_p \sin \theta}{V_r + V_p \cos \theta} = \frac{\sin \theta}{\cos \theta + (V_r/V_p)} \quad . \qquad (1)$$

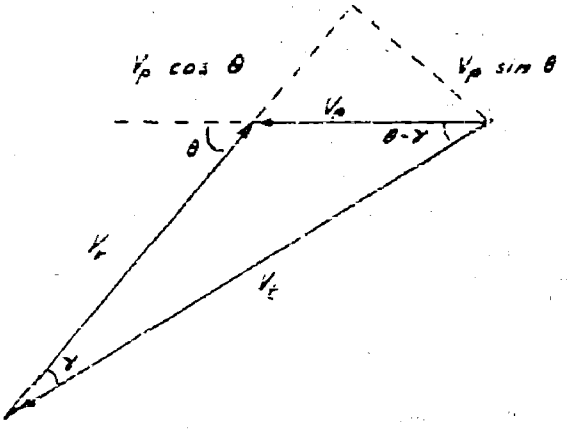


Fig. V-2A-1

A graph of γ versus θ is given for various ratios of the velocity of the rocket to the velocity of the target (Graph V-2A-1).

It is assumed that the salvo has a rocket distribution that is symmetrical about the axis through the center of gravity parallel to the direction of flight. This direction will be called the z-direction. The y-direction is normal to the velocity of the salvo and is in the same plane as the velocity of the aircraft. The x direction is normal to both y and z. The probability that there will be one rocket in the volume dx dy dz at the point x, y, z is given by the expression

$$P(x, y, z)dx\,dy\,dz = \frac{1}{\pi^{3/2}XYZ} \exp\left\{-\frac{x^2}{X^2} - \frac{y^2}{Y^2} - \frac{z^2}{Z^2}\right\} dx\,dy\,dz \quad . \quad (2)$$

This expression is normalized to unity. The meaning of X is that, at a point along the x-axis a distance X from the center of gravity of distribution, the probability has decreased by a factor 1/e of the maximum probability, and similarly for Y and Z. If we assume that the salvo has a distribution that is symmetrical about the z-axis, then X and Y are equal.

Consider the volume that is swept out by an area $\Delta x \Delta\sigma$ as it moves through the distribution at an angle γ to the z-axis. The center of this area passes at a distance y_o from the center of gravity, and the motion is in the y, z plane, that is, x = 0. We wish to find the probability that there will be a rocket in

this volume. The relationship between $\Delta\sigma$ and Δy is that

$$\Delta y = \frac{\Delta\sigma}{\cos\gamma}, \tag{3}$$

and integration is restricted along the line

$$y = \tan\gamma\,(z_o - z). \tag{4}$$

The probability that there will be a rocket in this volume is given by

$$\frac{\Delta x\,\Delta\sigma}{\pi^{3/2}X^2 Z\cos\gamma}\int_{-\infty}^{\infty}\exp\left\{-\frac{\tan^2\gamma(z_o-z)^2}{X^2}-\frac{z^2}{Z^2}\right\}dz. \tag{5}$$

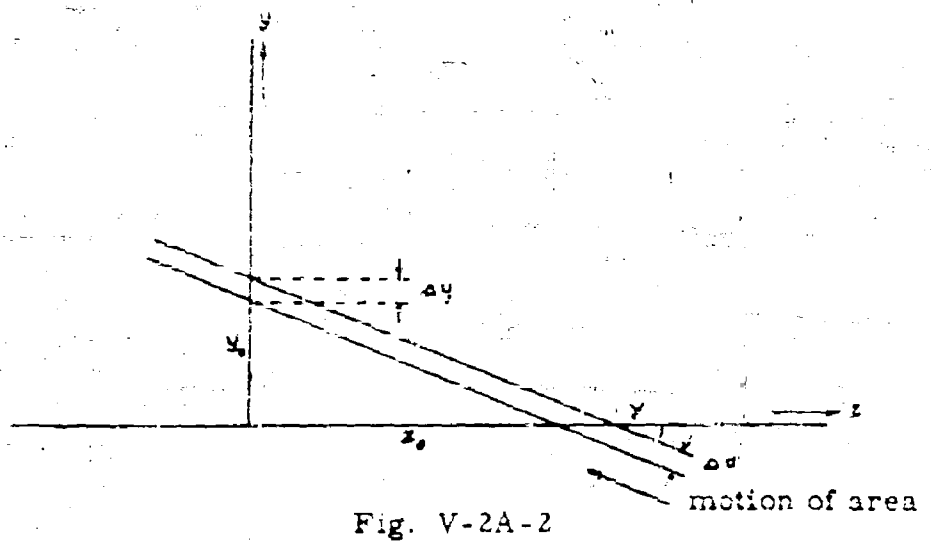


Fig. V-2A-2

This relation reduces to

$$\frac{\Delta x\,\Delta\sigma\cos\alpha}{\pi X^2\cos\gamma}\exp\left[-\sin^2\alpha\,\frac{z_o^2}{Z^2}\right], \tag{6}$$

where α is defined as the angle such that

$$\tan\alpha = \frac{\tan\gamma}{X/Z} \tag{7}$$

If the path had been in the y, z plane at a distance x from the center of gravity of the salvo, this probability would be reduced by a factor

$$\exp\left[-\frac{x^2}{X^2}\right]. \tag{8}$$

For a completely spherical distribution of rockets, X = Z and $\alpha = \gamma$ and the quantity $\sin \alpha \, z_o$ becomes equal to the miss distance (in the z = 0 plane) from the center of gravity. We see that the probability of the elementary area $\Delta x \Delta \sigma$ intercepting one rocket is just the ratio of this area to the area πX^2 multiplied by the exponential reduction factor, i.e.,

$$\frac{\Delta x \, \Delta \sigma}{\pi X^2} \exp\left[-\frac{r^2}{X^2}\right], \tag{9}$$

where r^2 is the distance of closest approach to the center of gravity of the rockets.

If we consider Eq. (2) and calculate the probability of finding a rocket within a cylinder of radius r whose axis is along the z-axis and extends from minus infinity to plus infinity, under the assumption that X equals Y, we find that this probability is equal to

$$1 - \exp\left[-\frac{r^2}{X^2}\right] \tag{10}$$

Therefore, within a cylinder of radius X the probability of finding a rocket is 1 − 1/e or 0.63, or, in other words, 63 per cent of the rockets pass through a circle of radius X about the axis; and the area πX^2 of this circle is the area with which the incremental area $\Delta x \, \Delta \sigma$ is to be compared, and gives the probability of finding one rocket for a circular distribution when the path is through the center of gravity.

The factor $(\cos \alpha / \cos \gamma)$, which is due to the nonspherical probability distribution of the rockets, is plotted as a function of the angle of approach for the different values of the ratio X/Z, the rocket distribution asymmetry factor, and for different values of the ratio of the velocity of the rocket to the velocity of the aircraft (Graphs V-2A-2, V-2A-3, V-2A-4). It is seen that for cigar-shaped distribution the probability of encountering the rocket decreases with increasing angle of approach, but the effect is less, the greater the ratio of the rocket velocity to aircraft velocity. For watch-shaped distribution X > Z, the factor $(\cos \alpha / \cos \gamma)$ increases with increasing angle of approach, the increase is less for larger values of (V_r/V_p). For values of $\theta \leq 45°$, $(V_r/V_p) \geq 2$ and $0.5 \leq X/Z \leq 2$, the value of $(\cos \alpha / \cos \gamma)$ always lies in the range

from 0.95 to 1.02, so that to a good first approximation we may neglect the effect on nonsymmetrical rocket density distribution.

Presented Area of the Aircraft

Account must be taken of the larger vulnerable area to rockets when the rockets approach broadside to an aircraft, compared with the head-on approach. Tests were made on a B-29 with charges of one pound, 1.5 pounds, and 2 pounds, placed at different positions on the aircraft.* These tests indicated the vulnerability as a function of the angle from head-on attack. For example, with a 2-pound static charge of high explosives, there was 185 square feet for head-on aspect, 520 square feet for 45° off-the-nose, 630 square feet for a side attack which, in the opinion of independent observers, would cause the aircraft to be out of commission with 100 per cent probability within a few minutes. These figures are quoted, not to indicate the lethality of rockets against the B-29, but only to give an estimate of the larger effective contact area of the aircraft from side view. If we assume that the presented area from the front is A and that that from the side is B, then the area at any other angle might be represented by the equation

$$a = A \cos(\theta - \gamma) + B \sin(\theta - \gamma) \quad . \qquad (11)$$

Graphs of the function a/A are given as a function of angle approach θ for different values of the ratio of the velocity of the rocket to the velocity of the target and for different ratios of the broadside area to frontal area (Graphs V-2A-7, V-2A-8, V-2A-9). It is believed that a representative value of B/A for a B-29 might be a factor of 4, and that for a 1.5-pound charge A might be 100 square feet, conservatively.

In obtaining Eq. (6) for the probability that one rocket will be within a volume swept out by a small area $\Delta x \Delta o$, we have not considered the finite extent of this incremental area and the modification that this would introduce. However, since the vulnerable areas of the plane are concentrated and of linear dimensions 1/5 to 1/10 of the values of X or Z which are to be expected with the

*Hughes Report, Technical Memo No. 243, November 10, 1950.

use of rockets at a range of about one mile, no serious error is introduced by performing the integration as though the area of the plane was concentrated at a point, and $\Delta x \Delta \sigma$ may be replaced by a for the area of the aircraft. A plot of $(a \cos \alpha)/(\cos \gamma)$ is given for representative values of B/A and V_r/V_p as a function of the approach angle θ (Graph V-2A-10). It is seen that, with these values of the parameters, even though $(\cos \alpha)/(\cos \gamma)$ decreases with increasing θ, the increase in a more than counterbalances.

Probability of at Least One Hit

All the preceding has been dealing with the probability that one rocket will hit the aircraft. We must now calculate the effect of N rockets in a salvo. If P_1 is the probability of one rocket's hitting an aircraft, then $1-P_1$ is the probability of a miss with only one rocket. The quantity $1-P_1$ raised to the Nth power is the probability of a miss with N rockets, and one minus this quantity would be the probability of at least one hit with N rockets.

$$P_N = 1-(1-P_1)^N \quad . \tag{12}$$

If the number of rockets is large, then we may use

$$P_N = 1 - \exp\left[-NP_1\right] \tag{13}$$

We may now express the probability that an aircraft of area a be hit by at least one of the N rockets, where the transverse linear dispersion of the rockets is X and the effective miss distance of the aircraft relative to the center of the rocket distribution is Σ:

$$P_N = 1 - \exp\left\{-\frac{Na\cos\alpha}{\pi X^2 \cos\gamma} \exp\left[-\frac{\Sigma^2}{X^2}\right]\right\} \quad , \tag{14}$$

where Σ^2 is defined by the relation

$$\Sigma^2 = x_o^2 + \cos^2\alpha \, y_o^2 \quad , \tag{15}$$

x_o is the miss distance perpendicular to the plane which contains the velocity vector of the rocket and velocity of the aircraft, and y_o is the miss distance in this plane perpendicular to the line of flight of the rockets. It is to be remembered that the $\cos\alpha$ term is due to the effect of the nonspherical distribution

of the rockets. If the distribution were symmetrical, cos α would be cos γ and the quantity cos α y_o would be the miss distance in the y, z plane. The probability of at least one hit is plotted as a function of the miss distance for various representative values of the effective presented area of the aircraft and for different numbers of rockets and for different values of the transverse rocket dispersion distance X (Graphs V-2A-11, V-2A-12, V-2A-13 and V-2A-14). These also are assuming that the rocket distribution is symmetrical. The effect of probable departures from spherical rocket distribution is negligible.

If Σ is the miss distance measured from the center of gravity in the x,y plane, and if the probability that a miss distance of amount Σ in a given direction will occur is given by the expression

$$dP(\Sigma) = \frac{1}{\pi S^2} \exp\left[-\frac{\Sigma^2}{S^2}\right] dA \qquad (16)$$

(where A = area), then, since Σ may have any orientation in the x,y plane, we must multiply by 2π and Σ to take into account all possible orientation of the miss distance. Thus, we obtain the probability that a miss will be of magnitude Σ:

$$dP\,\frac{\Sigma}{S} = 2\frac{\Sigma}{S} \exp\left[-\left(\frac{\Sigma}{S}\right)^2\right] \frac{d\Sigma}{S}.$$

Integration of the product of this probability by the probability of there being one rocket at this value of the miss distance [Eq. (6)] over the range of values of Σ from 0 to ∞, we obtain the probability of one hit.

$$P_1 = \frac{a}{\pi X^2} \frac{\cos\alpha}{\cos\gamma} \frac{1}{S^2} \int_0^\infty \exp\left[-\left(\frac{1}{X^2} + \frac{1}{S^2}\right)\Sigma^2\right] d\Sigma^2$$

$$= \frac{a}{\pi(S^2 + X^2)} \frac{\cos\alpha}{\cos\gamma}$$

Hence the probability of at least one hit with N rockets is

$$P_N = 1 - \exp\left[-\frac{Na}{\pi(S^2 + X^2)a} \frac{\cos\alpha}{\cos\gamma}\right]. \qquad (17)$$

It is to be noticed that the miss dispersion distance S and the rocket dispersion distance X enter equally, i.e., as the sum of the squares, and that

presented area of the target $\mathcal{A}$ and the total number of rockets N enter as the product; for the same probability of at least one hit, for one-half the target area, we shall need twice as many rockets. These values of P_N have been put on the appropriate curves with S = X.

Determination of Miss Distance

It now remains to calculate the miss distance in terms of the bore-sight error of the launcher, the error in calculation of the velocity vector of the airplane, the error in the determination of the position of the aircraft at the time of rocket launching, and the timing error. It will be assumed that each one of these errors has a Gaussian distribution and, therefore, that the resultant error squared will be the sum of the individual errors squared.

If the bore-sight error of the launcher is δ and the distance the rocket travels to the interception point is b, then $b\delta$ will be the contribution to both x_o and y_o.

If ΔV_{pt} is the transverse velocity, which is due to the fact that the direction of the velocity of the aircraft was not correctly determined, then the contribution to x_o will be $(\Delta V_{pt}/V_p)a$, where a is the distance the aircraft travels during the time of flight of the rockets from launching to interception. The contribution to y_o will be this quantity multiplied by $\cos(\theta - \gamma)/\cos\gamma$, as can be seen from Fig. V-2A-3 with the use of the law of sines.

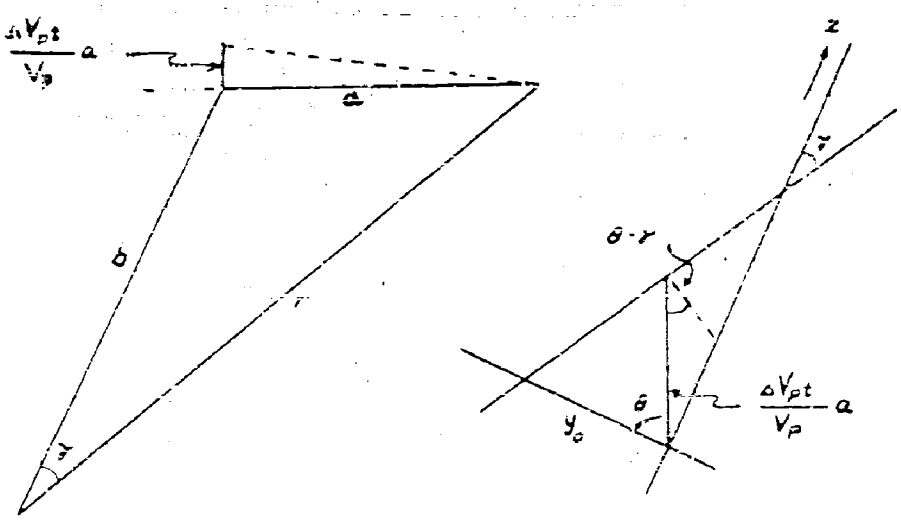


Fig. V-2A-3. Transverse velocity error

If the angular position of the target at the time of the launching of the rocket is in error by the angle ρ, then this corresponds to a linear error of ρr, where r is the distance from the target to the launcher at the time of firing. The contribution to x_o would be ρr, and the contribution to y_o would be $\rho r \sec\gamma$, as can be seen from Fig. V-2A-4.

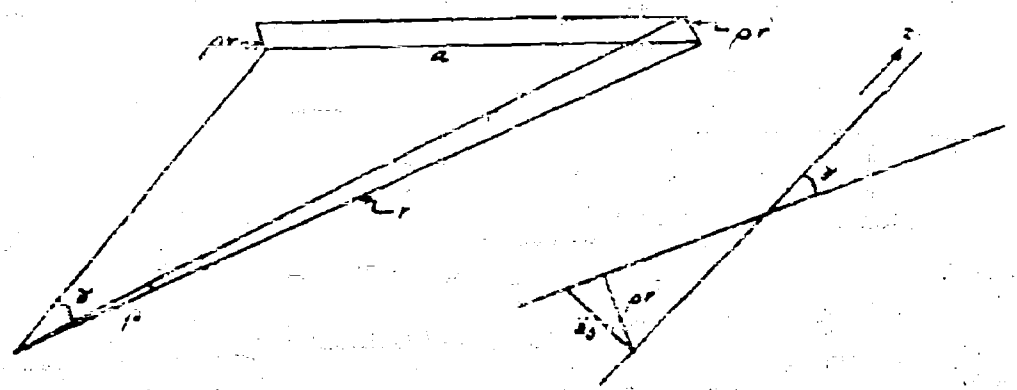


Fig. V-2A-4 Angular error of target.

If the velocity of the plane is in the correct direction, but the magnitude is in error by ΔV_p, then the contribution of this to y_o is

$$\frac{\Delta V_p}{V_p} a \frac{\sin(\theta - \gamma)}{\cos\gamma} .$$

There is no contribution to x_o. This derivation can be seen from Fig. V-2A-5.

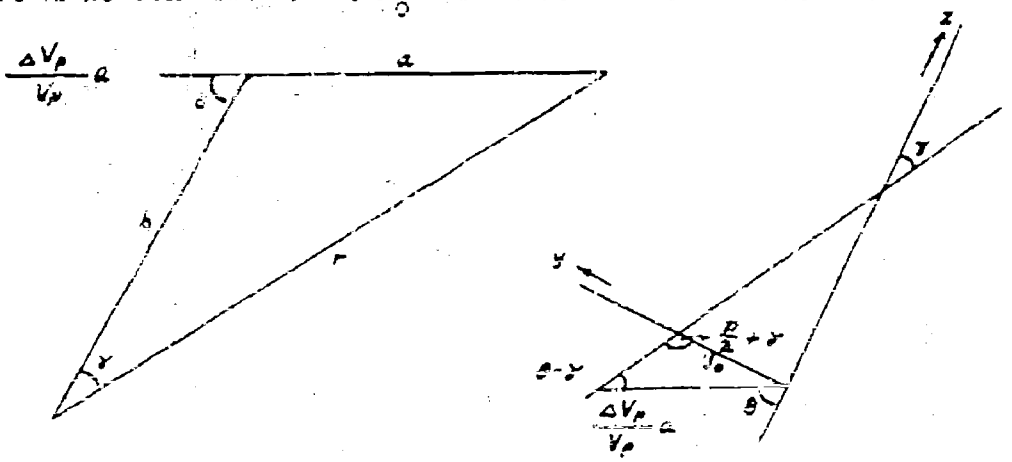


Fig. V-2A-5 Speed error of target

There will be a contribution to y_o due to an error in the time of firing. This error in time of firing might be due to a computing-time error or an error in the average velocity of the rockets. In any case, this would result in a z_o of $(\tau/T)b$, where τ is the firing-time error in seconds, T is the time of flight of the rockets, and b is the distance flown. This is equivalent to a y_o of $b\tau\tan\gamma/T$.

The effect of all these errors may now be computed by taking the sum of the squares of the contributions to x_o plus the product of $\cos^2\alpha$ times the sum of the squares of the contributions to y_o. In addition, let us assume that the direction of the velocity is computed with the same accuracy as the magnitude of the speed, that is, we assume that ΔV_{pt} is equal ΔV_p. Further, let us express the distance the plane travels in terms of that of the rockets during the time from launcher to interception, that is, $a = b(V_p/V_r)$. Thus the value of Σ^2 is

$$\Sigma^2 = b^2\left[\ell^2(1+\cos^2\alpha) + \tan^2\gamma\cos^2\alpha\left(\frac{1}{T}\right)^2 + \left\{\left(\frac{\Delta V_p}{V_p}\right)^2\left(\frac{V_p}{V_r}\right)^2 + \frac{\rho^2 r^2}{b^2}\right\}\left(1+\frac{\cos^2\alpha}{\cos^2\gamma}\right)\right] \qquad (18)$$

From an examination of Eq. (18), it is seen that, to minimize the excessive contribution of any particular component error, the contributions of the errors due to launcher bore sight, target velocity, and target angular position should be roughly equal. Notice that there is no effect of the timing error for head-on approach, but only for large angles of γ. But the other errors also contribute greatly in this region. Thus, if we limit the allowable value of τ to that such that $\tau = \ell T$, which could easily be true, then Eq. (18) reduces to

$$\Sigma^2 = b^2\left(1+\frac{\cos^2\alpha}{\cos^2\gamma}\right)\left\{\ell^2 + \left(\frac{\Delta V_p}{V_p}\right)^2\left(\frac{V_p}{V_r}\right)^2 + \frac{\rho^2 r^2}{b^2}\right\}. \qquad (19)$$

If it is assumed that the most difficult error contribution to minimize is that due to launcher bore-sight error, then the other errors may be expressed in terms of the bore-sight error, ℓ, such that the contribution would be equal. Hence

$$\rho \leq \frac{b}{r}\ell \quad , \qquad (20)$$

and the range of b/r is from two-thirds to one. If the angular accuracy of

determining the position of the target is three times that of the accuracy of the launcher, there will be little relative contribution to the miss distance. Also,

$$\frac{\Delta V_p}{V_p} \leq \frac{V_r}{V_p}\, \ell \ .$$

The smallest value of V_r/V_p to be expected is 2, so that we should keep

$$\frac{\Delta V_p}{V_p} < 2\ell \qquad (21)$$

For an 8-mil launcher error, the relative error in the determination of the velocity should be less than 1.6 per cent.

Plots of miss distance vs approach angle (Graphs V-2A-15, V-2A-16, V-2A-17, V-2A-18) show that for $V_r/V_p \geq 2$, the effect of nonspherical density distribution of the rockets is negligible.

For spherical distribution of the rockets ($a = \gamma$), the condition that $P_N = 0.63$ is, from Eq. (17), that

$$\frac{Na}{S^2 + X^2} = 1 \ .$$

Now, both the miss dispersion distance S and the rocket distribution dispersion distance X are proportional to the distance b the rockets fly from launching to interception, if the inequality Eq. (20) is maintained. Taking into account the manner in which the presented area of the target a increases with approach angle, say, Eq. (11), the interception range b may be increased accordingly.

Let S = sb where

$$s = \sqrt{2}\left(\ell^2 + \frac{\Delta V_p^{\ 2}}{V_r}\right)^{1/2} \ , \quad \text{and } X = xb \ .$$

Then

$$b = \left\{\frac{N\left[A\cos(\theta - \gamma) + B\sin(\theta - \gamma)\right]}{\pi(s^2 + x^2)}\right\}^{1/2} \ .$$

This is plotted (Graph V-2A-18) for N = 100, A = 100 ft.^{2}, B = 500 ft.^{2}, $V_r/V_p = 2$, $\ell = 8.15$ mils, $\Delta V_p/V_p = 1.63$ per cent, x = 16.3 mils, where the bore-sight error and the error in the determination of the velocity of the aircraft are chosen such that the range b is 4500 ft. for $\theta = 45°$ and the two errors

are contributing equally and the two together are contributing equally with the rocket dispersion. We see that for head-on approach we should wait until the intercept range is 2500 feet rather than 4500 feet in order to keep the probability of at least one hit 0.63.

On the other hand, if it is desired to have the interception range of 4500 feet for head-on approach, then the tolerance for bore-sight error and relative velocity determination error must be tightened to 4.4 mils and 0.88 per cent, respectively, and a rocket dispersion of 8.8 mils, or the number of rockets must be raised to 337 to keep the probability of one hit 0.63.

For the case $V_r/V_p = 4$, the distances or angles are only 6 per cent different and the areas or number of rockets 12 per cent different from the case $V_r/V_p = 2$.

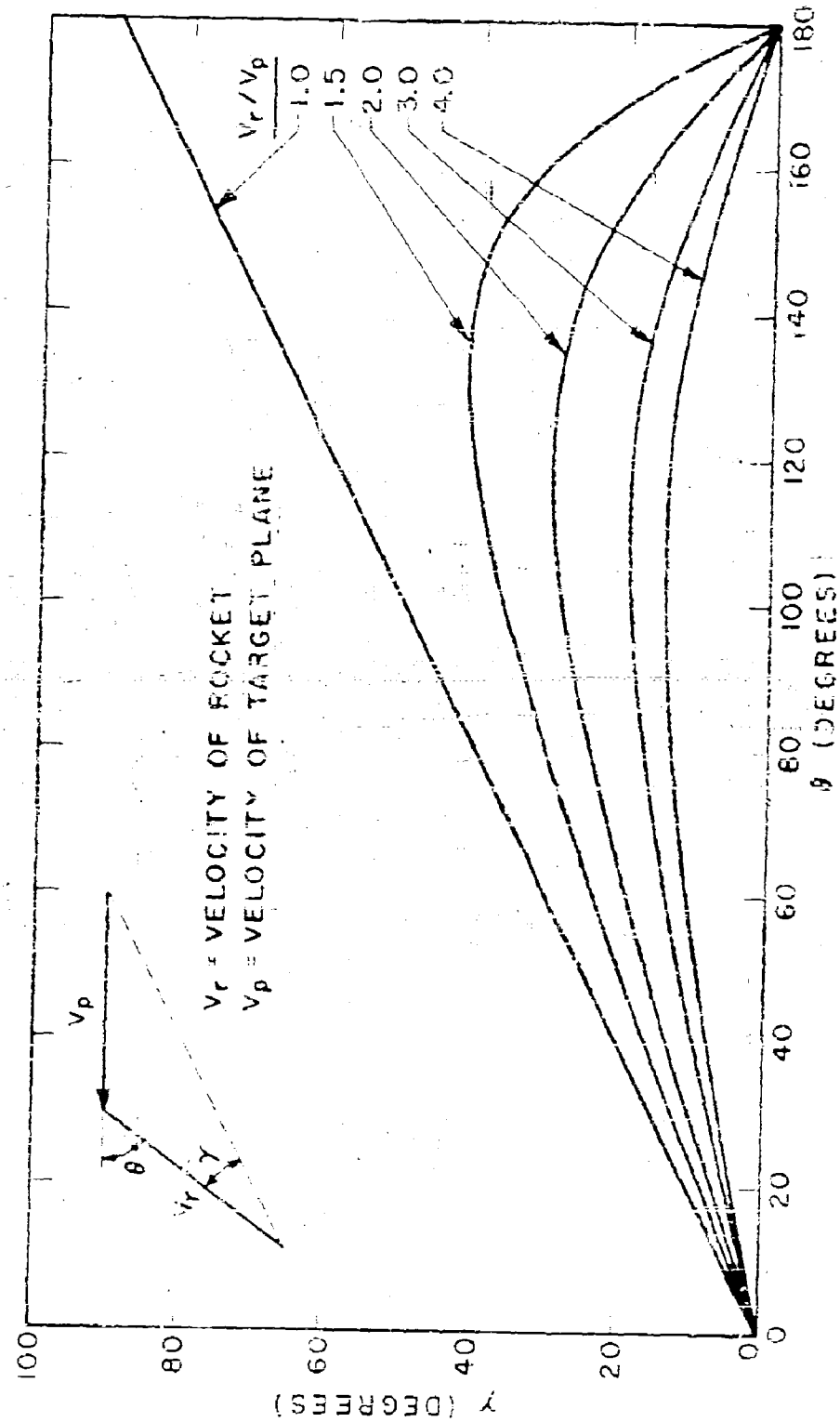
It has been stated that X is a distance such that 63 per cent of the rockets pass within a circle of radius X centered about the maximum of the distribution. It should be noted that in many reports on ballistics a distance defined as the standard dispersion distance is used and is equal to $X/\sqrt{2}$; through a circle of this radius only 40 per cent of the rockets pass. In some cases, a third distance is used to describe the dispersion: the distance such that a circle of this radius would encompass 50 per cent of the rockets. The third distance is equal to X/1.2.

Conclusion

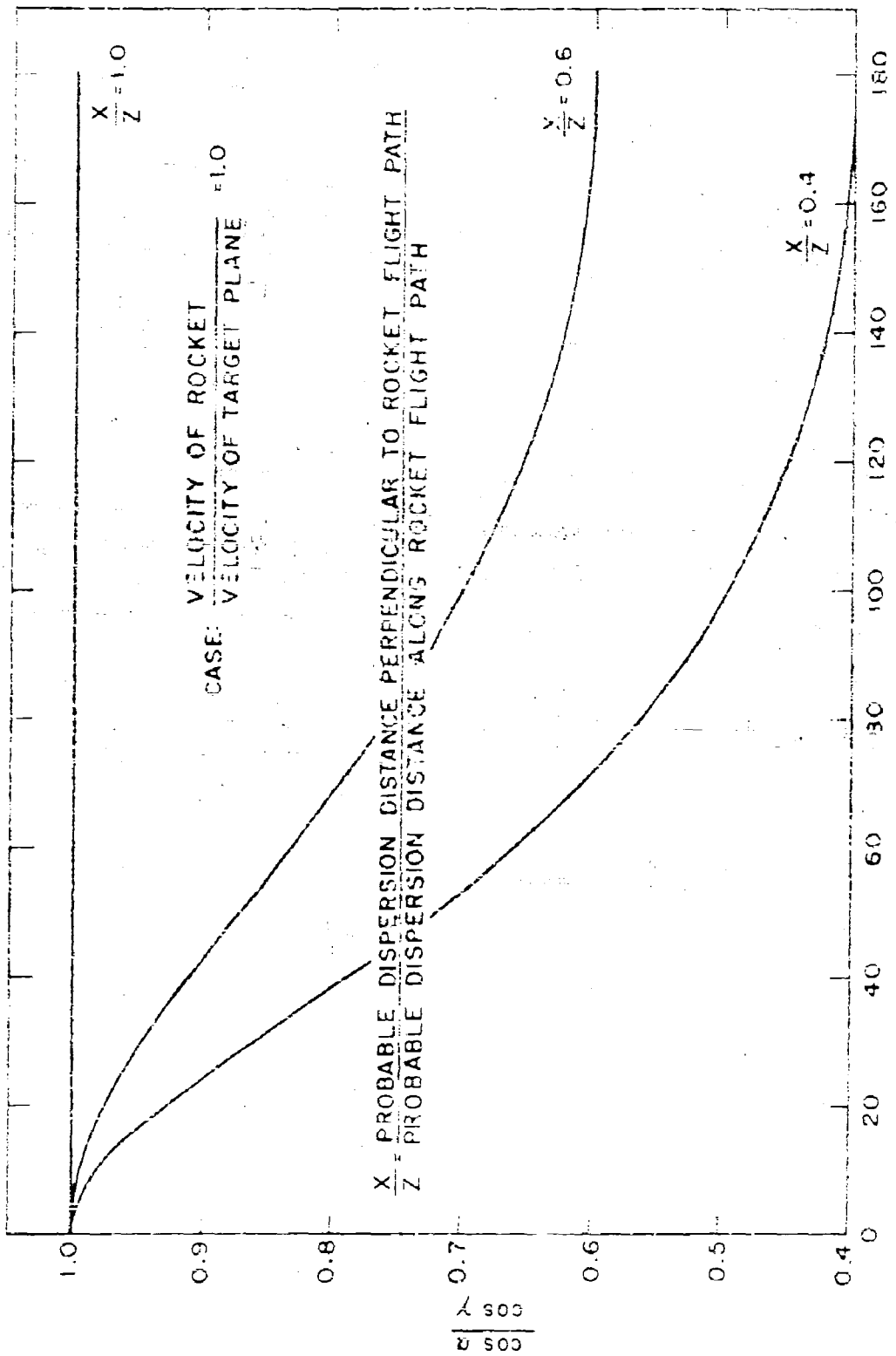
For representative values of the presented area of the target, and for the range of rocket velocities greater than twice that of the target, it is shown that the bore-sight error of the launcher must be of the order of 0.5°, the determination of the speed of the aircraft must be of the order of 1.5 per cent, and the direction of the velocity of the aircraft determined to 1° if the probability of at least one hit with 100 rockets is to be 0.6. This is based on the assumption that the dispersion of the rockets is such that 63 per cent of them are within a circle of radius 16 mils.

The advantages of "holding fire" for head-on attack are pointed out; if the intercept range is 4500 feet for an angle of approach of 45°, then the head-on range should be limited to 2500 feet.

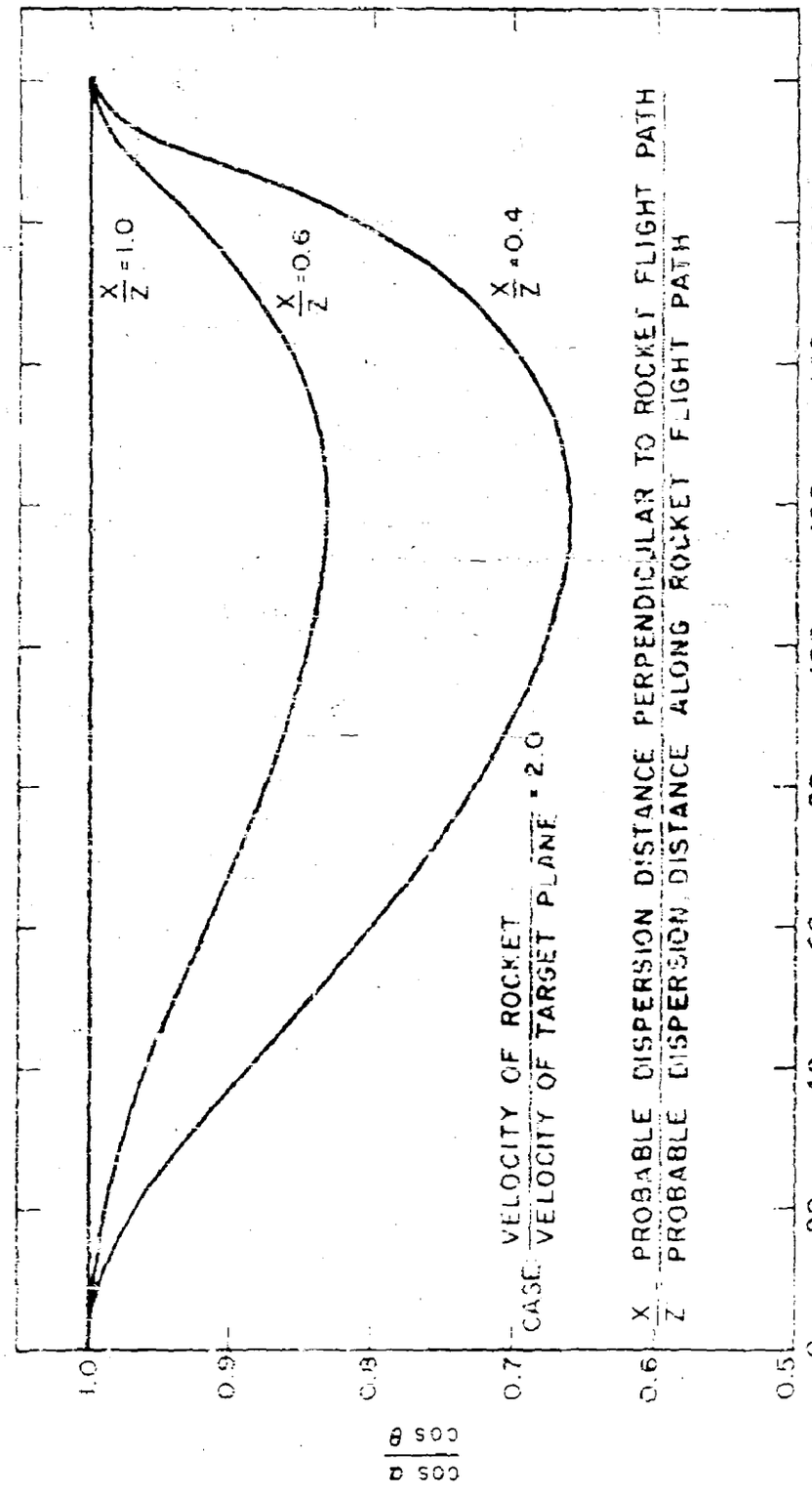
S. B. Welles



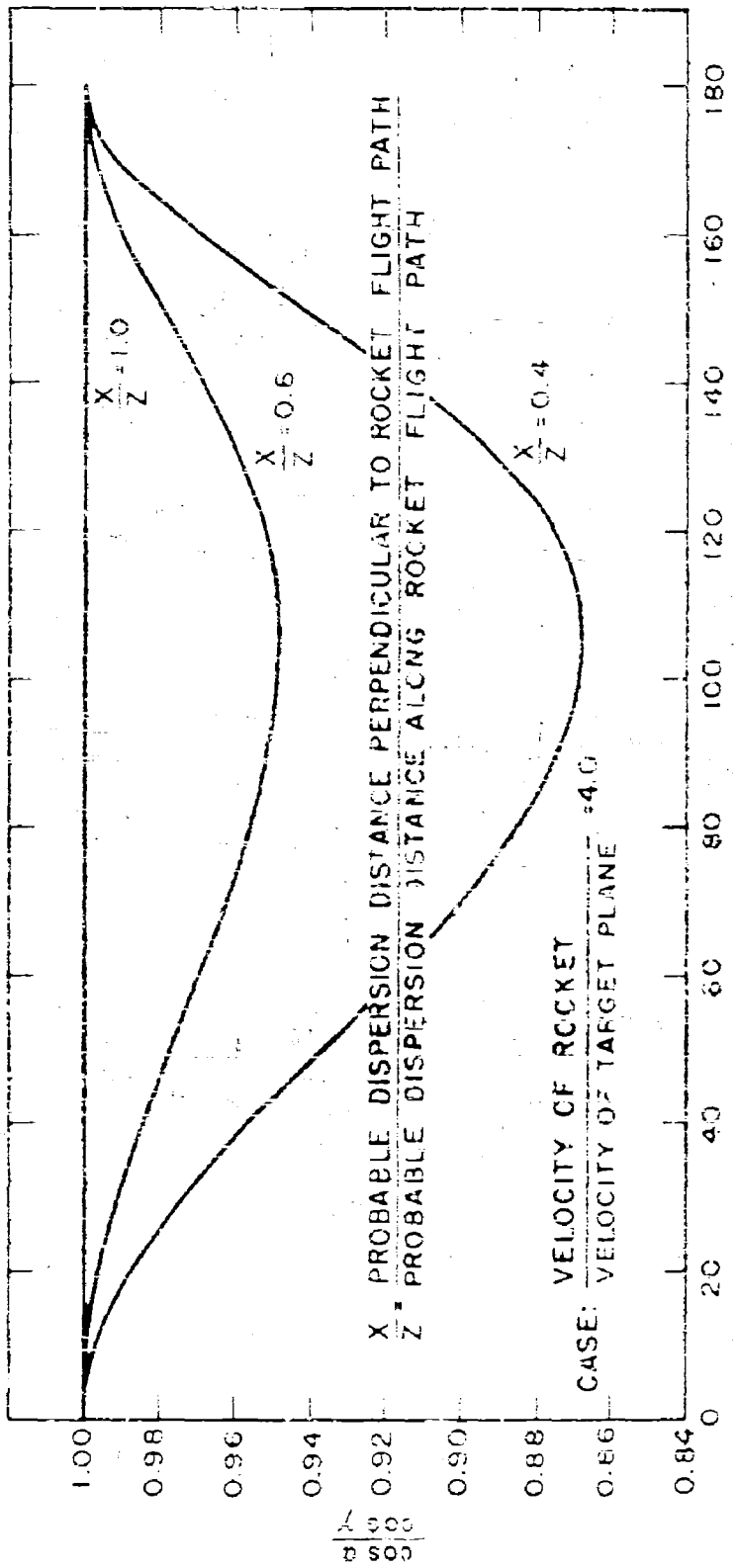
Graph V-2A-1 Angle of path of target relative to direction of flight of rockets (γ) vs. angle between velocity of rocket and velocity of target (θ).



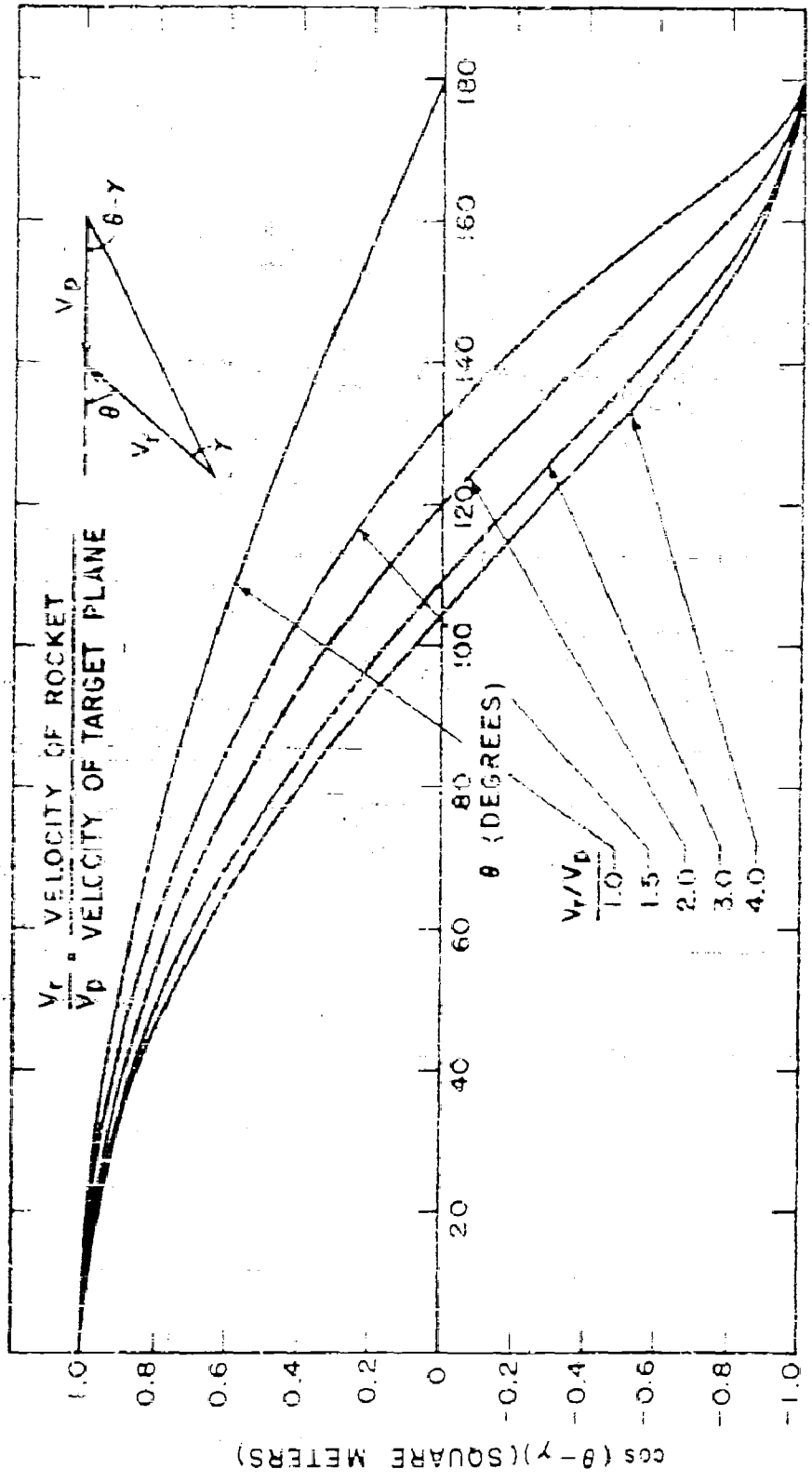
Graph V-2A-2 Factor ($\cos \alpha / \cos \gamma$) due to nonspherical rocket probability distribution, by which presented area is multiplied, vs. approach angle (θ). Case: velocity of rocket/velocity of target plane = 1.0.



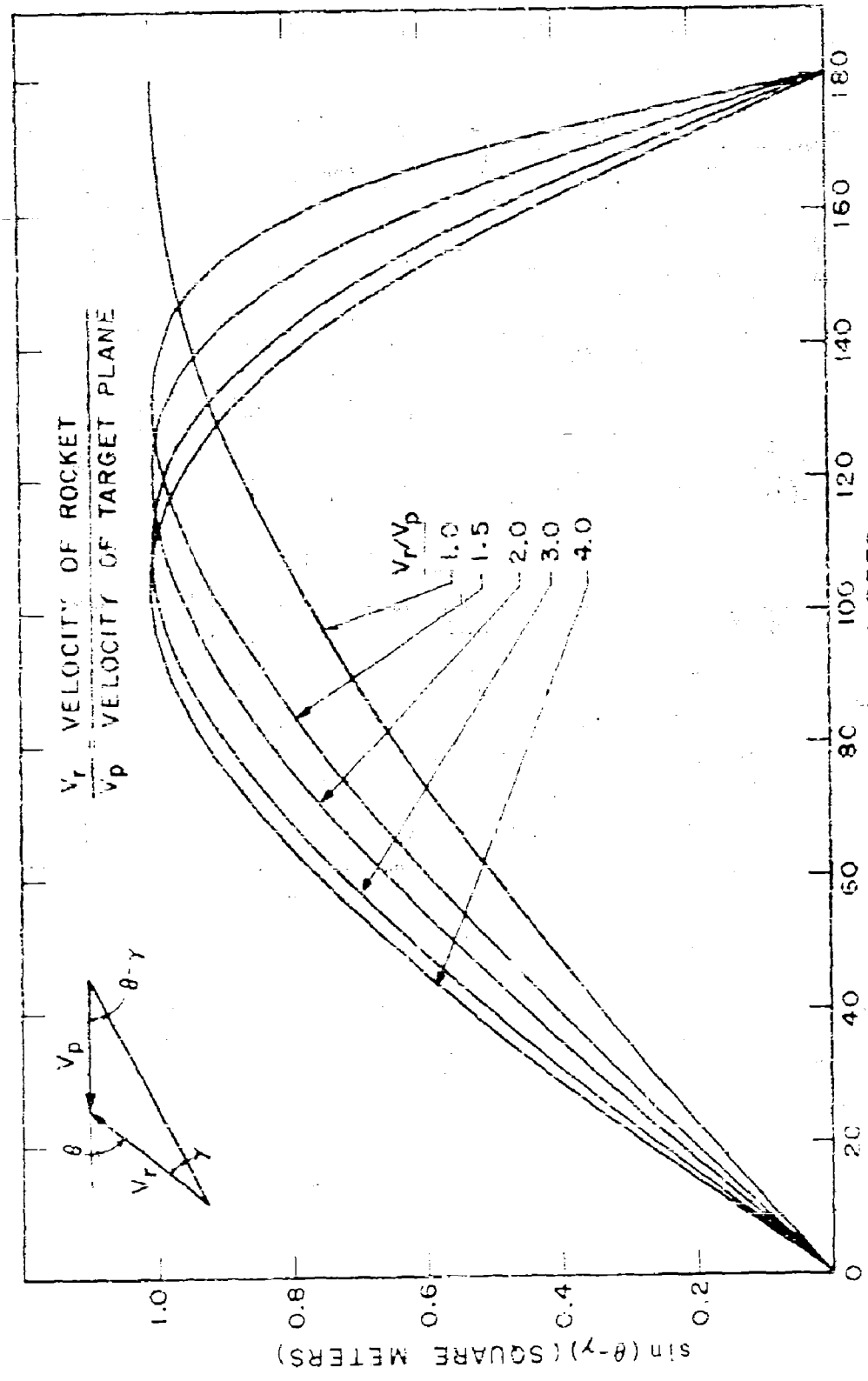
Graph V-2A-3 Factor ($\cos\theta/\cos\gamma$) due to nonspherical rocket probability distribution, by which presented area is multiplied, vs. approach angle (θ). Case: velocity of rocket/velocity of target plane = 2.0.



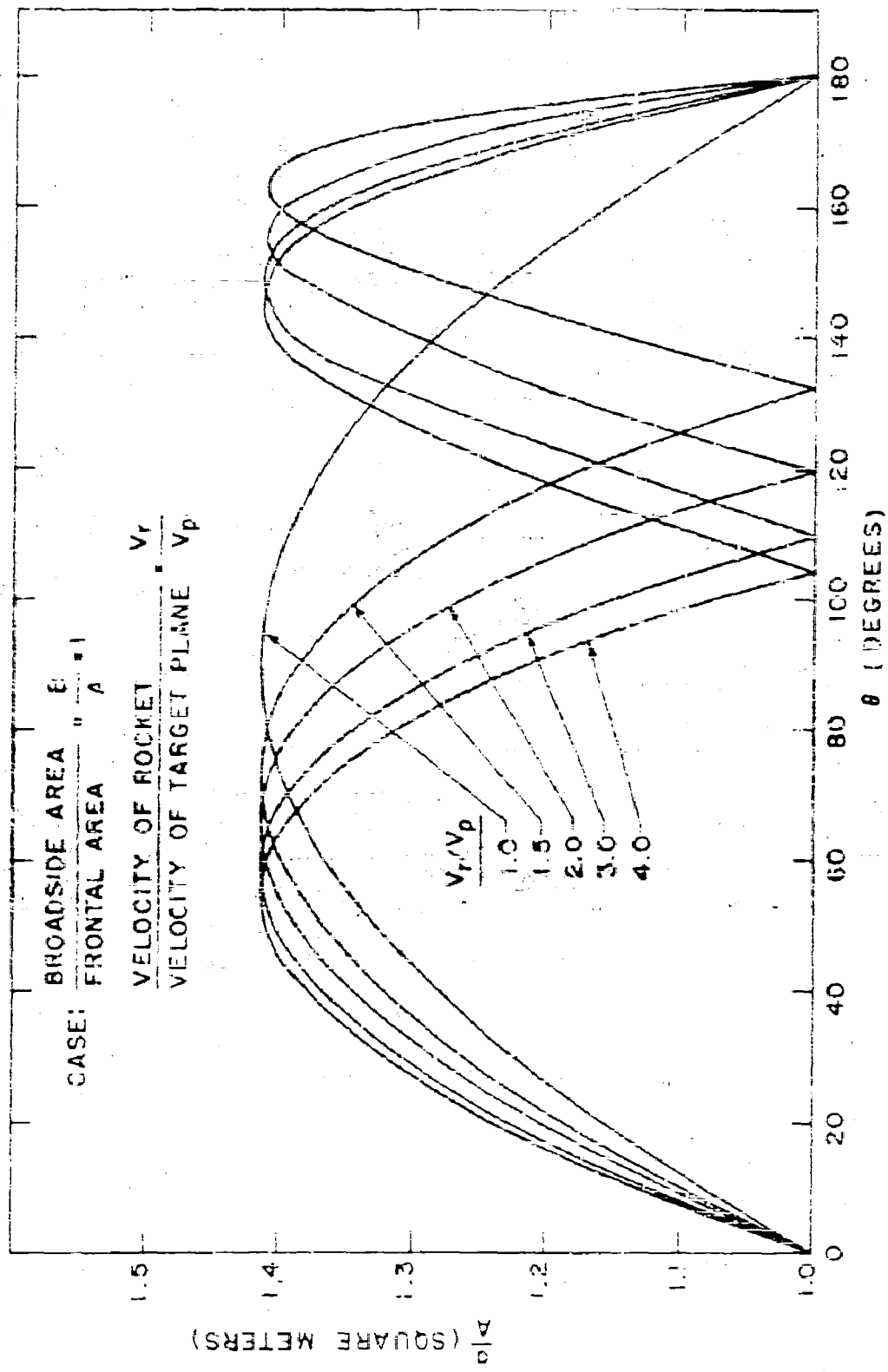
Graph V-2A-4 Factor ($\cos\alpha/\cos\gamma$) due to nonspherical rocket probability distribution, by which presented area is multiplied, vs. approach angle (θ). Case: velocity of rocket/velocity of target plane = 4.0.



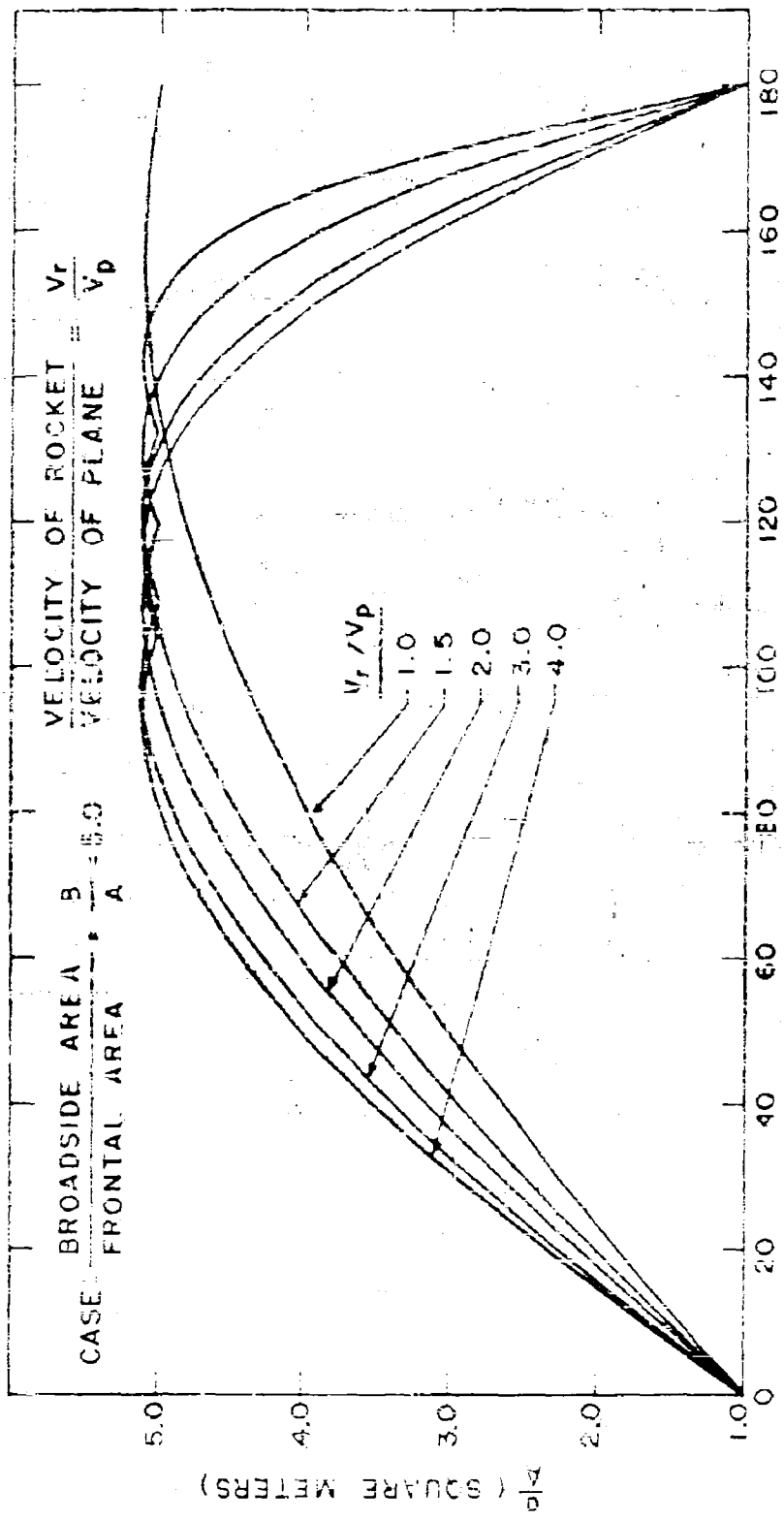
Graph V-2A-5 Contribution of frontal area [cos (θ-γ)] vs. approach angle (θ).



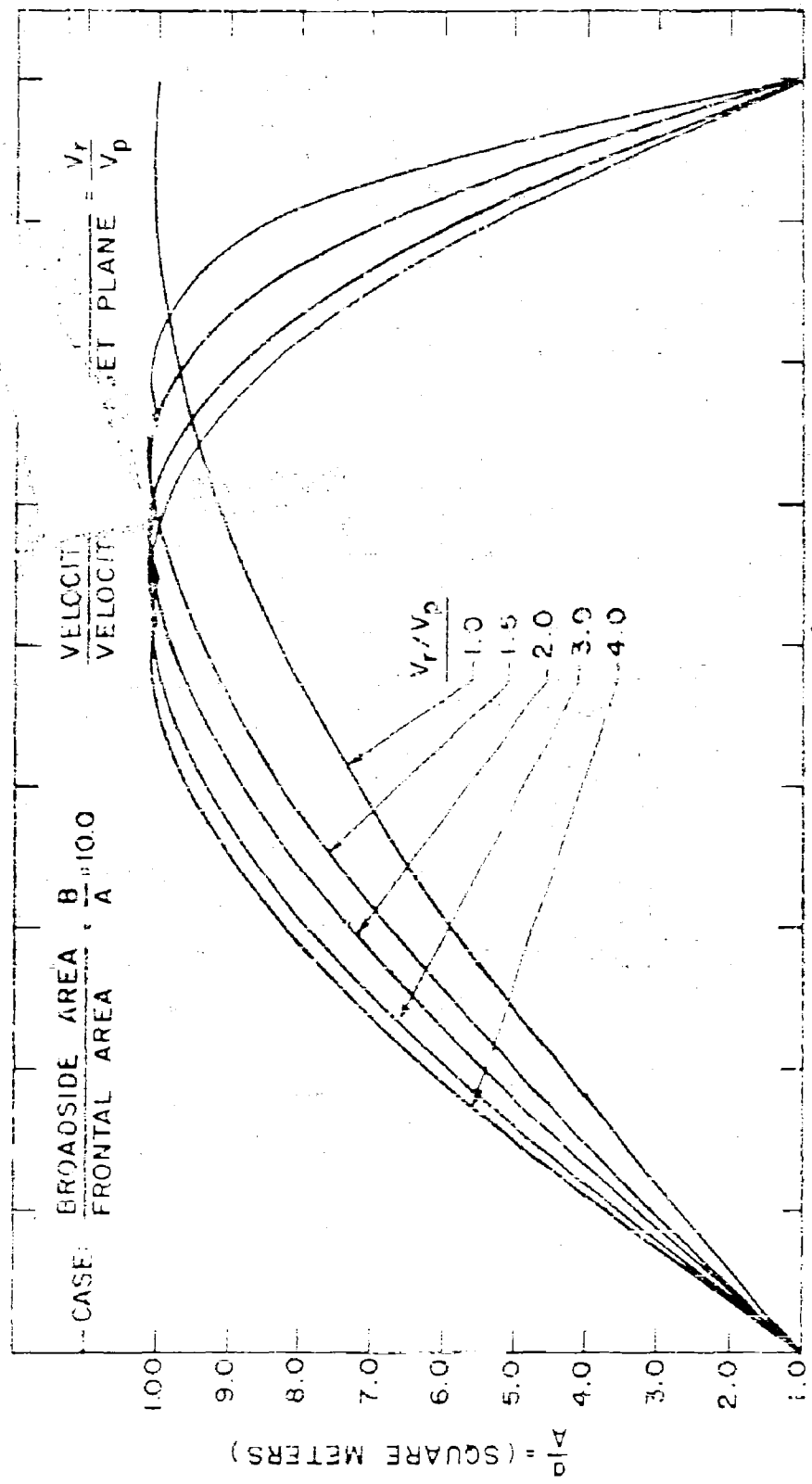
Graph V-2A-6 Contribution of broadside area $[\sin(\theta-\gamma)]$ vs. approach angle (θ).



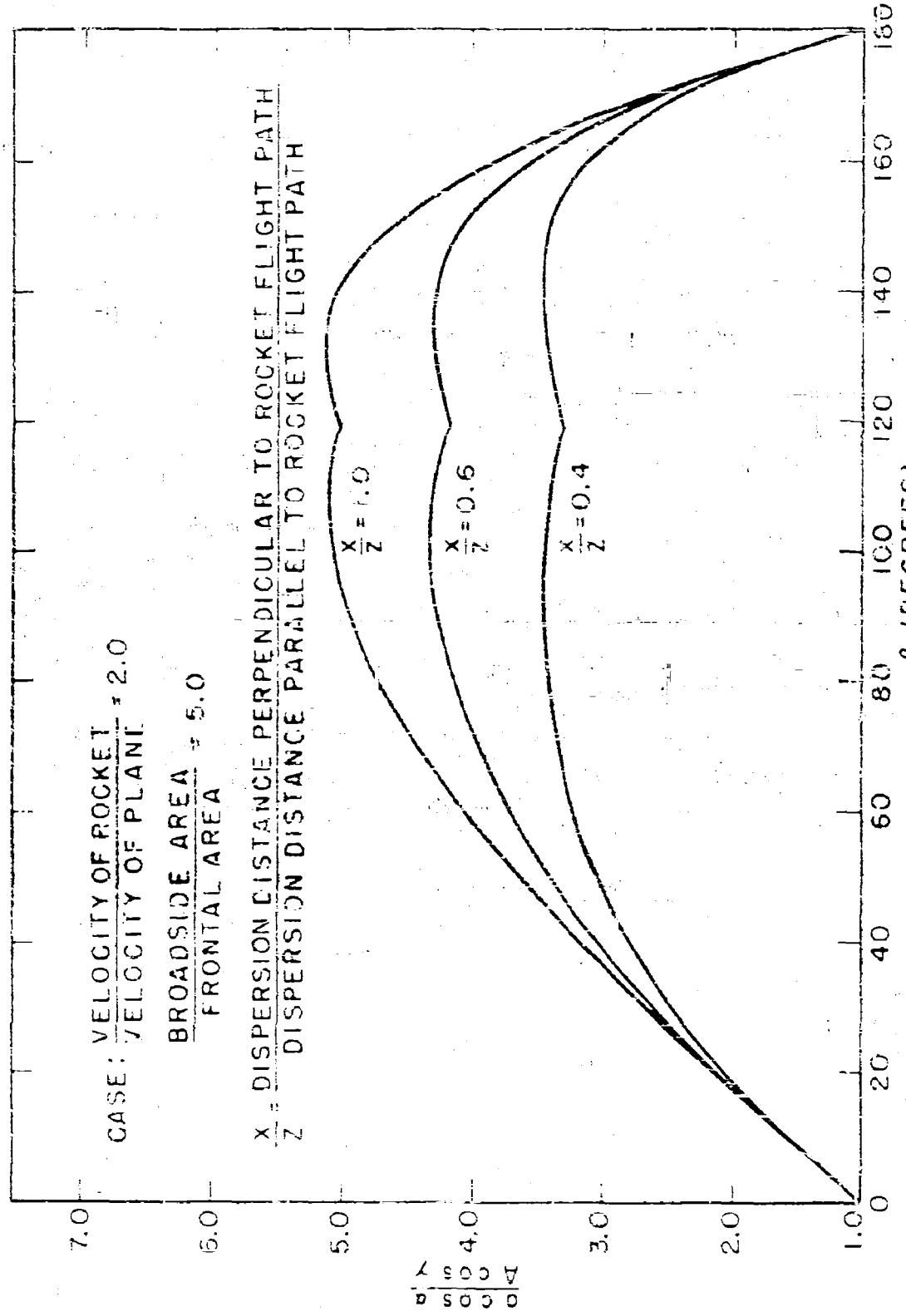
Graph V-2A-7. Ratio of presented area to minimum frontal area (σ/A) vs. approach angle (θ). Case: broadside area/frontal area = B/A = 1.



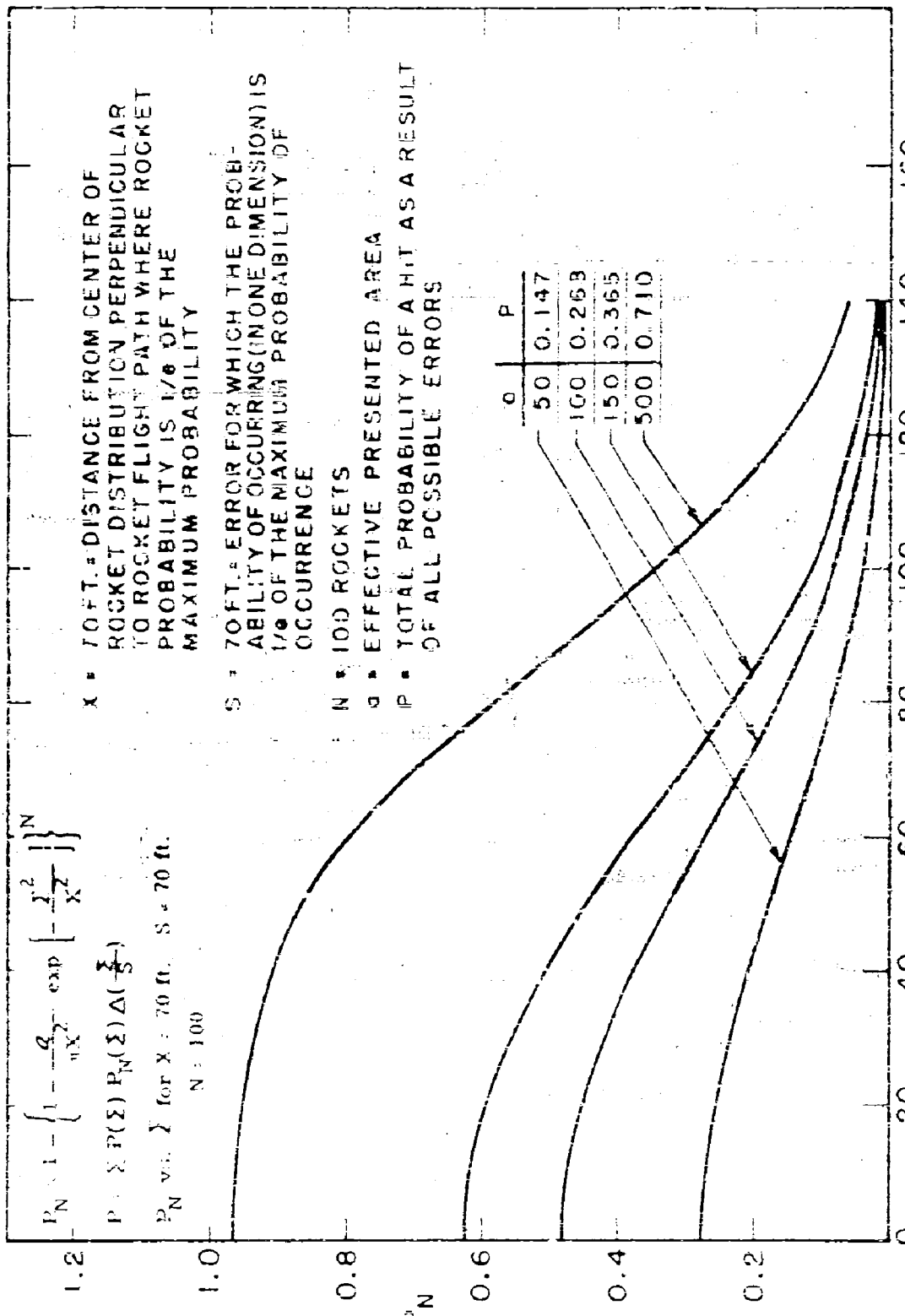
Graph V-2A-8. Ratio of presented area to maximum frontal area (a/A) vs. approach angle (θ). Case: broadside area/frontal area = B/A = 5.0.



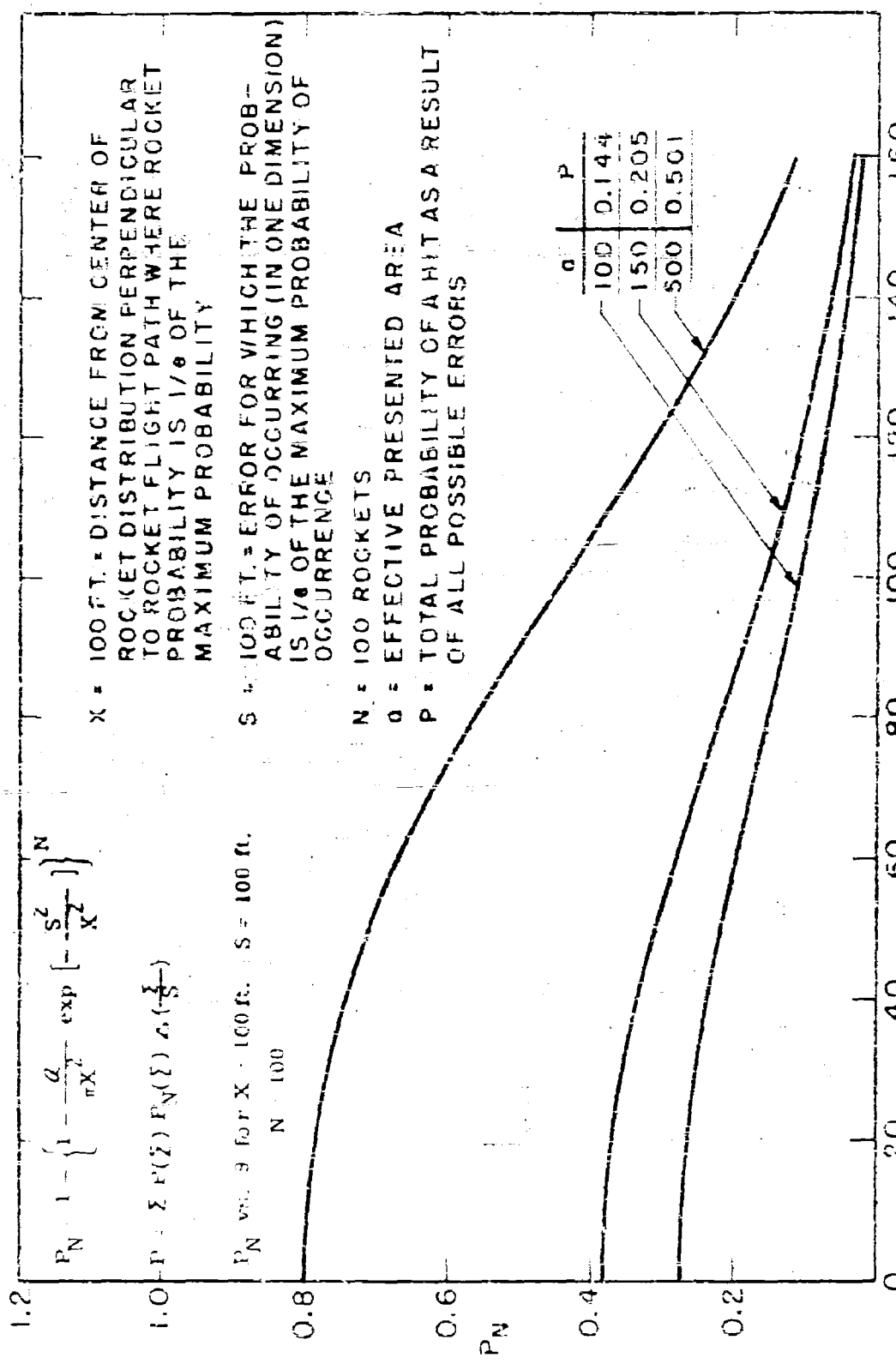
Graph V-2A-9 Ratio of presented area to minimum frontal area (α/A) vs. approach angle (θ). Case: broadside area/frontal area = B/A = 10.0.



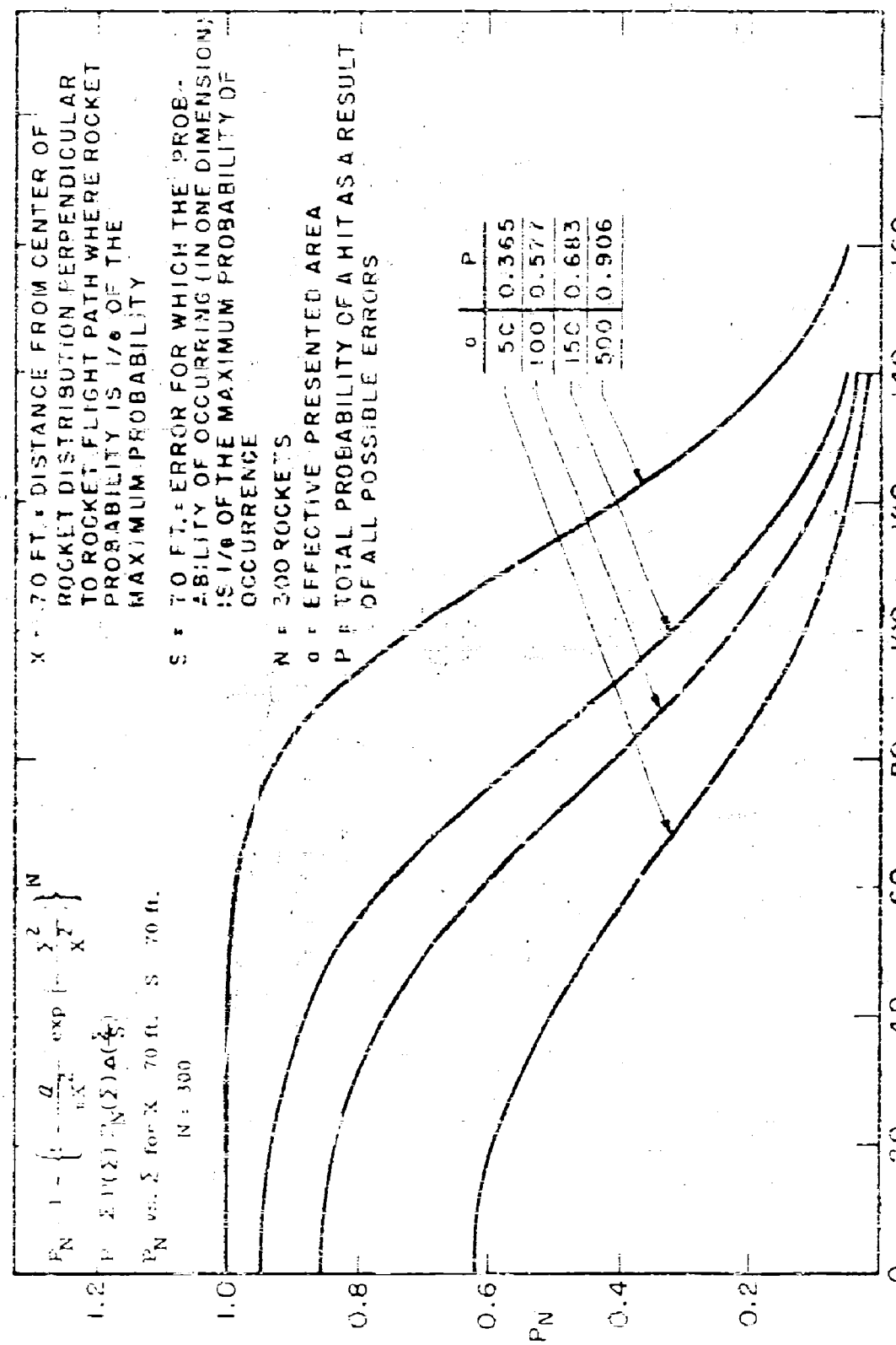
Graph V-2A-10 Ratio of effective presented area to frontal area $[(a/A)(\cos a/\cos \gamma)]$ vs. approach angle (θ). Case: velocity of rocket/velocity of plane = 2.0; broadside area/frontal area = 5.0.



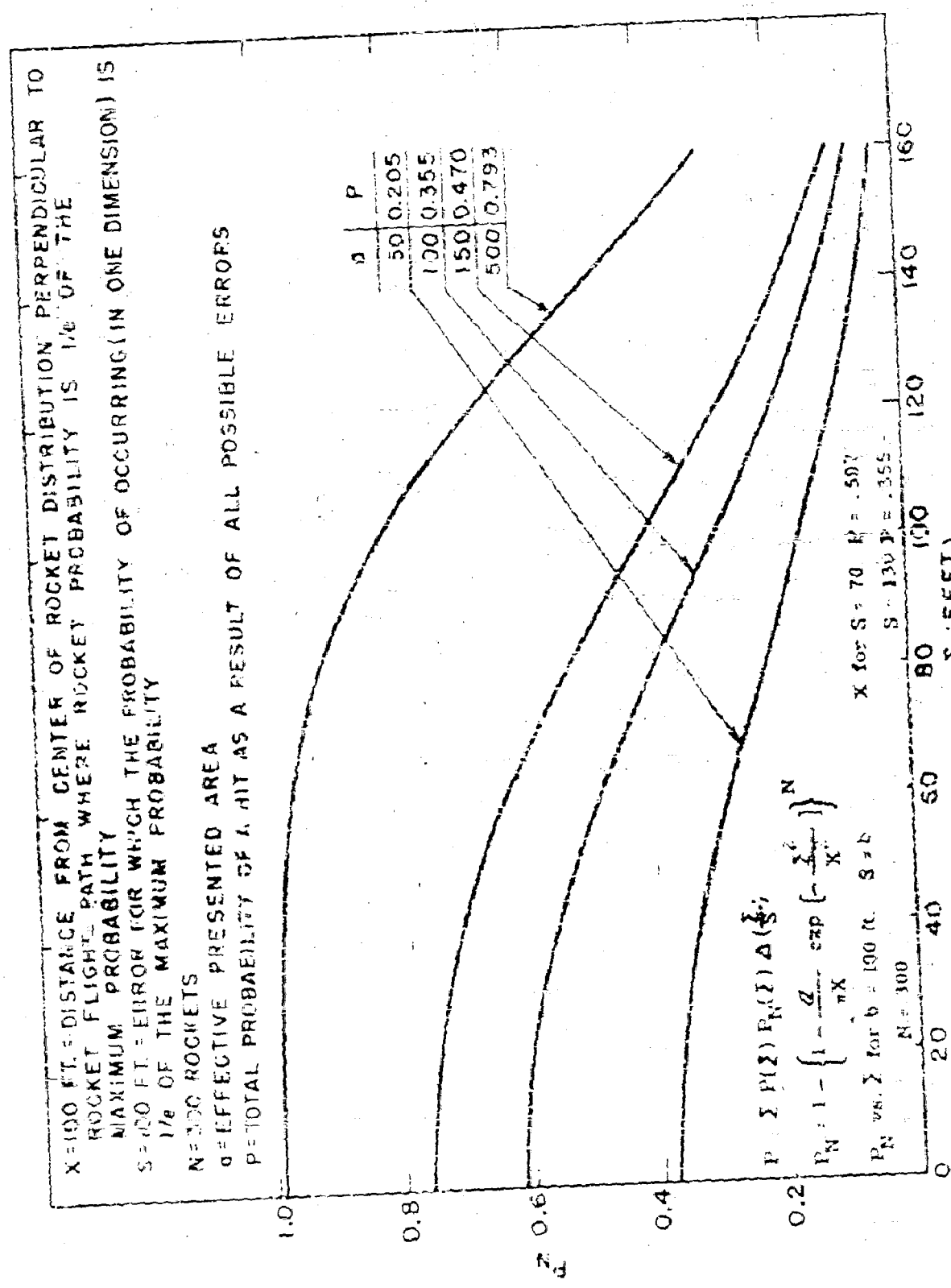
Graph V-2A-11 Probability of a hit with N rockets (P_N) vs. miss distance (Σ).



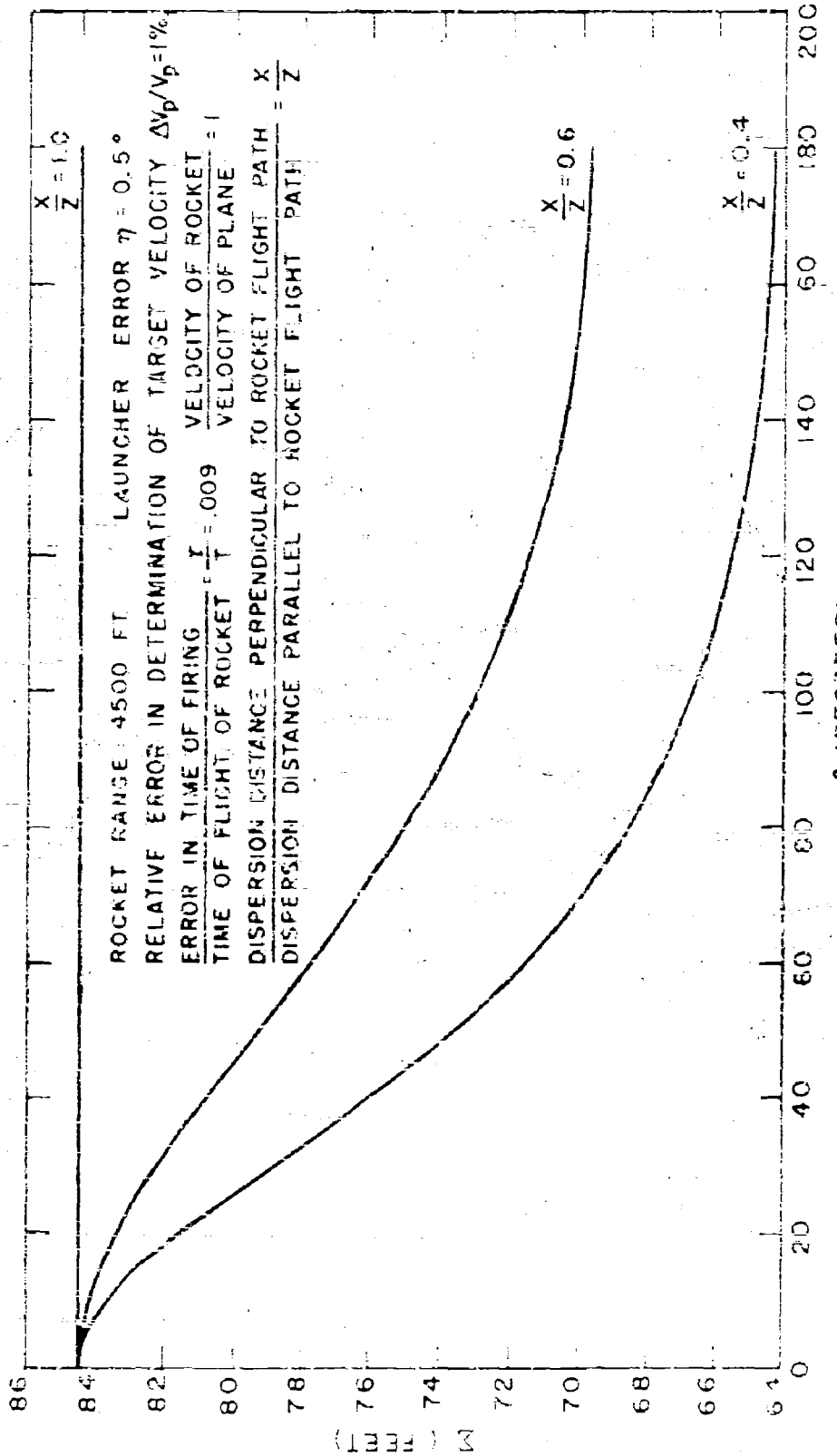
Graph V-2A-12 Probability of a hit with N rockets (P_N) vs. miss distance (Σ).



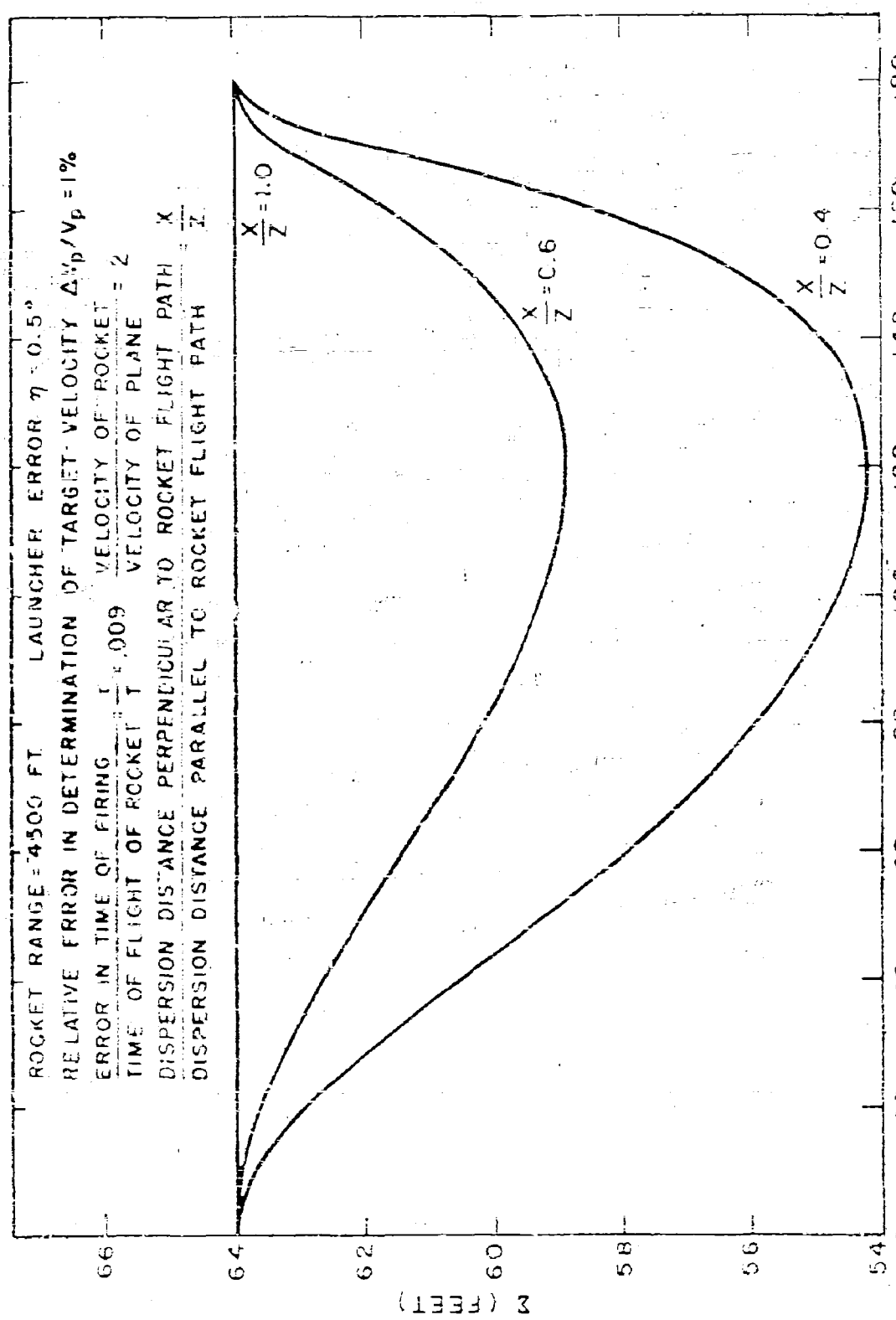
Graph V-2A-13 Probability of a hit with N rockets (P_N) vs. miss distance (Σ).



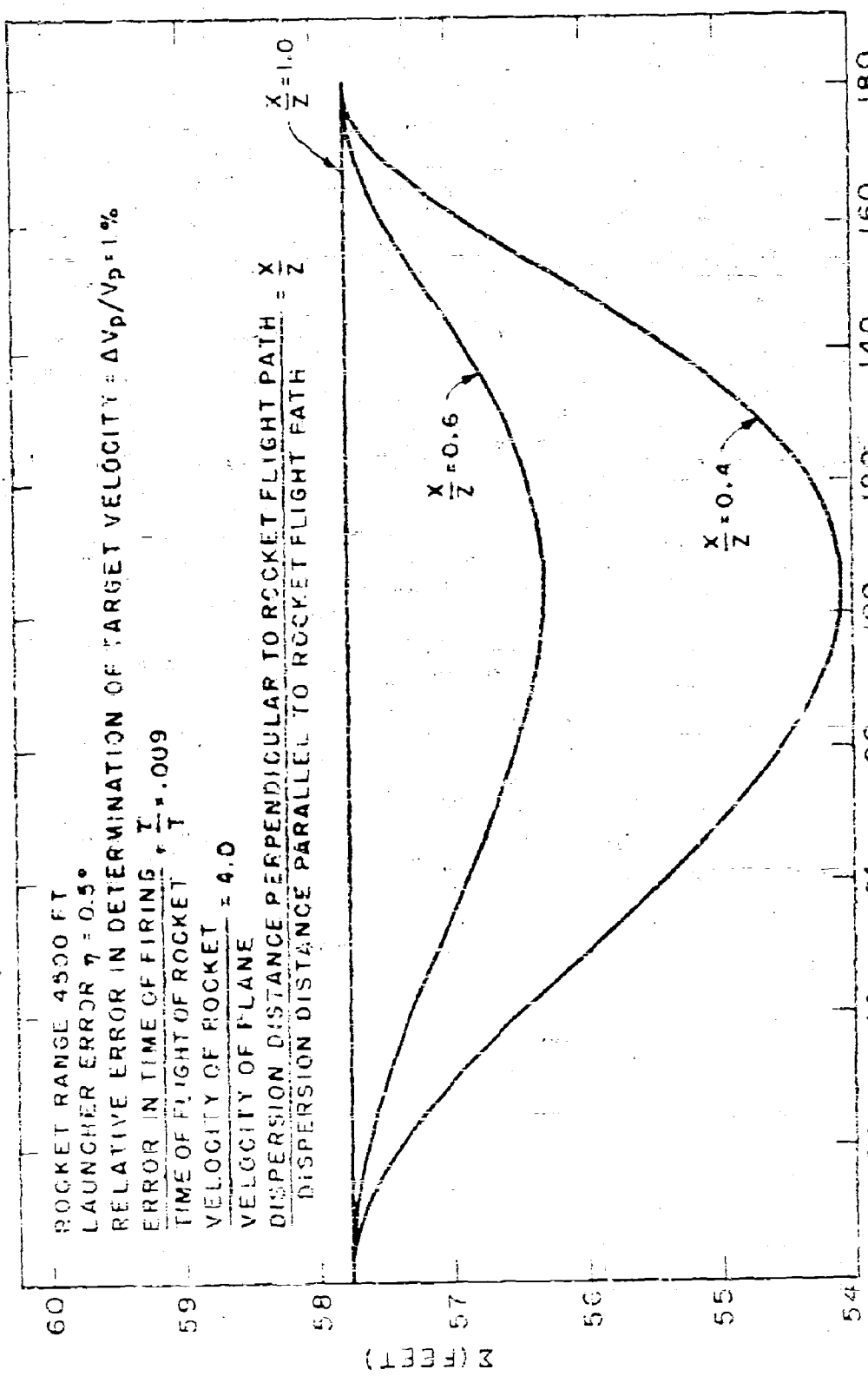
Graph V-2A-14 Probability of a hit with N rockets (P_N) vs. miss distance (Σ).



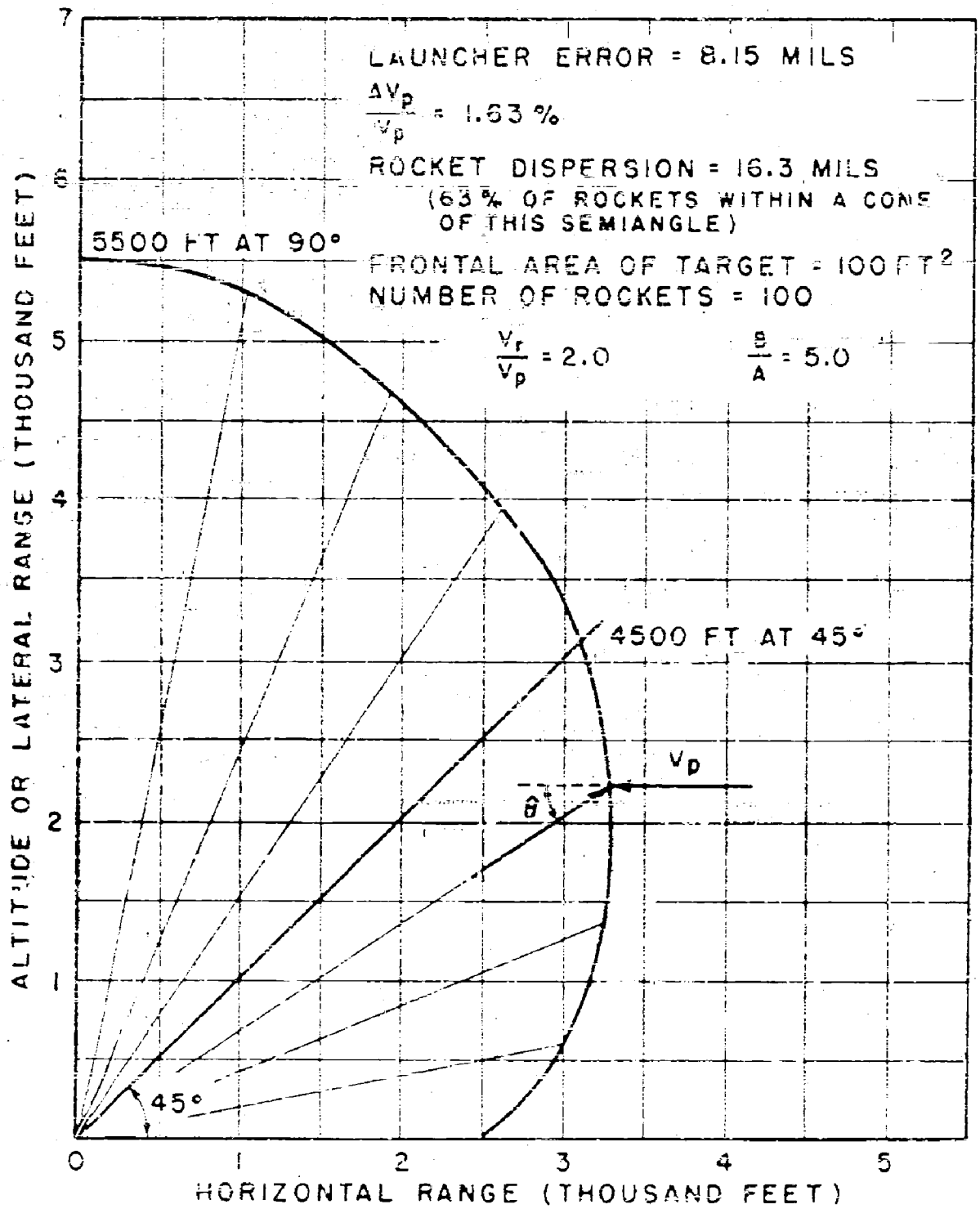
Graph V-2A-15 Miss distance (M) vs. approach angle (θ). Velocity of rocket/velocity of plane = 1.0.



Graph V-2A-16 Miss distance (ε) vs. approach angle (θ). Velocity of rocket/velocity of plane = 2.0.



Graph V-2A-17 Miss distance (Z) vs. approach angle (θ). Velocity of rocket/velocity of plane = 4.0.



Graph V-2A-18 Polar plot of interception range vs. approach angle.

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SECURITY INFORMATION

This document contains 150 pages. No. of 1500 copies 540

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROBLEMS OF AIR DEFENSE

Appendices

to

Final Report

of

PROJECT CHARLES

VOLUME III
of
Three Volumes

1 August 1951

Contract No. DA36-039sc-5450

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CAMBRIDGE MASSACHUSETTS

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APPENDIX VI-1

THE CONTROL OF ELECTROMAGNETIC RADIATIONS

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THE CONTROL OF ELECTROMAGNETIC RADIATIONS

A. INTRODUCTION

In considering the control of electromagnetic radiations during an alert and under full wartime conditions in continental United States, two basic yardsticks should be applied in deciding what to do about any particular source: first, "Can it be an aid to an enemy?" and second, "What do we sacrifice by its elimination or curtailment?" In the absence of intelligence and actual combat conditions and experience, it is well to plan for control of all likely damaging emissions and to implement the plan fully upon initial alert. In full war conditions, after more positive intelligence is obtained on enemy navigational methods, the decisions and calculated risks involved in the use or curtailment of any particular type of service should be re-examined, and desirable modifications to the control plans made.

Sources that offer the enemy means for navigation to a particular area must be given primary consideration. Successful, accurate navigation prior to final bomb run is generally accomplished by cross-checking all the navigation means available – dead reckoning, celestial observations, direction-finding (DF) bearings on available sources, and direct use of special navigation aids. The prevention of enemy use of our own radiations for the latter two methods, most certainly reduces his capability of arriving at a particular location, and increases his need to expend effort in the development and production of self-contained navigation aids.

Another consideration is the desirability for proper control, so that monitoring operations can be conducted to reduce to a minimum undetected illicit transmissions that could provide homing stations or furnish the enemy intelligence information.

A review has been made of the present plans for electromagnetic radiation control as developed by the Federal Communications Commission (FCC) and the Civil Aeronautics Authority (CAA) at the request of and in conjunction with the Air Defense Command (ADC). Before these plans can be officially

formalized as effective instruments, it is necessary to have an Executive Order giving the Air Defense Commander the statutory authority to order such control. The signing of such an order, expected momentarily, is urgently needed.

The CAA has prepared plans* for the control of civil navigation aids. As of today, the FCC has developed plans** for the control of amplitude-modulation (AM), frequency-modulation (FM), and television (TV) broadcast stations, and for the amateurs, and have under consideration the control of other emissions over which the FCC has licensing control.

Consideration of any plan involving control of a particular type of service, such as standard AM broadcast stations, must be projected against the plans for all other services that may provide similar aid to an enemy. This may include any emissions from the lowest frequency to about 5 Mc, the very-high- and ultra-high-frequency (VHF and UHF) regions and possibly higher frequencies. Special attention must be given to the low- or medium-frequency (LF or MF) regions since the Soviets are known to take DF bearings against beacons in these frequency ranges for standard navigation inside the Soviet Union.

It is dangerous to argue the relative necessity of various services lest it lead merely to a very partial reduction of aid to the enemy. It would be hard to evaluate this reduction since security would not be good enough to prevent the enemy from knowing just what aids he could depend on. It is equally dangerous to conclude that, if some services are impossible to control, none should be controlled.

The objective of control, then, should be to render useless to the enemy all electromagnetic radiations that are considered of potential use. Obviously, the only completely effective denial of use is to turn off the emitting facilities.

---

*"Operational Procedures for Control of Electromagnetic Radiations – National Outline," CAA, Dec. 15, 1950.

**"Interim and Early Morning Plan of Operation for the Control of Electromagnetic Radiations Concerning AM, FM, and TV Broadcast Stations," FCC, Feb. 15, 1951.
"Informal Government-Industry Technical Conference Relative to Emergency Operation of AM, FM, and TV Broadcast Stations," FCC, March 26, 1951.

However, where there are really essential requirements to provide services during alert conditions – such as the need for civil defense broadcasts to supply information to the general public – means must be sought to so alter the character of the emissions that their usefulness to the enemy is destroyed.

B. NAVIGATION AIDS

The CAA plan for control of civil navigation aids is intimately connected with the plan for control of aircraft movement under alert conditions. Since the CAA has a responsibility for the safety of aircraft under their traffic control, particularly under instrument flying conditions, the plan is first to clear the air in alert areas by immediate grounding of aircraft or diverting into a clear area, and then to progressively turn off the navigation facilities. The time element allowed in turning off facilities is considered a function of the condition of alert. For example, under yellow alert (condition defined as attack likely), the plan states: "Unattended facilities within the alert area shall be shut down as soon as possible. Other navigation facilities should be shut down within 20 minutes except key stations and the Instrument Landing System (ILS) which shall be kept on as required." Under red alert (attack imminent), "All facilities except those required by SAC [Strategic Air Command] or key stations specifically authorized by ADCC [Air Defense Command Center] shall be shut down immediately after broadcasting the alert." (Key stations are defined as those facilities within the area of alert that the Air Defense Controller allows to continue operation for a sufficient period of time during an alert so as to provide guidance for aircraft being diverted from the alert area, or for other purposes.)

The priority for facility shutdown has been grouped as follows, depending on the degree of alert, although the distinction between the two groupings is not very clear.

Group I

Loran

Low-frequency radio ranges (200-400 kc)

Low-frequency radio beacons, "H" facilities

Group II

VHF radio ranges (VAR and VOR)

Radar beacons

Ground-to-air civil radio facilities (transmissions are to be as limited as possible and no identification given)

ILS and such surveillance radars as required.

In listing these, the statement is made that, in general, facilities that can be shut down on a moment's notice may thus be left on the air until a predetermined deadline, while the others will be shut down as soon as possible after the alert.

It is further understood that under present planning, the requirements for the dispersal of SAC aircraft and of such Military Air Transport Service (MATS) aircraft as deemed essential by the National Security Resources Board (NSRB) will take precedence in the retention of some aids until such aircraft have been cleared from or through the area.

The chain of action for exerting control over facilities is from ADCC by direct interphone to CAA Traffic Control Center and thence to towers, airways, communications stations and facilities themselves.

The general principle of denying our civil navigation aids to the enemy is clearly established in this plan, but inherent or planned delays in shutdown and the exceptions implicit in the SAC dispersal priorities may materially reduce its effectiveness. It would appear imperative that the capability of almost instantaneous shutdown be provided, especially for the peripheral aids whose coverage extends into and beyond Air Defense Identification Zones (ADIZ). Unattended aids should be fitted with a remote-control shutdown system in the hands of personnel who can be alerted in the order of two minutes. These remarks apply especially to the low-frequency radio ranges and beacons which, it is our belief, are most vulnerable to enemy use and some of which can provide overwater services 200 to 400 miles beyond our shores.

Under visual flying conditions in the alert areas, all aids can be immediately shut down. In clearing the air of traffic in regions under alert in instrument flying conditions, every effort should be made to divert aircraft away from peripheral areas toward interior clear areas and to shut down

peripheral stations immediately. The use of key stations for diversion must be applied sparingly, and always in such a way as to lead away from critical target areas.

In this regard, the use of certain facilities for diversion of SAC aircraft appears to us particularly disturbing, inasmuch as this operation may require these facilities to be left on for a considerable time. If this is truly the case, it appears advisable to give serious considerations to the use of other navigation means for such diversions, which would be less vulnerable to enemy use than the radio-range and beacon systems. One possibility that might be considered is the use of ground-radar beacons in conjuction with the aircraft's airborne radars. A few such beacons especially located by SAC for their use only might suffice.

The problem of the Loran stations which provide widespread coverage over water in the North Atlantic appears to be a special one. In a surprise attack, it is likely that an enemy utilizing Loran will have derived its major benefit from its use prior to arousing an alert. Furthermore, it is our understanding that primary use is made of the Loran chain by the maritime services, rather than by aviation. Serious consideration must be given to the effect of the denial of Loran use to essential shipping. Although PROJECT CHARLES has not examined in any technical detail the efforts to introduce planned confusion in Loran transmissions, it is urged that every effort be made to arrive at such a solution in preference to the complete shutdown of Loran under extended alert conditions.

It is certainly evident that, in order to obtain efficient operation of the CAA plan in an emergency, it must be widely circularized to all fliers, and trials of at least the shutoff operations must be practiced. Pending executive approval of the control authority, this has not yet been done.

The CAA plans that have been described to us are presumably to be applied in periods of alert of relatively short duration. It seems to us that, in planning for extended alert conditions after an initial attack where it will be necessary to maintain a continuous flow of essential civil and military transport traffic on our airways, serious consideration should be given to limiting the civil navigation aids to the VHF omni-ranges and to shutting off the LF or

MF ranges and beacons. This would require that all civil traffic flying under such conditions carry a VHF navigation receiver. This recommendation is made on the basis of the relative vulnerability of the LF or MF aids to enemy use, and the desirability of reducing the complexity of the CAA's control problem in the event of repeated enemy attacks. Shutdown of these VHF aids may still be required when regions are actually under attack, but the usefulness to the enemy of his radio compass will have been destroyed.

C. AM, FM, AND TV BROADCAST STATIONS

The FCC plans for control in the AM, FM, and TV bands have been discussed with the broadcast industry and their voluntary cooperation sought. FM and TV stations are to be deemed unessential under alert and closed down. The basic objective in regard to the regular AM broadcast stations is to supply the vital broadcast facilities necessary for public morale and for civil defense use, but to deny enemy use as a homing facility by introducing ambiguity and confusion into his reception.

Under the suggested plan, all stations that desire to remain on the air during alert would operate on one of two assigned frequencies, 640 kc or 1240 kc, at a maximum power of 5 kw. No attempt would be made to obtain "tight" synchronization, since stations are to be allowed to operate within ± 20 cycles of the specified frequency. This pseudo-synchronous operation is to be coupled with the "sequential" and/or "pulsating power" methods of operation for closely spaced stations operating as "clusters". Stations in a cluster (say, a metropolitan area) would receive the same modulation for information broadcasts plus recorded materials. These stations would operate in controlled random sequence, and be roughly normalized as to radiated power. An extension of the plan contemplates having cluster stations pulsate power by making randomly timed changes of about 10 db.

Small-scale preliminary tests have been made in early morning operations which give favorable indications for belief in the eventually successful operation of the complete plan. Further testing is scheduled in forthcoming exercises, although no daytime nor extensive overwater tests have been planned.

Plans for alerting the broadcast stations by means of telephone and radio, utilizing particular key stations as alerting relay points, have been worked out, and the facilities have been partially implemented.

The entire cost of the plan, other than for alerting lines, is to be borne by the station owners; however, it is a voluntary plan.

The FCC plan appears to be well conceived and, if carried out with energy and dispatch, is likely to be successful. It has deficiencies and weaknesses, most of which are intrinsic to the problem and not to the particular plan.

In a plan involving changing from one type of operation to another, the time element is exceedingly important. The participating stations should have instantaneous (and preferably automatic) changeover, and all other stations should shut down instantly. For those owning standby equipment, the rapid changeover features now available for use in the event of failure of their regular equipment, could be utilized for the emergency transmitter.

The question of how widely spaced cluster stations utilizing the same modulation can or need to be requires clarification by further engineering study and actual testing.

Where stations are arranged in widely separated groups, the deception is impaired since the navigator has only to resolve the ambiguity by very rough checks. Present planning contemplates the use of portable mobile transmitters, but permanent, government financed, installations may be required.

The plan will give poor coverage in suburban and rural areas presently served by 50-kw stations and in areas served by stations that choose not to participate. If such coverage is considered of vital importance for civil defense, portable mobile station operation could be provided.

In order to answer some of the doubtful points as to necessary coverage and to the achievement of successful deception of DF, it is urged that carefully planned daytime and overwater tests of the system be made as soon as feasible. These tests should be planned in conjunction with the civil defense agencies so that proper notice can be given the public to prevent undue alarm and so that proper program content can be provided. Such tests could serve as a vehicle to reassure the public that the necessary preparations are being made to meet possible alert conditions. It is clear that insufficient attention has as yet been

given to the morale effect of the broadcast programs during alert. It is of vital importance that civil defense authorities integrate the broadcasters into their planned functions.

It is felt, further, that too much emphasis has been given to the temporary nature of an alert condition. After an initial attack, alert conditions may have to be extended over a considerable period of time. Plans should be formulated now among the FCC, civil defense agencies, and the broadcast industry to provide for continued programmed broadcasting in the public interest during such extended alert conditions.

In view of the likelihood of fairly good radio coverage of urban areas in times of emergency, one interesting civil defense possibility suggests itself. The FCC estimates good service to the 10-millivolts-per-meter contour of stations operating under their plan; such a signal is adequate for a simple inexpensive crystal receiver. If these were produced in quantity and distributed generally, they could provide the population with the necessary receiving equipment, independent of power, and would eliminate the necessity of carrying bulky receivers.

Inasmuch as careful planning for control of other licensed services is just beginning, only a few general comments will be included in the following discussion.

D. OTHER SERVICES

1. Amateurs

Under normal conditions, the amateurs provide a poorer potential navigation aid to an enemy than many other sources. During an alert or an attack, however, they can serve no useful purpose, and should be shut down. After an attack, they can provide a supplementary "disaster" communication channel, were they properly organized and directed by civil defense authorities. It is doubtful that under these conditions they would render a useful service to an enemy. The problems of alerting and controlling remain, but the general plan of shutting down amateurs during alerts and then allowing organized operation seems satisfactory.

The amateur bands do, however, offer an easy means for use by the covert intruder. It is well to note, from British wartime experience, the desirability

of requiring strict control over the possession and actual installation of transmitting equipment during warfare. It was found necessary to require the dismantling of amateur equipment, including antenna installations, except for those equipments that actually served as part of the civil defense operations.

2. Police and Fire Services

Normal operation of police radio in all bands is a highly intermittent one; also, there is considerable duplication of frequencies among towns and cities. Thus, the use of police radio as a navigation aid cannot be considered a very serious possibility. Obviously, it will become a communication channel of major importance during an alert. The problem here is one of education towards minimum intermittent operation and no identification either from disclosure of the location or from the message content.

A study should be made to determine if there are any notable exceptions to the type of "normal" operation described above.

3. Point-to-Point and Press Services

In the case of point-to-point and press stations, one of our most vulnerable elements is our overseas communication channels. Since it is fairly easy to "home" on such installations, continued operation during an alert would expose them to destruction, in addition to providing a fix. The Voice of America stations fall into this same category.

4. Service-Operated Installations

The Services have installations that cut broadly across all the civilian types; hence, the same factors apply as in the respective categories. The basic difference is that military activities become paramount during alert periods. The problem here, therefore, seems to be a realistic appraisal of the calculated risks involved in retaining a service for military use.

5. Industrial Appliances

Radiations from industrial and therapeutic devices have been sufficiently numerous and powerful to present a problem of control in peacetime. While

it is true that adaptation of these sources to hostile use is not easy, a resourceful enemy might evolve such a scheme when other aids are denied him. It is the intention of the FCC to shut down all such sources during an alert. If conformance is expected, the problem will be that of disseminating the alert message.

6. Carrier and Other Services

There are many services such as taxi, common carrier, etc., that are presently scheduled for shutdown. For most of these, the curtailment is not serious, although traffic control of vehicles will be important after, and probably during, alert periods. Operators of such services should be asked to make plans for their vehicles during these periods.

Microwave relay links are few, and are used chiefly for the transmission of television programs; thus, there will be no need for keeping them on in view of the contemplated shutdown of TV and FM stations.

Guided radio on power transmission lines represents a hazard only if the enemy specifically chooses to equip himself for the guidance this might provide to power sites. The urgent need for this service would not obtain during alert periods, but would immediately afterwards, so that shutdown should not be a serious handicap.

7. Monitoring Facilities

Proposals have been made that the monitoring services of the FCC be used in time of alert to detect illicit transmissions. The clearing of much of the frequency spectrum, as discussed above, should make it possible to do a fair job of monitoring, at least in very critical areas. The monitoring service will no doubt need to be augmented as to personnel and DF equipment for such emergency activities.

Since in many cases the time required for detection and exact location of illicit transmissions is likely to be too long to permit effective police action before harm has been done, the proposal to equip the FCC monitoring services with the necessary jamming transmitters should be implemented as a practical measure for making ineffectual such transmission in critical areas.

It is considered essential to be able to exert such control over the emissions of electromagnetic radiations as will prevent the enemy from using our civil navigational aids and from navigating by direction-finding methods on emission sources of known locations.

Under initial attack conditions, a complete plan must be in effect which closes down most facilities or makes them unintelligible to the enemy. After direct knowledge is obtained of the actual methods of enemy navigation during attack, it may be possible to relax some restrictions, or it may be necessary to make some still more stringent.

E. RECOMMENDATIONS

1. The CAA-ADC plans for control of navigational aids should be immediately implemented but with the following additions:

(a) All LF ranges and beacon facilities, and at least those VHF ranges whose coverage extends beyond our periphery, should be capable of immediate shutdown. Thus, unattended stations must be provided with facilities for remote-control shutoff.

(b) The Air Force should be urged to find navigation methods for the dispersal of SAC aircraft other than the use of range- and radio-beacon facilities.

(c) Plans should be made and published to the effect that, after an initial attack, all LF ranges and beacons will be shut off and not again turned on. Under extended alert conditions, necessary airway traffic would utilize the VHF or UHF aids.

2. The well-considered FCC-ADC plan for the control of standard broadcast stations should be given full and well-publicized daytime and overwater tests as soon as feasible, to determine whether it succeeds in confusing DF homing devices while providing sufficient broadcast coverage.

3. The broadcasting industry should be integrated into civil defense planning so that proper program content in the public interest can be effected

during alert conditions. This is especially necessary for periods of extended alert when synchronous broadcasting may be required over long periods of time.

4. The FCC should be urged to complete and put into effect as rapidly as possible plans for control over other types of services.

5. The FCC monitoring service should be further implemented with necessary receiving and jamming equipment for detection and jamming of illicit transmissions.

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APPENDIX VII-1

ECONOMIC ASPECTS OF PASSIVE DEFENSE

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15 June 1951

APPENDIX VII-1

ECONOMIC ASPECTS OF PASSIVE DEFENSE

A. VULNERABILITY OF THE U.S. TO ENEMY AIR ATTACK

The locational pattern of economic activity and population makes the United States highly vulnerable to atomic bombing. The degree of vulnerability depends, of course, on the number of atomic bombs that an enemy can deliver on-target. For small numbers of bombs on-target – say, 30 – our locational pattern is sufficiently dispersed so that the nation need not fear a knockout blow; in the face of an enemy attack of this dimension, we are strong. However, the pattern is sufficiently concentrated that severe damage can be done to our war potential by even a small number of bombs. And for a larger number of bombs on-target – above, say, 150 – the ability of the nation to wage war is seriously threatened.

The first need of a passive defense program is an examination of the existing locational pattern of the country to determine the nature of our vulnerability. The direction of our passive defense effort must depend on the answers to the question: where would a rational enemy aim his bombs in order to inflict the most damage with a given expenditure of his own scarce resources. It is not necessary to assume that enemy strategy will in fact be completely rational. Whatever his strategy, our safest defensive move is to assume that, within his capabilities, he will choose those targets whose destruction will inflict the greatest damage on our war potential. If he wastes bombs on targets of less consequence, we shall have cause for relief that we miscalculated his strategy.

1. Enemy Bombing Strategies

It is convenient to consider the vulnerability of the country by examining three broad classes of enemy bombing strategy: (a) bombing of selected critical economic targets; (b) bombing of general productive capacity; (c) bombing of population. A mixed strategy is, of course, entirely possible. The optimum enemy strategy depends on the number of bombs he can place on-target, and, therefore, on the date hostilities commence.

a. Selected Critical Economic Targets ("Vertical" Bombing of Industry)

Bombing of selected critical economic targets, often called "vertical" bombing of industry, has as its aim the destruction of a set of targets that would deprive the American economy of some product or service essential to its war potential. An example would be an attempt to destroy most of our steel or oil-refining capacity. In a vertical bombing strategy, knocking out the third quarter of our steel industry would be regarded as more rewarding than knocking out the first quarter of either the steel industry or some other large important industry. Approximate simultaneity is important, because it is much more disastrous to lose 37 steel plants all at once than to have them knocked out in succession at intervals that permit restoration of some before others are hit. Also, if the attacks are successive, active defenses can be shifted to protect steel capacity as it becomes scarcer. The importance of a large number of bombs is that the loss of 90 per cent of steel capacity for example, is much more than 9 times as serious as the loss of 10 per cent.

Because of the interdependence of the parts of a modern industrial economy and the importance of concentrated large-scale production, it is easy to overestimate vulnerability to this type of attack. Actually the economy also has certain natural defenses against this strategy: (1) stocks (inventories or stockpiles); (2) diversion of products from nonessential uses; (3) substitution; (4) recuperability.

Stocks: Destruction of the capacity to produce an important product will not be crippling if large dispersed stocks of the product exist, since these can be used to meet urgent war needs while productive facilities are being restored. In this way, many of the special consequences of vertical bombing can be avoided and the cost to the American economy can be reduced to that of reconstruction of destroyed facilities. The importance of stocks attaches to products at all stages of the economic process, from raw metals to finished military goods. Moreover, stocks are a defensive asset in any hands – government, industry or households; in an emergency, if their whereabouts are known, they can be obtained for urgent military purposes.

Diversion from nonessential uses: The high living standards of the United States, supported by a tremendous use and accumulation of durable goods, provide us with a margin of safety against vertical bombing. The size of this margin varies from commodity to commodity; it is, for example, smaller in aluminum than in steel because civilian use of aluminum is relatively less important than civilian use of steel. The magnitude of the cushion depends on the military situation at that time. The cushion will be smaller if: (1) we are engaged in a total war involving land and sea operations as well as air conflict; (2) we have been deprived of the economic and military resources of our allies, and (3) we have not had time to accumulate a large stockpile of armaments. The uncertainty about the size of the cushion at the relevant time makes it important to take advantage of the substantial cushions that undeniably exist now, by building stocks at the expense of nonessential civilian demands. Numerous uses of nondurable goods can be restricted or eliminated and new production of durable goods can be reduced or prohibited, without materially impairing even the comfort of the population, let alone its productivity. A program of stockpiling should be considered no less a part of defense preparation than the production of armaments.*

Substitution: There are great possibilities of substituting for materials deemed essential in normal peacetime practice. Experience also shows that substitution is much greater under the actual pressure of necessity than is realized in advance. The same versatility is true of the conversion of productive facilities to the making of different products. For example, German experience in World War II showed that textile factories can be used for the assembly of aircraft and aircraft parts. Our own World War II experience, without even the pressure of damage from enemy air attack, found candy factories engaged in shell loading, automotive works producing tanks, etc. Thus, although in normal peacetime practice the production of a commodity may be

*The resources needed for both programs must be released from normal civilian uses by taxation and other economic controls in order to avoid inflation. In the long run, it is more economical to stockpile unfabricated materials than to stockpile weapons, etc. that may become obsolete.

highly concentrated, its potential dispersion by the conversion of other facilities elsewhere is often considerable.

Recuperability: Serious damage to war potential from attacks of the vertical type can occur only if the facilities are physically vulnerable and their repair is costly and time-consuming. As is true of substitution, the recuperation potential shows great increases under the pressure of wartime necessity. This is especially true if preparations for speedy repair of bomb damage are made in advance of attack. To take another experience from World War II as an example, the Germans created a special organization, the Geilenberg Corps, with 100,000 workers and stockpiles of spare parts of all sorts, to maintain production in the synthetic oil industry when it was under heavy attack by the USAAF. With this technique, heavily hit plants were put back into partial production within two weeks after an attack.

The capacity to recover easily from attack may make unattractive what would otherwise be a good target. Thus the bombing of railroads (for other than tactical purposes) requires a great weight of continuous attack to achieve significant results, because the repair of damaged lines and yards is relatively quick and easy.

In reckoning the time and co. of repair, we must remember that after a serious bombing attack materials are likely to be in shorter supply than they are now. We must, therefore, in all of our calculations, use postbombing-dollar valuations, not present-dollar valuations.

(1) General Conclusions on Vulnerability to Vertical Bombing

Contrary to popular belief, there does not exist in the United States an "Achilles heel" – a target industry, concentrated in location, producing some irreplaceable vital component. Aside from stocks and cushions of nonessential uses, substitution possibilities are safeguards against attacks on specialized product industries. Ball bearings, pumps and compressors, vacuum tubes, abrasives, etc. are important, but, provided our general industrial capacity remains, we could in brief time restore production of minimum requirements of such specialized products, draw on existing stocks, or find substitutes.

However, the United States is more vulnerable in certain basic industries involving large production units and immobile specialized equipment; here, substitutions in use or in production would be impossible, or, at very best, difficult and costly. In this connection, PROJECT CHARLES has considered three such industries: steel, oil refining and aluminum.

(a) Steel

The steel industry occupies a special position with respect to economic vulnerability. Not only is steel the basic material of an industrial economy, but the industry requires its own product for its own reconstruction. To destroy 50 per cent of steel ingot capacity, the 17 biggest plants would have to be knocked out; this would require approximately 34 atomic bombs on-target. For 75 per cent, the numbers are 37 plants and some 74 bombs; for 90 per cent, 59 plants, or 108 bombs. Even greater concentration exists in certain types of finished steel. For instance, the present production facilities for plates, a very important product during wartime, are concentrated in such a way that 5 plants account for more than 50 per cent of capacity, and 16 plants for 90 per cent. Tube rounds, the important semifinished product from which seamless tubes are made, are produced in only 11 plants; 4 of these have nearly 70 per cent of the capacity, and 6 have nearly 90 per cent. Seamless tube production itself is less concentrated, but still much more so than ingot: the largest four producers account for 55 per cent of the capacity, the largest nine for 80 per cent. Even sheet and strip, the most widely made single rolled products, show greater concentration of facilities than ingot production: the largest 8 producers account for more than 50 per cent of total capacity, and only 24 plants are required to account for 90 per cent. Despite these concentrations, rolling facilities for particular products (as opposed to steelmaking capacity) are not in themselves good targets. Through moderate expenditures, mills can be adapted to roll different products than they were originally designed for, and there is the possibility of some substitution in use between one type of rolled product and another – e.g., welded pipe for seamless tube.

Since most big steel plants are integrated, an attack on steelmaking capacity will yield bonuses in the form of destruction of finishing capacity. The 17

largest steel plants, which account for 50 per cent of the present steel ingot capacity, also have 50 per cent of the plate capacity, 46 per cent of the skelp capacity (skelp is the semifinished product from which welded pipe is made), 39 per cent of the bar capacity, and 34 per cent of the sheet and strip capacity. On the other hand, the diversity of product lines among the various plants provides some protection by what might be called "internal dispersion." Thus the same group of large ingot producers accounts for only 17 per cent of the seamless tube capacity, and only about 10 per cent of the important electric furnace steel capacity for making high-alloy steel.

At the present time, a considerable cushion exists in ingot steel. More than 75 per cent of steel production is being used for civilian consumption. Many of the present civilian uses are "luxury" uses which could be cut down easily. Even during wartime, only about half the steel production goes directly into military end products, and the rest goes into indirect war uses, such as construction, and the supply of "essential" civilian needs. These uses could be reduced in part, at least for a year or two, without serious reductions in war potential. These present cushions provided by large nonessential uses could be used now, in part at least, for the construction of new and dispersed steel capacity.

(b) Oil Refining

The oil refining industry concentrates 50 per cent of its capacity in 33 plants (33 bombs), 75 per cent in 98 plants, 90 per cent in 110 plants. The present cushion of dispensable civilian uses is large; about 40 per cent of the industry capacity is now devoted to the operation of passenger automobiles. Even in wartime, there remains a substantial cushion of civilian use that can be foregone if necessary.

(c) Aluminum

In the aluminum industry, the two basic processes – alumina production and reduction – are highly concentrated, the former in 6 plants (6 bombs). Reduction is concentrated in 12 plants (one bomb each); the largest has 40 per cent of total capacity, and the largest five have 75 per cent. Potential

conversion of other facilities – e.g., cement factories – to alumina production renders that phase of the industry less vulnerable than the reduction phase. The cushion in aluminum is, at the present time, smaller than in steel or oil and would virtually disappear in wartime.

The power of the aluminum industry to recuperate from bombing is potentially much greater than that of steel, since the capital costs are relatively low. Given an adequate power source, construction of aluminum capacity is not a very time-consuming process.

A further factor in reducing the vulnerability of aluminum to an attack is the possibility of using scrap as a substitute for virgin metal. During the war years of peak production, output of secondary aluminum was three-quarters that of virgin output. At present, secondary is not considered a good substitute for virgin in aircraft production; however, under the duress of high bomb damage the substitution possibilities may be expected to increase. The possible reclamation of secondary aluminum means that large aircraft production now creates a stockpile of aluminum for future use in the event of serious damage to production facilities.

Despite these possibilities, the vulnerability of the aluminum industry remains great, even relative to small enemy capabilities. This means that the creation of more dispersed capacity, and the stockpiling of aluminum ingot are urgent requirements. These two programs can complement each other.

(d) Other Industries

Steel, oil refining, and aluminum are certainly vital, but they do not comprise a complete list of the important industrial target systems that should be included in a definitive study. The electric power industry, which would appear to be another obvious target, is, however, widely dispersed, and interconnections generally protect specific regions from loss of power. The promotion of further interconnection is a desirable and cheap measure of passive defense. The western part of the country, it is true, is dependent on a few hydroelectric power dams, but these, we have been told, are difficult to destroy by ordinary atomic bombs.

(2) Summary of Vertical Bombing

Except for the case of aluminum and possibly for certain items of finished steel, the present study indicates that the United States is not vulnerable to vertical bombing except to an enemy who can place more than 50 to 75 bombs on-target within a short period of time. The existence of stocks and of the cushion of civilian demands means that effective vertical bombing requires enough bombs on-target to destroy nearly all the capacity of an industry. In general, the importance of large numbers of bombs for this strategy is accentuated by the necessity of also destroying possible substitute facilities. Thus, this strategy gains in attractiveness (relative to the other strategies) with increase of number of bombs that the enemy can place on-target.

An obvious and economical measure of passive defense against vertical bombing is a program of dispersed stockpiling of vital commodities whose productive facilities are vulnerable.

An elementary precaution, which should be a part of a passive defense program, is the formulation of advance plans (1) for the conservation of critical materials by their users, and (2) for the conversion of designated plants from their normal uses to the production of critical materials.

Vulnerability can be greatly reduced if each strategic plant maintains a stock of replacement parts, and trains at least a part of its labor force in repair techniques. In addition to this, dispersed stocks of replacement equipment, and central mobile repair teams should be maintained in each industrial center.

b. General Capital (Horizontal) Bombing

A second bombing strategy is one that ranks targets according to the general value of the capital installations that could be destroyed by a bomb (the so-called "Congreve" or "horizontal" attack). Vulnerability of a locality to this strategy implies a high density of capital-installation value per square mile, over a circular area whose radius depends both on the radius of effective bomb damage and on the error of aim. In contrast to the vertical strategy, this method of choosing targets does not attack a particular kind of productive facility in depth. Its objective is not to deprive the economy of certain critical products but, with a given delivery of bombs, to inflict on the economy the maximum cost for reconstruction in terms of diverted resources. Compared to vertical bombing, it aims at a long-run weakening of the general economic potential of the country rather than at a short-run weakening of the ability of the nation to fight. Its short-run impact is less because, in an emergency war situation, much of the reconstruction necessitated by general capital bombing could be postponed.

In economic terms, the essential difference between this strategy and the selected industry strategy is a difference in the price system at which capital is valued. The general capital bombing strategy values capital according to a normal peacetime price system, reflecting its long-run peacetime replacement costs. The vertical bombing strategy values capital according to a price system that reflects the values of goods in a war situation when bombs are dropping. Thus a steel plant is more valuable than a dog-racing stadium of equal peacetime cost (in terms of labor and other resources); moreover, the value of the steel plant increases as other installations are destroyed.

The vulnerability of the nation to this strategy lies in the unevenness of the geographical distribution of capital installations. The concentration of capital installations (especially when buildings and transportation facilities are counted along with manufacturing facilities) roughly coincides with the concentration of population in cities. Therefore, this strategy leads to a selection of targets similar to those for the third strategy discussed below. Probably the best aiming points for horizontal bombing would be within the city limits of our largest urban centers.

c. Population Bombing

A strategy of population bombing ranks targets according to the number of human casualties achieved. Vulnerability of a locality to this strategy depends on a number of factors, including population density and physical vulnerability of structures.

From the point of view of population density, the best aiming point is the center of the circle of a given size that encloses the greatest number of people. The radius of the circle depends on both the radius of effective bomb damage and the enemy's error of aim. If the aims were perfect, the best aiming point would be the most populous circle of bomb-damage radius. If there are aiming errors, the possibility of a miss must be considered, and the size of the relevant circle for ranking aiming points is larger; therefore the population outside the bomb-damage circle becomes important. For example, Cambridge, Massachusetts is a better target than New Haven, Connecticut, since if Cambridge is missed the bomb will hit another dense city, whereas if New Haven is missed the bomb strikes only open country or the sea.

In connection with population bombing, it is necessary to distinguish between daytime and nighttime densities. Certain areas, notably the Manhattan financial district and the Chicago Loop, have very large daytime densities and insignificant nighttime populations. Their daytime densities exceed the worst nighttime concentrations elsewhere.

The physical vulnerability of structures to atomic bomb effects -- to fire, blast, radiation -- must also be considered. Another reason for discounting to some extent the heavy daytime concentrations is that they occur in office-building districts, where buildings are less vulnerable than residential structures. This consideration also reduces the attractiveness as targets of some of the heaviest residential concentrations, which occur in apartment-building areas in Manhattan and Chicago. On the other hand, there is a high correlation between population density and one of the factors most important in determining the vulnerability of an area to fire -- the "built-up" ratio of roof to ground area.

It was suggested above that there is a reasonable correspondence between the ranking of aiming points for general capital bombing and their ranking for population bombing. Clearly, this correspondence is not perfect; between two

targets of equal population density the one that has the greater capital density will be chosen. For example, the port and river installations of lower Manhattan would be a bonus attached to an attack on the heavy daytime population of the financial district.

Large urban concentrations in the United States provide great vulnerability to population bombing. Nevertheless, in contrast to vertical bombing, which yields increasing returns to the enemy with number of bombs on-target, population bombing turns out to yield decreasing returns. Using Manhattan Island as an example, and assuming a possible human casualty radius of 1-1/2 miles, 5 bombs could cause 2,000,000 casualties at night and possibly 3,500,000 casualties during working hours. The next 2,000,000 casualties would require considerably more bombs.* A daytime bomb in the central business district of Chicago would catch some 400,000 to 500,000 people. To hit 1,000,000 people in Chicago at night would require 9 bombs. The same tendency toward diminishing returns to population bombing is evident for larger numbers of bombs. The Rand Corporation has calculated the figures in Table VII-1-1.

TABLE VII-1-1

Number of Bombs	Number of People Homeless*
9	5,000,000
26	10,000,000
125	25,000,000
183	30,000,000
261	35,000,000

*Their calculation is based on the destruction of homes rather than on human casualties, and consequently assumes a bigger damage radius. To cause the same number of casualties would require roughly 3 times as many bombs. The ranking of targets would also be somewhat different for a casualty objective than for a housing-destruction objective. But in either case there would be a similar decline in the return from an additional bomb on target.

*The Bronx and Brooklyn have average densities less than half the residential density of Manhattan, but still greater than other American cities.

It is difficult to assess the comparative attractiveness of vertical and population bombing for any given number of bombs. But on cold-blooded economic grounds, the loss of urban manpower is scarcely so disastrous to the short-run war effort as the loss that the same number of bombs could inflict by depriving the economy of a major proportion of its steel or aluminum capacity. Nor is the largely residential capital destroyed by population bombing the same loss to war potential as the capital destroyed by an equal amount of vertical bombing. Nevertheless, with any number of bombs it is hard to believe that population bombing will not be a part of enemy strategy.

There are several reasons for this. First, population bombing is easier navigationally and requires less accuracy. Moreover, in population bombing, the effectiveness of each individual bomb is less dependent on the success of other missions against the target system. Second, the creation of social and political disorganization and the effects on public morale may greatly magnify the economic consequences of bombing cities. Third, the destruction of a city is a more spectacular and tangible achievement for the enemy than the subtle and uncertain consequences of attacking a factory; it is probably of greater psychological value to the enemy air force and command and of greater propaganda value in the enemy's own country and elsewhere abroad. Probably, too, the enemy can calculate that a certain amount of population bombing will cause us to engage significantly increased resources in defense of cities; thus, there is considerable pay-off to him if he can distort our efforts. So long as population bombing is a probable part of any enemy strategy, the United States has a humanitarian as well as a strategic economic interest in defense against it.

Despite major improvements in our air defense system, enemy aircraft may succeed in placing bombs on U.S. targets.

With small numbers of bombs, populations are likely to be the prime target; with increasing numbers of bombs, vertical bombing of industrial targets becomes probable.

B. DISPERSAL AS A MEASURE OF PASSIVE DEFENSE

Since the source of our vulnerability to any strategy is geographical concentration, whether of industry or of people, an obvious remedy is dispersal. Every time we make it necessary for the enemy to drop another bomb in order to do the same amount of damage, the value of his stockpile of bombs is reduced. However, dispersal is necessarily a slow and gradual process; the locational pattern of concentration is the product of decades and cannot be undone in a year or even in ten. Only in the long run can dispersal be a significant deterrent to enemy attack; its effect in gradually reducing the value of any given enemy stockpile will, in absolute terms, certainly be more than offset by the growth of that stockpile. But this is no argument against dispersal or against beginning such a program now. Whatever date of attack and whatever stockpile is assumed, we would be more vulnerable were dispersal not started in 1951. Moreover, even if attack comes before dispersal has sufficient time to become a significant deterrent or to alter the enemy's choice of targets, every person dispersed is potentially a life saved, and every plant dispersed is that much capacity preserved.

Concentration has not occurred arbitrarily or accidentally. It reflects definite economic and social advantages over a dispersed locational pattern, which would be significant even if the country were to be rebuilt. The costs of any dispersal program would include the sacrifice of some of the economic advantages of concentration, and these costs would increase with rapidity of a dispersal program. The location of new facilities or new houses in sparse rather than in dense areas is more costly to the nation if it means the premature abandonment of existing capital in dense areas than if it involves a net addition to the nation's stock or a replacement of obsolete or worn-out capital. A policy of "guiding the increment" – of dispersing the net additions to capital stock and the normal replacements without abandoning prematurely any capital installations wherever located – would sacrifice only the potential gains of still greater concentration. This sacrifice would be small relative to the advantages in reducing vulnerability. Indeed, it is doubtful that such a limited dispersal policy goes far enough and takes proper account of the change in economic circumstances due to enemy possession of the atomic bomb.

On any rational calculation, the possibility of enemy attack has radically changed, in favor of dispersal, the values to individuals and to society of alternative locations of particular installations, whether factories or houses. A man who is deciding whether his new house should be built in Manhattan or in Fairfield, Connecticut should now include an allowance for the distinct possibility that in Manhattan both his house and his family will be destroyed. His decisions should also make due allowance for the fact that, if he builds a frame house on a vacant lot in Manhattan, he adds to the vulnerability of his neighbors, by increasing both the target attractiveness and the danger of fire. Similar considerations should enter the calculations of an oil company balancing the advantages of expansion of an existing refinery or building a new plant elsewhere. These considerations apparently do not now enter in any important degree the decisions of most private individuals and corporations. First, there is insufficient awareness of the problem: either the danger is dismissed or it is considered so cataclysmic that it is impossible to base any actions on it. Second, there is a widespread view that any losses from enemy action will be borne not by private owners but by the government. Third, some of the costs of concentrated location are social costs but not private costs; like the pollution of a stream which hurts downstream users, they are not, in the natural functioning of the economy, charges against the person whose operations cause them. Thus there is no mechanism by which the social cost of locating a steel mill in such a way that the enemy can knock out 90 per cent of the industry with one less bomb enters the locational decisions of individual steel companies. Government action to influence locational decisions by no means forces the economy into an unnatural and uneconomic pattern, but quite the contrary.

Any policy that is undertaken now must be made in the face of tremendous uncertainties about the future international situation and offensive and defensive capabilities. Since it is always possible that new technological developments will obsolete any defensive measure, it seems prudent to explore the chances that in 5 or 10 years the dispersal program begun in 1951 was a mistake. There are two ways in which the policy could be in error (of which the first is much more serious than the second):

(1) Instead of reducing the vulnerability of the locational pattern, dispersal actually turned out to increase it;

(2) The resources devoted to dispersal could have been used to better advantage.

The first error holds true if the development of active local defenses proceeds much more rapidly than the improvement of offensive capabilities. If so, an alternative to dispersal would be concentration of important potential targets under an active defense "umbrella." So long as the radius of a defense umbrella (8 to 10 miles) is large relative to the radius of bomb damage and aiming error, there is little conflict between the concepts of dispersal and the defense umbrella. Even if a new steel plant is to be sheltered under the same umbrella as an old plant, it can and should be located so that, in case of imperfections in defense, a single bomb will not destroy both. Moreover, defense against vertical bombing dictates that it would be preferable to locate the new steel plant under the defense umbrella of an existing oil refinery rather than that of an existing steel plant – still maintaining the principle that the new facilities should be outside the damage circle of the old.

Dispersing the increment can not make the locational pattern absolutely more vulnerable even if active local defense becomes highly effective. Placing small new steel plants in dispersed locations does not affect the defense of existing concentrations under umbrellas.

Effective local defense is likely to be high in cost, and accordingly the number of umbrellas will be limited. There will thus be enough key installations that cannot be dispersed, at least for decades, to give ample scope for the umbrella policy, while less important targets are dispersed.

The second and less serious kind of error could be produced by a lasting improvement in international relations. In this event, dispersal would have been one of the least of the retrospective wastes of resources; indeed many would regard it as a salutary development under any circumstances. This kind of error could also be produced in the event that a new weapon, to which concentration per se was not vulnerable, replaced the atomic bomb as the danger. We lack the information to assess the significance of bacteriological warfare in this connection.

1. Population Dispersal

The trend of the location of population and housing in this country is in one sense favorable and in another sense unfavorable to dispersal. Cities naturally grow outwards; the centers become relatively less concentrated compared to the peripheries. At the same time, the urban population grows relative to the total population, and the numbers in metropolitan areas show the greatest growth. The results are: (1) metropolitan centers become, in absolute numbers, better targets, although they account for a smaller proportion of the total population; (2) the areas adjacent to metropolitan centers become better targets (they have smaller densities than the city centers but grow into much higher densities than the average for the country); (3) the normal process of metropolitan growth creates an increasing area of attractive targets, with densities smaller than the centers but larger than those of the rural areas, the small towns, and the small cities from which these areas draw.

During the decade 1940 to 1950 the population of the United States increased 14.5 per cent. The population of the 168 standard metropolitan areas (Census definition) increased 21.2 per cent; that within the central cities of these areas, 13.0 per cent; that in outlying parts, 34.0 per cent. Of the increment in total population during the decade, more than 80 per cent occurred in metropolitan areas, and 50 per cent occurred in the outlying parts of those areas.

The critical importance of New York as a target for population bombing makes it useful to use the New York-Northeast New Jersey area as an example of locational trends within a metropolitan area. During the decade 1940 to 1950, the whole area increased in population by 10 per cent. Manhattan increased by only 2.5 per cent, while Queens, the least dense of the four major boroughs, grew by 19.0 per cent. This relative shift is favorable, in the sense that it is better for Queens than for Manhattan to grow. But even Queens would rank high among population bombing targets; its density is greater than that of Boston, for example. Another decade of growth of this kind will make Queens an even better target. Therefore, although development is favorable, relative to Manhattan, it is unfavorable in that it would be better to have the growth in Fairfield County, Connecticut. The population of the area outside New York City grew 19 per cent, while that of the City grew 5 per cent. The 19 per cent

growth outside the City was in areas of low average density (by urban standards); this is a favorable development that should be encouraged, but it should be stopped far short of producing another Queens.

Evidently, the natural trends cannot be relied upon to accomplish a reduction in vulnerability to population bombing. It is therefore necessary to explore the possibilities of a dispersal program, in which the following factors are important.

(a) The capacity of the construction industry to build homes and ancillary community facilities, in the light of the other defense demands upon the capacity of the industry and upon the materials it uses.

(b) The success of an effort to encourage construction in dispersal locations and to discourage it in dense areas.

(c) The success of an effort to induce residents of dense areas to move into homes in dispersed locations.

The second and third factors are the major obstacles in the way of population dispersal. Under present conditions, at any rate, our building capacity is sufficient to permit a remarkable degree of dispersal in the course of 10 to 20 years, which is illustrated by re-examining the example of New York.

At present it is government policy to limit residential building to a national rate of 800,000 dwelling units per year, compared to the 1,400,000 starts in the peak year of 1950. (It is doubtful that the measures by which the government is attempting to accomplish this cut – largely restrictions on mortgage credit – will in fact have the designed result.) Under a dispersal policy, a cut of this magnitude need have no effect on dwelling construction in and adjacent to metropolitan areas. The cut can and should be absorbed in areas where new-dwelling construction makes no contribution either to the housing of defense workers or to the reduction of vulnerability.

In the New York metropolitan area, the experience of 1950 shows that the industry can produce 130,000 units a year. This is probably a conservative estimate of capacity, provided the industry is not restricted by materials shortages. For one thing, the limitations on expensive houses – over $35,000* – now in effect will enable the industry to produce more units with the same

*Now, houses over 2500 square feet.

resources; further gains from this kind of limitation are possible. Also, the industry of the building area can be reinforced by drawing on the capacity of neighboring areas that will be affected by the national cut in house building. Of these 130,000 units, 40,000 in 1950 were located within New York City. The objective of a dispersal policy would be to reduce this number to zero and to make these units available in outlying areas.

Projecting the 1940-1950 increase in population for the area, construction of 40,000 new units a year is needed for new families. The remaining 90,000 new units are available for rehousing existing families. Thus, in 11 years one million families (3 million persons) could be moved from the City to sparse outlying areas. Density in the City could be reduced from 26,000 per square mile to about 15,000, and the average densities of Manhattan (88,000), the Bronx (35,000), and Brooklyn (38,000) reduced nearly to that of Queens (14,000). In two decades, sufficient new housing could be built to even out the density throughout the metropolitan area; the City as well as the rest of the area could then have a density of 4,000 per square mile. In other metropolitan areas, similar rates of dispersal are feasible, so far as the capacity to build houses is concerned; Chicago, Boston and Washington have been examined in this connection.

House-building capacity is, therefore, no obstacle to fairly rapid dispersal. The trouble is that channeling house building to outlying areas will not automatically cause the desired movement of population. It would do so only if the number of persons per dwelling unit were maintained at its present level in the suburbs and reduced drastically in the City. This ratio is now the same in the suburbs as it is in the City. (The reason that population density is higher in the City is not that there are more persons per dwelling unit but that there are many more dwelling units per square mile.) Historically, new dwelling units are built not only to accommodate new families but to provide all families, old and new, with more interior elbow room. Over the next decade or two, the normal consequence of building more units than are needed for the increase in number of families would be a general reduction, in the City as well as outside, of the number of persons per dwelling unit. Apartments that were occupied by 4-person families would be taken over by childless couples, and units formerly

occupied by couples would go to spinsters and bachelors. The problem of dispersal is to ensure that none of this increase in elbow room occurs in sparse areas – that all of it occurs in dense areas.

One method of accomplishing this aim is to destroy dwelling units in the dense areas of the City, thus forcing the former occupants to take advantage of the units that the construction industry can build in outlying areas. Substandard units are obvious candidates for such demolition. In New York City, there are 400,000 substandard units among the total of 2,500,000 dwelling units. In the course of normal urban redevelopment, many of these will be eventually demolished; and in response to a dispersal program, such clearance can be accelerated rather than postponed. (It is important, however, to alter the normal redevelopment plans that contemplate rebuilding on the same sites.)

This demolition would leave in the City 2.1 million units; within 10 years these, according to the rate of dispersal discussed above, would be occupied by 3 million fewer people than now live in the City's 2.5 million dwelling units – an average ratio of 2.3 persons per dwelling unit, instead of the 3.1 ratio in the City now and in the suburbs both now and then. This reduction in the ratio would not occur voluntarily and automatically under normal conditions. Indeed, any migration to the suburbs makes Manhattan apartments more attractive. Rent control and the swing in taste to one-family houses are favorable factors, but are insufficient of themselves. Unless stronger government measures and education in the perils of the bomb foster an outward movement, the amount of dispersal that building capacity permits will not in fact be approached.

If the same construction and demolition rates were maintained (but no dwelling units built in the City), and the ratio of persons per dwelling unit were the same in and out of the city, then in 11 years:

The 14 million residents of the area would live in 5 million units;

Six million people would live in the City's 2.1 million units;

The population of the City would be reduced by 2 million;

The average density of the City would be reduced from 26,000 to 20,000.

The distribution of this improvement in density would be largely dependent on the location of the demolished substandard units, and consequently would not

be optimal for reducing vulnerability. If this demolition were not carried out, the reduction in the City's population would be only one million – still on the assumption that migration will take place to the extent necessary to equalize interior elbow room. Even these estimates are probably overoptimistic, since, if construction in the City were impossible, there might well be a preference for crowding in the City to having more elbow room in the suburbs. To put the same point another way, demand sufficient to utilize the entire capacity of the construction industry might not exist if building in the City were prohibited, without the introduction of special inducements to move outside.

The movement of the daytime population from concentrated areas is even more difficult to accomplish than is the dispersal of the nighttime population. Here, construction capacity can be a bottleneck. Annual construction of office space is a much smaller proportion of the existing stock than is housing. Dispersal of office workers would entail, to a greater extent than residential dispersal, the economic cost of underutilization or premature abandonment of existing installations. The mere prohibition of new office-building construction in the City would have a slower dispersal effect than would the prohibition of residential construction; again, some inducement to move, other than the prohibition of new construction, would be required. The seriousness with which this problem is viewed depends, as mentioned before, on an estimate of the night day attack probabilities.

2. Industrial Dispersal

The possibility of decreasing, by a program of dispersal, the vulnerability of any strategic industry to vertical attack depends on three factors. The first of these is the expected future rate of growth of the industry over the near future – say, the next ten years. The greater this rate of growth, other conditions given, the easier it will be to achieve dispersal of the industry as a whole simply by influencing the size and location of new plants as they are built. Conversely, if the industry is not expected to grow at all, then the achievement of a greater-than-existing decree of dispersal requires the abandonment of existing installations, and the construction of new ones which would not otherwise be needed: an operation which might be expensive, and therefore difficult to accomplish.

The second factor governing dispersal possibilities is the minimum size of the efficient technical unit in the particular industry; a balance must be achieved between gains in security through dispersal and wastes in production through the creation of units of too-small size for the efficient use of resources. To state the problem as simply that of finding the size of the minimum efficient unit, however, is to oversimplify it. In general, it can be said that there is some scale of plant that achieves all the economies of concentration, and that larger plants are no more efficient (and much larger ones may sometimes be less efficient). For plants smaller than this size, efficiency decreases more or less gradually as plant size decreases, although there may well be a lower limit of plant size below which no production can be achieved. All the above can be summed up in terms of the cost curve (long run average costs) showing the relation between the cost of producing a level of output in a given plant, and the scale of the plant. This curve has the shape shown in Fig. VII-1-1.

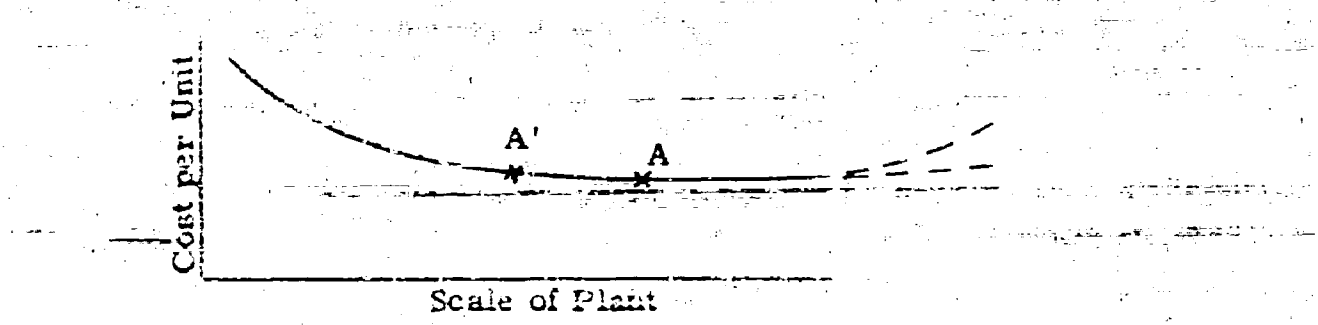


Fig. VII-1-1. Cost curve for a given plant.

Point A represents the minimum-efficient-size unit. However, this curve is what may be called a "pre-bomb" cost curve; it does not take into account the change in the cost regime created by the existence of a stockpile of atomic bombs in hostile hands, and the consequent risk of destruction attaching to any important plant. Since this risk, in general, increases with the size of the plant, the larger the plant the more attractive the target. A new "post-bomb" curve would show a "minimum-efficient-scale" point A' to the left of A, at a smaller scale of plant. Our true problem, then, is to find the size of plant corresponding to A' for each strategic industry. But this problem is difficult to solve; the answer depends on the size of the enemy's stockpile of bombs,

his delivery capabilities, his view of the relative importance of various target systems, etc. But it is clear that if we take A as an approximation to A', and aim for dispersal of an industry such that no plant is larger than A, we are in no danger of getting too much dispersal. Further, if we know that, for some particular industry, the cost curve slopes upward very slightly to the left of A for some distance, we may safely pick a smaller-scale plant than A as the limit of dispersal.

The selection of a lower limit of size for dispersal plants cannot be made with reference to existing cost conditions only. Production technology is constantly changing, with resulting changes in the relation between scale and efficiency. Since the achievement of any significant change in the concentration of facilities in industry is inevitably a matter of years, some attention must be given to the probable future changes in the shape of the cost curve. Such changes can never be predicted with any degree of accuracy; at best, informed guesses as to the direction of change are possible. This necessarily introduces a substantial area of uncertainty into specific recommendations on size limitations for plants to be built in the future. It is important to remember, however, that technological change is not random; if industrial research were dispersal-oriented, it is safe to predict that methods would be found to overcome many of the present diseconomies of small-scale production.

The third important factor on which the possibility of achieving an increased dispersal of facilities in strategic industries depends is the capital cost per unit of output. This factor operates in a substitution relation with the first factor, expected future growth. If expected growth is large, then new facilities will be built, and their capital cost is not important with respect to achieving dispersal. On the other hand, if the expected rate of growth is not large, then the achievement of a substantial degree of dispersal depends on construction of facilities that would not otherwise be built, and will be cheap and easy if capital costs are low, and expensive and difficult if they are high. ("Costs" here refer to money costs in general.) In specific situations, however, where the rapid construction of new facilities might require heavy use of scarce resources, the past money costs of facilities in the industry will not be a good guide to the cost of additions; and the supply of specific "bottlenecks" equipment must be separately studied.

The importance of heavy capital costs per unit of output as a deterrent to dispersal also depends on the minimum-size efficient unit. If the minimum-efficient plant is small, a given increase in the degree of dispersal can be achieved by a smaller addition to capacity, and the deterrent effect of high capital costs is not so great.

Any attempt to predict the degree of dispersal of strategic industries achievable in the future must go beyond the consideration of possibilities; we must examine the forces actually at work on the pattern of concentration, and must consider new influences that would have to be created to accelerate dispersal. Here we will examine the possibilities of dispersal in three specific strategic industries – steel, oil refining, and aluminum.

a. Steel

(1) Growth and Changes in Concentration

The steel industry has undergone fairly substantial expansion in the past decade. Ingot capacity was 84.1 million tons in 1941; it increased to 94.2 million tons by 1948, and to 104.2 million tons by 1951. This expansion resulted in little or no change in the over-all degree of concentration of the industry. In steel ingots, concentration was about the same in 1948 (the last year for which data are available) as for 1938 (when capacity was 73.1 million tons); in rolled products, increases in some products were balanced by decreases in others, leaving the total picture substantially unchanged. The next decade will probably produce a further growth of 10 to 20 per cent in capacity, some of which is already under way. This relatively small growth expectation suggests that only a limited increase in the degree of dispersion can be expected from decisions that affect new capacity to be built, in the absence of a specific program of building dispersal plants.

(2) Minimum-Efficient-Size Plant

Under present technology, an efficient integrated steel plant, containing facilities from coke ovens through rolling mills, and including finishing facilities for pipe, wire, and containers, must have about one million tons per year ingot capacity (or about 750,000 tons per year of rolled products). There may

be further economies to be achieved in bigger plants, up to perhaps 3 or even 4 million tons ingot capacity, but these are small at best. At present, there are 30 steel plants of 1.1 million ingot tons capacity or more, producing 69 per cent of the steel output; the biggest of these is 6 times the minimum unit. If this portion of the output were produced by million-ton plants, the number of installations producing this share of the output would be 65 – more than double the present number. If the expected increment to capacity of, say, 20 million tons were to be provided by 20 new minimum-size plants, with existing plants retaining their present capacity, then the 30 largest producers would produce only 57 per cent of the total output, and it would take an additional 22 plants to get up to the 69 per cent level. This represents a limited, but important, change in the degree of concentration now existing; it is the best that can be achieved by influencing the expected increments to existing capacity over the next ten years. Of course, if, under the pressure of high military demand, the growth in the steel industry in the next decade exceeds 20 million tons, a greater change in the degree of dispersion can result.

The present Defense Production Administration (DPA) program of authorizations for accelerated amortization is not helping to promote dispersal. One entirely new 2-million-ton plant to be built near Trenton by the U.S. Steel Corporation has been approved. Most of the authorizations have been for expenditures to add to capacity in existing plants, and several of these (such as one to Bethlehem for additions to steel capacity at its Johnstown, Pa., plant, which is the 13th largest producer, with 2-million-ton capacity) will result in the enlargement of existing attractive targets. The wisdom of this policy will be further considered below in the discussion of capital costs for steel plants.

The minimum figure for plant size of one million ingot tons per year is based on present technology and refers to a plant integrated from coking facilities through rolling mills and with some fabricating capacity. New technologies in experimental use here or practiced abroad appear to provide hope that substantially smaller units will be efficient. If so, it will be possible to achieve a greater degree of dispersion than has been indicated above. The major demands for large size in steel making come, under present techniques, from two stages in the process: the production of pig iron in the blast furnace and the rolling of

ingots into blooms, billets and slabs in the blooming mill (the first stage of the rolling process). Several possible processes for the direct reduction of iron ore, without the use of the blast furnace and without the necessity for using coke, have been tried out in Europe, including the Tysland-Hole electric furnace, the Krupp-Renn process, and the Wiberg-Soderfors sponge iron process. These, combined with electric-furnace steel making, may permit efficient steel-making plants of capacities as low as 300,000 tons per year, or about one-third the present limit. Moreover, these processes could use lower-grade ores, low-grade coals which cannot be coked, including lignite, and large amounts of scrap, making it possible for much wider geographic dispersion of steel making. The South and Southwest, with cheap hydro- and natural-gas electric power, could expect to support substantial steel-making capacity under these new techniques. The second important technical change, now in an experimental stage in the United States, is continuous casting. This eliminates the blooming mill and the soaking pits, and makes economical smaller-size rolling mills.

If the full promise of these techniques is realized soon, and, say, 20 million tons of ingot steel capacity is added in plants with a capacity of 500,000 tons per year (to take a figure larger than the extreme of 300,000 tons), while existing large plants remain as they are, it would take 62 plants to account for 69 per cent of the steel ingot capacity, instead of 30 as at present. The 30 largest producers would, under these assumptions, still account for 57 per cent of capacity. It might happen that these new processes resulted in substantially lower-cost production than the present techniques. In this case, given a fixed demand, some existing capacity would be supplanted by new capacity, and more than 20 million tons of new small-plant capacity would be built. This would, of course, further increase the degree of dispersal, especially if the obsolete plants were maintained in working order as standby capacity, rather than being scrapped or allowed to deteriorate.

The discussion so far has been in terms of ingot production, since, for reasons indicated above, this might be the primary target in the industry. But the possibilities of what might be called secondary dispersion, which would reduce the amount of bonus in the way of destruction of rolling mill and

finishing facilities by bombs aimed at steel works, are of some importance. The maximum achievable in this direction would be the building of no new integrated plants. Only separate blast furnaces and steelworks, and separate rolling mills would be constructed. The diseconomies involved in such a program with present techniques are not known. There are clearly some heat economies in the integration of rolling mill and steel works; but the fact that nearly every major integrated producer operates some nonintegrated plants suggests that these economies cannot be of decisive importance. Again, the present DPA accelerated depreciation approvals are doing nothing in this direction. The largest single application approved in the period 27 January to 6 April 1951 was for the addition of a seamless tube mill to an existing plant.

A substantial decrease in the size of new steel plants, and dispersal of them in a local sense, need make only negligible changes in the transportation costs incurred by the industry, since these depend on location in the regional rather than the local sense.

(3) Capital Costs

Capital costs of new facilities in the steel industry are high. At present prices, a new integrated plant costs about $300 a ton. Of this total, about 20 per cent goes for coke ovens and blast furnaces, 10 per cent for steelmaking furnaces, 20 per cent for general plant facilities, and the remaining 50 per cent for rolling mills and finishing facilities. On this basis, the replacement cost of the present capacity is about 30 billion dollars (although it is carried on the books at about 5 billion dollars, in terms of original cost). This means 300 million dollars to replace one per cent of present capacity by a new plant – a high figure. Additions to capacity in the postwar period have been made by improving existing facilities and "rounding out" capacities of existing plants. This type of capital addition is much cheaper than building from scratch, and costs only about $150 a ton. This discrepancy in capital costs between building new and improving old plants would be a strong force against dispersal and for increased concentration. To a large extent, however, the opportunities for expansion by piecemeal patching have been used up in the postwar expansion program, and therefore any major addition of capacity will require the construction of whole new plants.

But to the extent that any opportunity for piecemeal expansion remains, the problem of whether the security gain of not doing so is worth the extra cost of not doing so still exists. And, of course, the problem of whether or not to go on building integrated steel plants is fundamentally similar. Though capital costs for new plants are twice those for piecemeal additions, the relevant comparison is that between the costs of making steel in the two kinds of new capacity. Since capital costs are at most 15 per cent, and probably nearer to 10 per cent, of the costs of making steel, a doubling of capital cost would lead to, at most, a 15 per cent increase in the cost of steel. Is this too high a price to pay for the increased security against atomic destruction?

In addition to its high costs in general resource terms (money), additional steel capacity is costly in terms of steel itself. The steel industry, to a substantial extent, reproduces itself; about 35 per cent of the cost of new facilities, other than construction costs, represents the purchase of products of the steel industry, and most of the remaining nonconstruction expenditure goes to purchase products made from steel, such as blowers, cutting shears, etc. About one half ton of steel is required to make one ton of steel capacity. This suggests the importance of creating capacity in advance of its destruction by air attack, and in advance of the period of maximum military needs for steel. It also suggests some limits to the rate at which addition of capacity can take place without encroaching on other important uses of steel.

(4) Summary on Steel

The prospects for further dispersal in steel are not too good. Given the growth of total capacity likely over the next decade, a program that would limit strictly the size of new plants would change the present degree of concentration moderately. At present, the 21 largest plants have 57 per cent of the ingot steel capacity, and 22 more are needed to account for 80 per cent of capacity. If a million-ton limit on the size of new plants were enforced (appropriate to present techniques), it would take 30 plants to cover 57 per cent of the ingot capacity, and a further 23 plants to account for 80 per cent. On not unreasonable assumptions as to changes in techniques, the situation could be further improved with respect to the second bracket, 32 additional plants,

instead of 23, being required to go from 57 per cent to 80 per cent of total capacity. In other words, whereas at present – on the basis of two aiming points per plant – 86 hits must be scored to destroy 80 per cent of our steel capacity, on the best assumptions as to what could be done by controlling the size and location of new capacity, this figure could be increased to 124 necessary hits.

If more than this change is thought necessary in view of enemy capabilities, it must be achieved by making additional expenditures that would not otherwise be made, in order to create new plants. These expenditures would be fairly substantial. The expenditure of $10 billion might, for instance, be required to double the number of aiming points necessary to account for 80 per cent of the steel ingot production; and this effort would require a substantial time period, perhaps of the order of 5 to 10 years.

In addition, some "secondary dispersion" can be achieved, perhaps at a small increase in steel-making costs, by separating future steel works and rolling mills.

b. Oil Refining

(1) Rate of Growth and Change in Concentration

Oil-refining capacity, as measured by crude charging capacity, increased 42 per cent from 1941 to 1950. An increase of the same order of magnitude can be expected in the next decade. Judging by the experience of the last ten years, however, the continued growth of the next ten promises, by itself, no favorable change in the degree of concentration of refining facilities. In the decade 1941 to 1950, the share of the 25 largest refineries in total charging capacity was 44 per cent; by 1950 it had increased to 48 per cent. Ninety-eight refineries in 1941 accounted for 75 per cent of total capacity; in 1951 they accounted for 83 per cent, and only 72 were required to account for 75 per cent of capacity.

The fact that expected growth in the next decade is large, relative to steel, means that the possibility of achieving a substantial increase in the degree of dispersal by influencing the location of new capacity is favorable.

(2) Minimum-Efficient-Size Plant

A modern refinery and cracking plant of 60,000-barrels-per-day crude charging capacity is sufficiently large to achieve all the economies of scale. If all new plants were limited to this size, the addition to present refinery crude charging capacity of, say, 40 per cent, or 2.6 million barrels per day, in the next ten years would create about 43 new refineries. On the basis of the present size distribution of refineries, these would be the 27th to the 69th largest refineries of the total of 367 in the country. If existing refineries retained their present sizes, the end of the decade would see a situation in which the 25 largest refineries accounted for about 35 per cent of the total capacity rather than the 48 per cent they now represent. Fifteen more refineries, a total of 40, would be required to account for 48 per cent. To account for 75 per cent of 1960 capacity, 77 refineries would be required rather than the 72 which do in 1950.

Although a 60,000-barrels-per-day crude charging capacity plant is the smallest efficient refinery under the present cost conditions, it may be desirable to sacrifice some efficiencies in order to achieve even further dispersal. The importance of the loss in efficiency is small, since crude costs form a very high proportion of the cost of the refined product at the refinery gate - about 85 per cent. Thus, if we consider a 15,000-barrels-per-day refinery instead of a 60,000-barrels-per-day refinery, the refining cost of the smaller plant is about 20 per cent greater than that of the more efficient plant. But the difference in the cost of the refined product is only about 3 per cent.

Thus it does not appear unreasonable to think of limiting refineries not to 60,000-barrels-per-day charging capacity, but to 15,000. If 2.6 million barrels were added to present capacity on this basis, it would mean the addition of 173 new small refineries, which would occupy positions 99 to 271 on the size list, if present plants remained unchanged. Under these circumstances, 44 plants would be required to cover 48 per cent of the total capacity; but 144 would be required to cover 80 per cent of the total. This contrasts with 72 now, and 75 if new plants were limited only to 60,000 barrels per day in size.

In setting limitations on refinery size, due consideration must be given to the importance of location with access to crude oil on the basis of cheap transportation. At present, about 63 per cent of the refining capacity is located at

coastal points, and water transportation plays an important part in the oil economy. This is especially true of the big East Coast refineries (accounting for about 15 per cent of total capacity) which depend on water shipment of crude from the Gulf Coast, and to some extent from the Caribbean. Part of the concentration of existing refinery capacity is due to concentration of facilities around a single dock area.

The economies of cheap transport could be maintained in the face of dispersal in several ways. The easiest might be the substitution of pipeline facilities for tankers in the Gulf Coast-East Coast traffic, and the location of new refineries serving the inland Northeastern and East-North-Central United States along the pipelines, rather than at coastal points. World War II experience with the Big Inch and Little Inch pipelines indicates that such pipeline transport of both crude and refined products is competitive with tanker transportation. This change would have the additional virtue of reducing the vulnerability of oil movements to submarines in time of war. If pipelines are built, they should be made sufficiently big to take care of at least a substantial part of the movements now carried by tanker, as well as the increment required by new refineries, so as to make possible the release of tankers for military duty in the event of full-scale war.

In view of the large prospective increase in output of refinery products and the rapidly changing character of technology in the industry, the assumption that existing plants would continue to function at their present sizes for the next decade is a patently unrealistic one. This assumption was the basis of the calculations on the possible decrease in concentration achievable over a decade above. To the extent that it is wrong, and prospective future changes in technology do not seem to favor larger-size units, a much greater decrease of concentration may be achievable in the refining industry than is indicated by the calculations above.

In view of this conclusion, it seems unnecessary to enter into a discussion of the capital costs of constructing new refinery capacity, in addition to what would otherwise be built, in order to increase even further the dispersion of refinery facilities. It might be noted, however, that capital costs per one per cent of present capacity are of the order of $30 million, or one-tenth those of the steel industry.

c. Aluminum

(1) Changes in Capacity and Concentration

Aluminum capacity in the United States grew spectacularly under the pressure of war from 223,000 short tons in 1939 to a peak of nearly 1,200,000 short tons by 1944. Canadian capacity experienced almost as large an increase in the same period - from somewhat less than 100,000 short tons to about 561,000. Thus total North American capacity multiplied almost sevenfold in the period of the second World War. Much of this capacity was redundant immediately after the war; but under the pressure of military demand it is now being drawn back into use. If military demand continues high, a substantial increase in capacity over the next decade can be expected. While the large increase in capacity since 1939 has reduced the degree of concentration of facilities, it still remains very high. It is not clear that future increases in capacity alone will produce significant changes in the degree of concentration relative to enemy capabilities.

(2) Minimum-Efficient-Size Unit

For aluminum production itself (the electrolytic reduction of alumina to aluminum), there are practically no significant economies of scale over a very wide size range. The unit of production is a pot line; these vary in capacity from 10,000 to 20,000 tons per annum. A plant may have anywhere from 2 to 20 pot lines. Thus, units one-tenth as large as the existing largest plant (at Arvida, Quebec), or even smaller, can achieve all the economies of scale in reduction. If no existing plant were larger than this minimum size of 10,000 tons, there would be 132 plants producing the total output, instead of the 12 at present. This degree of dispersal cannot, of course, be achieved. But some change in the present situation, depending on the amount of new capacity added, can and should be made.

The main reason for the existence of large reduction plants is historical: they were tied to large privately owned hydropower developments, and designed to use all or nearly all the firm power generated. At present, with new plants being located chiefly on government-owned hydropower developments, with

other customers for firm power, this reason has disappeared. Since the typical price policy of the government projects – TVA and Bonneville, for instance – is to sell at uniform rates over the entire project area, dispersed small plants are both feasible and economic.

In the alumina stage of production – the conversion of bauxite into alumina – larger-size units are necessary. About 100,000 tons represents the minimum efficient size; this is approximately one-eighth the largest present plant. An important consideration in locating alumina plants is transportation economy with respect to overseas bauxite, 2 tons of which are required for each ton of alumina. These economies need not be sacrificed in smaller plants. If total present capacity were divided among 100,000-ton units, there would be about 31 plants instead of the present 6. This would still represent a fairly small number of targets; and, of course, it represents a far greater degree of dispersion than can be achieved by dealing only with increments to existing capacity.

(3) Capital Costs of New Facilities

Capital costs for aluminum run about $370 per ton. In terms of existing capacity, this means roughly $52 million per one per cent of existing capacity, or 2 per cent of the analogous figure for steel. Capital costs for alumina are much greater, about $500 per ton, or about $15 million per one per cent of existing capacity. Thus the cost of a dispersal program for both alumina and aluminum, aimed at creating 25 per cent addition to present capacity in the form of new units of minimum size, over and above other additions that will take place in response to a growth in demand, would be $500 million. This is of the order of 60 per cent more than the World War II government investment in alumina and aluminum facilities, which was made over a period of three years; it represents a perfectly feasible five-year program. Such a program would naturally be tied to the proposal to stockpile pig aluminum, as discussed earlier.

C. THE IMPLEMENTATION OF DISPERSAL POLICY

In any consideration of industry dispersal, a balance must be achieved between the gain in security promoted by dispersal and the wastes in production engendered by inefficient size, redundant capacity or excessive costs. Further, any attempt to predict the degree of dispersal achievable in the future must go beyond the examination of possibilities. The forces actually at work on the pattern of concentration must be analyzed if we are to know what new influences must be created to accelerate dispersal. This section describes some of the means that may be utilized to implement dispersal possibilities, should this policy be adopted.

1. Education and Example

One of the reasons that private decisions concerning location apparently do not take proper account of vulnerability to air attack is the lack of general understanding of the danger. It is obviously desirable to increase this understanding by all possible means: statements by the President, the Secretary of Defense, the Director of Defense Mobilization, etc.; well-publicized examples set by key private corporations; "public interest" advertising campaigns on the subject by private advertising groups, for example. The well-understood techniques of mass persuasion can do the job.

But, even if an educational program is successful, it cannot alone do the job. Understanding of the problem is only one of several reasons for failure to make desirable locational decisions. The other reasons – confidence that the government will bear the costs of calamity, and divergence of private costs from social costs, in favor of concentration – will not be removed by education; they must be offset by governmental policies.

2. The Location of Governmental Facilities

The examples of government agencies themselves can be a powerful force in educating the public. The location of government facilities, whether civilian or military, should obviously be determined with a consideration of the need for dispersal. This is the least that can be expected of the government. The defeat in Congress of the administration's proposal for dispersal of office

buildings was unfortunate in itself and a poor example to the country. "Decentralization" – using office space in cities other than Washington – is a poor substitute to the extent that it merely shifts some daytime and nighttime concentration from Washington to other crowded cities.

3. The Use of Existing Government Aids

Federal aid to private individuals, corporations, and state and local governments should embody a stipulation that it not be used to increase concentration and vulnerability but, wherever possible, that it further dispersal. Various examples are cited below.

a. Accelerated Amortization

The Defense Production Authority grants certificates of necessity and convenience to private business firms entitling them to amortize in five years, for tax purposes, new facilities that DPA considers important to the defense economy. The agency has statutory authority to deny certificates for facilities that are to be vulnerably located from the point of view of "military security." This authority has not been exercised; indeed, in oil refining and steel, certificates have been granted for facilities that will increase concentration (see Annex A).

b. Urban Redevelopment and Public Housing

The Housing and Home Finance Agency gives financial aid to localities for planning and for the acquisition of sites for slum clearance and urban redevelopment. Authority exists for financing the acquisition of sites for rebuilding, different from those selected for clearance, even if the new sites are outside the city. At present, the Agency is providing funds only for planning and for demolition, not for rebuilding, which is being postponed in view of the cut in new housing construction. Typically, urban redevelopment plans envisage rebuilding on the cleared sites or nearby. An example is the current redevelopment of Washington Square in New York. The Agency should now give grants only for plans that leave vacant any cleared sites in dense areas, and should rebuild in sparse areas. For the latter, prohibition on rebuilding should be

lifted. Similar criteria should apply to federal grants in support of public housing projects. Legislation is required to permit or to direct the Agency to use its funds in this way which would strengthen the Agency's hand in dealing with local governments, even if its discretion is now technically adequate.

c. Financial Aid to Home Buyers

The Federal Housing Administration insures home mortgages, and the Veterans' Administration guarantees and partially subsidizes interest charges on many. These services and subsidies could, in a general dispersal-oriented program, be withheld from home construction in dense areas. Again, legislation is needed to permit or to direct the agencies to discriminate among locations in this manner.

d. Other Subsidies and Grants-in-Aid

Other agencies of the federal government make grants-in-aid to state and local governments in support of highway and hospital construction. These, and possible future grants-in-aid for school construction, should be administered with a view to the importance of these facilities in relation to dispersal and, indeed, for more immediate programs of passive defense.

4. The Use of Existing Government Controls

The federal government already exercises a wide variety of discretionary economic controls which can influence the location of construction activity. These can be used to further dispersal both by relaxing them in favor of dispersed locations and by tightening them with respect to concentrated locations.

a. Housing Credit Restrictions

The Federal Reserve Board and the Veterans' Administration now restrict the terms on which mortgage credit for new home construction may be granted. Exemptions from these restrictions can be granted for "defense areas"; for example, an exemption has been given for housing construction at Aiken, S.C. If population dispersal is regarded as a defense measure, the sparse districts of metropolitan areas could be similarly treated.

b. Direct Controls over Construction

The Defense Production Authority now exercises direct control over private nonresidential construction projects; any sizable project for "nonessential" purposes must be submitted to DPA for approval. The DPA also limits the use of critical materials, principally copper, in residential construction. These controls are now administered with a view to conserving scarce materials for the defense effort and for essential civilian uses. They could be administered with the additional objective of guiding the location of new construction, possibly without any new legislative mandate.

5. Government War Risk Insurance

The methods so far listed, by which the federal government could implement dispersal policy, all relate to powers or administrative devices already in use for other purposes. Those to be discussed now are new tools of policy specifically designed to further a dispersal program. The most important, government war risk insurance, is designed to introduce vulnerability considerations into private calculations regarding location. It is also designed to remove from private decisions the effects of confidence that war damage, even to buildings newly constructed in vulnerable locations, will be a government, rather than a private, burden.

There are two kinds of war risk against which insurance is required: property damage and human casualties.

a. Property Insurance

Under a program of war-risk property insurance, an annual premium would be levied on the owner of property. The rate of this premium, relative to the replacement cost of the improvements on the site, would depend on the following factors:

(1) The attractiveness as a target of the area within which the property is located. More precisely, this factor involves the probability that, by any given date, the enemy will choose an aiming point near enough to the property to result in damage to it (allowing for errors in aim). This means, for example, that the owner of an apartment house in Manhattan would be subject to a higher premium than the owner of a similar property in Boston. It means that the

owner of a factory next to a great steel plant would pay a higher premium than the owner of a similar property in a sparse residential area. These differentials in rates would give a financial incentive toward location in less vulnerable areas.

(2) The physical vulnerability of the property. (Alternatively, this could be allowed for in computing the distance from an aiming point that is "near enough" in the preceding paragraph.) A fire-resistant reinforced concrete building should bear a lower premium than a frame building of equal value. This kind of differential in rates would give a financial incentive for less vulnerable kinds of construction, offsetting their greater costs under the existing price system.

b. Casualty Insurance

Under a war-risk casualty* insurance program, an individual would be charged an annual premium that reflects both his nighttime and his daytime vulnerability. His nighttime vulnerability depends on the locational and physical vulnerability of his residence, his daytime vulnerability on the locational and physical vulnerability of his place of work. Consequently, an insignificant charge or no charge at all should be levied on a farmer, while probably the maximum charge should be levied on an East Side Manhattan resident who works in Wall Street. These differentials would create a financial incentive to live and work in sparse areas. The scheme would therefore provide an inducement to move from dense areas, which was found in an earlier section to be the principal requisite of a program to disperse population. Similarly, the scheme would provide a financial inducement to move office work and other operations that contribute to high daytime concentration.

c. Combining the Two Kinds of Premiums

Whether the casualty premium for an individual is levied directly on the individual or on the owner of the property in which he lives or works is more a question of administrative convenience than of economic significance. The essential economic results of the rate differentials will be the same in either case. Since the crucial factors are places of residence and work, it might

*The beneficiary is the individual himself, or, in case of death, his next-of-kin.

well be more convenient to levy the casualty insurance premiums, as well as the property insurance premiums, on the owner of property. If this were done, it would mean that the total premium of a property owner would depend not only on the replacement value of his property but on the number of persons exposed to casualty by the current use of his property. The incentive effects of the casualty premium differentials can then be seen by reflecting that the owner of a vacant apartment or office building would pay smaller premiums than the owner of a packed building. The desired shift of city dwelling space from large families to small would be encouraged by the fact that in the city, in contrast to the country, rents for the same space would vary directly with number of occupants.

d. Government Insurance and Compensation for Capital Losses

The important feature of a government insurance scheme is not the absolute level of the premium collections but the existence and size of rate differentials. It is these differentials that influence locational decisions. Consequently, the scheme can and should be considered separately from a related question, i.e., the capital losses on existing vulnerable property. From the point of view of the whole economy, these capital losses have already occurred; they occurred the day the U.S.S.R. obtained the atomic bomb. The high cost of insuring such property merely formalizes that occurrence. By itself, the insurance scheme would place these capital losses on the persons who own vulnerable property when the scheme is inaugurated. It may be that society believes that capital losses due to the existence of the enemy atomic bombs should in justice be borne not by individual property owners but by society at large. Property owners have frequently in the past been protected from losses due to causes much less outside the range of normal business risks. The important thing is that, if this view is taken, a property owner should be compensated for his capital loss now and in a lump sum. The compensation should not take the form of free war-risk insurance. The reason for insisting on this separation of the two problems is simple. Lump-sum compensation now leaves the property owner subject to the influence of the insurance premiums on his future

decisions regarding the use and the eventual replacement of his property.* Compensation in the form of free insurance exempts him from all these influences and removes any incentives for him to use his property in ways that reduce vulnerability and to shift his investment, in time, to a less vulnerable location.

e. Government Insurance and Charges on Essential Industries

It may seem paradoxical that, at a time when the output of steel is increasingly essential, a steel plant, because of its vulnerability, should be subjected to additional charges. It might be feared that this would deter new investment in steel and make it more difficult to obtain a labor force for the industry. There are several answers to this paradox.

First, the atomic bomb itself has made an essential industry like steel a risky investment. Insurance, by pooling risks, should actually make steel a relatively more attractive investment in view of existence of the bomb. The same remarks apply to the labor force. It is the atomic bomb that has decreased the attractiveness to labor of working in a steel plant, compared to working in a safer location; insurance really reduces the force of this effect.

Second, the same revision of our scale of economic values that is the basis for the insurance scheme enhances the relative value of steel, and consequently of steel-making facilities and steelworkers. It is quite appropriate to permit the steel industry to cover the increases in costs due to its vulnerability by increases in its prices. This would enable the industry to pay the increased wages, inclusive of casualty insurance premiums, necessary to keep its labor force. It would not be appropriate for the candy factory next door to the steel plant to cover its vulnerability costs in the same way. If the candy industry loses labor because it is vulnerably located, that is as it should be.

Third, the important thing is to give incentives to steel plant managers to reduce vulnerability. Reductions in casualty insurance rates should be given

*This compensation need not be spendable immediately. It could be partly or wholly in deferred non-negotiable claims against the government.

when adequate shelters are provided. Reductions in all rates should be given for small plants in dispersed locations.

It has been possible to present only the outlines of a government insurance program. Clearly, the detailed design of such a scheme is highly technical and complex. The general level of premiums will always be a guess, because it involves assessing the probabilities that, by given dates and in given amounts of strength, the Soviet Union will attack the United States. There is likely to be some kind of insurance scheme; hearings on the subject have already begun in Congress. It is important that the program be conceived as a technique for influencing the allocation of resources, particularly their location, rather than simply as a means of indemnifying unfortunate citizens.

During World War II, the U.S. government, through the War Damage Corporation, a subsidiary of the Reconstruction Finance Corporation, offered insurance of property against war damage. The premiums were, for each class of property insured, geographically uniform. Following the outbreak of the Korean war, sentiment for the revival of the WDC resulted in the introduction of several bills in Congress and the holding of hearings in December, 1950. These bills were modeled on the insurance program of World War II, except that some proposals covered workmen's compensation for injury or death while working as well as for property damage. They all authorized the RFC to advance $1 billion in capital to the revived WDC to enable it to commence operations. This legislation failed of passage in the 80th Congress, although one of the bills, without the workmen's compensation feature, passed the House. The bills were reintroduced in the 81st Congress. On April 26, the Administration announced, through the testimony of Elmer Staats of the Bureau of the Budget before the Senate Subcommittee considering the matter, that it was opposed to the revival of war damage insurance on the World War II model and that it was working on an alternative plan. This plan was presented to the same subcommittee July 11, and a bill to implement it (S. 1848), which is now under consideration by the subcommittee, was introduced July 12.

The Administration's proposal is a comprehensive plan for dealing with a war disaster. It authorizes the President to "take such action as may be necessary to restore and rehabilitate war-damaged community facilities and

war-interrupted community services" or industrial facilities essential to the national defense, either by direct federal action or by assistance – including financial aid – to state and local governments or private persons or organizations. It provides for a program of benefits to injured civilians or to the dependents of civilians who are killed. The amount and form of the benefits are left to Presidential discretion in determining needs after the event. The President is also authorized to relieve private and public life and casualty insurance, pension, and workmen's compensation systems of their liabilities for war-caused injuries and deaths, provided a federal system of benefits is put into operation. Concerning property, the bill authorizes $20 billion for compensation for war damage to private property (and $2 billion for public property). The amount of indemnification, compared to the amount of damage, is subject to determination by the "War Damage Administrator" in the light of the relation of total claims to the total authorization. It will in no case exceed 90 per cent of the claim less $100. All claims for $5000 or less will be paid first, and $4410 will also be paid on larger claims. The additional payment on larger claims will then be on a pro rata basis, to keep total payments within the authorized total expenditure.

The Administration's proposal reflects a much more realistic view of the danger than the insurance bills, which were modeled too closely on the last war. It provides for personal casualties much more completely than the other bills. The objection to it is that it provides free protection, and consequently provides no incentive for dispersal. This is no argument in favor of the World War II plan and the proposals modeled after it. They provided for geographically and structurally uniform premiums, which are equally useless as dispersal incentives. Differential premiums, reflecting differential vulnerabilities, are the heart of a program that seeks to do something about the danger before an attack instead of later.

An important question concerning an insurance scheme with differential premiums is whether it should be compulsory or voluntary. Both the British scheme and ours in World War II had uniform premiums; theirs was compulsory, ours was voluntary. With uniform premiums, a voluntary scheme suffers from adverse selection of risks: only those in vulnerable locations

find it worth while to take out insurance. Such adverse selection would not be so serious under differential premiums, which in this respect remove one of the drawbacks of a voluntary plan. Clearly, a compulsory scheme would have more certain dispersal effects than a voluntary plan. If the plan were voluntary, the mere existence of the insurance and of the differentials would bring home the danger; and, indeed, there would be a certain amount of private pressure, as from mortgagees, on property owners to avail themselves of the insurance. But persons who did not take out insurance might remain convinced that, when the calamity occurred, they, along with the insured, would be indemnified by the government. The uninsured would have a good argument especially if attack came relatively soon, so that accumulated premiums had to be supplemented by large general appropriations in order to meet claims. A compulsory plan would avoid these difficulties. It would certainly be more difficult to sell politically, but it would be worth the additional effort.

There will be intense political opposition to a government insurance scheme from numerous powerful quarters: from the affected property owners, from the local governments that their taxes now support, from the residents, employers, and workers in vulnerable high-rate areas. Indeed, the fact that this proposal is the heart of a dispersal policy will be evident by the mobilization against it of all the groups with vested interests in concentration. Some of the opposition can be removed by coupling with the insurance scheme the conceptually separate but politically related policy of lump-sum compensation of property owners for capital losses, including some compensation to the affected municipalities for their loss of tax base. But compensation will always be said to be inadequate; and the rate differentials, which are essential to the scheme, will be said to be regionally discriminatory and unfair. New York congressmen, for instance, will say that the government should defend New York, not tax it.

Nevertheless, the insurance scheme should be vigorously pushed. It is the natural adjustment to the atomic age of an economy like ours, which relies mainly on prices and costs to influence private decisions. It will be persistent and automatic in its effects. In the long run, it can accomplish more dispersal with less pain than any constellation of ad hoc administrative controls. It is

true that the price system engineers major economic adjustments only slowly. In the short run, the other governmental devices discussed above are certainly necessary to get dispersal started and to correct the most critical situations of concentration.

6. Stockpiling and Constructing New Industrial Capacity

The government at present is engaged in a program of stockpiling critical imported raw materials. This program should be greatly widened to include stockpiling of materials domestically produced in vulnerable installations – pig aluminum is one example; tetraethyl lead, which is produced in two plants, is another. The present strategic situation certainly does not justify the view, implicit in our concentration on stockpiling imports, that domestic sources of supply are secure while foreign sources are insecure. It is true that accumulation of finished armaments is stockpiling in an important sense. But this can proceed only at the rate at which armament production is possible, and it entails the risks of obsolescence and the costs and sometimes impossibilities of recovering basic ingredients from obsolete finished goods. Stockpiling for its own sake should be done at the earliest stage of production after the material has passed through the concentrated, vulnerable part of its processing. It cannot be overemphasized that stockpiling is a method of using in the future, after bombs drop, our present cushion of nonessential consumption.

In one sense, stockpiling and the construction of new capacity in dispersed locations are substitute policies. If a heterogeneous, made-to-specification, product is manufactured in concentrated, vulnerable capacity, setting up new capacity elsewhere – even if there is no current demand for its output – may be a better defense than stockpiling. Certain kinds of finished steel are an example. But, in another important sense, the two policies are complementary; stockpiling is a short-run defense; dispersed facilities are a long-run defense. In many commodities, where we need both, stockpiling can provide the immediate demand necessary to stimulate private construction of new capacity (the new capacity will be guided to dispersed locations by the other instruments of policy previously discussed). In aluminum, concentration is so extreme that effective dispersal of the industry will take a long time. Meanwhile, stockpiling

is not only necessary in itself but can provide the demand stimulus to accelerate the dispersal expansion of the industry. In the case of aluminum, both stockpiling and new dispersed capacity are needed.

Stockpiling of domestic commodities is, of course, a program subject to abuse. Only those commodities should be stockpiled that the Department of Defense will certify are: (1) essential to the war effort after an attack, (2) produced by industries that are vulnerable to nearly complete destruction.

In some cases, private investment may not be forthcoming to provide new facilities as rapidly as is desirable for dispersal, even with the additional demand stimulus of the proposed stockpiling progr. ... Indeed, stockpiling is not feasible for some critical products. In those cases, it will be necessary for the government itself to take the initiative and to assume the risk of building capacity ahead of demand, as was done in World War II. This government-built capacity was operated by private firms and later sold to private industry, a procedure that c n be followed again.

7. Administration and Legislation

Dispersal is a policy that should operate on many fronts and through many government instrumentalities. It does not need and should not have created a new agency empowered to make all dispersal decisions and administer all dispersal programs. Dispersal is, rather, a philosophy with which the whole administration should be imbued; it is an important new element that should now enter all administrative decisions. Legislation is required to authorize – perhaps, better, to compel – this criterion to be considered in the administration of grants-in-aid, housing credit, materials allocations, production controls, etc. Legislation is needed to set up a new program of compulsory insurance. Legislation and appropriations are needed to enlarge the stockpiling program to include domestically produced materials.

The policy of dispersal will inevitably entail new intervention into the economic life of the country by governments, and particularly by the national government charged with the responsibility for the common defense. Our recommendations are designed to minimize those interventions and to make use, so far as possible, of the kinds of intervention that are already in existence

for other purposes. It is the new strategic situation that requires this extension of government activity for passive defense, just as for active defense. Peace is essential for a free private enterprise economy. That citizens, acting together, have to protect themselves is a sad fact; but it is the necessity that is sad, not the citizens' recognition of the necessity. Their failure to recognize the necessity would be even sadder.

D. OTHER METHODS OF PASSIVE DEFENSE

Dispersal of population and strategic industry is a permanent and effective means of defense; but it is slow and gradual in its effects. It must be supplemented, therefore, by other means of passive defense: shelters, warning systems, drills, short-run damage-control plans, etc. Concerning the technical and administrative phases of these civilian defense programs we have no special competence except to suggest that present aspects of civil defense appear to be predicated on a "disaster relief" role after bombs have fallen, rather than on measures to alleviate the situation beforehand. It can be said, however, that civilian defense will never be successful unless and until it is financed almost wholly by the federal government. The lower echelons of government simply do not have the necessary sources of revenue, and dispersal will increase their financial problems. To qualify for federal funds, states should not be asked to put up money, but to conform to national standards and to fit into a coordinated national plan. Active and passive defense measures should be considered as competitors for the public dollar.

E. CONCLUSIONS

We do not think that the broad conclusions presented would be changed by further and more detailed factual economic investigations. But those investigations are certainly needed. The implementation of many of the policy measures we have recommended requires an assessment of vulnerabilities in the greatest detail.

Detailed investigations that are needed include the following:

(1) A detailed study of cities to determine, for a large number of aiming points, the number of people who would be killed, injured, or rendered homeless in nighttime or daytime attack, under various

assumptions regarding warning, and taking systematic account not only of population densities, but also of quality of structures. This study should be integrated with the Congreve report* which, according to our understanding, will give detailed information on the locational distribution of industrial capital facilities. The objective of such studies should be an intelligent detailed ranking of urban aiming points, as a guide to construction policy, insurance premium differentials, etc.

(2) A detailed re-examination of the development plans for key metropolitan areas, in cooperation with the local planning authorities, to determine the locations available for dispersed housing, the needs for and costs of new nonresidential facilities in those locations (roads, schools, etc.), the capacity of the local construction industry to provide the needed residential and nonresidential building, and the opportunities for clearance of existing substandard dwelling units in dense locations.

(3) A detailed examination of specific strategic industries to determine: the locational concentration of existing capacity; the physical vulnerability of the facilities; the recuperability of the facilities, under various assumptions concerning supplies of needed materials and the state of damage control preparedness; the possibility, time requirement, and cost of diverting facilities normally outside the industry to this use; the possibility and cost of substituting other products in the war-essential uses of the product of the industry; the size of normal stocks, and the technical possibilities and costs of maintaining a useful dispersed stockpile; the locational ties of the industry to specific sites and the magnitudes of the diseconomies in "second best sites"; and the existence and magnitude of economies of scale.

It is appropriate to reiterate what is obvious enough to be forgotten: the previous discussion is conceived within a certain framework of enemy capabilities. If the enemy can put 1000 bombs on American targets, the situation must be conceived of in radically different terms; dispersal must become our primary national activity, or perhaps the situation has already become hopeless. On the other hand, if the enemy can put no more than 25 bombs on-target, dispersal is a minor problem, subsidiary to many others, and can safely be left to itself.

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15 June 1951

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APPENDIX VII-1

Annex A

THE STEEL INDUSTRY

Carl Kaysen

TABLE A-1

Steel Ingot 1948 Plant Capacity in Descending Order*

Rank	Company and Location	Per Cent	Acc. Per Cent
1	Carnegie Illinois, Gary, Ind.	6.069	6.069
2	Bethlehem, Sparrows Pt., Md.	4.936	11.005
3	Carnegie Illinois, So. Chicago, Ill.	4.802	15.81
4	Carnegie Illinois, Munhall, Pa.	4.541	20.35
5	Inland Steel, Indiana Harbor, Ind.	3.608	23.96
6	Bethlehem, Lackawanna, N.Y.	3.311	27.27
7	Bethlehem, Bethlehem, Pa.	2.743	30.01
8	Carnegie Illinois, Youngstown, O.	2.487	32.50
9	Republic, Youngstown, O.	2.282	34.78
10	Jones & Laughlin, Pittsburgh, Pa.	2.268	37.05
11	Great Lakes, Ecorse, Mich.	2.229	39.28
12	Weirton, Weirton, W. Va.	2.069	41.35
13	Bethlehem, Johnstown, Pa.	2.016	43.36
14	National Tube, Lorain, O.	1.980	45.36
15	Jones & Laughlin, Aliquippa, Pa.	1.872	47.23
16	Carnegie Illinois, Braddock, Pa.	1.860	49.09
17	Carnegie Illinois, Duquesne, Pa.	1.849	50.94
18	Tenn. Coal & Iron, Ensley, Ala.	1.664	52.61
19	Republic, Cleveland, O.	1.592	54.40
20	Youngstown Sheet & Tube, Campbell, O.	1.541	55.74
21	Youngstown Sheet & Tube, E. Chicago, Ind.	1.534	57.27
22	Geneva Steel, Geneva, Utah	1.367	58.63
23	Tenn. Coal & Iron, Fairfield, Ala.	1.360	59.99
24	Col. Fuel & Iron, Pueblo, Col.	1.350	61.34
25	Republic Steel, So. Chicago, Ill.	1.300	62.64
26	National Tube, McKeesport, Pa.	1.235	63.88
27	Ford Motor, Dearborn, Mich.	1.221	65.10

TABLE A-1 (cont'd)

Rank	Company and Location	Per Cent	Acc. Per Cent
28	Youngstown Sheet & Tube, Youngstown, O.	1.172	66.27
29	Wheeling Steel, Steubenville, O.	1.139	67.41
30	Pittsburgh Steel, Monessen, Pa.	1.138	68.55
31	Sharon Steel, Farrell, Pa.	1.061	69.61
32	Crucible Steel, Midland, Pa.	1.059	70.67
33	Armco Steel, Middletown, O.	1.031	71.70
34	Intl. Harvester, So. Chicago, Ill.	0.955	72.66
35	Bethlehem, Steelton, Pa.	0.940	73.60
36	Kaiser, Fontana, Cal.	0.923	74.52
37	Republic, Warren, O.	0.913	75.43
38	Am. Steel & Wire, Donora, Pa.	0.894	76.33
39	Jones & Laughlin, Cleveland, O.	0.891	77.22
40	Republic, Buffalo, N.Y.	0.881	78.10
41	Armco Steel, Ashland, Ky.	0.879	78.98
42	Carnegie Illinois, Clairton, Pa.	0.854	79.83
43	Republic, Canton, O.	0.822	80.65
44	Portsmouth Steel, Portsmouth, O.	0.764	81.42
45	Am. Steel & Wire, Duluth, Minn.	0.732	82.15
46	Republic, Gadsden, Ala.	0.690	82.84
47	Lukens Steel, Coatesville, Pa.	0.662	83.50
48	Granite City Steel, Granite City, Ill.	0.658	84.16
49	Republic, Massillon, O.	0.647	84.81
50	Sharon Steel, Lowellville, O.	0.607	85.41
51	Sheffield Steel, Houston, Tex.	0.594	86.01
52	Alan Wood Steel, Ivy Rock, Pa.	0.584	86.59
53	Timken Roller Bearing, Canton, O.	0.581	87.17
54	Midvale, Philadelphia, Pa.	0.556	87.73
55	Carnegie Illinois, Vandergrift, Pa.	0.531	88.26
56	Worth Steel, Claymont, Del.	0.488	88.75
57	Copperweld Steel, Warren, O.	0.478	89.22

TABLE A-1 (cont'd)

Rank	Company and Location	Per Cent	Acc. Per Cent
58	Armco Steel, Butler, Pa.	0.458	89.68
59	Allegheny Ludlam, Brackenridge, Pa.	0.457	90.14
60	Sheffield Steel, Kansas City, Mo.	0.452	90.59

Total, all plants, 1948 - 94.2 million tons

*American Iron & Steel Institute, Directory of Iron & Steel Works, 1948.

TABLE A-2

Steel Ingot 1938 Plant Capacity in Descending Order*

Rank	Company and Location	Per Cent	Acc. Per Cent
1	Carnegie Illinois, Gary, Ind.	6.90	6.90
2	Carnegie Illinois, So. Chicago, Ill.	5.31	12.21
3	Bethlehem, Sparrows Pt., Md.	4.06	16.27
4	Carnegie Illinois, Munhall, Pa.	3.99	20.26
5	Inland Steel, Indiana Harbor, Ind.	3.78	24.04
6	Bethlehem, Lackawanna, N.Y.	3.55	27.59
7	Jones & Laughlin, Pittsburgh, Pa.	2.92	30.51
8	Carnegie Illinois, Youngstown, O.	2.72	33.23
9	Great Lakes, Ecorse, Mich.	2.68	35.91
10	Bethlehem, Bethlehem, Pa.	2.52	38.43
11	Carnegie Illinois, Duquesne, Pa.	2.49	40.92
12	Carnegie Illinois, Braddock, Pa.	2.22	43.14
13	Bethlehem, Johnstown, Pa.	2.20	45.34
14	National Tube, Lorain, O.	2.14	47.48
15	Jones & Laughlin, Aliquippa, Pa.	2.11	49.59
16	Republic, Youngstown, O.	2.07	51.66
17	Weirton, Weirton, W. Va.	1.97	53.63
18	Youngstown Sheet & Tube, Campbell, O.	1.81	55.44
19	Republic, Cleveland, O.	1.50	56.94
20	National Tube, McKeesport, Pa.	1.32	58.26
21	Tenn. Coal, Iron & Railroad, Ensley, Ala.	1.31	59.57
22	Youngstown Sheet & Tube, E. Chicago, Ind.	1.31	60.88
23	Ford Motor, Dearborn, Mich.	1.27	62.15
24	Wheeling Steel, Steubenville, O.	1.23	63.38
25	Col. Fuel & Iron, Pueblo, Col.	1.22	64.60
26	Tenn. Coal, Iron & Railroad, Fairfield, Ala.	1.15	65.75
27	Youngstown Sheet & Tube, Brier Hill Works, Youngstown, O.	1.15	66.90
28	Pittsburgh Steel, Monessen, Pa.	1.11	68.01
29	Republic, Canton, O.	1.07	69.08

TABLE A-2 (cont'd)

Rank	Company and Location	Per Cent	Acc. Per Cent
30	American Rolling Mill, Middletown, O.	1.03	70.11
31	Carnegie Illinois, Farrell, Pa.	.99	71.10
32	Carnegie Illinois, Clairton, Pa.	.98	72.08
33	Otis Steel, Riverside Wks, Cleveland, O.	.92	73.00
34	Republic, Buffalo, N.Y.	.92	73.92
35	Republic, Warren, O.	.91	74.83
36	Alan Wood, Ivy Rock, Pa.	.90	75.73
37	American Rolling Mill, Ashland, Ky.	.90	76.63
38	Bethlehem, Steelton, Pa.	.90	77.53
39	Int'l Harvester, So. Chicago, Ill.	.89	78.42
40	Lukens Steel, Coatesville, Pa.	.87	79.29
41	American Steel & Wire, Donora, Pa.	.86	80.15
42	Pittsburgh Crucible, Midland, Pa.	.85	81.00
43	American Rolling Mill, Butler, Pa.	.82	81.82
44	Carnegie Illinois, Mingo Junction, O.	.82	82.64
45	Wheeling Steel, Portsmouth, O.	.75	83.39
46	Republic, Massillon, O.	.75	84.14
47	Republic, Gulfsteel Dist., Gadsden, Ala.	.71	84.85
48	Sharon Steel, Lowellville, O.	.68	85.53

Total, all plants, 1938 -- 73,047,000 tons 100.00

*American Iron & Steel Institute, Directory of Iron & Steel Works, 1938.

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TABLE A-3

Changes in Concentration of Production Capacity 1938-1948
for Selected Rolled Products, by Plants*

Product	1938 n Largest Plants	1938 Per Cent of Total Capacity	1948 n Largest Plants	1948 Per Cent of Total Capacity	1938 n Largest Plants	1938 Per Cent of Total Capacity	1948 n Largest Plants	1948 Per Cent of Total Capacity	1938-48 Change
Shapes and Rails	4	51	11	33	4	45	11	79	small decrease
Plates	3	55	10	33	3	39	10	77	decrease
Bars	10	50	30	30	10	50	30	79	no change
Skelp	3	52	7	33	3	48	7	83	no change
					4	58			
Tube Rounds	2	48	6	31	2	43	6	89	no change
	3	57			3	57			
Sheet and Strip	10	50	23	30	7	48	17	81	increase
					10	60	23	89	

*Tabulation of information in American Iron & Steel Institute: Directory of Iron & Steel Works, 1938 and 1948.

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TABLE A-4

Steel: Miscellaneous Material, Sources and Further Data for Appendix VII-1

Expansion of Steel Industry

(1) Ingot steel capacity

1938	73.0 million tons
1941	84.2 million tons
1948	94.2 million tons
1951	104.2 million tons

Sources: 1938-48 figures, Directory of American Iron & Steel Works, 1938, 1941, 1948.

1951 figures, American Iron & Steel Institute, communication dated 4 May 51.

(2) Capital costs of expansion

Present capital costs of new plant	$300 per ton
Prewar capital costs of new plant	$100 per ton
Present cost of "piecemeal" expansion	$150 to $200 per ton

Sources: J. Cumberland: Prospects of a New England Steel Industry, Ph.D. dissertation, 1951, Harvard College Library, p. 146 ff.

C. F. Sullivan, Article in Iron Age, 6 Jan 1949, p. 198-205.

H. Barloon, Article in Harvard Business Review, March 1948.

Celler Committee (Committee on the Judiciary, House of Representatives, Subcommittee on the Study of Monopoly Power, 81st Congress, 1st Session) Hearings, Part 4A, p. 416-17.

Minimum-Efficient-Size Unit

(1) Present techniques

Sources: Cumberland, op. cit., p. 167 ff.
Celler Committee, op. cit., p. 416-17, p. 834-5.

(2) Possible new techniques

Sources: Celler Committee, op. cit., p. 750-769.

Steel Requirements Per Ton of Steel Capacity

Sources: Figure of 0.3 ton for "equipment" increased to ~0.5 to allow for steel used in construction, railway facilities, etc.

American Iron & Steel Institute: America's Steel Capacity, 1948, p. 35.

TABLE A-5

DPA Authorizations of Accelerated Amortization for Steel Works

27 January - 6 April 1951

Authorizations of $1 million and over, in order of size

Rank	Company and Location	Amount of New Construction Authorized (millions of dollars)
1	Pueblo Steel, Pueblo, Colorado	80.0
2	Granite City Steel, Granite City, Ill.	66.2
3	Detroit Steel, Portsmouth, Ohio	47.8
4	Jones & Laughlin Steel, Cleveland, Ohio	28.9
5	Bethlehem Steel, Johnstown, Pa.	28.4
6	Republic Steel, So. Chicago, Ill.	21.5
7	National Steel, Wierton, W. Va.	17.8
8	Kaiser Steel, Fontana, Cal.	15.5
9	Pittsburgh Coke, Neville Island, Pa.	9.2
10	Youngstown Sheet & Tube, E. Chicago, Ind.	7.6
11	Allegheny-Ludlum Steel, Watervliet, N. Y.	6.4
12	Babcock & Wilcox Tube, Beaver Falls, Pa.	6.3
13	Bethlehem Steel, Bethlehem, Pa.	5.8
14	Youngstown Sheet & Tube, Youngstown, Ohio	4.5
15	Latrobe Electric Steel, Latrobe, Pa.	4.1
16	Jones & Laughlin Steel, Pittsburgh, Pa.	3.8
17	National Steel, Hancock, W. Va.	3.3
18	Jackson Iron & Steel, Jackson, Ohio	2.4
19	Universal Cyclops Steel, Budgeville, Pa.	2.4
20	Jones & Laughlin Steel, Aliquippa, Pa.	2.1
21	Great Lakes Steel, River Rouge, Mich.	2.1
22	Rotary Electric Steel, Macomb Co., Mich.	1.6
23	Bethlehem Steel, Seattle, Wash.	1.4
24	Cold Metal Products, Youngstown, Ohio	1.3
25	Bethlehem Steel, Lebanon, Pa.	1.2
26	Ohio Steel Foundry, Lima, Ohio	1.0

TABLE A-5 (cont'd)

The largest 5 authorizations accounted for $252 million. Of these, number 5, Bethlehem at Johnstown, is the 13th-largest ingot producer, and 16th-largest pig iron producer in the United States, and number 4 is a medium-size producer contributing almost 1 per cent of total ingot production. Every one of the 5 is a case of expansion at an existing plant.

Bethlehem at Bethlehem, number 13, is the 7th-largest U.S. producer of ingot; and the funds are for further ingot capacity expansion.

Youngstown at E. Chicago and Republic at So. Chicago, numbers 10 and 6 on the list, are, respectively, the 21st and 25th-largest ingot producers in the country.

APPENDIX VII-1

ANNEX B

THE CONCENTRATION OF FACILITIES IN THE U.S. PETROLEUM REFINING INDUSTRY

Summary

With a refinery charging capacity in the neighborhood of 60,000 barrels per day, it should be possible to achieve most of the economies of large-scale production. As of January 1, 1950, the 25 largest refineries had capacities in excess of this amount. Between them, their capacity amounted to 40 per cent of the national total. If the same amount of capacity were distributed evenly among units no larger than the 25th, it would be possible to increase this number from 25 to 49.

Unless some positive action is adopted by the industry, however, little improvement can be expected. Total charging capacity increased by 42 per cent from 1941 to 1950, yet there was no tendency toward dispersal. In fact, the 25 largest units grew from 44 per cent of the total charging capacity in 1941 to 48 per cent in 1950. Current plans for expansion will do little to reduce the industry's vulnerability. Of the amounts authorized by DPA between January and April, 1951, 37 per cent is being directed toward 8 plants that are already among the 25 largest.

Alan S. Manne

15 June 1951

PART 1

A. The Problem of Efficient Plant Size

Without first making some estimate of the real costs involved, it would be unrealistic to discuss the possibilities of reducing concentration in the oil refinery target system. Even if we are willing to assume that wartime real costs are closely correlated with peacetime dollar costs, there are only a few rough guides. Table B-1 contains one set of data that are frequently cited in this connection - 1939 figures presented in testimony by R. E. Wilson before the Temporary National Economic Committee. "Refinery operating costs" are the most significant numbers for the present purposes. It will be seen that there are substantial economies of scale in oil refining. As the plant size increases from 5000 barrels per day (B/D) of charging capacity to 60,000, the operating costs decline from $0.337 per barrel $0.201. (Note that these costs are inclusive of depreciation.) This by no means indicates that there are indefinitely great economies of scale. Even the 15,000 B/D refinery achieves a respectable performance in comparison with the smaller one.

It is particularly important to realize that these cost differences apply only to operating expenses - i.e., "value added." When crude costs are counted in also, total costs for the 60,000 B/D refinery are at least 90 per cent of those in the 5000 B/D plant. (Of course, the figures on total costs presented in the original table are deceptive. It is assumed there that the small plant enjoys enormous advantages in the price of its crude.)

One other feature of this table deserves our interest. The capacity of the 60,000 B/D plant is 12 times that of the smallest one, but the initial investment is only 8 times as high. In other words, for the large plant initial investment per unit of capacity is 67 per cent of that of the small one. This has important wartime implications. It means that during a war there would be a strong incentive to economize on scarce construction materials by building large-scale plants. If a deconcentration policy were adopted well in advance of an actual war, though, smaller individual units would not necessarily be uneconomical.

As of 1939, therefore, a 60,000 B/D plant was able to reach most of the economies of scale for a combination refinery. Since that time, the most

important developments have centered around catalytic cracking methods. Apparently it has been possible to extend these new techniques to small plants. According to engineers of the Houdry Process Corporation, "Studies have been prepared which show that the process (Thermofor Catalytic Cracking) is feasible for the refiner processing 3000 or more barrels per day of crude oil."* By themselves, refining economies do not account for plant sizes in excess of 60,000 B/D. It is more likely that refineries of this size are built in order to take advantage of individual harbor locations or in order to make central administration easier.

B. The Degree of Concentration, 1941 and 1950

A special tabulation was run to rank oil refineries according to size in both 1941 and 1950 (see Part 2 for the details). The results are summarized in Table B-2 and also on Figs. B-1 and B-2. For each of these years, two indices of size are available: the crude oil charging capacity and the gasoline cracking capacity. Needless to say, there is an element of arbitrariness in the matter of defining the unit to be ranked. Should all the capacity within a city be considered as one target? What about adjacent refineries belonging to different firms? If an individual refinery extends over many miles, should all of its capacity be counted? Rather than becoming involved in detailed topographical considerations, the unit finally adopted was the total capacity in any one town belonging to a particular firm. This may overstate or understate the actual target area. It would certainly require more than one Hiroshima-size bomb to destroy the Humble Company's Baytown refinery; on the other hand, new weapons might conceivably wipe out an even larger region. The individual firm's total capacity appears to be as reasonable a compromise as any.

In comparison with many of our industries, therefore, oil refineries are rather dispersed. As of January 1, 1950, the 25 largest units had only 48 per cent of the crude charging capacity and 51 per cent of the gasoline cracking capacity. Tetraethyl lead, magnesium, and alumina facilities are all far more

*H. D. Noll and V. O. Bowles, "Small-Scale Catalytic Cracking," Petroleum Refiner, Vol. 24, No. 10, October, 1945.

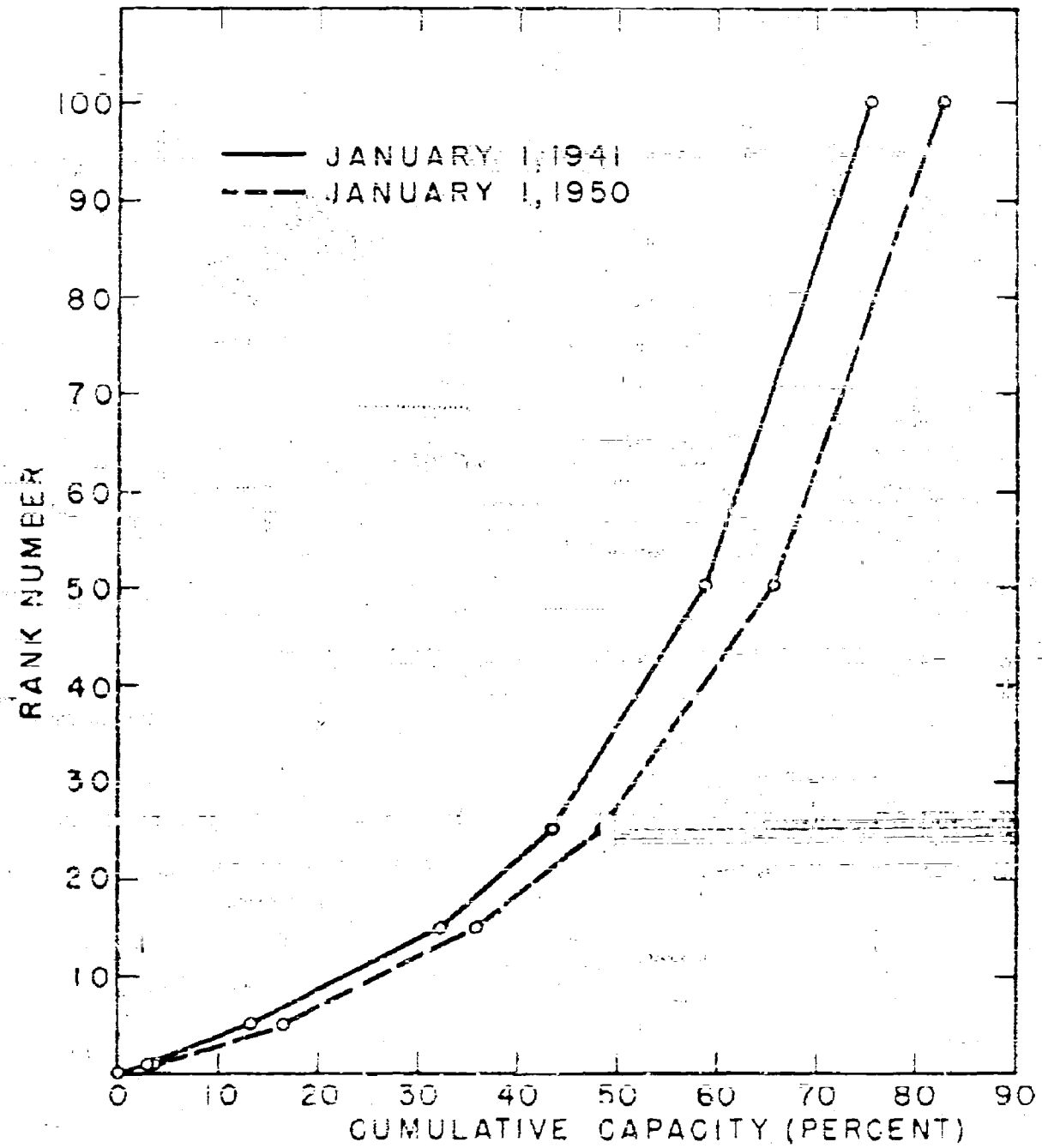


Fig. B-1 Cumulative crude charging capacity.

concentrated percentagewise, and in that sense represent more attractive target systems. If, on the other hand, an enemy decided to attack an industry representing a large sector of the entire economy, he might well select American oil refineries. It should be recalled that this industry was, in fact, the primary Allied target in Germany during the last phase of World War II.

It is at least conceivable that, over the next ten or twenty years, the industry's natural growth would eliminate the dispersal problem. (This would be roughly analogous to the recent exodus of population to the suburbs of metropolitan regions.) After all, crude charging capacity increased by 42 per cent from 1941 to 1950, and gasoline cracking capacity by 65 per cent. The actual results during this period do not lend much support to this point of view. True, the percentage of gasoline capacity among the 25 largest units declined from 53 to 51 per cent, but the reverse is true for the crude charging facilities. According to that index, the 25 largest units increased from 44 to 48 per cent of the total. Of course, the last digits in all these numbers should not be taken too seriously. What is significant is the fact that concentration has not been decreasing over time, despite the substantial increase in the total volume of the industry's capacity.

In this connection, it is instructive to determine the increase in dispersal that would be provided by distributing capacity of the very large refineries in a more even manner. For instance, in 1950 the 25 largest had a cumulative total crude oil capacity of 3,239,600 B/D. The 25th-largest itself had a capacity of 66,000. (On the basis of our previous cost considerations, this should certainly not represent an uneconomical scale of operations.) Now if the total of 3,239,600 B/D were distributed evenly among units all of this size, it would be possible to increase the number of these refineries to 49 – a factor of two. Similar theoretical calculations were made at other levels of concentration for both crude oil and gasoline facilities. (Table B-3.) If the upper limit were imposed at 14,000 B/D, the size of the 100th-largest, dispersal would be increased by a factor of four. Detailed cost figures would be essential before any responsible authority urged this degree of dispersal. Nevertheless, it would be quite proper to question the need for refineries as large as those that are now among the first 25. It is particularly dubious whether the industry

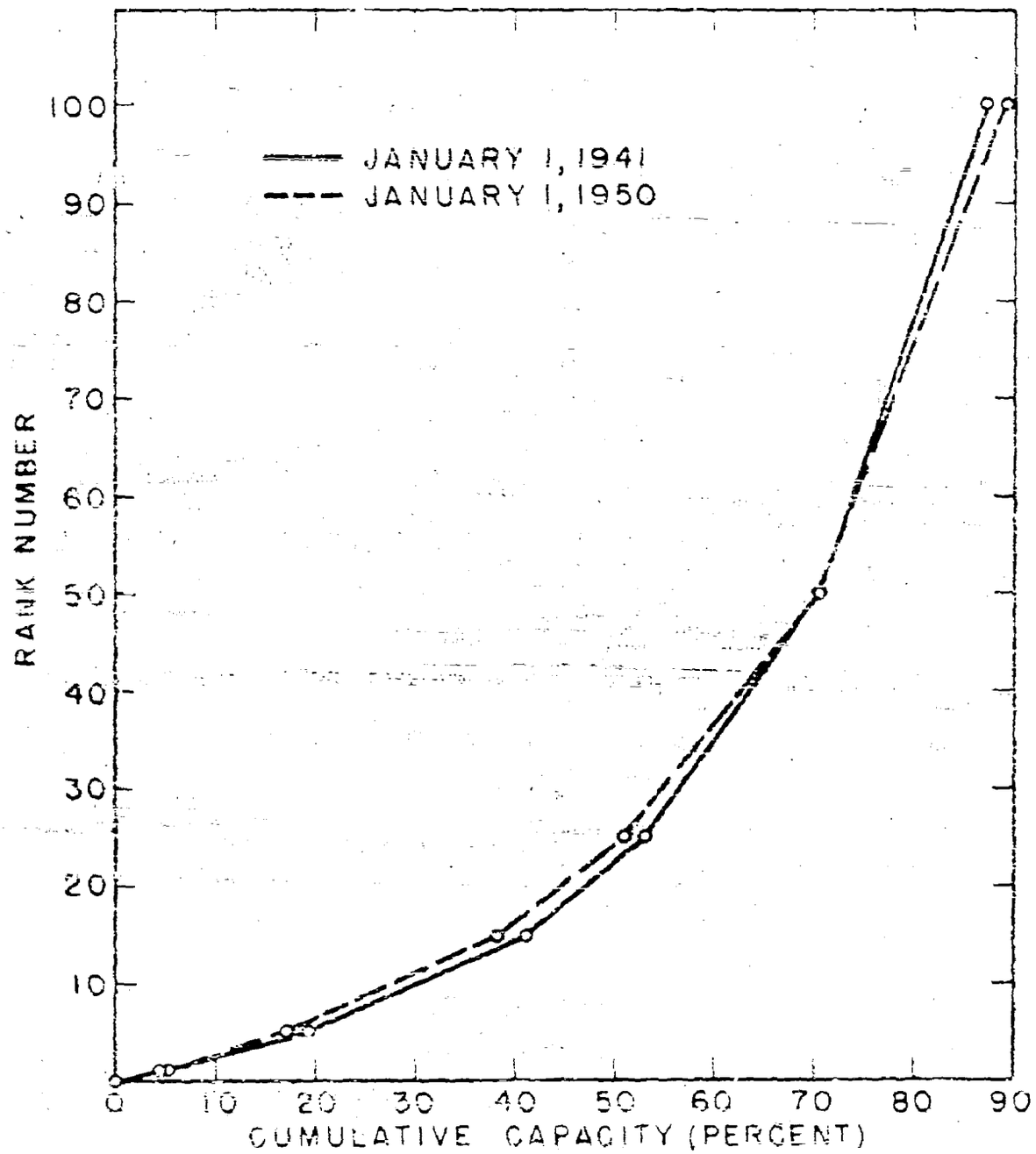


Fig. B-2 Cumulative gasoline cracking capacity.

should be permitted to add still further to these 25 -- with the exception of a few facilities for removing bottlenecks and for rearranging the product mix.

C. Present Expansion Plans

From January 25 through April 6, 1951, the Defense Production Administration approved 36 applications for accelerated amortization of oil refining facilities. (A summary appears in Table B-4, but the full list is given in Part 3.) Two of these applications refer to facilities of the same company in the same town, hence only 34 distinct targets need be considered. The total amount eligible for tax relief – $285 millions – represents a sizeable part of the investment in new defense production facilities.

It will be seen from Table B-4 that little is being done to guide this increment in such a way as to reduce the existing concentration. Only 27 per cent is being directed into new facilities or into unspecified locations, while $106 millions (37 percent of the total) is going into 8 plants that are already among the 25 largest. It seems hard to believe that the production authorities today can be much concerned about the need for dispersal.

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TABLE B-1

Combination Cracking Refinery

Charge Stock: 36.0° - 38.9° Crude*

	Location of Refinery		
	Mid-Continent	Gulf Coast	Chicago District
Capacity, B/D of crude	5000	15000	60000
Initial investment (millions of dollars)	2	5	16
Cost of crude at refinery (dollars per barrel)	1.070	1.275	1.415
Refinery operating costs (dollars per barrel)**	0.337	0.259	0.201
Total costs (dollars per barrel)	1.407	1.534	1.616

*"Hearings before the Temporary National Economic Committee," Congress of the United States, 75th Congress, Second Session, 1940, Part 15, p. 8636, Testimony of R. E. Wilson Standard Oil Co. (Indiana).

**Inclusive of depreciation.

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TABLE E-2

Plant Capacity Ranked in Descending Order
Summary and Comparison

Rank No.	Crude Charging Cumulative Capacity (Per Cent)		Crude Charging Actual Capacity B/D (barrels per day)	Gasoline Cracking Cumulative Capacity (Per Cent)		Gasoline Cracking Actual Capacity B/D (barrels per day)
	1941	1950	1950	1941	1950	1950
1	2.97	3.88	260,000	4.62	4.94	90,000
5	13.29	16.44	175,800	19.23	16.96	52,500
15	32.49	35.79	110,000	41.22	38.38	29,000
25	43.61	48.38	66,000	55.60	51.01	17,700
50	58.96	65.89	37,000	70.78	70.81	11,000
100	75.60	82.85	14,000	87.22	89.65	3,690
Total Number	556	367				
Total Capacity	4,718,969	6,696,300	142% (1950÷1941)	1,103,048	1,820,683	165% (1950÷1941)

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TABLE B-3

Theoretical Number of Units if Cumulative Capacity Were Distributed Evenly
(January 1, 1950)

Unit Rank No.	Crude Oil	Gasoline
1	1.0	1.0
5	6.3	5.9
15	22	24
25	43	52
50	119	117
100	396	443

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TABLE B-4

Summary of DPA Oil Refinery Authorizations
(Jan. 25 through Apr. 6, 1951)

Plant Rank Size According to Crude Oil Charging Capacity January 1, 1950	Location	Amount Eligible	Cumulative Total
3	Port Arthur, Texas	$33,812,342	$33,812,342
5	Whiting, Ind.	10,957,145	44,869,487
6	Marcus Hook, Pa.	2,327,500	47,196,987
10			
11	El Segundo, Cal.	14,000,000	61,196,987
14	Texas City, Texas	1,100,000	62,296,987
20	Houston, Texas	27,000,000	89,296,987
24	Oleum, Cal.	4,500,000	93,796,987
25	Wilmington, Cal.	12,000,000	105,796,987
28	Borger, Texas	15,573,700	121,370,687
30			
40			
49	Sugar Creek, Mo.	21,170,000	142,540,687
50			
57	Corpus Christi, Texas	5,057,493	147,598,180
60			
70			
79	Duncan, Okla.	1,750,866	148,349,046
80			
90			
97	Ponca City, Okla.	6,500,000	155,849,046
100			

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TABLE E-4 (Con't)

Authorization for enlargement of existing refineries not among 100 largest in U.S.	
No. of Authorizations	9
Total Volume of Authorizations	$51,194,271
New plants and not-specified locations	
No. of Authorizations	12
Total Volume of Authorizations	$77,712,687
Total Volume of Authorizations in the U.S.	$284,756,004
Total No. of Authorizations	34

Source: Part 3

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ANNEX B

PART 2

Plant Capacity Ranked in Descending Order

Source: "Petroleum Refineries, including Cracking Plants, in the United States," January 1, 1941 and January 1, 1950, Information Circulars 7141 and 7578, U.S. Bureau of Mines.

N. B. These figures all refer to the total of operating plus shut-down capacity. They do not include the amounts under construction.

TABLE B-5

Plant Capacity in Descending Order

Crude Charging Facilities

(January 1, 1950)

	Location	Crude Charge Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
1	Baytown, Texas, 9B	260,000	260,000	3.88
2.	Baton Rouge, La., 6B	245,000	505,000	7.54
3.	Port Arthur, Texas, 7B	230,000	735,000	10.98
4.	Port Arthur, Texas, 25B	190,000	925,000	13.81
5.	Whiting, Ind., 8	175,800	1,100,800	16.44
6.	Linden, New Jersey, 3	155,000	1,255,800	18.75
7.	Beaumont, Texas, 10B	150,000	1,405,800	20.99
8.	Marcus Hook, Pa., 4A	140,000	1,545,800	23.08
9.	Richmond, Cal., 44	138,000	1,683,800	25.15
10.	Lake Charles, La., 3B	130,000	1,813,800	27.09
11.	El Segundo, Cal., 43	127,000	1,940,800	28.98
12.	Philadelphia, Pa., 1A	117,000	2,057,800	30.73
13.	Roxana (Wood River), Ill., 12	115,000	2,172,800	32.45
14.	Texas City, Texas, 12B	114,000	2,286,800	34.15
15.	Houston (Deer Park), Texas, 19B	110,000	2,396,800	35.79
16.	Giraud Point, Pa., 2A	107,000	2,503,800	37.39
17.	Torrance, Cal., 17	100,000	2,603,800	38.91
18.	Watson, Cal., 36	91,000	2,694,800	40.24
19.	East Chicago, Ind., 6	85,000	2,779,800	41.51
20.	Houston, Texas, 22B	85,000	2,864,800	42.78
21.	Avon, Cal., 51	85,000	2,949,800	44.05
22.	Marcus Hook, Pa., 3A	80,000	3,029,800	45.25
23.	Bayonne, N. J., 6	74,000	3,103,800	46.35
24.	Oleum, Cal., 55	69,800	3,173,600	47.39
25.	Wilmington, Cal., 56	66,000	3,239,600	48.38
26.	Lockport, Ill., 17	60,000	3,299,600	49.27

TABLE B-5 (cont'd)

	Location	Crude Charge Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
27.	Nederland, Texas, 16B	58,200	3,357,800	50.14
28.	Paulsboro, N. J., 4	58,000	3,415,800	51.01
29.	Borger, Texas, 22A	56,000	3,471,800	51.85
30.	Ponca City, Okla., 8	52,500	3,524,300	52.63
31.	Wilmington, Cal., 41	52,000	3,576,300	53.41
32.	Westville, N. J., 5	50,000	3,626,300	54.15
33.	Kansas City, Kans., 11	50,000	3,676,300	54.90
34.	Wilmington, Cal., 50	50,000	3,726,300	55.65
35.	Texas City, Texas, 13B	50,000	3,776,300	56.39
36.	Baltimore, Md., 2	47,450	3,823,750	57.10
37.	Catlettsburg, Ky., 2	45,000	3,868,750	57.77
38.	Sweeny, Texas, 14B	45,000	3,913,750	58.46
39.	Norco, La., 10B	45,000	3,958,750	59.12
40.	Martinez, Cal., 40	45,000	4,003,750	59.79
41.	Atreco (Pt. Arthur), Texas, 2B	45,200	4,048,750	60.46
42.	Tulsa, Okla., 14	44,000	4,090,750	61.09
43.	Robinson, Ill., 10	43,500	4,134,250	61.74
44.	Wood River, Ill., 15	42,800	4,177,050	62.38
45.	Cleveland, Ohio 3A	42,500	4,218,550	63.01
46.	Toledo, Ohio, 3B	41,000	4,259,550	63.61
47.	Port Neches, Texas, 26B	40,000	4,299,550	64.20
48.	Everett, Mass., 1	38,000	4,337,550	64.78
49.	Sugar Creek, Mo., 1	37,800	4,375,350	65.34
50.	Toledo, Ohio, 8B	37,000	4,412,350	65.89
51.	East Chicago, Indiana, 1	35,000	4,447,350	66.42
52.	Houston, Texas, 5B	35,000	4,482,350	66.94
53.	Texas City, Texas, 17B	34,000	4,516,350	67.43
54.	Houston (Pasadena), Texas, 4B	32,000	4,548,350	67.92

TABLE B-5 (cont'd)

Location	Crude Charge Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
55. Lemont, Ill., 6	31,925	4,580,275	68.40
56. East Chicago, Ind., 7	31,000	4,611,275	68.86
57. Corpus Christi, Texas, 24B	31,000	4,642,275	69.33
58. West Tulsa, Okla., 22	30,000	4,672,275	69.77
59. East St. Louis, Ill., 13	30,000	4,702,275	70.22
60. Toledo, Ohio, 5B	29,400	4,731,675	70.66
61. Cleves, Ohio, 2B	28,000	4,759,675	71.08
62. Lawrenceville, Ill., 16	27,000	4,786,675	71.48
63. Augusta, Kans., 14	26,500	4,813,175	71.88
64. Salt Lake City, Utah	26,000	4,839,175	72.27
65. Brooklyn, N.Y., 2A	26,000	4,865,175	72.68
66. Hartford, Ill., 9	25,000	4,890,175	73.03
67. El Dorado, Kans., 13	25,000	4,915,175	73.40
68. Trenton, Mich., 17	25,000	4,940,175	73.77
69. Barber, N.J., 1	25,000	4,965,175	74.15
70. Wilmington, Cal., 31	25,000	4,990,175	74.52
71. Salt Lake City, Utah, 2	24,000	5,014,175	74.88
72. El Dorado, Ark., 6	23,250	5,037,425	75.23
73. Lebec, Cal., 16	23,000	5,060,425	75.57
74. Norwalk, Cal., 58	22,000	5,082,425	75.90
75. Buffalo, N.Y., 3B	22,000	5,104,425	76.23
76. El Dorado, Ark., 4	22,000	5,126,425	76.56
77. Corpus Christi, Texas, 21B	21,000	5,147,425	76.86
78. Toledo, Ohio, 7B	21,000	5,168,425	77.18
79. Duncan, Okla., 21	20,000	5,188,425	77.48
80. Enid, Okla., 6	20,000	5,208,425	77.78
81. Sinclair, Wy., 14	20,000	5,228,425	78.08
82. Billings, Mont., 2	20,000	5,248,425	78.38

TABLE B-5 (cont'd)

	Location	Crude Charge Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
83.	Texas City, Texas, 20B	20,000	5,268,425	78.68
84.	Gulfport (Staten Island), N. Y., 1A	19,000	5,287,425	78.96
85.	El Paso, Texas, 33A	18,000	5,305,425	79.23
86.	McPherson, Kans., 10	18,000	5,323,425	79.50
87.	Corpus Christi, Texas, 23B	18,000	5,341,425	79.77
88.	Coffeyville, Kan., 4	18,000	5,359,425	80.04
89.	Seguro (Bakersfield), Cal., 45	18,000	5,377,425	80.30
90.	Lima, Ohio, 6B	17,500	5,394,925	80.57
91.	Corpus Christi, Texas, 15L	16,750	5,411,675	80.82
92.	Latonia, Ky., 6	16,500	5,428,175	81.06
93.	Detroit, Mich., 1	16,000	5,444,175	81.30
94.	Heath (Newark), Ohio, 2A	15,500	5,459,675	81.53
95.	Casper, Wy., 17	15,200	5,474,875	81.76
96.	Big Spring, Texas, 7A	15,000	5,489,375	81.98
97.	Ponca City, Okla., 7	15,000	5,504,875	82.21
98.	Linden, N. J., 2	15,000	5,519,875	82.43
99.	Neville Island, Pa., 4B	14,000	5,533,875	82.64
100.	Watson, Cal., 52	14,000	5,547,875	82.85

TABLE B-6

Plant Capacity Ranked in Descending Order
Gasoline Cracking Facilities (January 1, 1950)

	Location	Gas. Crack. Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
1.	Port Arthur, Texas, 25B	90,000	90,000	4.94
2.	Baton Rouge, La., 6B	57,300	147,300	8.09
3.	Port Arthur, Texas, 7B	56,050	203,350	11.17
4.	Marcus Hook, Pa., 4A	53,000	256,350	14.08
5.	Linden, N. J., 3	52,500	308,850	16.96
6.	Whiting, Ind., 8	50,800	359,650	18.75
7.	Texas City, Texas, 12B	48,000	407,650	22.39
8.	Baytown, Texas, 9B	45,600	452,250	24.84
9.	Lake Charles, La., 3B	42,000	495,250	27.20
10.	Philadelphia, Pa., 1A	37,500	532.750	29.26
11.	Norma, Ill., 12	36,800	569.550	31.28
12.	Houston (Deer Park), Texas, 19B	35,000	604,550	33.20
13.	Beaumont, Texas, 10B	34,630	639,180	35.1
14.	Richmond, Cal., 44	30,600	669,780	36.79
15.	East Chicago, Ind., 6	29,000	698,780	38.38
16.	Marcus Hook, Pa., 3A	29,000	727,780	39.97
17.	Houston, Texas, 22B	26,500	754,280	41.43
18.	Torrance, Cal., 17	26,000	780,280	42.99
19.	Lockport, Ill., 17	24,000	804,280	44.17
20.	Giraud Point, Pa., 2A	23,700	827,980	45.47
21.	Borger, Texas, 22A	23,000	850,980	46.74
22.	El Segundo, Cal., 43	21,200	872,180	47.90
23.	Wilmington, Cal., 56	20,300	892,480	49.02
24.	Ponca City, Okla., 8	18,550	911,030	50.04
25.	Wilmington, Cal., 41	17,700	928,730	51.01
26.	Watson, Cal., 36	17,500	946,230	51.97

TABLE B-6 (cont'd)

Location	Gas. Crack. Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
27. Tulsa, Okla., 14	16,700	962,930	52.89
28. Nederland, Texas, 16B	16,500	979,430	53.79
29. Cleves, Ohio, 2B	16,480	995,910	54.70
30. Westville, N. J., 5	16,000	1,011,910	55.58
31. Cleveland, Ohio, 3A	16,000	1,027,910	56.46
32. West Tulsa, Okla., 22	16,000	1,043,910	57.33
33. Bayonne, N. J., 6	15,600	1,059,510	58.19
34. Sugar Creek, Mo., 1	15,500	1,075,010	59.04
35. Avon, Cal., 9I	15,400	1,090,410	59.89
36. Lima, Ohio, 6B	15,000	1,105,410	60.71
37. Toledo, Ohio, 5B	14,800	1,120,210	61.53
38. Baltimore, Md., 2	14,260	1,134,470	62.31
39. Robinson, Ill., 10	14,200	1,148,670	63.09
40. Kansas City, Kan., 11	14,000	1,162,670	63.86
41. Toledo, Ohio, 6B	13,700	1,176,370	64.61
42. Catlettsburg, Ky., 2	13,500	1,189,870	65.35
43. East Chicago, Ind., 1	13,500	1,203,370	66.09
44. Toledo, Ohio, 3B	13,200	1,216,570	66.82
45. Wilmington, Cal., 80	13,000	1,229,570	67.53
46. Stamford, Ill., 10	12,500	1,242,070	68.25
47. Wood River, Ill., 15	12,000	1,254,070	68.88
48. Big Spring, Texas, 7A	12,000	1,266,070	69.54
49. Paulsboro, N. J., 4	11,950	1,278,020	70.19
50. Sweeney, Texas, 14B	11,000	1,289,020	70.81
51. Detroit, Mich., 1	11,000	1,300,020	71.40
52. Houston (Pasadena), Texas, 4B	10,950	1,310,970	72.00
53. Oleum, Cal., 8G	10,850	1,321,820	72.60
54. Texas City, Texas, 17B	10,500	1,332,320	73.18

TABLE B-6 (Cont'd)

Location	Gas. Crack. Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
55. Corpus Christi, Texas, 21A	10,500	1,34[illegible]820	73.75
56. Duncan, Okla., 21	10,000	1,352,8[illegible]	74.30
57. Norwalk, Cal., 58	9,000	1,361,82[illegible]	74.80
58. Enid, Okla., 6	9,000	1,370,820	75.29
59. Lemont, Ill., 6	8,750	1,379,570	75.77
60. Norco, La., 49B	8,500	1,388,170	76.24
61. Salt Lake City, Utah, 4	[illegible] 198	1,396,368	[illegible].69
62. Martinez, Cal., 40	8,[illegible]00	1,404,368	7[illegible]13
63. Everett, Mass., 1	8,0[illegible]	1,412,368	77.[illegible]
64. East Chicago, Ind., 7	8,000	1,420,368	78.0[illegible]
65. Lawrenceville, Ill., 16	[illegible],000	1,428,368	78.45
66. El Dorado, Kansas, 13	8,000	1,436,368	78.89
67. Sinclair, Wy., 14	8,000	[illegible],444,369	79.33
68. Heath (Newark), Ohio, 2A	7,950	[illegible]452,318	79.77
69. East St. Louis, Ill., 13	7,880	1,[illegible]60,198	80.20
70. Toledo, Ohio, 7B	7,800	1,46[illegible]998	80.63
71. Alma, Mich., 6	7,750	1,[illegible]68,748	81.05
72. Atreco (Port Arthur), Texas, 2B	7,400	1,[illegible]76,148	81.46
73. Casper, Wy., 17	7,400	1,484,548	81.87
74. Trenton, Mich., 17	7,299	1,497,847	82.27
75. Augusta, Kansas, 14	6,900	1,504,747	82.65
76. Buffalo, N. Y., 3B	6,900	1,511,647	83.03
77. Barber, N. J., 1	6,700	1,518,347	[illegible]83
78. Houston, Texas, 5B	6,500	1,524,847	[illegible]8
79. El Paso, Texas, 33A	6,000	1,530,847	84.[illegible]0
80. Latonia, Ky., 6	6,000	1,536,847	84.38
81. Brooklyn, N. Y., 2A	5,500	1,542,347	84.73
82. Cheyenne, Wy., 7	5,750	1,548,397	85.04

TABLE B-6 (cont'd)

Location	Gas. Crack. Capacity (B/D)	Cumulative Capacity (B/D)	Cumulative Capacity (per cent)
83. Wichita, Kans., 1	5,650	1,554,047	85.36
84. McPherson, Kans., 10	5,400	1,559,447	85.65
85. Findley, Ohio, 4B	5,400	1,564,847	85.95
86. El Dorado, Ark., 6	5,000	1,569,847	86.22
87. Corpus Christi, Texas, 23B	5,000	1,574,847	86.49
88. Cushing, Okla., 9	5,000	1,579,847	86.77
89. Rock Island, Ind., 5	5,000	1,584,847	87.05
90. Billings, Mont., 2	4,900	1,589,747	87.32
91. [illegible]eville Island, Pa., 4B	4,800	1,594,547	87.57
92. [illegible]seville, Pa., 7B	4,569	1,599,116	87.83
93. [illegible]ess City, Texas, 20B	4,500	1,603,616	88.08
94. [illegible], Texas, 18A	4,500	1,608,116	88.32
95. Sun [illegible], Texas, 31A	4,300	1,612,416	88.78
96. Coffe[illegible]ville, Kans., 4	4,200	1,616,616	88.79
97. Texas [illegible], Texas, 13B	4,000	1,620,616	89.01
98. Neodesha, [illegible]ans., 15	4,000	1,624,616	89.23
99. Arkansas C[illegible], Kans., 8	4,000	1,628,616	89.45
100. Westlake ([illegible] Charles), La., 5B	3,690	1,632,306	89.65

TABLE B-7

Plant Capacity in Descending Order

Crude Charging Capacity (January 1, 1941)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
1.	Baytown, Texas	40	140,000	140,000	2.9667
2.	Port Arthur, Texas	113	135,000	275,000	5.8274
3.	Port Arthur, Texas	34	130,000	405,000	8.5824
4.	Whiting, Ind.	7	117,800	522,800	11.0786
5.	Bayonne, N.J.	6	104,500	627,300	13.2932
6.	El Segundo, Cal.	73	100,000	727,300	15.4123
7.	Richmond, Cal.	74	100,000	827,300	17.5314
8.	Baton Rouge, La.	16	100,000	927,300	19.6505
9.	Beaumont, Texas	54	100,000	1,027,300	21.7695
10.	Texas City, Texas	76	97,000	1,124,300	23.8251
11.	Marcus Hook, Pa.	22	90,000	1,214,300	25.7323
12.	Philadelphia, Pa.	1	90,000	1,304,300	27.6395
13.	Watson, Cal.	62	80,000	1,384,300	29.3348
14.	Wood River, Ill.	20	75,000	1,459,300	30.9241
15.	Houston, Texas	84	74,000	1,533,300	32.4922
16.	Torrance, Cal.	25	60,000	1,593,300	33.7637
17.	Wilmington, Cal.	87	60,000	1,653,300	35.0352
18.	Houston, Texas	97	60,000	1,713,300	36.3067
19.	Nederland, Texas	86	59,000	1,772,300	37.5569
20.	Bayonne, N.J.	7	57,000	1,829,300	38.7647
21.	Hynes, Cal.	60	55,000	1,884,300	39.9302
22.	E. Chicago, Ind.	5	45,000	1,929,300	40.8838
23.	Marcus Hook, Pa.	21	45,000	1,974,300	41.8374
24.	Avon, Cal.	79	43,600	2,017,900	42.7613
25.	West Tulsa, Okla.	18	40,000	2,057,900	43.6089

TABLE B-7 (cont'd)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
26.	Giraud Point, Pa.	11	40,000	2,097,900	44.4565
27.	Port Neches, Texas	114	40,000	2,137,900	45.3041
28.	Wilmington, Cal.	68	38,000	2,175,900	46.1094
29.	Lockport, Ill.	24	38,000	2,213,900	46.9147
30.	Wilmington, Cal.	78	37,000	2,250,900	47.6990
31.	Berger, Texas	76	35,000	2,285,900	48.4407
32.	Everett, Mass.	3	32,600	2,318,500	49.1315
33.	Oleum, Cal.	96	30,000	2,348,500	49.7672
34.	E. Chicago, Ind.	1	30,000	2,378,500	50.4029
35.	Ingleside, Texas	41	30,000	2,408,500	51.0386
36.	Vernon, Cal.	26	28,000	2,436,500	51.6318
37.	Baltimore, Md.	3	27,000	2,463,500	52.2041
38.	Martinez, Cal.	67	26,500	2,490,000	52.7657
39.	Ponca City, Okla.	10	26,000	2,516,000	53.3167
40.	Paulsboro, N.J.	5	25,200	2,541,200	53.8507
41.	Seguro, Cal.	75	25,000	2,566,200	54.3805
42.	Lawrenceville, Ill.	15	25,000	2,591,200	54.9103
43.	Toledo, Ohio	13	25,000	2,616,200	55.4401
44.	Houston, Texas	112	25,000	2,641,200	55.9699
45.	Trenton, N.J.	28	24,500	2,665,700	56.4891
46.	Sugar Creek, Mo.	3	23,900	2,689,600	56.9956
47.	Wood River, Ill.	22	23,800	2,713,400	57.4999
48.	El Dorado, Kans.	21	23,000	2,736,400	57.9873
49.	Kansas City, Kans.	16	23,000	2,759,400	58.4747
50.	Bossier City, La.	1	23,000	2,782,400	58.9621
51.	Cleveland, Ohio	10	23,000	2,805,400	59.4495
52.	Toledo, Ohio	9	22,500	2,827,900	59.9263
53.	Lemont, Ill.	12	22,000	2,849,900	60.3924

TABLE B-7 (cont'd)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
54.	Augusta, Kans.	22	21,500	2,871,400	60.8481
55.	Norco, La.	14	21,000	2,892,400	61.2931
56.	Toledo, Ohio	12	21,000	2,913,400	61.7381
57.	Atreco, Texas	5	20,600	2,934,000	62.1746
58.	E. Braintree, Mass.	1	20,000	2,954,000	62.5984
59.	Petty's Island, N.J.	3	20,000	2,974,000	63.0222
60.	Corpus Christi, Texas	107	20,000	2,994,000	63.4460
61.	Texas City, Texas	98	20,000	3,014,000	63.8698
62.	Brooklyn, N.Y.	5	18,000	3,033,000	64.2724
63.	Hooven, Ohio	3	18,000	3,051,000	64.6538
64.	Toledo, Ohio	4	18,000	3,069,000	65.0352
65.	W. Tulsa, Okla.	29	18,000	3,087,000	65.4166
66.	Pasadena, Texas	20	18,000	3,105,000	65.7980
67.	El Dorado, Ark.	3	17,000	3,122,000	66.1584
68.	E. St. Louis, Ill.	21	16,000	3,138,000	66.4973
69.	E. Chicago, Ind.	6	16,000	3,154,000	66.8364
70.	Enid, Okla.	7	16,000	3,170,000	67.1755
71.	Big Spring, Texas	18	16,000	3,186,000	67.5146
72.	Texas City, Texas	90	16,000	3,202,000	67.8537
73.	Arkansas City, Kans.	12	15,500	3,217,500	68.1822
74.	Corpus Christi, Texas	7	15,500	3,233,000	68.5107
75.	McPherson, Kans.	11	15,000	3,248,000	68.8286
76.	Corpus Christi, Texas	83	15,000	3,263,000	69.1465
77.	Houston, Texas	26	15,000	3,278,000	69.4644
78.	W. Dallas, Texas	116	15,000	3,293,000	69.7823
79.	Buffalo, N.Y.	6	14,500	3,307,500	70.0895
80.	Watson, Cal.	60	14,000	3,321,500	70.3863

TABLE B-7 (cont'd)

Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
81. El Paso, Texas	102	14,000	3,335,500	70.6830
82. Barber, N.J.	1	13,750	3,349,250	70.9744
83. Norwalk, Cal.	89	13,500	3,362,750	71.2605
84. Gulfport, N.Y.	-	13,000	3,375,750	71.5360
85. Casper, Wyo.	25	13,000	3,388,750	71.8115
86. Long Beach, Cal.	30	12,500	3,401,250	72.0764
87. Robinson, Ill.	18	12,500	3,413,750	72.3413
88. Colorado City, Texas	16	12,500	3,426,250	72.6062
89. Heath, Ohio	6	12,400	3,438,650	72.8690
90. Lebec, Cal.	24	12,000	3,450,650	73.1233
91. Coffeyville, Kans	19	12,000	3,462,650	73.3776
92. Latonia, Ky.	4	12,000	3,474,650	73.6319
93. Linden, N.J.	2	12,000	3,486,650	73.8862
94. Drumright, Okla.	30	12,000	3,498,650	74.1405
95. Ponca City, Okla.	9	12,000	3,510,650	74.3948
96. Corpus Christi, Texas	108	12,000	3,522,650	74.6491
97. Corpus Christi, Texas	100	12,000	3,534,650	74.9033
98. Corpus Christi, Texas	3	11,500	3,546,150	75.1471
99. Kansas City, Kans.	20	11,000	3,557,150	75.3802
100. Rouseville, Pa.	18	10,500	3,567,650	75.6027

TABLE B-8

Plant Capacity in Descending Order

Gasoline Cracking Facilities (January 1, 1941)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
1.	Port Arthur, Texas	113	51,000	51,000	4.6236
2.	Whiting, Indiana	7	47,700	98,700	8.9480
3.	Marcus Hook	22	38,500	137,200	12.4383
4.	Port Arthur, Texas	34	37,900	175,100	15.8742
5.	Texas City, Texas	70	37,000	212,100	19.2285
6.	Wood River, Ill.	20	33,000	245,100	22.2202
7.	Bayonne, N. J.	6	30,300	275,400	24.9672
8.	Baytown, Texas	40	30,000	305,400	27.6869
9.	Philadelphia, Pa.	1	25,300	330,700	29.9806
10.	Beaumont, Texas	54	22,500	353,200	32.0204
11.	Baton Rouge, La.	16	22,050	375,250	34.0184
12.	Houston, Texas	94	21,900	397,150	36.0048
13.	El Segundo, Cal.	73	21,000	418,150	37.9086
14.	Nederland, Texas	86	19,500	437,650	38.6764
15.	Berger, Texas	76	17,000	454,650	41.2176
16.	Watson, Cal.	62	16,500	471,150	42.7135
17.	Richmond, Cal.	74	14,000	485,150	43.9827
18.	Lockport, Ill.	24	13,500	498,650	45.2066
19.	E. Chicago, Ind.	5	13,000	511,650	46.3851
20.	Toledo, Ohio	13	13,000	524,650	47.5637
21.	Houston, Texas	97	13,000	537,650	48.7422
22.	Kansas City, Kans.	16	12,000	549,650	49.8301
23.	Giraud Point, Pa.	11	12,000	561,650	50.9180
24.	Marcus Hook, Pa.	21	12,000	573,650	52.0059
25.	Wilmington, Cal.	68	11,000	584,650	53.0031
26.	Augusta, Kansas	22	10,000	594,650	53.9097

TABLE B-8 (cont'd)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
27.	E. Chicago, Ind.	1	9,900	604,550	54.8072
28.	Toledo, Ohio	9	9,800	614,350	55.6957
29.	Trenton, N. J.	28	9,600	623,950	56.5660
30.	Cleveland, Ohio	10	9,000	632,950	57.3819
31.	El Dorado, Kans.	21	8,850	641,800	58.1842
32.	Bayonne, N. J.	7	8,300	650,100	58.9367
33.	Avon, Cal.	79	8,000	658,100	59.6620
34.	Paulsboro, N. J.	5	8,000	666,100	60.3872
35.	Heaven, Ohio	3	8,000	674,100	61.1125
36.	W. Tulsa, Okla.	18	8,000	682,100	61.8377
37.	Atreco, Texas	5	8,000	690,100	62.5630
38.	Martinez, Cal.	67	7,800	697,900	63.2701
39.	Everett, Mass.	2	7,720	705,620	63.9700
40.	Bossier City, La.	1	7,300	712,920	64.6318
41.	Baltimore, Md.	3	7,300	720,220	65.3390
42.	Buffalo, N. Y.	6	7,200	727,420	65.9464
43.	Toledo, Ohio	12	7,200	734,620	66.5981
44.	Ingleside, Texas	41	7,000	741,620	67.2337
45.	W. Dallas, Texas	116	7,000	748,620	67.8693
46.	Ponca City, Okla.	10	6,550	755,170	68.4621
47.	Lawrenceville, Ill.	15	6,500	761,670	69.0514
48.	Big Spring, Texas	18	6,500	768,170	69.6407
49.	Wood River, Ill.	22	6,410	774,580	70.2218
50.	Norco, La.	14	6,200	780,780	70.7839
51.	W. Tulsa, Okla.	29	6,000	786,780	71.3278
52.	Sugar Creek, Mo.	3	5,900	792,680	71.8627
53.	Toledo, Ohio	4	5,500	798,180	72.3613
54.	Torrance, Cal.	25	5,300	803,480	72.8418

TABLE B-8 (cont'd)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
55.	Brooklyn, N. Y.	5	5,200	808,680	73.3132
56.	Lemont, Ill.	12	5,000	813,680	73.7665
57.	Corpus Christi, Texas	107	5,000	818,680	74.2198
58.	Heath, Ohio	8	4,960	823,640	74.6695
59.	Wilmington, Cal.	87	4,900	828,540	75.1137
60.	E. St. Louis, Ill.	21	4,800	833,340	75.5488
61.	Latonia, Ky.	4	4,600	837,940	75.9659
62.	Texas City, Texas	90	4,600	842,540	76.3829
63.	Petty's Island, N. J.	3	4,500	847,040	76.7909
64.	Pasadena, Texas	20	4,500	851,540	77.1988
65.	Norwalk, Cal.	99	4,450	855,990	77.6022
66.	Roseville, Pa.	18	4,155	860,145	77.9789
67.	Wilmington, Cal.	78	4,000	864,145	78.3416
68.	Enid, Okla.	7	4,000	868,145	78.7042
69.	E. Chicago, Ind.	6	3,900	872,045	79.0578
70.	Casper, Wy.	25	3,800	875,845	79.4023
71.	Robinson, Ill.	18	3,750	879,595	79.7422
72.	E. Braintree, Mass.	1	3,600	883,195	80.0686
73.	Neville Island, Pa.	12	3,600	886,795	80.3950
74.	Casper, Wy.	29	3,600	890,395	80.7213
75.	Hynes, Cal.	60	3,500	893,895	81.0386
76.	Oleum, Cal.	86	3,500	897,395	81.3550
77.	El Dorado, Ark.	5	3,000	900,395	81.6279
78.	El Dorado, Kans.	8	3,000	903,395	81.8999
79.	McPherson, Kans.	11	3,000	906,395	82.1719
80.	Lima, Ohio	11	3,000	909,395	82.4438
81.	Cyril, Okla.	2	3,000	912,395	82.7158

TABLE B-8 (cont'd)

	Location	No. in State	Operating Plus Shut-down Capacity (B/D)	Cumulative Total (B/D)	Per Cent
82.	Houston, Texas	26	3,000	915,395	82.9878
83.	Longview, Texas	27	3,000	918,395	83.2597
84.	Texas City, Texas	99	3,000	921,395	83.5317
85.	Shreveport, La.	13	2,800	924,195	83.7856
86.	Corpus Christi, Texas	7	2,750	926,945	84.0349
87.	Neodesha, Kans.	23	2,640	929,585	84.2742
88.	Salt Lake, Utah	2	2,560	932,145	84.5062
89.	Long Beach, Cal.	54	2,500	934,645	84.7329
90.	Coffeyville, Kans.	16	2,500	937,145	84.9596
91.	Kansas City, Kans.	20	2,500	939,645	85.1862
92.	Wichita, Kans.	7	2,500	942,145	85.4129
93.	Chalmette, La.	4	2,500	944,645	85.6395
94.	Shreveport, La.	2	2,500	947,145	85.8662
95.	Sunburst, Montana	30	2,500	949,645	86.0926
96.	Wellsville, N. Y.	4	2,500	952,145	86.3195
97.	Beckett, Okla.	25	2,500	954,645	86.5461
98.	Cushing, Okla.	13	2,500	957,145	86.7727
99.	Parco, Wy.	23	2,500	959,645	86.9994
100.	Ponca City, Okla.	9	2,475	962,120	87.2238
101.	Amarillo, Texas	110	2,400	964,520	87.4413
102.	Drumright, Okla.	30	2,300	966,820	87.6499
103.	Arkansas City, Kans.	12	2,000	968,820	87.8312
104.	Coffeyville, Kans.	14	2,000	970,820	88.0125
105.	Allen, Okla.	28	2,000	972,820	88.1938
106.	Blackwell, Okla.	15	2,000	974,820	88.3751
107.	El Paso, Texas	102	2,000	976,820	88.5564
108.	Longview, Texas	21	2,000	978,820	88.7378
109.	San Antonio, Texas	115	2,000	980,820	88.9191

ANNEX B

PART 3

DPA Oil Refinery Authorizations
(January 25 through April 6, 1951)

Source: Defense Production Administration press releases:
DPA 11 (dated March 14, 1951) "Certificates Issued January 25 through March 7, 1951."
DPA 19 (dated April 12, 1951) "Certificates Issued March 7 through April 6, 1951."

N. B. The only facilities counted were those directly involved in oil refining. This list does not include oil distribution or transportation equipment.

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TABLE B-9

DPA Oil Refinery Authorizations

(January 25 through April 6, 1951)

Name of Company Location of Facilities	Product or Service	Amount Applied For (dollars)	Amount Eligible (dollars)	Per Cent Certified
Ben Hur Refining Corp. Long Beach, Calif.	Gasoline, fuel oil		2,330,000	
Rothchild Oil Co. Sante Fe Springs, Calif.	Components for aviation gas		2,050,000	
Standard Oil Co. of Calif. El Segundo, Calif.	Benzene and gasoline		14,000,000	
Union Oil Co. of Calif.	Gasoline and components		4,500,000	
Union Oil Co. of Calif. Wilmington, Calif.	Gasoline and fuel oil		12,000,000	
Petco Corp. Blue Island, Ill.	Fuel oil and gasoline		1,936,000	
Standard Oil Co. of Ind. Whiting, Ind.	Aviation gasoline	same	2,327,500	100
Wood River Oil Refining Co., Inc. Gary, Ind.	Gasoline and fuel oil		7,086,000	
Derby Oil Co.	High octane gas and fuel		2,606,041	
Kanotex Refining Co. Arkansas City, Kansas	High octane gasoline	same	2,347,423	75
Standard Oil Co. of Ind. Neodesha, Kansas	Gasoline	same	10,029,000	80
Atlas Processing Co. Shreveport, La.	Benzene		2,600,000	

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TABLE B-9 (Cont'd)

Name of Company Location of Facilities	Product or Service	Amount Applied For (dollars)	Amount Eligible (dollars)	Per Cent Certified
The Bay Petroleum Co. Chalmette, La.	Gasoline components		1,726,500	
Continental Oil Co. Lake Charles, La.	Gasoline components and by-products	same	23,820,150	80
Pan-American Southern Corp. New Orleans, La.	Gasoline		5,500,000	
Northwestern Refining Co. St. Paul, Minn.	Octane gasoline		2,074,998	
Western Oil & Fuel Co. Between Duluth & Superior on county highway	Gasoline, fuel oil		5,892,000	
Standard Oil Co. of Ind. Sugar Creek, Mo.	Gasoline, kerosene	same	21,170,000	75
California Refining Co. Perth Amboy, N. J.	Gasoline, fuels	same	32,950,583	80
Ashland Oil and Refining Co. Canton, Ohio	Gasoline, butane, jet fuels	same	3,870,000	75
Cities Service Oil Co. Ponca City, Okla.	Gasoline, fuel oil	same	6,500,000	75
Sunray Oil Corp. Stephens County, Okla.	Gasoline components		1,750,866	
Sun Oil Co. Marcus Hook, Pa.	Benzene, toluene	same	8,380,000	85
Sun Oil Co. Marcus Hook, Pa.	Aviation gasoline	same	2,577,145	100
M. F. A. Oil Co. Memphis, Tenn.	Gasoline	1,720,000	——— *	

*In the summary of Table B-4, it was assumed that the amount eligible was identical with the amount applied for.

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TABLE B-9 (Cont'd)

Name of Company Location of Facilities	Product or Service	Amount Applied For (dollars)	Amount Eligible (dollars)	Per Cent Certified
Carroll B. Fallon & William H. Olmstead San Antonio, Texas	Aviation gasoline	12,000,000	11,925,000	80
Gulf Oil Corp. Port Arthur, Texas	Isobutane gasoline		18,485,342	
Gulf Oil Corp. Port Arthur, Texas	Ethylene	same	15,427,000	80
Levelland Refining Co. Levelland, Texas	Aviation gasoline		2,441,763	
Pan-American Refining Co. Texas City, Texas	Benzene		1,100,000	
Phillips Oil Co. Borger, Texas	Aviation alkylate, gasoline and diesel fuel	same	15,573,700	75
Premier Petroleum Co. Ft. Worth, Texas	Jet fuel, butane, gasoline	same	3,580,000	75
Sinclair Refining Co. Houston, Texas	Normal butylenes	same	27,000,000	75
Taylor Refining Co. Corpus Christi, Texas	Butanes, gasoline and oil	same	5,057,483	75
Western States Refining Co. North Salt Lake, Utah	Gasoline	1,413,250	1,092,700	75
Superior Refinery Owners, Inc. Superior, Wis.	Gasoline, oil		1,226,800	

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APPENDIX VII-1

Annex C

THE ALUMINUM INDUSTRY

Carl Kaysen

TABLE C-1

Concentration of Alumina Production Capacity by Plant - 1950*

Rank	Location	Per Cent Total Capacity	Cumulative Per Cent
1	Hurricane Creek, Arkansas	25.9	
2	Mobile, Alabama	22.3	48.2
3	Arvida, Quebec (Canada)	17.4	65.6
4	Baton Rouge, Louisiana	16.7	82.3
5	East St. Louis, Illinois	14.3	96.6
6	Listerhill, Alabama	3.4	100.0
Total		3100 thousand short tons	

TABLE C-2

Concentration of Aluminum Production [Reduction] Capacity by Plant - 1950*

Rank	Location	Per Cent Total Capacity	Cumulative Per Cent
1	Arvida, Quebec (Canada)	40.5	
2	Alcoa, Tennessee	12.8	54.3
3	Spokane, Washington	8.3	62.6
4	Vancouver, Washington	6.9	69.5
5	Massena, New York	6.0	75.5
6	Troutdale, Oregon	5.5	81.0
7	Jones Hill, Arkansas	5.5	86.5
8	Badin, North Carolina	4.2	90.7
9	Listerhill, Alabama	3.9	94.6
10	Longview, Washington	2.4	97.0
11	Tacoma, Washington	1.6	98.6
12	Niagra Falls, New York	1.4	100.0
Total		1320 thousand short tons	

*Extract from Dishington Report, RAND Corporation.

TABLE C-3

Aluminum: Miscellaneous Materials and Sources for Appendix VII-1

Minimum-efficient-size plant

(1) Alumina

Sources: D. H. Wallace, "Market Control in the Aluminum Industry" (1937), p. 190 ff.

Engle, Gregory, and Mossé, "Aluminum" (1944) p. 221 – 223.

(2) Reduction

Sources: Wallace, op. cit., p. 190 ff.

Capital costs

(1) Alumina

Sources: Engle, Gregory, and Mossé, op. cit., p. 222.

Report of Surplus Property Board, September 21, 1945, passim.

(2) Alumina

Sources: Engle, Gregory, and Mossé, op. cit., p. 210.

Report of Surplus Property Board, passim.

Substitutability of other plants for alumina plants

Source: EOU studies of German aluminum industry in World War II, cf. files of Strategic Vulnerability Branch, Air Targets Division, Director of Intelligence, USAF.

APPENDIX VII-1

Annex D

THE STEEL AND OIL INDUSTRIES VULNERABILITY TO SUBMARINE ATTACK

Alan S. Manne

APPENDIX VII-1

Annex D

THE STEEL AND OIL INDUSTRIES VULNERABILITY TO SUBMARINE ATTACK

Summary

It has been suggested that the U.S. economy may be quite vulnerable to attack by submarine-launched missiles. In this Annex, two representative industries – steel and oil – are considered in turn. For these purposes, it is assumed that the present danger zone for such missiles extends no further than 100 miles inland.

On this range assumption, it is reasonably clear that the American steel industry is in no danger of destruction by submarine attack. However, with oil, the situation is far more serious. On January 1, 1950, 63 per cent of the total crude charging capacity was in coastal districts. Of the 25 largest refineries in the country, 22 of them, with 45 per cent of the total charging capacity, were in such locations.

In view of these findings, it would be worth while to locate at least some of the new refining facilities inland. This shift, if well planned, need be accompanied by only a moderate increase in transportation costs. Large-diameter pipelines and barges could transport crude to new refineries in the Ohio, Western Pennsylvania, and Western New York region. Additional pipelines might also be needed in order to bring products from new inland Texas refineries to the Gulf Coast for further shipment overseas. This shift away from Gulf Coast – East Coast tanker transportation would be accompanied by an important bonus – freedom from submarine attack on the tankers themselves.

A. THE IRON AND STEEL INDUSTRY

Table D-1 summarizes the location of American iron and steel capacity as of 1938. In view of the recent expansions at Sparrows Point, Maryland, and at Morrisville, Pennsylvania, the picture is presumably changed, but is still not radically different. As of 1938, 76 per cent of the total pig iron

capacity was located in the region between the Great Lakes and West Virginia. Only 9 per cent of the pig iron capacity and 11 per cent of the steel ingot capacity was in the Eastern Pennsylvania and Eastern Maryland region. Missile-bearing submarines would require a range of far more than 100 miles in order to do serious damage to the steel industry.

TABLE D-1

Location of U.S. Iron and Steel Capacity, (1938)*
(percentages of total capacity)

	Pig Iron (per cent)	Steel Ingot (per cent)
Southwestern Pensylvania North East Ohio Northern West Virginia	47	47
Chicago-Gary	19	19
Eastern Pennsylvania Eastern Maryland	9	11
Total	75	77

*Reference (1) p. 102. This report states that, if other Great Lakes centers are included, pig iron capacity in all these regions would amount to 85 per cent of the total in the United States. Great Lakes locations not listed here must therefore contain around 10 per cent of the total.

B. THE OIL REFINING INDUSTRY

Table D-2 classifies refining capacity into inland and coastal locations. It also distinguishes between crude oil charging and gasoline cracking capacity. These figures relate to January 1, 1950, and are therefore quite up-to-date. This industry is clearly oriented toward ocean-going transportation, for 65 per cent of the crude charging capacity and 56 per cent of the cracking capacity lies in coastal refineries.

TABLE D-2

Capacity of Petroleum Refineries by Districts (Jan. 1, 1950)*
(total of operating plus shut-down capacity)
(barrels per day)

	Crude Oil through-put Capacity		Gasoline Cracking Capacity	
Coastal				
East Coast	992,450		274,710	
Texas Gulf Coast	1,615,250		427,460	
Louisiana Gulf Coast	467,000		116,852	
California	1,138,900		203,350	
Total coastal	4,213,600		1,022,372	
Per cent of total U.S.		62.92		56.15
Inland				
Appalachian No. 1	119,750		36,664	
Appalachian No. 2	70,000		25,750	
Ind., Ill., Ky., etc.	1,156,825		385,909	
Okla., Kans., Mo., etc.	532,800		185,495	
Texas Inland	264,400		89,700	
Ark. & La. Inland	83,850		11,200	
New Mexico	18,000		3,270	
Other Rocky Mountain	237,075		60,323	
Total inland	2,482,700		798,311	
Per cent of total U.S.		37.08		43.85
Total U.S.	6,696,300		1,820,683	

*Reference (2) pp. 4, 6.

Using Reference (2), a special tabulation has been run to rank the refineries according to size. Out of the 25 largest with respect to crude charging capacity, 22 (with 43 per cent of U.S. capacity) were in coastal districts. And of the 25 largest with repsect to gasoline cracking facilities, 20 (with 42 per cent of the total,) were in such locations. A submarine attack could potentially wipe out a significant segment of this industry.

Figures in Reference (2) give a graphical indication of the methods used to bring crude oil from the largest producing areas – Texas and Oklahoma – to the large consuming regions along the Atlantic Coast. The bulk of this traffic in peacetime is carried by tankers. Figure 3 indicates the origins and destinations of gasoline rail shipments for a typical day in 1939.* It is important to note that a large amount of the oil shipped to ports such as New York, Baltimore and Philadelphia is refined into products that are not used directly at those points, but, rather, that are shipped into the interior. One consignment appears to go as far inland as Cleveland.

In other words, products from new refineries located in Western New York, Western Pennsylvania, and Ohio would not necessarily be distributed along the seaboard. Rather, they could displace products now being shipped in from the seaboard. It might not be at all necessary to have a double movement – crude oil moving inland and products moving back again toward the coast.

Still more important from the viewpoint of transportation costs, such new inland refineries need not depend upon tanker movements at all. During World War II, the Big Inch pipelines were able to compete eastwise with tankers, even for destinations directly on the Atlantic Coast. Inland refineries need not be under crude oil transportation disadvantages, provided large-diameter pipelines are made available to them. Barge movements along the inland waterways could also be fitted into this network.

Three sets of cost figures were introduced as testimony during the 1945 Senate Hearings on the disposal of the Big Inch pipelines.** Even some of those witnesses opposed to peacetime oil operations along the lines were willing to admit that they could be competitive with tankers during peacetime, if operated at or near capacity. One of these, Mr. S.A. Swensrud, vice president of the

*Sources of Figures 1, 2, and 3 are, respectively, Figures 30, 31, and 22, Reference (3).

**The Big Inch Line (a 24-inch line) carried crude oil only, and operated between Longview, Texas, and Linden, New Jersey. The Little Big Inch Line (20 inches in diameter) ran from Beaumont, Texas, to Linden, and carried refined products ranging from 100-octane aviation gasoline down through heating oil (Reference (4), pp. 431-437).

Standard Oil Company of Ohio, considered the lines uneconomical largely because no single shipper would have enough business to justify the purchase for his own individual use.* Enforced pooling of shipments during an emergency could certainly overcome this particular difficulty.

Jesse Jones made a public statement on November 9, 1944, comparing costs along the Big Inch pipelines with current tank car rail tariffs and with the tanker rates set by the War Shipping Administration. Full costs (including depreciation and amortization of the investment in 20 years) of transporting crude oil along the 24-inch line from Longview to New York were estimated at $0.38 per barrel. Rail charges (including gathering costs) for this same distance would come to $1.597 per barrel, and tanker charges to $0.606. Similar calculations for shipping products along the 20-inch line give the following results: pipeline, $0.243 per barrel; tankers, $0.40; and tank cars, $1.74.** Wartime marine insurance premiums clearly put the tankers at a cost disadvantage, both for shipping products and for crude oil.

It will be noticed that Jesse Jones' 1944 statement was an estimate rather than an accounting record of actual pipeline costs. W. A. Jones, president of War Emergency Pipelines, Inc., released the following figures on total costs through August 31, 1945, and compared these with the equivalent tanker charges (Table D-3).***

Total pipeline costs estimated in this way are, of course, higher than tanker rates. To make a proper comparison for peacetime purposes, it would be much more appropriate to take depreciation costs over the period of operation rather than to take the initial construction costs of the lines. (The Big Inch did not start delivering all the way to the East Coast until August 14, 1943, and the 20-inch line did not start deliveries until March 2, 1944.)**** Even with this accounting peculiarity, the Big Inch system involved total costs only 38 per cent higher than the "normal" tanker charges on this volume of traffic.

One more set of comparisons – those of Mr. Spal of the Interstate Commerce Commission – showed that the Big Inch Line, operating near capacity

*Reference (5), p. 227.

**Ibid, p. 28.

***Ibid, Chart 14, p. 17.

****Reference (4), p. 104.

at 300,000 barrels per day, could cover costs at a tariff of 16 cents per barrel. At 200,000 barrels per day, 20 cents per barrel would be required. A T-2 tanker could operate between the Gulf Coast and New York for only 18.3 cents for each barrel carried.* **

TABLE D-3

Pipelines Costs (through August 31, 1945)

(thousands of dollars)

	Big Inch System	20-inch Products System
Pipeline costs and expenses		
Construction cost of lines	78,500	60,000
Out-of-pocket operating costs	18,240	12,279
Paid to carriers delivering oil to receiving terminals of big lines	58,740	136
Total paid by DPC and DSC	155,480	72,415
Normal tanker rate, Gulf Coast to East Coast	112,585	42,918

All these transportation cost figures point to the conclusion that it would be feasible to install new refining capacity inland in the Northeast states rather than directly on the Atlantic Coast. Experience with the Little Big Inch Line also indicates that large products pipelines are economical, and that they can handle a wide range of refined oils with a minimum of contamination.***

*Cited by S.A. Swensrud, Reference (5), p. 227.

**No worth-while material has been found in the published data comparing the construction costs of the Big Inch Lines with the corresponding initial costs for equivalent tanker capacity along the Gulf Coast-East Coast route. In the 1945 Congressional Hearings, there is a reference to a Ford, Bacon, and Davis study of this sort. (Reference (5), p. 243), but the study itself does not appear in the hearings.

***Reference (4), p. 435.

This means that it would be quite practical to locate additional refineries in the interior of Texas rather than directly on the Gulf Coast. Products could be piped from these interior points to the coast to await tanker shipment overseas. These inland refineries should be oriented toward fields containing light grades of crude, and should have extensive cracking facilities. In this way, production of residual oil would be held to a minimum, and expensive rail transportation of that product could be avoided.

References

(1) "The Economics of Iron and Steel Transportation", Board of Investigation and Research, Senate Document No. 80, 79th Congress, First Session, September 20, 1944.

(2) "Petroleum Refineries, including Cracking Plants, in the United States," January 1, 1950, Bureau of Mines, Information Circular 7578, U.S. Department of the Interior, August, 1950.

(3) "The National Traffic Pattern," Board of Investigation and Research, Senate Document No. 83, 79th Congress, First Session, September 20, 1944.

(4) John W. Frey and H. Chandler Ide, "A History of the Petroleum Administration for War, 1941-1945," Washington, 1946.

(5) "War Emergency Pipe-Line Systems and Other Petroleum Facilities," Hearings before the Special Committee Investigating Petroleum Resources, U.S. Senate, 79th Congress, First Session, November 15, 16, and 17, 1945.

APPENDIX VII-2

SUMMARY OF THE CAPACITY OF THE CONSTRUCTION INDUSTRY RELATIVE TO THE DISPERSION OF POPULATION

SECRET

APPENDIX VII-2

SUMMARY OF THE CAPACITY OF THE CONSTRUCTION INDUSTRY RELATIVE TO THE DISPERSION OF POPULATION

1. New construction in 1950 was $27.7 billion in current prices, and $12.7 billion in 1939 prices – a record. Residential construction accounted for 45 per cent of the total, an abnormally high proportion exceeded only in the boom of the 20's. In 1950, 1.4 million dwelling units were started, again a record. In appraising the capacity of the industry for the defense economy, the following considerations are relevant:

(a) The industry appears to have greater capacity for nonresidential building than for housing. Not until 1949 was the 1942 volume of construction (largely industrial and military) equaled in a normal peacetime production. A shift from house-building to industrial and military building should increase the volume of construction that the industry is able to perform.

(b) Average hours worked per week in the industry are under 40, and seldom exceed it even in wartime. In a "crash" program, the capacity of the industry could be expanded by longer working hours, at the expense of overtime wages.

(c) The great seasonal fluctuation in construction is not entirely technically necessary, but is in part oriented to demand and to convention. (There is seasonal fluctuation in warm climates.) In an urgent program, use of the excess capacity of the industry in the winter could increase its annual output, perhaps by as much as 10 per cent.

(d) The materials shortages threatening to limit construction activity are copper, steel, and iron. But there seems little doubt that there are measures of conservation, rationalization, and standardization that would permit the same volume and quality of construction with considerably less use of these and other materials, and of labor as well. (The American Institute of Architects – National Association of Home Builders, Technical Recommendations in Architectural Forum, estimate houses can be built with 75 per cent less copper, 50 per cent less cast iron, and similar savings in other materials; less spectacular savings are also possible in nonresidential construction.) Of course, there are big political problems attached to taking advantage of these possibilities – building codes, etc. – but defense controls offer an opportunity.

2. The present program of the government is to limit housing starts to 800,000 to 850,000 a year. (However, the only control thus far invoked to

accomplish this is housing credit control; and it is not yet clear that this, even in combination with copper shortages and other materials limitations, will do the trick.) This program would release some $5 billion of 1950 construction capacity ($2.5 billion in 1930 dollars) for defense construction, and more will be released by the limitations on commercial and nondefense industrial and public construction. In addition, as mentioned above, this shift will increase the capacity of the industry. It is by no means clear that in a protracted cold war such a diversion from housebuilding will be necessary for very many years. The bulk of construction of military and industrial facilities for the last war occurred in 1942 and 1943, and this construction was tapering off rapidly as the war ended. And this time the defense construction is on top of a large industrial and public utility construction program that was already taking place. It may well be that in two or three years, when defense production capacity has been expanded and military facilities built, construction capacity will again be available for housebuilding on the 1950 scale. More will be available – and sooner – if various capacity-increasing measures are adopted.

3. From the point of view of dispersion, the location of construction capacity is important. About 40 per cent of housebuilding capacity is in 29 major metropolitan industrial areas. If starts are limited to 800,000, the capacity of these areas could be used to the full to produce 500,000 to 600,000 houses in outlying metropolitan areas, and the remaining number mainly allocated to areas of new defense plants. Thus, the diversion of resources to nonresidential construction would be at the expense of nonmetropolitan housing. From a dispersion point of view, this is as it should be, because new defense production and military facilities presumably should not be located in metropolitan areas. A similar allocation could be made of permitted commercial and nondefense industrial and public utility construction in order to provide the necessary nondwelling facilities to accompany the residential expansion of outlying metropolitan areas. This is one of a number of measures that, in a sense, can contribute to dispersion without cost – i.e., without interfering with the magnitude of other programs – because all it involves is geographical redirection of residential construction, not over-all expansion.

4. Construction of 500,000 to 550,000 dwelling units a year is needed to keep up with the increase in number of families. Above that number, new

units are available (a) to replace obsolete and substandard units; (b) to provide in new locations offsets to any surplus housing due to normal emigration from some localities; (c) to take care of relocation of population in a dispersal program. These four uses of new housing are of course not mutually exclusive. In view of the general rise in population of families, few areas are likely to suffer an absolute decline that makes surplus housing. Even fewer areas will suffer an absolute decline in number of families in excess of the number of substandard units that should be abandoned anyway. Housebuilding for dispersal can provide successively for the increase in number of families in metropolitan areas and for the replacement (in new locations) of substandard units in the dense parts of metropolitan areas. Since 2 million units in the urban parts of metropolitan areas are substandard, a dispersal building program has a good deal of leeway before it has to begin to make vacant acceptable units in dense parts of metropolitan areas. Moreover, most of the increase in family units would normally be in metropolitan areas. (80 per cent of the population increase in the last decade was in census metropolitan areas, but a good many census areas are not metropolitan for dispersal purposes.) Probably 500,000 units outside metropolitan areas could handle new families and normal replacement there, and these could be located especially in areas of defense plant and military expansion. (Present defense housing plans are for 100,000 units, not all in one year.) The remainder of yearly national housing construction would be available for the combined functions of providing for new families, replacing substandard units, and dispersal in metropolitan areas. Size of this remainder depends not only on the national capacity of the construction industry and nonhousing demands upon it but, as noted above, on local metropolitan capacity. If dispersal is not merely from central cities to sparse regions of metropolitan areas but also from metropolitan areas to other areas, more of the human capacity of the industry can be utilized. But this would require a bigger program of industrial decentralization.

5. New York City provides an example, more instructive than national figures, of what the present capacity of the housebuilding industry could accomplish in the way of dispersal, even without special measures to increase production, provided the location of new dwelling units and of old units to be

abandoned were controlled from this point of view. In the metropolitan area are 4.1 million dwelling units, and new units are being started at a rate of about 130,000 a year. The City accounts for 2.5 million existing units and for 40,000 starts. (Thus, even uncontrolled, new construction is gradually dispersing the population in a relative sense. The area grew 10 per cent in the last decade, while the City grew only 5 per cent. Within the City, Queens is the least-dense and fastest-growing borough.) Projecting the 1940-1950 increase in population for the area, construction of 40,000 new units a year is needed for new families. Hence, if housing construction in this area were not curtailed, there would be 90,000 units a year available for rehousing existing families. If new construction in the City were prohibted, one million families or 3 million persons could be moved in 11 years to outlying areas. Density in the City would be reduced from 26,000 per square mile to about 15,000, and the density of Manhattan, Brooklyn, and Bronx could be made, by concentrating on the abandonment of dwelling units in those boroughs, very little more than the density of Queens. In 22 years, population density in the City could, in principle, be reduced to the average for the whole metropolitan area (about 4000 per square mile). An early dividend of this policy – during the first decade – would be the abandonment and replacement elsewhere of all the 400,000 substandard units in the City, creating vacant spaces useful as fire breaks as well as for numerous social peacetime purposes. No doubt the process could be greatly accelerated, even without the devotion of more resources, by abandoning the construction of high-priced custom-built houses and, further, by some rationalization of the industry.

6. The prohibition of new construction in the City, and the channeling of housebuilding to outlying areas, will not automatically cause the movement of population from dense areas described in the last section. It would do so only if the number of persons per dwelling unit were maintained at its present level in the suburbs and reduced drastically in the City. Historically, we have built new dwelling units not only to accommodate new families but to provide all families, old and new, with more interior elbow room. The normal consequence of building (in the New York area over the next decade) more units than are needed for the increase in number of families would be a general reduction in the City as well as outside, of the number of persons per dwelling

unit. Apartments that used to be occupied by four-person families would be taken over by childless couples, and units formerly occupied by couples would go to spinsters and bachelors. The problem of dispersal, aside from the location of new construction, is to ensure that none of this increase in elbow room occurs in sparse areas – that all of it occurs in dense areas.

a. One method of accomplishing this aim is to destroy dwelling units in the dense areas of the City. This forces their former occupants to take advantage of the units that the construction industry can build in the outlying areas. The 400,000 substandard units in the City are obvious candidates for such demolition. But if a million families are to move out of the City in a decade, and the number of persons per dwelling unit within the City is to remain unchanged, 600,000 additional acceptable units would have to be demolished. Such destruction would be an unnecessary social waste.

b. The alternative is to induce or to enforce a great reduction of persons per dwelling unit in the City. If only the 400,000 substandard units are demolished, there would be 2.1 million units left in the City to be occupied by a population of 4.8 million eleven years hence – 3 million less people than now live in the City's 2.5 million dwelling units. This would mean an average occupancy ratio of 2.3, instead of the 3.1 now. This reduction in the occupancy ratio, which is essential to the desired emigration, would not occur voluntarily and automatically under normal conditions. Indeed, any migration to the suburbs that does occur makes Manhattan apartments more attractive. Rent control, by permitting single individuals and small families to occupy lots of dwelling space at low costs in the City, is a favorable factor to dispersal. And the swing in taste to one-family houses enhances the drawing power of the suburbs. But some public intervention would clearly be necessary. One possibility is simply direct control of the number of persons per dwelling unit in the dense areas of New York City. This amounts to enforced displacement of particular families; it certainly would and very likely should encounter considerable resistance. A more feasible measure would be a scheme of compulsory war risk insurance (see Appendix VII-1). According to such a plan, residential property in the City would be assessed an insurance "premium" that depends on the number of occupants of the property per square

foot of ground space. The rate of this premium would also depend on the density of the neighborhood. New York would be divided into sectors, so that, of two buildings with the same number of persons per square foot, one in Queens would pay a higher premium than one in mid-town Manhattan. Within a sector, of course, a skyscraper apartment would pay a higher premium than a one-family house. This plan would make it very costly to rent an apartment to large families and, in effect, force them to move to the suburbs unless they are willing to pay for the privilege of staying in New York City and of increasing its vulnerability. (A similar scheme for nonresidential property is obviously possible (see Appendix VII-1).

7. A generous estimate of the housing construction costs of the above program in New York is $130 million (1950) a year. This is not a measure of the cost to the nation, to the extent that this number of houses would have been built somewhere anyway. The opportunity cost is the houses that with the same resources including scarce metals, might have been built in other regions. The redirection of the location of these houses does, however, entail some other costs.

a. First, there are the costs of construction of the nonresidential adjuncts of residential building in undeveloped areas. These would be greater than the nondwelling construction costs associated with residential expansion within the City. But here it should be remembered that less than one-third of the new units in the area would normally be built within the City and that a good many of these would be in relatively undeveloped areas, e.g., in Queens. Site improvement costs, in building on outlying vacant land, appear to amount to about 20 per cent of dwelling construction costs; these cover streets, sewers, utility connections. In addition, nonresidential facilities for a new residential neighborhood – stores, police stations, etc. – require 25 per cent of dwelling construction costs. (This estimate does not include theaters.) New schools – assuming an average of one school-age child for each family – require another 7 or 8 per cent. But, of course, the area would require some new schools for the expanded population anyway, and some within the City would have to be replaced and could now be replaced elsewhere instead of on the same site. In addition, expansion of public utilities and of transportation

facilities would be required. Perhaps the nondwelling construction costs should be placed at the same figure as the dwelling construction costs, but not more than one-third of this could properly be attributed to the dispersal aspects of the program.

b. The question of transport requirements and commuting costs occasioned by dispersal to the outlying parts of the metropolitan area depends largely on the direction of causation between job locations and residence locations. It has been estimated that, for every job in New York that is tied to its site by some basic locational necessity or economy (e.g., docks, financial centralization), there are two that are located because of the concentration of businesses and residences. A rough check on this estimate is provided by the fact that in 1940 about one of every three gainfully employed persons resident in the metropolitan area outside Manhattan was employed in Manhattan. The movement of population from the City to the outlying areas will itself create "secondary" (from a locational standpoint) jobs in those areas – teachers, retailers, policemen, lawyers, real estate agents, construction workers. The burden of dispersal on transportation facilities can therefore be easily overestimated. It should be mentioned that New York has an atypically high ratio of locationally secondary to primary jobs.

c. The obverse of the point just discussed is the question how many jobs must be moved out of the City to move a certain number of people without increasing commuting-to-work costs. If the ratio given above is taken seriously, moving one primary job will enable the movement of nine persons (3 jobholders plus dependents). A good many jobs in New York City should not be difficult to move. The physical tie of the textile industry to its location in the City is, for example, very slight.

d. The present urban redevelopment plan of New York City calls for municipal acquisition and demolition, with Federal financial aid, of blighted areas and for rebuilding on these sites (at only slightly lower densities) projects of the insurance company "village" type. Such a plan for Washington Square is now under way, although at present Federal regulations do not permit proceeding beyond the demolition and clearing stage. In the interests of dispersal – if necessary, by use of the controls the Federal government has

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over urban redevelopment by virtue of holding the purse strings – this sort of thing should be stopped. The cleared land should be left vacant and the rebuilding planned for outlying sites, for which Federal assistance in acquisition can be obtained.

James Tobin

APPENDIX VII-3

THE FIRE EFFECTS OF BOMBING AND DEFENSE OF THE CIVILIAN POPULATION

APPENDIX VII-3

THE FIRE EFFECTS OF BOMBING AND DEFENSE OF THE CIVILIAN POPULATION

Section 1

Defense of population centers against air attack must be based on:

(a) A warning system;

(b) Maximum shelter availability for non-dispersable population for protection from blast, mechanical injury, flash burns, and radiation;

(c) A minimization of fire-storm and conflagration potential.

The ideal distribution of expenditure (for any constant dollar appropriation) should equalize the "value" (in terms of potential lives saved) of the last dollar spent on each of the three. It is important to note that (a) and (b) alone are not enough. European and Japanese experience indicates that carbon monoxide poisoning, heat, and hot gases accounted for a major share of casualties in most big air raids. Conventional shelters often turned out to be death traps, particularly when they were situated in fire-storm areas. This was as marked in Germany, where in most raids close to half the bomb tonnage consisted of high explosive bombs, as in Japan where incendiaries generally constituted 90 per cent or more of the load. The Kassel raid, for example, was estimated to have killed 8700 people; only 15 per cent of these died of "mechanical" injuries. Burns and hot gases killed 15 per cent; 70 per cent died of carbon monoxide poisoning.

Section 2

It is sometimes claimed that the relative importance of fire under atomic attack is far less than when conventional (high explosive and incendiary) bombs are used. It is argued:

(a) That a few atomic bombs are less likely to start a great many simultaneous fires over a large area than a widely dispersed load of incendiaries;

(b) That the blast of an atomic bomb is likely to clear a fire-break around ground zero, opening an unburnable hole in the middle of the potential fire-storm area;

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(c) That the atomic bomb's blast effect is so overwhelming as to dwarf all other effects;

(d) That the Hiroshima experience is not applicable to Western cities since Hiroshima was "made of paper";

(e) That Nagasaki, despite its typically combustible construction, did not suffer a fire storm.

A study of the very meager evidence does not definitely establish the validity of this point of view.

(a) An atomic bomb explosion is likely to start a number of fires over a substantial area, induced by flash heat and secondary blast effects (short circuits, overturned braziers, thatched roofs collapsing into hot charcoal fires, etc.). At Hiroshima, for example, hundreds of fires broke out simultaneously with the explosion. It is true that the range of primary fires, at Hiroshima at least, was only about 3500 feet; within that range however, most highly combustible substances such as dark cloth, paper, dry-rotted wood, etc., ignited immediately following the explosion. At Nagasaki, on the other hand, primary fires were started within a radius close to 10,000 feet. Of greater importance (at Hiroshima, though not at Nagasaki*) were secondary fires. The Hiroshima explosion started such blast-induced fires as far as 13,700 feet from ground zero.

At any rate, the Hiroshima bomb started enough fires to make a fire storm that covered an area of 4.4 square miles. Nor did the Nagasaki experience confirm the contention that atomic bombs do not effect simultaneous ignition of many points over an area large enough to support a fire storm.

(b) Hiroshima effectively disproves the claim that the blast makes a circular firebreak out of the area around ground zero. If flimsily constructed Hiroshima could support a fire storm over a 4.4-square mile area centered on ground zero, the blast is not likely to "level" midtown Manhattan to the point where there is nothing left to burn. It is true, of course, that better construction in itself reduces the probability of fire storms, but that is irrelevant to the "firebreak" argument.

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* At Nagasaki, more fires were caused directly (flash heat) than indirectly (in a ratio of 6:4).

(c) It is generally agreed by the experts that the fire storm was the most important single factor in the destruction of about 68,000 of Hiroshima's 75,000 buildings. As concerns population, burns caused over 50 per cent of the initial atomic bomb casualties. It is true that close to half of these were flash-burn (direct exposure) cases, hence irrelevant as regards fire susceptibility. But it is not obvious from the evidence that the blast effect was so overwhelming as to make the fire results negligible.

(d) It is not sufficient to show that better construction reduces the absolute danger of fire (as it obviously does), since it also reduces absolute vulnerability to blast. The question is whether the relative importance of fire due to atomic attack is made negligible by "western" construction. For some of the relevant considerations see Section 4.

(e) The fact that there was no fire storm at Nagasaki can be explained by structural and topological conditions (see Section 4); it is likely that a conventional raid would not have produced a fire storm either.

It is impossible to reach definitive conclusions on the basis of a sample of two. It is probably fair to say that the evidence is not conclusive as to the relative negligibility of fire under atomic attack. It is possible, of course, that post-Nagasaki developments in atomic bomb construction make irrelevant even the little evidence we have.

Section 3

It is useful to distinguish fire storms and conflagrations from each other and from sporadic spot fires, since the three have discontinuously different effects.

(a) Fire Storms are characterized by rapid and simultaneous ignition of many points in an area, in such a way as to cause the formation of a column of burning and hot unignited gases (a thermal), rising almost vertically. The rising of the superheated mass of air creates a low-pressure region in the center of the area, this in turn induces an inflow of air from the periphery which reaches gale proportions and causes the fire to spread toward the center. (If the thermal column comes into contact with a stratum of cold air, condensation on soot and debris will cause "black rain" to leeward of the fire area.)

(b) Conflagrations are characterized by the development of a thermal that is subsequently "bent" by high natural winds at an angle and driven beyond the area of the original fire, thus spreading the fire in a solid front to leeward.

Fire storms are not likely to occur if surface winds are above 4 to 5 miles per hour, since higher-velocity ground winds prevent the formation of the requisite pressure gradient.

Defining fire spread as the ratio between burned ground area in which no bombs fell to burned ground area in which bombs did fall, studies have indicated that the extent of fire spread was about 25 per cent in cities where there were fire storms, compared to 100 per cent in cities subject to conflagration. (Presumably some rather heroic ceteris parivus assumptions had to be made.)

It is the consensus of experts that: once a fire storm develops, it is almost impossible to mitigate its effects inside the affected area: almost nothing of a combustible nature is preserved; those in shelters in the area are almost certain to die of carbon monoxide poisoning or heat: escape, once the storm has developed, is next to impossible. Temperatures in fire-storm areas have been estimated to reach 1470°.

Section 4

On the basis of the above, an examination of conditions conducive to fire storms is called for – in particular, those structural conditions that are, to a greater or lesser extent, alterable over time.

(a) Building Density (ratio of roof area to ground area) is a primary determinant of fire storm susceptibility. All fire storms and conflagrations on record occurred in areas of high building density. The density of the fire-storm area of Hamburg was about 30 per cent, of Hiroshima between 37 per cent and 42 per cent; Tokyo had 22.5 square miles of residential area, 46 per cent built-up. NSRB study* concludes that "it is probable that great mass fires of fire storm and conflagration proportions can be expected only in areas of over 20 per cent building density." An interesting study was made of the influence

*Fire Effects of Atomic Bombing Attacks, National Security Resources Board (1950).

of built-upness on fire spread in Japan. In one particular city, the tendency of fire to spread from bomb-ignited areas through different degrees of building density (presumably wind, etc.) had a negligible effect, and other things were more or less equal. Sixteen per cent of the 5-20 per cent built-up zone, 65 per cent of the 20-40 per cent zone, and 82 per cent of the 40-50 per cent zone was damaged. The NSRB study concluded that relatively low building density (as well as terrain) was instrumental in the prevention of a fire storm at Nagasaki.

(b) Combustibility of Structures is another important determinant of fire spread. Most buildings fall into one of four categories:

(1) All-frame construction, combustible exterior;

(2) Masonry, but with combustible material in principal structural members;

(3) Noncombustible construction, vulnerable to structural deformation under intense heat (unprotected steel-frame structures, etc.);

(4) Fire-resistive (reinforced concrete, concrete and masonry on protected steel frame, etc.).

Category (1) buildings will spread fires by exposure; Category (2) will contain fires within the building except under fire-storm conditions; Category (3) will form fire breaks except in fire storms which will cause them to buckle and give; Category (4) will remain undamaged even in conflagration, though the interiors are most likely to burn out.

The figures indicating (very roughly) "combustibility" of principal U.S. cities (1940) are rather striking, and are given in Table VII-3-I.

The percentages given in Table VII-3-I are based on numbers of buildings rather than on numbers of dwelling (and office) units; skyscrapers and outhouses are weighed equally; hence the situation is not so unfavorable as the figures at first glance indicate. Also, since fire-resistive structures are generally concentrated in the high-building-density zones, to some exient the fire storm hazard is mitigated.

Nevertheless, it is probable that, on the average, buildings in most cities in the U.S. are more susceptible to mass fire than were structures in cities of similar size in Germany (1940). Outside walls in German construction were generally thicker, most inside room and stair-well partitions were of brick, very little use was made of woodlath or plaster on wood. Also, wooden porches,

TABLE VII-3-1

Combustibility of U.S. Cities
(1940)

City	Total Reported	Wood	Brick	Stucco	Other (including Blast Fire Resistive)	Per Cent Fire-Resistive Construction
Chicago	382,628	131,148	233,959	5,791	6,724	1.7
Detroit	267,677	165,488	84,333	1,923	5,633	2.2
New York	591,318	236,879	299,452	41,661	13,297	2.3
San Francisco	105,180	61,173	2,334	40,902	722	<1
Washington	156,359	48,971	85,639	5,764	5,685	3.6

TABLE VII-3-2

Efficiency of Fire Breaks in Residential Areas
(Distances in Linear Miles)

Width	Length	Subjected to Fire	Per Cent Total	Fire Stopped*	Per Cent Stopped
150 ft. or over	18.1	9.2	50.8	6.9	75.0
65 ft. – 150 ft.	18.9	11.2	59.2	3.9	34.8
Total	37.0	20.4	55.1	10.8	52.9

*Fires were considered "stopped" where incendiary damage existed directly on one side of the fire break only. This is, therefore, a measure of minimum efficiency, because fires on both sides were often caused by bombs falling on both sides and not by fire spread.

fences, garages, sheds, etc., so frequent in residential areas of most U.S. cities (especially in the congested slum districts of metropolitan areas), were only infrequently found in Germany. The roofs of most German buildings were supported on combustible frames, however, and their "fire resistive" buildings did not measure up to U.S. standards.

It is generally agreed that Japanese cities were much more susceptible to fire storms than are U.S. cities, because of both high building densities and highly combustible construction.

(c) Firebreaks. Open spaces, fire-resistive buildings, parapeted fire walls, etc. all influence fire spread, depending on location, width, length, nature of areas separated, wind, type of attack, etc. It is very difficult to set up specific criteria for "effective" fire breaks, since weather conditions, bomb distribution, extent of radiant heat; etc. will materially affect the effectiveness of particular "breaks." The U.S. Strategic Bombing Survey did make a study of the efficiency of fire breaks in residential areas of Nagoya where neither ground winds nor fire-storm conditions obscured the result. They compiled the figures given in Table VII-3-2.

The influence of parapeted fire walls was hotly argued during the planning phases of the Allied attacks on Germany. Horatio Bond, an American fire expert, explained the non-burning of Berlin by the fact that the city was honeycombed with parapeted fire walls. The experts' conclusion seems to be that fire walls do have a distinct effect on the pattern of fire spread.

(d) The size of high-density areas capable of supporting a fire storm is also a factor to be considered. The size of such vulnerable zones influences the number of individual fires that could be started to produce a mass fire. The fire-storm area of Hamburg was 4.5 square miles, Kassel 2.9 square miles, and Darmstadt 1.5 square miles. At Nagasaki, several mass fires of smaller than one square mile area did not result in a fire storm. The NSRB conclusion is that "the minimum size of the area capable of sustaining a fire storm is uncertain, but a study of the data suggests that it is unlikely to be less than one square mile."*

*Fire Effects of Atomic Bombing Attacks, op. cit.

Section 5

The following are usually listed as contributing factors to fire initiation and fire spread:

(a) Continuity of combustible construction: combustible exteriors, porches, garages, fences, etc. (i.e., the extent of continuous stretches of Category (4) construction).

(b) Occupancy combustibility.

(c) Size of buildings: The nature of the influence on fire susceptibility is not clear from the literature. Assuming that X dwelling units are to be provided on an area of Y acres, is it better to build a single multistory unit, surrounded by substantial open space on all sides, or should we rather build many small units leaving whatever space may remain in between? What are the criteria for an optimum "arrangement"?

Very roughly, it is probably a good guess that, from the point of view of the areas peripheral to the Y acres, a single unit in the middle with open spaces around it would be preferable. From the point of view of the inhabitants of the X dwelling units themselves, the answer is a function of the relative probability of fire spread in a single large unit (of necessarily superior construction) as opposed to that among a larger and larger number of smaller units closer and closer together; it is also a function of the relative probability of being hit (affected by what floor one may be on), the relative probability of being attacked (attractiveness of target to enemy), and so forth. Cost considerations are also to be considered; comparison should not be made between single-story frame shanties and a 100 per cent fire-resistive skyscraper.

(d) Topography is an important consideration. One of the reasons that the Nagasaki bomb did less damage than the smaller Hiroshima one was that a good part of Nagasaki was shielded from air and ground zero by high ground. Cities built on the flat are more vulnerable than those effectively segmented by rivers, high ground, etc.

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USA Contr. No. DA36-039-sc-5450

Air Defense Systems
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Military Operations (24)
Defense (8)

[redacted]

NTIS, Auth: MIT/LL ltr, 2 Nov 81
FLD/GP 15/3, 3.1, 7

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[redacted] Auth: DOD DIR 5200.10, 29 JUN 80

U Auth: MIT ltr, 28 May 75
(AMC ltr 23 April 75 + DAMI ltr attached to MIT ltr above)