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TOWARD NEW HORIZONS

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SCIENCE, the Key to Air Supremacy

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By: Dir, RSI – Init: mk
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TOWARD NEW HORIZONS

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203.1

A Report to

GENERAL OF THE ARMY H.H. ARNOLD

Submitted on behalf of the [redacted]

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A.A.F. SCIENTIFIC ADVISORY GROUP

by

TH. VON KARMAN

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SCIENCE, the Key to Air Supremacy

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HEADQUARTERS, ARMY AIR FORCES
WASHINGTON

IN REPLY REFER TO:

7 November 1944

MEMORANDUM FOR DR. VON KARMAN:

Subject: AAF Long Range Development Program

1. I believe the security of the United States of America will continue to rest in part in developments instituted by our educational and professional scientists. I am anxious that Air Forces postwar and next-war research and development programs be placed on a sound and continuing basis. In addition, I am desirous that these programs be in such form and contain such well thought out, long range thinking that, in addition to guaranteeing the security of our nation and serving as a guide for the next 10-20 year period, that the recommended programs can be used as a basis for adequate Congressional appropriations.

2. To assist you and your associates in our current concepts of war, may I review our principles. The object of total war is to destroy the enemy's will to resist, thereby enabling us to force our will on him. The attainment of war's objective divides itself into three phases: political, strategic and tactical. Political action is directed against the enemy's governing power, strategic action against his economic resources, and tactical action against his armed forces. Strategical and tactical actions are our main concern and are governed by the principles of objective, surprise, simplicity, mass, offensive, movement, economy of forces, cooperation and security.

3. I believe it is axiomatic that:

a. We as a nation are now one of the predominant powers.

b. We will no doubt have potential enemies that will constitute a continuing threat to the nation.

c. While major wars will continue to be fought principally between the 30th and 60th parallels, north, global war must be contemplated.

d. Our prewar research and development has often been inferior to our enemies.

e. Offensive, not defensive, weapons win wars. Countermeasures are of secondary importance.

f. Our country will not support a large standing army.

OSR · 9 · 1784

g. Peacetime economy requirements indicate that, while the AAF now receives 43% of current War Department appropriations, this allotment or this proportion may not continue.

h. Obsolete equipment, now available in large quantities, may stalemate development and give Congress a false sense of security.

i. While our scientists do not necessarily have the questionable advantage of basic military training, conversely our AAF officers cannot by necessity be professional scientists.

j. Human-sighted (and perhaps radar or television assisted) weapons have more potential efficiency and flexibility than mechanically assisted weapons.

k. It is a fundamental principle of American democracy that personnel casualties are distasteful. We will continue to fight mechanical rather than manpower wars.

l. As yet we have not overcome the problems of great distances, weather and darkness.

m. More potent explosives, supersonic speed, greater mass offensive efficiency, increased weapon flexibility and control, are requirements.

n. The present trend toward terror weapons such as buzz bombs, phosphorous and napaim may further continue toward gas and bacteriological warfare.

4. The possibility of future major wars cannot be overlooked. We, as a nation, may not always have friendly major powers or great oceanic distances as barriers. Likewise, I presume methods of stopping aircraft power plants may soon be available to our enemies. Is it not now possible to determine if another totally different weapon will replace the airplane? Are manless remote-controlled radar or television assisted precision military rockets or multiple purpose seekers a possibility? Is atomic propulsion a thought for consideration in future warfare?

5. Except perhaps to review current techniques and research trends, I am asking you and your associates to divorce yourselves from the present war in order to investigate all the possibilities and desirabilities for postwar and future war's development as respects the AAF. Upon completion of your studies, please then give me a report or guide for recommended future AAF research and development programs.

OSR-9-1784

May I ask that your final report also include recommendations to the following questions:

a. What assistance should we give or ask from our educational and commercial scientific organizations during peacetime?

b. Is the time approaching when all our scientists and their organizations must give a small portion of their time and resources to assist in avoiding future national peril and winning the next war?

c. What are the best methods of instituting the pilot production of required nonrevenue equipments of no commercial value developed exclusively for the postwar period?

d. What proportion of available money should be allocated to research and development?

6. Pending completion of your final report ,may I ask that you give me a short monthly written progress report. Meanwhile, I have specifically directed the AC/AS, OC&R (General Wilson) to be responsible for your direct administrative and staff needs. Also, as I have already told you, I welcome you and your associates into my Headquarters. May I again say that the services of the AAF are at your disposal to assist in solving these difficult problems.

H H Arnold

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HEADQUARTERS, ARMY AIR FORCES
WASHINGTON

IN REPLY REFER TO:

15 December 1945

General of the Army H. H. Arnold
Commanding General, Army Air Forces
Washington 25, D. C.

Dear General Arnold:

In your basic memorandum of the seventh of November 1944, you directed me to prepare a report as a guide for recommended future Army Air Forces research and development progress.

In cooperation with a group of selected associates, experts in various branches of the sciences involved, I have tried to review the scientific requirements involved in the functions of the future Air Forces, and I submit herewith the results of our study.

The first volume contains a discussion of the relation between science and aerial warfare; an analysis of the main research problems of the air forces, from the point of view of its functions; and recommendations on organization of research. The twelve volumes which follow contain thirty-two scientific monographs, with detailed research programs in specific fields.

The general conclusions of this study may be summarized as follows:

1. The discovery of atomic means of destruction makes a powerful Air Forces even more imperative than before. This subject is discussed in Chapter I of the first volume.

2. The scientific discoveries in aerodynamics, propulsion, electronics, and nuclear physics, open new horizons for the use of air power.

3. The next ten years should be a period of systematic, vigorous development, devoted to the realization of the potentialities of scientific progress, with the following principal goals: supersonic flight, pilotless aircraft, all-weather flying, perfected navigation and communication, remote-controlled and automatic fighter and bomber forces, and aerial transportation of entire armies.

4. The research problems, as analyzed in Chapter II of the first volume, should be considered in their relation to the functions of the Air Forces, rather than as isolated scientific problems.

5. Therefore, development centers should be established for new types of equipment and for making novel methods suggested by scientific discoveries practical. Such development centers for definite tasks are more efficient than separate laboratories for certain branches of science.

6. The use of scientific means and equipment requires the infiltration of scientific thought and knowledge throughout the Air Forces and, therefore, certain organizatory changes in recruiting personnel, in training, and in staff work. Pertinent suggestions are made in Chapter III of the first volume of this report.

7. A global strategy for the application of novel equipment and methods, especially pilotless aircraft, should be studied and worked out. The full application of air power requires a properly distributed network of bases within and beyond the limits of the continental United States.

8. As new equipment becomes available, experimental pilotless aircraft units should be formed and personnel systematically trained for operation of the new devices.

9. According to the outcome of a practical testing period, a proper balance between weapons directed by humans, assisted by electronic devices, and purely automatic weapons should be established.

10. The men in charge of the future Air Forces should always remember that problems never have final or universal solutions, and only a constant inquisitive attitude toward science and a ceaseless and swift adaptation to new developments can maintain the security of this nation through world air supremacy.

In your basic memorandum, you also desired recommendations on the following questions:

"a. What assistance should be given or ask from our educational and commercial scientific organizations during peacetime?

"b. Is the time approaching when all our scientists and their organizations must give a small portion of their time and resources to assist in avoiding future national peril and winning the next war?

"c. What are the best methods of instituting the pilot production of required nonrevenue equipments of no commercial value developed exclusively for the post war period?

"d. What proportion of available money should be allocated to research and development?"

Recommendations on the first three points are included in the sections of the report dealing with cooperation between science, industry, and the Air Forces. I am somewhat reluctant to give a definite answer to your fourth question. I prefer to submit the following consideration. The money to be allocated for research and development should be related to the cost of one year's aerial warfare. It appears that spending for research in peacetime five percent of one war year's expenditures, in order to be prepared for or avoid a future war, is not an exaggerated drain on the nation's pocketbook. A quick inquiry showed that our large industrial concerns spend a percentage of this order of the total sum involved in their year's business for research. If in peacetime 15-20 percent of the sum spent in a war year were allowed for total expenditures of the Air Forces, the amount required for research and development should constitute 25-33 percent of the total Air Forces budget.

Respectfully yours,

Th. v. Karman

TH. VON KARMAN
Director
AAF Scientific Advisory Group

The AAF Scientific Advisory Group was activated late in 1944 by General of the Army H. H. Arnold. He secured the services of Dr. Theodore von Karman, renowned scientist and consultant in aeronautics, who agreed to organize and direct the group.

Dr. von Karman gathered about him a group of American scientists from every field of research having a bearing on air power. These men then analyzed important developments in the basic sciences, both here and abroad, and attempted to evaluate the effects of their application to air power.

This volume is one of a group of reports made to the Army Air Forces by the Scientific Advisory Group.

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CONTRIBUTIONS
TO
"TOWARD NEW HORIZONS"

A Report to General of the Army H. H. Arnold
by the AAF Scientific Advisory Group

SCIENCE, THE KEY TO AIR SUPREMACY

By

Theodore von Karman

•

WHERE WE STAND

By

Theodore von Karman

•

TECHNICAL INTELLIGENCE SUPPLEMENT

•

AERODYNAMICS AND AIRCRAFT DESIGN

Part I — HIGH SPEED AERODYNAMICS

By

H. S. Tsien

Part II — THE AIRPLANE — PROSPECTS AND PROBLEMS

By

W. R. Sears
I. L. Ashkenas
C. N. Hasert

Part III — AIRCRAFT MATERIALS AND STRUCTURES

By

N. M. Newmark

FUTURE AIRBORNE ARMIES

By

T. F. Walkowicz

•

AIRCRAFT POWER PLANTS

Part I — GAS TURBINE PROPULSION

By

F. L. Wattendorf

Part II — EXPERIMENTAL AND THEORETICAL PERFORMANCE OF AEROPULSE ENGINES

By

H. S. Tsien

Part III — PERFORMANCE OF RAMJETS AND THEIR DESIGN PROBLEMS

By

H. S. Tsien

PART IV — FUTURE TRENDS IN THE DESIGN AND DEVELOPMENT OF SOLID AND LIQUID FUEL ROCKETS

By

H. S. Tsien

Part V — HIGH TEMPERATURE MATERIALS

By

Pol Duwez

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AIRCRAFT FUELS AND PROPELLANTS

Part I — RESEARCH ON HYDROCARBON FUELS FOR AIRCRAFT PROPULSION

By

W. J. Sweeney

Part II — PETROLEUM: ITS USE FOR MOTIVE POWER

By

W. J. Sweeney

Part III — SOLID PROPELLANTS FOR ROCKETS AND OTHER JET PROPELLED DEVICES

By

L. P. Hammet

Part IV — LIQUID PROPELLANTS FOR ROCKET TYPE MOTORS

By

A. J. Stosick

Part V — POSSIBILITY OF ATOMIC FUELS FOR AIRCRAFT PROPULSION OF POWER PLANTS

By

H. S. Tsien

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GUIDED MISSILES AND PILOTLESS AIRCRAFT

Part I — PRESENT STATE OF THE GUIDED MISSILE ART

By

H. L. Dryden

Part II — AUTOMATIC CONTROL OF FLIGHT

By

W. H. Pickering

Part III — THE LAUNCHING OF A WINGED MISSILE FOR SUPERSONIC FLIGHT

By

H. S. Tsien

Part IV — PROPERTIES OF LONG RANGE ROCKET TRAJECTORIES IN VACUO

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G. B. Schubauer

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GUIDANCE AND HOMING OF MISSILES AND PILOTLESS AIRCRAFT

Part I — SELECTED GUIDED MISSILES NOW DEVELOPED OR UNDER DEVELOPMENT

By

H. L. Dryden

Part II — HEAT AND TELEVISION GUIDED MISSILES

By

G. A. Morton

Part III — RADAR AIDS FOR THE GUIDANCE OF MISSILES

By

I. A. Getting

Part IV — RADAR HOMING MISSILES

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H. L. Dryden

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EXPLOSIVES AND TERMINAL BALLISTICS

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Part II — PROPERTIES OF HIGH EXPLOSIVES

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D. P. McDougall

Part III — TERMINAL BALLISTICS AND DESTRUCTIVE EFFECTS

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RADAR AND COMMUNICATIONS

Part I — THE USE OF RADAR IN AIR FORCES OPERATIONS

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L. A. DuBridge
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By

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Part III — AIRCRAFT RADIO COMMUNICATION EQUIPMENT

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WEATHER

By

I. P. Krick

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AVIATION MEDICINE AND PSYCHOLOGY

Part I — FUTURE TRENDS OF RESEARCH IN AVIATION MEDICINE

By

W. R. Lovelace

Part II — PSYCHOLOGICAL RESEARCH IN THE ARMY AIR FORCES

By

C. W. Bray

SCIENCE-THE KEY TO AIR SUPREMACY

Chapter I

● SCIENCE AND AERIAL WARFARE

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Chapter III PROBLEMS OF ORGANIZATION AND RECOMMENDATIONS

SCIENCE AND AERIAL WARFARE

INTRODUCTION

1.1 There have been two wars on a world scale in our time, in which the pendulum of victory seemed at first to swing far out in the direction of our enemies before indicating the final decision. In the First World War, victory or defeat was decided mainly by human endurance. Science and technology played an important but to some extent a secondary role. It is true, of course, that the superiority of the Allies in the design and production of tanks, as well as the paralyzing effect of the complete blockade on all branches of German industrial production, contributed very essentially to Germany's defeat in 1918. However, the complete exhaustion of human endurance on the German side was the main factor in the decision. The second war had, from the beginning, a technological character. The overwhelming technological preparation of Germany secured her first brilliant successes on the European continent. The shortcomings of the Luftwaffe in strategic bombing and the lack of experience of the German Army and its consequent poor preparation for amphibious operations, caused the attack against England to be stillborn. The mounting tide of Allied, especially American, air power became finally the main factor in Germany's defeat. Even in the East, although the bravery and endurance of the Russians were perhaps the most important factors in stopping the German Army, the Russian march of victory to the West could not have been achieved without technological superiority, due partly to Russian and partly to American production. An interesting sign of the technological character of this war is the fact that the time in which superiority in aircraft could be achieved was predicted, based on figures of industrial potential, at the beginning of the war. The predictions were fairly well verified by the actual events.

1.2 In addition to the technological character of this war, a new aspect became evident, which did not appear so obviously in the war of 1914-1918. This new element was the decisive contribution of organized science to effective weapons. Of course, scientific discoveries have been used in all wars since ancient times; it is related, for example, that Archimedes concentrated the heat of the sun by means of large mirrors to destroy enemy ships. However, never before have such large numbers of scientific workers been united for planned evaluation and utilization of scientific ideas for military purposes. Outstanding results of such planned cooperative research are, on our side, radar and atomic bombs, and on the German side, jet-propelled missiles.

1.3 The recognition of the growing technological character of modern war partly emerged from the experiences of the First World War, and the scientific character of any future warfare becomes obvious in the light of the war which has just ended. In this report an attempt is made to formulate some of the consequences of this conception for the program of the Air Forces.

THE POSITION OF THE AIR FORCES IN A SCIENTIFIC WARFARE

1.4 Until recently it was not generally recognized that destruction from the air is the most efficient method for defeating an enemy. This fact has now been proved by the results obtained in Germany and Japan. However, after the use of the atomic bomb, a strange change of opinion took place. Many leaders of public opinion seem to believe that destruction by means of a few airplanes or missiles carrying atomic bombs is the only method of future warfare, making a strong air force superfluous. Others say that international control of atomic energy will make war impossible for time to come.

1.5 We believe that all possible aspects of the complex problem introduced by this new scientific achievement must be considered:

First, we must consider the possibility that international control of atomic energy *cannot* be achieved in such a manner that the use of atomic destruction by potential enemies is impossible.

Second, the case has to be considered that international control of atomic energy will be achieved by agreement; it must be recognized, however, that such control will probably have to be supported by force.

Finally, we must also assume that, in spite of the international control of atomic energy and the outlawing of war by international organizations, the possibility of desperate attacks against the United States or its vital interests somewhere on the globe cannot be excluded.

1.6 The first assumption (international control of atomic energy cannot be achieved) means total war, with full use of atomic energy on both sides. Atomic energy will be used in the form of explosives, and, in all probability, as a means for jet propulsion. Atomic engineering and atomic industry will be simply a part of the war-making potential of a nation, perhaps the most important one. Consequently, one of the first aims of warfare will be the destruction of this potential. Fortunately, at least at present, production of atomic energy requires rather extensive plants, which can hardly be completely hidden and made safe against destruction. Of course, great effort will be expended upon keeping secret the places of research, development, and production. Hence, it will be one of the fundamental problems of the intelligence service to gather the most accurate information possible concerning these potential targets and evaluate it from the scientific, technological, and military points of view.

1.7 It can be assumed that the first attack in any war will be against targets connected with the production of atomic devices for destruction and propulsion. It is evident that such an attack will be the primary responsibility of the Air Forces. The places of research and production will certainly be removed as far as possible from the land and sea frontiers. An attempt will be made, of course, to annihilate the enemy's installations by bombs carried by piloted and pilotless airplanes. However, because of intricate defense measures by the enemy, who will probably put the most important installations underground, it may be necessary to land troops and to occupy certain territories. Thus, all aspects of modern aerial warfare may enter into the picture; strategic bombing, air superiority, and airborne armies.

1.8 It is evident that preparations must be made for strategic bombing of enemy targets involved in atomic work, by proper location of bases, especially bases for pilotless airplanes. In the past, systems of fortification, communication lines, and transportation facilities were built according to the strategic requirements of warefare on land and on sea. Today's strategic considerations refer to the three-dimensional space surrounding the globe. They must be worked out with the same imagination and thoroughness displayed by old-time strategists in solving the problems of attacking and defending certain lines extending on the surface of the earth, or certain points which controlled traffic on the seas.

1.9 It may be argued that the devastation and loss of life caused by atomic bombs is so tremendous that total atomic warfare will never occur. I believe the answer is the following: No man in the past centuries could, by any stretch of the imagination, foresee the devastation and loss of life produced by two consecutive wars in our time. Humans adjust themselves rapidly to new concepts. What is considered an incredibly large loss of life today may appear inevitable in years to come. I believe we must agree with Dr. Einstein's view that, even in case of total atomic warfare, humanity and human civilization will not disappear. The number of lives lost in the two wars, which were separated by a relatively short interval, appears to us certainly disastrous. However, there is no proof that economic pressure and human passion cannot produce conflicts which lead to the annihilation of one-half or two-thirds of the population of a country. Preparedness certainly has to make provisions for such possibilities.

1.10 The second assumption (that international control of atomic energy will be achieved but will require support by force) seems to be the most probable solution of the atomic problem within the next decades. Then, the main responsibility of the Armed Forces will be the enforcement of international agreements. Here again the nation must rely on a powerful air force. It will be necessary to strike at any arbitrary point of the globe, to strike swiftly and forcefully. History shows that international agreements have not protected the signatories and have not prevented wars, either because there were no means available for swift and forceful action, or because political reasons prevented their use. No branch of the Armed Forces except the Air Forces can perform the required action in time to be effective.

1.11 The same requirements as in the second case apply to the third assumption (unexpected treacherous attacks cannot be excluded in spite of international agreement). However, in the latter case the matter of efficient defense must be emphasized. It must be realized that a one hundred per cent safe defense is impossible. It is easier to make offensive action efficient by scientific means than defensive action. The high speed of pilotless airplanes and missiles makes them almost safe against a hit; no effective means is yet known for stopping such missiles, once they are launched, and, the fact that one single airplane or missile is able to drop a bomb of immense destructive power puts an almost impossible task on the air defense. All that we can hope is that absolute air superiority, combined with highly developed and specialized warning and homing devices, will help us to erect an impregnable aeroelectronic wall, which will reduce to a minimum the possibility of any enemy device slipping through undetected and undestroyed.

1.12 The main conclusion of these considerations is the necessity for a powerful air force, which is capable of:

a. Reaching remote targets swiftly and hitting them with great destructive power.

b. Securing air superiority over any region of the globe.

c. Landing, in a short time, powerful forces, men and firepower, at any point on the globe.

d. Defending our own territory and bases in the most efficient way.

1.13 It is evident that only an air force which fully exploits all the knowledge and skill which science has available now and will have available in the future, will have a chance of accomplishing these tasks. Aerodynamics, thermodynamics, electronics, nuclear physics, and chemistry must reunite their efforts. In the following section, a short review is given of the most important scientific facts. These facts are important elements to be considered in selecting and training personnel and developing equipment for the future Air Forces.

SCIENCE'S MAIN CONTRIBUTIONS

1.14 The development of aviation is a struggle against the limitations imposed by nature upon man, created to live on the ground, but nevertheless endeavoring to move in the unlimited space surrounding our globe.

1.15 As the problem of heavier-than-air locomotion was solved in principle by the discovery of the airplane, speed and range were confined to narrow limits. Weather and night appeared as insurmountable obstacles, and human skill seemed to be an indispensable element for diverse uses of the airplane in peace and war.

1.16 Science has already removed many of these limitations:

a. By gradual improvement in aerodynamic design, the velocity and economy of the airplane have been greatly increased. Airplane designers have continuously endeavored to eliminate all possible drag which impairs economy: i.e., the parasite drag, by attempting to make the aircraft essentially into a flying wing; the turbulent friction of the air by creating laminar flow around the wing. In recent years our knowledge of supersonic phenomena has increased the velocity of the airplane and brought it closer and closer to the speed of sound, which for a long time appeared as a natural upper limit. This knowledge has opened the door for winged aircraft, both piloted and pilotless, to the threshold of velocities faster than sound. Until now only unmanned ballistic devices have attained such speeds.

b. Novel propulsive systems, using the reaction or jet principle, have facilitated the reaching of high speeds, because of their reduced weight and increasing efficiency with increasing speed. These systems replace the conventional engine and propeller at high speeds because the efficiency of a propeller decreases greatly when very high speeds are attained. The rocket principle makes propulsion independent of the use of the atmospheric air and rocket-driven aircraft are able to reach extraordinary altitudes in an extremely short time.

c. By gradual improvement, both in aerodynamic design and in engine construction, the performance and economy of airplane transportation have been tremendously increased. The spectacular increase in the range of our military aircraft and in the carrying capacity of our cargo aircraft is an indication of improved economy. Although essential improvements in aerodynamic and engine design can be expected to increase airplane economy further, the amount of heat which can be released by combustion of our most efficient fuels per unit weight or per unit volume, imposes a serious limitation on any large increase in range with conventional fuels. The use of nuclear energy, however, may radically change this situation and help to reach almost unlimited ranges, at least in the case of aircraft which do not carry human beings.

d. Navigation and instrument flying were greatly aided by use of the radio even in its early stages of development. The recent extension of the spectrum of radiation down to centimeter and millimeter wavelengths, and the application of the pulse and echo principles of radar, opened fundamentally new possibilities in the struggle of aviation against weather, clouds, and darkness. Blind landing, blind bombing and location of remote and invisible objects (aircraft or targets) are paramount examples of the contributions of radar technique. Seeing through darkness by night and seeing through clouds by day became routine facts in military aviation. Fighter control from the ground became an important element in warfare. It appears that a wide-open field exists for progress in communication and other applications of radio and electronics which are discussed at length in "Radar and Communications," by other members of the AAF Scientific Advisory Group.

e. Gradual improvements in gyroscopic devices led to the automatic pilot, which materially relieves the human pilot. In addition, the development of gryo and servo-motor devices made possible a great variety of remote control systems. Since we are able to transfer optical impressions by television devices, aircraft or missiles can be piloted to distant points from the ground or from the air by remote control. Radar location devices similarly can be applied to the remote control of aircraft.

f. The progress in electromagnetic radiation techniques made automatic homing (target seeking) possible and effective. A radar homing bomb was in use by the U. S. Navy in the Pacific at the close of the war. Infrared (heat) radiation proved to be one of the most promising methods. Radio, infrared, and radar have been applied to the problem of the proximity fuse and will have wide applications in target location. Radar has been found extremely useful in automatic fire control. Along with automatic homing, the design of automatic computers became a great practical domain of military engineering.

g. Combination of methods of automatic and remote control with homing devices will lead to a complete solution of the problem of pilotless aircraft, having tremendous speed, extraordinary range and ability to hit targets accurately. Although pilotless aircraft will never completely eliminate manned aircraft, they obviously will take over certain missions. Both in the German and in the Japanese theaters, our strategic bombing forces brought utter destruction to our enemies with the clocklike accuracy of a great machine. The future aim is to build up, for this purpose, a war machine in the proper sense of the word, consisting of technical devices only, and yet directed in all details by the mind and staff of some master strategist of the air.

PLAN OF ANALYSIS

1.17 The abundance and variety of applications of scientific ideas and devices in aerial warfare, sketched very briefly above, put a tremendous task before the men responsible for the future Air Forces. For the most part the scientific foundation of the applications mentioned has already been laid, and other applications will emerge as scientific research continues to be productive of new knowledge.

1.18 The scientific-technological questions are only a small part of the whole problem. We are fully aware that a report prepared by men of science can contribute only a small part of the solution.

1.19 Chapter II of this volume analyzes the problem of research and development from the point of view of the technical requirements which the Air Forces must meet in order to be able to carry out its task, securing the safety of the nation. It appears that the main requirements in which scientific methods, scientific research and development play an important role, may be listed as the abilities to:

a. Move swiftly and transport loads through the air.
b. Locate targets and recognize them.
c. Hit targets accurately.
d. Cause destruction.
e. Function independently of weather and darkness.
f. Defeat enemy interference.
g. Perfect communications from ground to air and from air to air.
h. Defend home territory.

1.20 Chapter III contains recommendations of an organizatory character as follows:

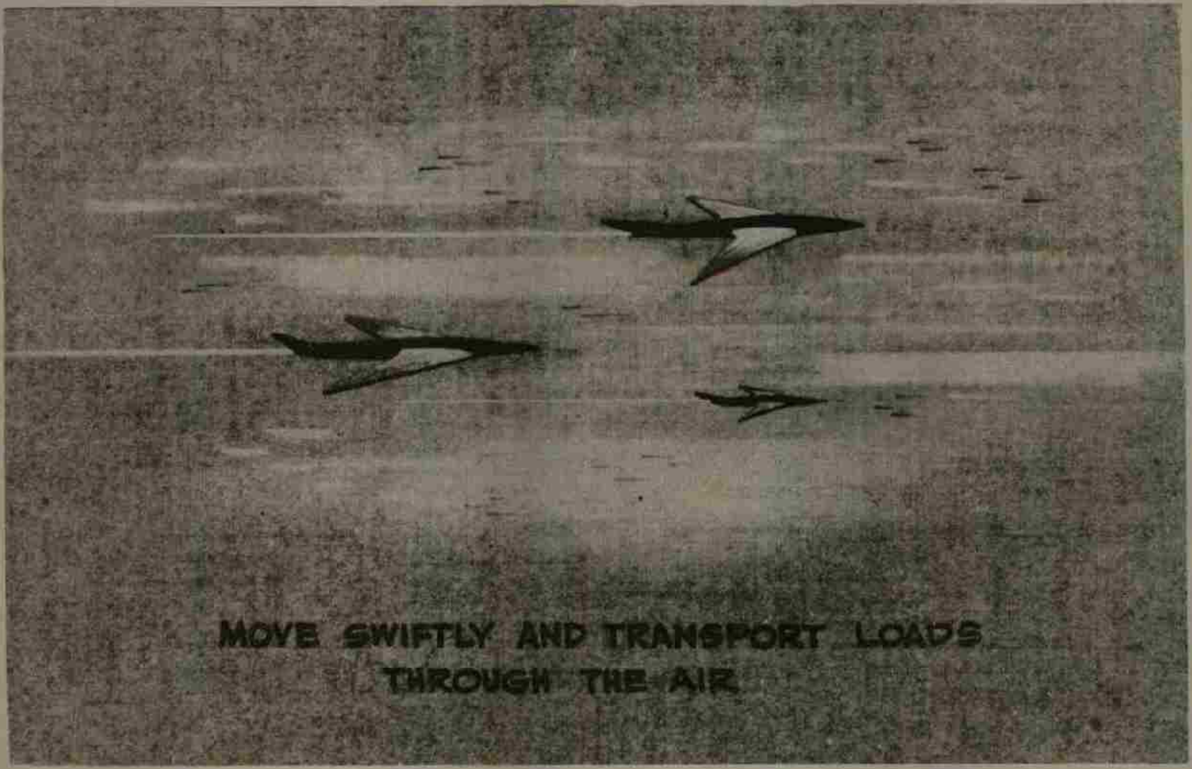
a. Fundamental principles for organization of research.
b. Cooperation between science and the Air Forces.
c. Cooperation between industry and the Air Forces.
d. Adequate facilities in the Air Forces for research and development.
e. Induction of scientific ideas into command and staff work.
f. Scientific and technological training of Air Forces personnel.

1.21 Further volumes of this general report contain individual studies prepared by members and collaborators of the Scientific Advisory Group on the main scientific topics. They may be used as a kind of guide for the direction of future research, starting from the present state of the art toward the realm of the unknown to be revealed in the years to come.

SCIENCE - THE KEY TO AIR SUPREMACY

Chapter II

● ANALYSIS OF RESEARCH PROBLEMS


MOVE SWIFTLY AND TRANSPORT LOADS
THROUGH THE AIR

ANALYSIS OF RESEARCH PROBLEMS

MOVE SWIFTLY AND TRANSPORT LOADS THROUGH THE AIR

2.1 This fundamental problem can also be described as the problem of the aerial vehicle. It includes the design and construction of manned and unmanned aircraft, subsonic and supersonic.

2.2 Looking back to the past, the aeronautical engineer certainly can be proud of the performance of the present day airplane. Speed, rate of climb, and range have been multiplied by factors of considerable magnitude in the twenty-seven years since the end of the First World War. A great portion of the progress was achieved during the last decade in the six years of conscious preparation by the Army Air Forces and in the four years of actual warfare. However, if the problem of war in the future is considered, we conclude that our best present type airplanes are still far from doing the job which they will have to achieve.

RANGE VS. SPEED

2.3 The two great problems of aerial locomotion are range and speed. The ideal solution is a combination of both.

2.4 Range is imperative because of the global character of aerial warfare. We have to reach enormous ranges, distances as great as half of the length of the equator, in order to be able to attack and occupy points located anywhere on the globe. With the possible exception of an airplane driven by atomic energy, the design of aircraft to carry very heavy loads to shorter ranges is essentially the same problem, because of the interchangeability of fuel and pay load.

2.5 Speed is imperative for effective action, safety against enemy countermeasures from the ground, and superiority over enemy aircraft.

2.6 Hence, it appears that for the crystallization of our ideas concerning the desired performance of future aircraft, we have to see clearly the fundamental relations between range and speed. The range of an airplane depends on three factors: (1) ratio between drag and lift, (2) fuel consumption per unit thrust horsepower, and (3) ratio between the weight of the fuel and the total weight of the airplane, at the beginning of the flight. The first factor is determined by aerodynamics of the iarplane, the second, by aerothermodynamics of the propulsive system, and the third, by construction and material.

2.7 The critical factor is the lift-drag ratio, which decreases abruptly at the approach to sonic velocity and in the supersonic range never again attains the favorable values realized in the subsonic regime. Even if we are very optimistic as to the future developments of our supersonic aerodynamics, it is improbable that the extreme ranges possible for subsonic airplanes can be realized for supersonic planes. On the other hand, the belief that supersonic flight is restricted to extremely short ranges is too pessimistic. For instance, if atomic energy can be used for propulsion, the range of jet and rocket planes will increase to unprecedented values. However, even with present fuels, improvements can be expected in the design of jet propulsion units which would bring the range of supersonic planes to 1500-2000 miles in the substratosphere and 3000-3500 miles in the stratosphere.

2.8 In the example represented by the diagram, the ranges are shown for two values of the ratio between fuel and initial weight, 0.5 and 0.7. For the lift-drag ratio and the thermal and propulsive efficiency of the propulsive system, best current values are used, and the flight is assumed to be carried out at the optimum values. The ranges given are for level flight at 20,000 ft altitude; fuel for take-off and climb is not considered.

2.9 The ranges realized or realizable with present engineering methods are discussed in detail in the report, "The Airplane — Prospects and Problems" by W. R. Sears and I. L. Ashkenas, in the SAG report *Aerodynamics and Aircraft Design.* The attainment of the values shown in the diagram, page 15, necessitates considerable improvements in aerodynamics, both in the subsonic and supersonic ranges, and radical changes in the propulsion units used in the supersonic range. At supersonic speeds the frontal area of the engine required for given thrust is the greatest impediment and must be greatly reduced. The ranges given in the diagram should be considered as goals of a systematic effort of the next decade to be achieved by close cooperation between airplane and engine research groups.

AIRPLANE TYPES

2.10 No attempt is made to write the specifications for the aircraft of 1965; however, it appears possible to indicate certain general functional requirements of future aircraft. The following classification is based on the analysis of the functions of the Air Forces given in paragraph 1.12.

2.11 The first function of the Air Forces is to reach swiftly, and hit with great destructive power, remote targets. Two classes of aircraft will be used for this function:

a. An aircraft which carries the means of destruction to the target and returns to its base or lands at some other predetermined base. This is the bomber in the proper sense of the word.

b. An aircraft which is expendable and hits the target by means of remote control or automatic homing, i.e., a pilotless bomber.

2.12 The development of bomber aircraft, in the proper sense of the word, will probably continue for a few years the trend followed in recent years. However, it is not envisioned that bombers will continue to grow in size. Increase of size cannot continue to increase speed and range indefinitely, but may be necessary to permit carrying sufficient defensive armament. Such armament in the future would include radio-controlled high-speed missiles, launched from the bomber, which would serve as fighter cover in case of necessity. The greatest increase of speed and range must be accomplished by improvements in aerodynamics and propulsive methods.

2.13 In the field of pilotless bombers the goal is the intercontinental missile. We assume a system of bases distributed in such a way that all possible target areas in the world can be reached by such missiles. Two types of pilotless bombers should be developed for this purpose. The first type should be a high-altitude, pilotless, jet-propelled bomber, with a speed equal to about twice the velocity of sound. This pilotless bomber will carry either atomic or conventional bombs. Launched by rockets or lifted to high altitude by piloted airplanes, it will be capable of level flight up to a range of 2500 to 3000 miles. The second type aimed for should be an ultrastratospheric pilotless bomber, equipped with wings, but not designed for level flight in the atmosphere. It should be endowed with extreme velocity during the acceleration period. The wings will be used for two purposes: (1) to increase the length of the trajectory, and (2) to secure a controllability which is not possible with the pure V-2 type projectile. The propulsion of this type of pilotless bomber will be accomplished by the rocket principle.

2.14 Atomic energy may be used for propulsion in both types of pilotless bombers, thus increasing their ranges to an unprecedented extent. (Cf. 2.51 to 2.56.)

2.15 To secure air superiority various types of combat aircraft will be needed. Tactical requirements will determine their design. The two principal categories will always be bombers and fighters, although there will be overlapping of the duties of these, as at present, and some bombers and fighters will also be developed for highly specialized auxiliary tasks, such as photoreconnaissance. The very large battleship of the air, bristling with defensive armament, seems destined to give way ultimately to smaller bombers having superior performance, fighter control, etc.

2.16 An important problem is the development of special aircraft for airborne armies. These aircraft must be capable of cruising at comparatively high speeds, while still retaining the ability to land and take off at safe, low speeds from small fields. Vigorous application of jet-assisted take-off, boundary layer control, high-lift devices, and deceleration devices on troop-carrier aircraft can make this possible. Troop-carrier airplanes must also be specially designed for rapid and easy loading and unloading of bulky items of ground equipment.

2.17 Every item of equipment in the Army (naturally, with the exception of railway guns, heavy seacoast defense guns, and the like) must be air-transportable. However, the number of different types and sizes of troop-carrier airplanes developed must be kept down to a practical minimum. There is immediate need for an over-all study of the weight and dimensional characteristics of every item of equipment in the Army. Only a complete study can show what types and sizes of future troop-carrier aircraft are required to move the Army by air with greatest possible efficiency. However, the entire burden of making the Army air-transportable must not be allowed to fall solely on the aircraft designer. There must be established a means of control over the weights and dimensions of Army equipment to insure that future equipment will be capable of being carried in future aircraft. This can be done and must be done without compromising battlefield requirements in any way. The cargo airplane and ground equipment development programs must be coordinated at frequent intervals by an agency charged with the specific responsibility of making the Army capable of movement by air.

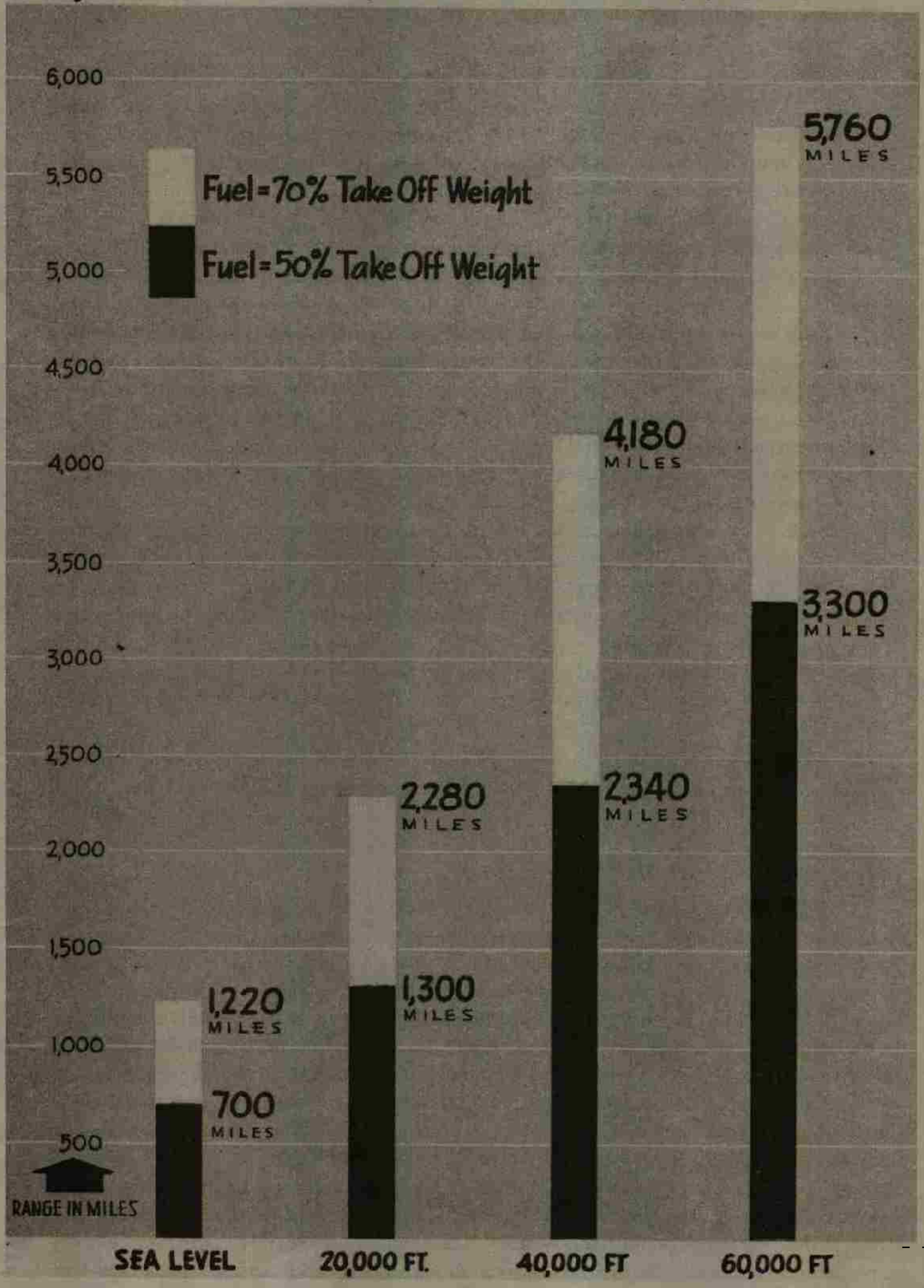
2.18 Gliders were used on a large scale (and with great effectiveness) for the first time in the airborne operations of World War II. The development of gliders and glider techniques must be continued since, at the present time, this is the safest, cheapest, most acceptable method of landing heavy equipment during the assault phase of an airborne operation. New glider developments should stress the following: adequate crash protection for crew and cargo; low landing speeds and use of deceleration devices for shortening the length of landing ground roll; rapid unloading through wide, rear-loading doors; adequate protection against small-arms fire for pilot and copilot; greater aerodynamic and structural efficiencies through the use of high-lift devices and metal construction; and the use of assisted takeoff techniques for decreasing the length of take-off run required by glider-towplane combinations. New gliders (towed-aircraft) must be and can be easily designed for rapid conversion to low-powered transports. This will eliminate some of the major shortcomings of gliders because ferrying to combat theaters and use as short-haul transports between airborne missions will be possible. The advantage of having such a transport, which can be easily and rapidly loaded and unloaded, for short-haul work immediately behind the lines cannot be overemphasized. Promising new techniques for the assault landing of heavy equipment must be developed and evaluated tactically. Important among these are the assault transport, the method of dropping heavy equipment by means of parachutes and decelerating rockets, aircraft with jettisonable cargo compartments, and rotary-wing aircraft. Stable (nonoscillating) parachutes with lower opening-loads must be developed for paratroopers.

2.19 The possibility of attacks by single aircraft with disastrous effects makes the defense of our frontiers, industrial equipment, and bases one of the most important tasks of the Air Forces. Piloted and pilotless interceptors are envisaged as the main instruments of defense. Speed and controllability are the main requirements for this type of aircraft.

AERODYNAMIC PROBLEMS

2.20 Improvements in the lift-drag ratio proportionately increase the range of an airplane. Therefore, efforts should be concentrated to attain such improvements. In 1935, an eminent American aerodynamicist, who, ironically enough, later became instrumental in the development of the laminar wing, declared that in his opinion no more major progress can be expected in aerodynamic science. He referred to the fact that with the discovery of the wing theory, lift and drag became calculable quantities, and the performance of the airplane could be fairly exactly predicted. Also, the designer learned the rules of streamlining and methods of eliminating superfluous drag by "cleaning up" the airplane. By use of systematic and detailed wind-tunnel tests, this cleaning up process became almost perfect, so that further improvements can be expected only in exceptional cases. However, even in the fairly well explored

Ranges Attainable at 1,000 MPH at Various Altitudes



subsonic speed range, new possibilities appeared with the discovery of the laminar wing section and the efforts to design an efficient flying wing.

2.21 The concept of the laminar wing is based on the fundamental fact that when the flow in the boundary layer of a surface moving in air is laminar, the surface friction is very much less than in the case when turbulent motion takes place in the same layer. The laminar wing sections which we are using in the present-day design, endeavor to keep the boundary layer laminar over a portion of the wing surface by means of an appropriate shape of the section. This method was applied in the design of quite a few of our modern airplanes, with considerable success. The proposal was first received with skepticism. Several objections were raised; that the expected effects of drag reduction could only be obtained if the wing surface is extremely smooth, and that the beneficial effect could only be attained for small values of the lift coefficient, thus restricting the benefit of the reduced friction to certain flight attitudes. Nevertheless, it appears that the initial successes of the laminar wing are so encouraging that in future research we should strive to go the whole way, i.e., to try to secure laminar flow in the boundary layer by positive measures along the entire wing and in a large range of angles of attack. It is known that theoretically this aim can be attained by the so-called boundary layer control. Results along this line are already available, for example, in the tests carried out by Professor J. Ackeret and his collaborators at the Technical University at Zurich. It is true that the process requires extremely smooth surfaces with relatively narrow slots extending spanwise along the wing. This might cause practical difficulties (for example, in the case of icing). However, looking into the future, extreme smoothness might be realized by materials now in the making, and it will certainly be worth-while to put in a great amount of research work to eliminate other possible practical obstacles. There is even the possibility of eventual elimination of conventional movable control surfaces, by use of boundary layer control to effect changes in lift and moment.

2.22 The same principle can be applied also to reductions of the drag of airplane bodies, for example, bodies with circular cross sections. In the case of wings, it will be necessary to subdivide the wing into a number of compartments with individually regulated boundary layer control. In the case of bodies, it might be sufficient to apply the control at a few critical cross sections.

2.23 The fundamental idea of the flying wing is the elimination of the parasite drag contributed by such parts of the airplane as do not produce lift. The tailless airplane is an even more controversial subject than the laminar wing. As does every unorthodox type, it introduces some new problems. The fact that the longitudinal control is placed in the wing involves control force characteristics which are different from those occurring in conventional airplanes. Much discussed problems are the proper method of securing directional stability, and the best arrangement for sweepback. As a matter of fact, the designs which have been produced up to now have not yet brought a final decision concerning the relative advantages and disadvantages of the flying wing and the tailless airplane. However, as the global character of aerial transportation, and especially aerial warfare, becomes more and more evident, it is apparent that our present airplanes are inadequate to meet the demand for range. Therefore, the two methods promising essential aerodynamic progress, namely boundary layer control and tailless design, should be explored with adequate facilities.

2.24 The large decrease in the value of the lift-drag ratio at a Mach number of about 0.8 is due to the rather sudden increase of the drag of the airplane. This increase is essentially due to the fact that the relative velocity of the air locally becomes larger than the velocity of sound. Simultaneously with the increase of the drag, difficulties are encountered, in most cases, in the stability and control of the airplane. Generally these phenomena are designated as compressibility effects; we prefer to use the designation "transonic problem." Obviously, in order to extend the speed limit of high-speed airplanes, a thorough investigation of the aerodynamic phenomena in the transonic range is needed. As a matter of fact, the aerodynamics of both the subsonic and supersonic ranges are better known than that of the transonic range, which extends approximately between the Mach numbers of 0.8 and 1.2. One reason is that the mathematical analysis is extremely difficult, since the flow around the airplane is partly subsonic and partly supersonic. Another great difficulty is caused by the unreliability of wind-tunnel tests in this range. Flight tests, dropping tests, and measurements on models carried by rockets are the main sources for experimental information.

2.25 Fighters and interceptors now in the making operate actually at the border of the transonic range. Hence, every method which is able to raise the limit of the rapid drag increase is of great importance. German scientists observed that increase of drag of the wing can be postponed to higher Mach numbers by sufficient sweepback. This method is generally used now in the design of fast fighters and interceptors. Designers are seeking means to reduce the excess weight and the difficulties in stability and control connected with the swept-back wing shape. However, this solution is not necessarily a final one. When our knowledge of aerodynamic phenomena in the transonic range has been more firmly established, we may find methods for eliminating the separation of the flow behind the shock wave, and the fundamental trouble, namely the occurrence of shock waves. In the subsonic range aerodynamic research brought rich returns. It can be expected that the same process will repeat itself and will lead to the solution of the transonic problem.

2.26 One of the main questions in the supersonic speed range is the feasibility of long-range flight. The supersonic airplane necessitates very high wing loading with small size of the wing. Hence, in most cases, the volume available in the wing for fuel or pay load is very small, and a disproportion appears between the sizes of the wing and the fuselage. In other words, the resistance of the body in comparison with the resistance of the wing is much greater than in the case of the conventional subsonic airplane. It appears that the best solution is offered by a fuselage of large fineness ratio. A rather thorough investigation of the problem was made by the Scientific Advisory Group on this question. These investigations suggest that, assuming a given ratio between fuel and total weight and a certain space required in the fuselage, the range is essentially a function of the altitude at which the supersonic flight takes place. The preceding diagram, page 15, shows an example of the variation of range with altitude. The ideal application of such a supersonic airplane is the pilotless bomber (Cf. 2.13). Similar types of supersonic airplanes will serve as pilotless interceptors (Cf. 2.19). The best speed range for the latter device may be between 1.2 and 1.5 times sound velocity.

2.27 The fact that in the case of the supersonic airplane, the body resistance contributes a relatively larger portion to the total drag than in the case of subsonic planes calls for study of an all-wing design. However, supersonic flight requires wings with small thickness-chord ratio. Hence, one can create sufficient space only by using a wing shape of very small aspect ratio. It is fortunate that, in the supersonic range, triangular-shaped wings give relatively high lift-drag ratios in comparison with other plan forms. Hence, for manned interceptors a series of all-wing airplanes should be tried, eventually with a small cockpit for a pilot. Such a series should extend from a tailless airplane similar to the Me-163 to pure triangular-shaped airplanes.

2.28 Besides the lift and drag properties, the questions of stability and control are the most important. The change of the flow regime introduces difficulties in the transonic range. But also in the pure supersonic range, very little is known about the efficiency of aerodynamic control surfaces and control forces. This field needs thorough exploration by all means available, starting with wind-tunnel tests and ending with flight tests. Possibly in addition to conventional means, displacements of weights or direct control of the pressure distribution by modification of the flow, as in the case of boundary layer control, are necessary.

2.29 The difficulties of landing are much more serious for supersonic than for subsonic airplanes because of their high-wing loading. The wing loading decreases with altitude and supersonic airplanes designed for stratospheric flight may land without special devices. However, systematic investigations are necessary of high-lift devices suitable for use on the thin, sharp-nosed airfoils that are desirable for supersonic flight. This must include the problem of raising the maximum lift of triangular, low-aspect-ratio wings, and particularly of reducing the extremely large angles at which such wings now attain their maximum lift. In addition, devices such as rockets, which produce simultaneously deceleratory thrust and increase of lift for the short period of landing should be studied.

PROPULSIVE PROBLEMS

2.30 All our airplanes actually used in the war were propelled by propellers driven by reciprocating engines. However, the progress made in the field of jet propulsion and gas turbines and the experience gathered in Great Britain and Germany, and also with our own experimental jet-propelled airplanes, enable us to choose the best propulsion system for any future project. In broad lines, the merit of a propulsive system is determined by two figures: the weight which has to be installed in the airplane for unit thrust-horsepower, and the fuel consumption per thrust-horsepower-hour. It is evident that for flight of short duration, small engine weight has the determining influence; for long duration flight, low fuel consumption is more essential. Fuel consumption per thrust-horsepower is determined by the efficiency of the engine and the propulsive efficiency of the system. At the present moment the reciprocating engine is still more economical than the gas turbine, and at subsonic speeds the propeller has higher propulsive efficiency than the jet. However, looking into the future, the following considerations appear important.

2.31 It appears to be rather difficult to attain radical improvements in the efficiency of reciprocating engines, whereas a wide open field is available for improvements in the case of the gas turbine. Hence, efforts should certainly be concentrated on developing the gas turbine for propeller drive, in order to secure the advantages of light weight, freedom from vibration, and reduction of nacelle drag connected with this system. Between the various engine systems, an intensive competition can be expected, to reach the best fuel economy at the lightest possible weight and the smallest space requirement.

2.32 The pure gas turbine has the advantage of simplicity, light weight and small dimensions. The reciprocating engine has at present an advantage over the simple gas turbine chiefly due to its utilization of higher pressures. However, it should be pointed out that the advantage of the reciprocating engine holds for the cruising condition only, but at maximum power output the gas turbine equals or surpasses the reciprocating engine in fuel economy.

2.33 There are many ways of improving the performance of the pure gas turbine, for instance:

a. Higher combustion temperature.

b. Higher pressure ratio.

c. Improving the aerodynamic efficiency.

d. Intercooling between compressor stages.

e. Reheating the air between turbine stages.

f. Use of separate turbine for propeller drive.

g. Regeneration by the use of a heat exchanger to extract heat from the turbeine exhaust, and utilize this heat to warm the air entering the combustion chamber.

These improvements involve partly metallurgical problems in search of better materials, partly aerodynamic problems, finally design problems to avoid undue penalties in size, weight, and complexity.

2.34 Improvement of reciprocating engines appears possible by utilization of somewhat higher pressure ratios, but in the pure reciprocating engine this tends to be offset by loss of heat in the exhaust. A promising development is the so-called compound engine in which the exhaust of a reciprocating engine drives a gas turbine which feeds back into the drive shaft. In this way the pistons of a reciprocating engine are used partly to drive a crankshaft and partly to serve as a gas generator for driving a gas turbine. The free piston-type of engine represents the extreme in this compounding principle. In this system the pistons are used solely as gas generators, and the products of combustion are used entirely to run a gas turbine. Both the compound engine and the free piston engine have not been explored enough to judge their ultimate possibilities.

2.35 With the practical realization of the gas turbine, the entire field of propulsion, aerial, maritime, and ground transportation came into a revolutionary stage. Science and industry are feverishly working on the analysis of related aerodynamic and thermodynamic phenomena, improvement of materials and construction. Undoubtedly in this field the Air Forces will receive in the next decade the benefit of many developments initiated by others. However, it will be necessary to give industry orientation in the direction of requirements of the Air Forces. Many of these requirements involve special problems in which industry in any case might not be primarily interested, for example, performance at extreme altitude and large excess power for short duration.

2.36 Jet propulsion will be generally used for transonic and supersonic speeds, i.e., in the speed range where the propulsive efficiency of the jet is superior to that of the propeller. However, the light weight of jet devices may justify their use also at lower speeds. For example, combined propeller and jet drive enables an airplane to cruise economically with the propeller drive at lower speed and reach high speeds for short duration by means of additional jet propulsion.

2.37 The various jet-propulsion systems utilizing hydrocarbon fuels in the atmosphere are listed in the SAG report *Where We Stand,* Theodore by Von Karman, as follows:

Reciprocating engine + ducted fan + jet	Motorjet
Gas turbine + ducted fan + jet	Turbofan
Gas turbine + jet	Turbojet
Continuous jet, compression by aerodynamic ram	Ramjet
Intermittent jet	Pulsojet

2.38 The chief limitations of the motorjet are those associated with the reciprocating engine. Since the reciprocating engine has a large frontal area in comparison with the gas turbine, units of large power become difficult to accommodate in the duct. The motorjet is considered a transition stage between the conventional engine-propeller combination and the turbofan. It is not considered, therefore, an important item in a long-range propulsion program. It is interesting to note that the Japanese also had a motorjet which they considered an interim jet motor pending development of the gas turbine.

2.39 In the turbofan the gas turbine drives, besides its own compressor, a larger compressor or fan in a duct. It appears to be a promising development for filling the speed range between the turbopropeller and turbojet. It has the advantage of greater efficiency over the turbojet in the high subsonic or transonic speed range because it moves a larger mass of air. It also has the advantage over the turbopropeller in the same range because the use of shrouded fans avoids the tip losses which propellers have at high Mach number. There has been very little development on this system up to the present, and much applied research is needed; for example, wind-tunnel testing at transonic speeds on gas turbine - ducted fan combinations in various duct arrangements.

2.40 The turbojet development of the last five years proved the practicability of the system beyond doubt, and realized considerable progress both in the size of units and in fuel economy. On the other hand, many problems are unsolved and call for intensive research. In addition to the problems related generally to gas turbines and discussed above, two methods of producing excess thrust are under investigation: afterburning in the tail pipe, and fluid injection. At present requirements of high thrust for a given frontal area and of fuel economy are conflicting, which constitutes a difficulty for the application of current turbojets to supersonic aircraft. However, possibilities for further improvement show definite promise of eliminating this difficulty and should make future turbojets applicable to supersonic flight provided sufficient development is concentrated on the subject. Since turbojets have an excellent propulsion efficiency at supersonic speeds, the effort of adapting them to this speed range should bring valuable returns. Supersonic aerodynamics applied to the blade design of compressors and gas turbines also should bring worth-while gains. For use in pilotless airplanes, expendable turbojets should be developed to have an endurance only slightly greater than that required by their mission.

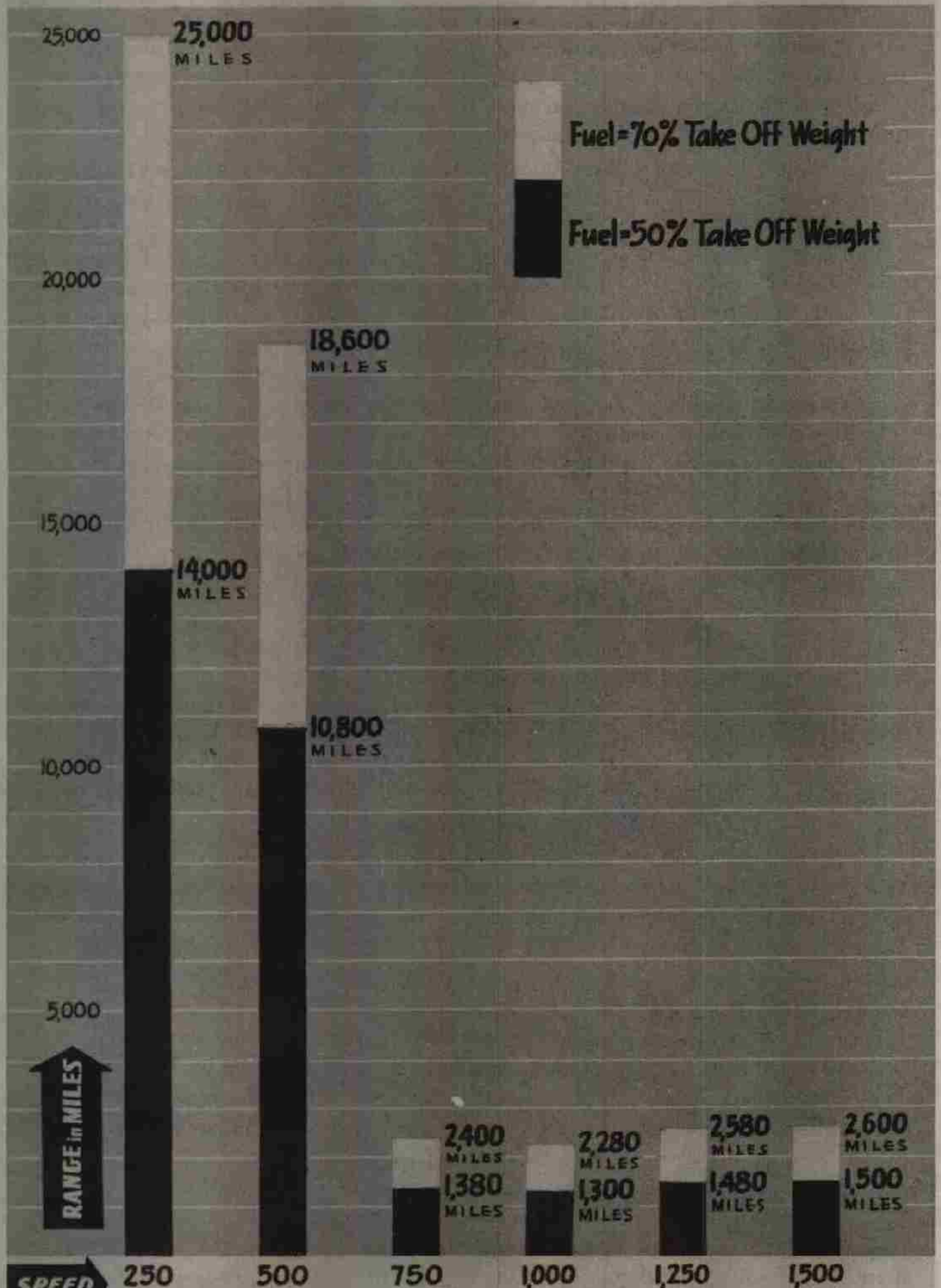
2.41 With increasing flight velocity, the inlet air pressure to a turbojet compressor increases due to ram compression. When the aircraft is flying at sonic velocity, the ram pressure is approximately twice the atmospheric pressure and an efficient duct design is able to utilize a high percentage of this pressure. For supersonic velocities beyond Mach number 2, the air pressure due to ram compression can be many times the atmospheric pressure and we can well dispense with the mechanical compressor and hence the turbine of the turbojet. The unit will then consists of an entrance air diffusor, the combustion chamber, and the exit nozzle. This is the ramjet. The ramjet is thus essentially a supersonic propulsive power plant. Its practicability at supersonic velocities is already demonstrated. The present theoretical calculation shows that for flight Mach numbers exceeding 2, the specific fuel consumption of the ramjet could be as low as two pounds per hour per pound-thrust. This is comparable with the specific fuel consumption of the turbojet. However, the ramjet has the further advantage of light weight due to much simpler construction and higher thrust per unit frontal area due to the higher combustion temperature permitted by the absence of highly stressed moving parts.

2.42 It seems then that the ramjet is the logical power plant for supersonic flight with speeds greater than twice the speed of sound. Of course for short duration boost, even applications at subsonic or transonic speeds may be considered. However, here the fuel consumption of the ramjet is high. Furthermore the drag of the duct when not in use is very large. Therefore, if a turbojet or turbofan is the main power plant of the aircraft, then a wiser plan is perhaps to inject fuel into the tail pipe of the main engine for obtaining a short burst of large thrust.

2.43 For supersonic application, it is essential to reduce the frontal area of the duct for low drag. This means a small combustion chamber cross section and high flow velocity. Efficient and intense heat release at high flow velocity is one of the most urgent problems in ramjet development. This problem and the problem of efficient diffusor and exit nozzle design have to be solved by concentrated efforts with the help of high speed wind tunnels.

2.44 The high fuel consumption of ramjets at subsonic velocities is due to the low pressure in the combustion chamber obtainable by ram. By carrying out the combustion in a confined chamber, like an explosion, the pressure at the end of combustion can be raised. This is the pulsojet. Its feasibility was first demonstrated by the engine of the German V-1 flying bomb. This type of engine in its present form has a fuel consumption between the ramjet and the turbojet in the subsonic and transonic range. Thus, its advantage in simplicity compared with the turbojet is counterbalanced by the high fuel consumption. Therefore, the answer to the question of whether it will be used for propelling pilotless aircraft in these speed ranges depends on two factors: (1) the development of simple expendable turbojet units, and (2) the possibility of improving the fuel economy by improved injection and combustion methods.

Ranges Attainable at Various Speeds



2.45 At supersonic speeds, the present type of pulsojet with the spring valve is definitely inferior to the ramjet. However, theoretical considerations show the possibility of removing the valve and depending on the inertia of the air column for valve action. If this could be done, then the performance of pulsojet would be comparable with that of the ramjet. Here the choice between pulsojet and ramjet is difficult because of present meager knowledge of these power plants. Only continued experiments can answer this question.

2.46 Jet-propulsion devices using chemical propellants without the benefit of the atmospheric air are called rockets. The combustion in the rocket motor is made possible by having the oxidizer and fuel contained either in a single compound or in separate compounds. In the first case, we have the monopropellant; in the second case, the multipropellant. Since the oxidizer is carried in the propellant, where as for the thermal jets, the oxidizer, oxygen, is supplied by the atmosphere, the specific consumption of propellant is much higher for rockets than for thermal jets. For rockets, this value is generally 14 to 16 lb/hr/lb-thrust. However, the rockets have two distinct advantages when compared with other types of jet-propulsion devices: First, the installed weight per pound of thrust of the power plant, excluding the propellant, is extremely small. For instance, the power plant weight for the V-2 rocket is only 0.03 lb/hr/lb of thrust. The second advantage is that the thrust of the rocket is independent of the forward motion and the altitude. In fact, the thrust of the rocket even increases slightly with increase in altitude. These characteristics of the rocket motor immediately indicate that their most efficient applications must be either (1) for short operating duration so that the total weight of the power plant plus the fuel is small in spite of the heavy consumption, or (2) at extremely high altitudes so that no other power plant can produce sufficient thrust.

2.47 As far as chemical energy is concerned, no great advance can be expected in increasing the heat value of the propellant so as to reduce specific consumption. The future development must rely on detailed improvement of the characteristics of the propellant so that a more compact and efficient power plant can be designed.

Since gas propellants require bulky containers, they are impractical for use in aircraft. Therefore, we are restricted to solid and liquid propellants. The solid propellant may be the lightest unit if the application calls for very short duration, for example, one to 30 seconds. Such applications are: assisted take-off, launching of pilotless aircraft, and boosting of aircraft during flight. Such boosting may be necessary when the aircraft has to pass through the sonic range of velocity. For short-time solid-propellant rockets are able to develop a very high thrust. If the application calls for somewhat longer duration, the liquid-propellant rocket will be, in general. more desirable. There are three methods of feeding the liquid propellant into the rocket motor, namely: by use of a pressurized gas, by means of a gas generator which produces the necessary gas pressure, and by pumping. The first method can be applied only for very short duration. For longer duration, one of the two other methods must be applied where the gas generator may be simpler in design and construction than the pump.

2.48 If the rocket is to operate in the dense atmosphere of lower altitudes, as in the case of antiaircraft missiles, the drag of the missile is of primary importance.

We wish to reduce the frontal area and, hence, the volume of the missile. Then the propellant should have the highest impulse per unit volume. At present, the best propellant in this respect is the nitric acid - aniline combination. If the rocket is to operate in the rare upper atmosphere, for example V-2 rockets, the drag of the missile is of secondary importance. Then, the propellant should have the highest impulse per unit weight. At present, the best propellant in this respect is the liquid oxygen and liquid hydrogen combination. The extremely low temperature of the liquid hydrogen may cause difficulties in the design. A more practical choice may be the combination of liquid oxygen and liquid hydrazine.

2.49 For more efficient design of the liquid-propellant rockets, improvements can be expected when we have a better understanding of the combustion and the flow in the motor. The cooling of the motor should be particularly studied for building long-duration rockets.

2.50 In case of solid propellant rockets, our aim in research and development should be a more versatile propellant or a series of propellants which can cover the range of applications as to operating duration and operating ambient temperature. Much reduction of the unit weight can be achieved by reducing the pressure in the motor during burning without causing unstable combustion.

2.51 Since the end of the war, the importance of atomic energy has become more and more evident. Without doubt extensive research will be done in all countries with the goal of using atomic energy as a source of power. From the point of view of aircraft propulsion the problem is centered on the question: Can we replace the combustion chamber of a rocket or a thermal jet by a nuclear reaction chamber? In the case of the rocket we have to transfer the heat released by the nuclear reaction to an appropriately related working fluid, in the case of the thermal jet, to the air.

2.52 The nuclear process in a system containing fissionable atoms, for example, a uranium pile, is characterized by the so-called multiplication factor. This factor indicates the increase of the number of neutrons produced by nuclear fission for every free neutron present in the system at a given time. If the multiplication factor is larger than unity, a chain reaction occurs. The number of neutrons, the number of atomic fissions, and the amount of released energy increase exponentially with time. If the multiplication factor is smaller than unity, the process stops. The first case corresponds to an explosion in a combustion chamber; the second case is analogous to an expiring flame. Hence, in order to substitute release of atmoic energy for steady fuel combustion, one needs a system in which the multiplication factor is exactly one. One needs a method which regulates the process in such a way that the multiplication factor is kept with sufficient accuracy at a value equal to unity.

2.53 As a matter of fact, such systems are already operating, for instance, in the manufacturing process of plutonium. However, they operate at the present time at low temperatures and are relatively heavy. At the level they now operate, they would be prohibitive for any aircraft or propulsive device. To be sure, the consumption of material per kilowatt hour is negligible, practically zero. However, the initial weight is large. By use of concentrated fissionable material the weight can certainly be reduced and one can imagine that the present difficulties of increasing the temperature at which the release of heat takes place will be overcome. However, two great impediments would remain: (1) The amount of fissionable material required for the process represents a very high cost and investment in comparison to the power used in any mission of a pilotless aircraft. (2) The strong neutron and gamma radiation makes the application in a piloted aircraft difficult if not impossible.

2.54 However, atomic engineering is at the beginning of its history and it can be expected that if the problems are clearly recognized they will also be solved. Evidently the first stage of development is finished: We have systems with a tremendous ratio between energy available for release and weight. However, we have no possibility, as yet, of releasing energy at any reasonable rate without using a minimum amount of material which represents an immense reservoir of energy out of all proportion to the energy actually needed for one flight, with the exception of the case in which the same fissionable matter is used both for propulsion and warhead. Assuming that the problem of energy release is solved, the following situation would be realized as far as aircraft propulsion is concerned.

2.55 In the case of the rocket ship, which does not use air, a working fluid has to be carried in the rocket. One will choose the lightest gas, i.e., hydrogen, since for the same energy released, hydrogen will give the greatest exhaust velocity and, therefore, the greatest thrust per unit weight of material consumed. It is estimated that if we are able to produce sufficiently high temperatures and high pressures, the thrust produced per unit weight of consumed material could be made about six times the present value. This would increase more than thirty times the range of V-2 type rockets using chemical propellants and would make rocket navigation possible up to the highest altitudes beyond the stratosphere. The "satellite" is a definite possibility.

2.56 If the substitution of nuclear reaction chambers for fuel combustion chambers in ramjets and turbojets is feasible, the question of range would automatically be solved. In other words, if a jet-propelled aircraft with atomic combustion chamber could carry itself in the atmosphere, it would have practically infinite range, since its fuel consumption is practically zero. For this purpose an atomic engine weighing as much as eight or nine pounds per brake-horsepower would be acceptable for use in large bombers for subsonic flight, but for greater performance, such as supersonic speeds, a better specific engine weight would be necessary. This weight must include all moderators and regulating devices, and radiation shielding.

2.57 The application of atomic energy to the propulsion of manned airplanes will probably be out of the question for a very long time because of the difficulty of protecting efficiently the personnel from the disastrous effects of radiation. The necessary shielding, at least at present, implies prohibitive weight. However, for a pilotless airplane there are definite possibilities. The problem should be attacked urgently and with adequate personnel and means.

PROBLEMS IN MATERIALS

2.58 Aircraft materials have been perfected continuously and new materials studied with much promise. Neverthless, it can be stated that we do not yet have the ideal material which would fulfill both the requirements for strength and for aerodynamic behavior. Whereas, for slow airplanes it was sufficient that the elastic limit of the material be not surpassed, for high-speed airplanes it is esesntial that the aerodynamic shape of wing and body be maintained with a minimum of deformation, avoiding any local waviness. Also, a perfectly smooth surface is necessary, and the possibility of keeping the surface smooth in service. These requirements call for improvement in properties of known materials or discovery of new materials of low specific weight, as well as development of methods of fabrication and production to take full advantage of the material properties.

2.59 Another equally important requirement is the development of high-temperature materials for gas turbines and jet propulsion devices. Great advances have been achieved during the past five years. However, the investigations were generally made by purely empirical methods, without consideration of the fundamental character of the solid state of metals from the physicist's point of view. This more fundamental approach will definitely open ways to new horizons in a field where old concepts and methods seem to yield diminishing returns. For application to individual design, a closer understanding of the particular requirements in each case will also aid greatly in material development. We must choose among the multitude of material properties (such as elasticity, plasticity, yield characteristics, impact strength, fatigue strength, etc.) the most important ones for a given design, and not require the optimum in every aspect. This means a closer analysis of the stresses of machine parts, especially under dynamic and high thermal stress conditions.

2.60 An entirely new possibility is the introduction of ceramics as a construction material. Ceramics are particularly heat resistant, as the melting points of these materials are generally much higher than those of the metals. However, the strength of the ceramics now known is usually too low to be used for highly stressed parts. On the other hand, ceramics have not been developed for such purposes before, and much remains to be learned. Two points need to be mentioned particularly: (1) The cost per pound of the ceramic material for machine parts could be many times that of the industrial ceramic materials now used, and thus the possible choice of basic components is much wider. (2) The ceramics can be used as a coating on metallic parts, and thus the temperature resisting property could be combined with the high strength property.

2.61 A different approach to the problem of increasing the inlet gas temperature in gas turbines consists of cooling the parts of the engine exposed to high temperatures. The cooling problem brings up new requirements for the material. Thermal conductivity and thermal extension may become more important than creep at high temperatures. The recently proposed method of cooling by injecting the coolant through a porous material will promote the development of new alloys.

2.62 In rocket motors the need for high temperature resisting material has grown with the increasing demand for longer duration of operation. In view of the very high temperature involved in the combustion of rocket fuels, liquid-cooled chambers and nozzles have been used for long-duration units. The erosion of the nozzle has been a very difficult problem from the material point of view. It seems, however, that erosion occurs only if the temperature of the surface reaches some critical value. Nozzles made of very soft material (aluminum) have been used successfully when properly cooled. It appears that the conditions the material should satisfy to operate properly in a liquid-cooled unit are different from those required for an uncooled unit. In the first case, metals can be used almost exclusively. Thermal conductivity, thermal extension, and machineability are the essential factors in this case. In the second case, most metals will not stand the combustion chamber temperature, and the use of high melting point metals (tungsten, molybdenum, tantalum) and of ceramic materials seems to be justified.

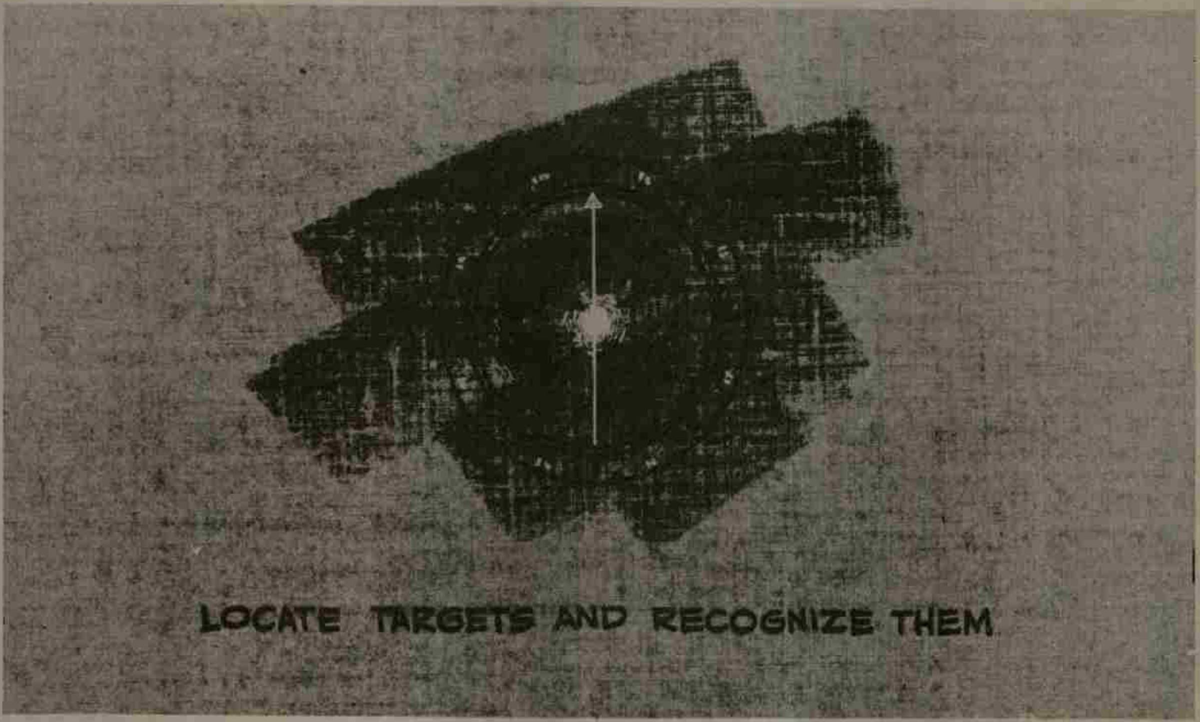
2.63 In the design of nuclear reaction chambers, quite different characteristics of the material must be considered, especially the absorption of neutrons, alpha particles, and radiation, combined with high temperature.

ROTARY-WING AIRCRAFT

2.64 No mention has been made so far of aircraft different from the airplane type. Certainly rotary-wing aircraft, in spite of serious limitations, have military applications in airborne operations, as well as a host of special duties such as rescue, liaison, etc. The application of jet propulsion to rotary-wing aircraft is worthy of further investigation, and other forms of rotary-wing aircraft, such as the cyclogyro and gyrodyne, should be more fully explored. A somewhat fantastic idea is a helicopter driven by atomic energy, which could serve as an observation station for a very long period of time at considerable altitude, reporting data to the ground or to an airplane.

AIRSHIPS

2.65 The airship is in principle a slow-velocity aerial vehicle, with the advantage of large cargo carrying capacity. Aerodynamic development and development in propulsion may considerably increase the speed of the airship. Since the greatest portion of the drag of an airship consists of skin friction, laminar boundary layer control may cause a very essential reduction of the drag. Another less important improvement could be derived from a rear propeller drive, consisting of shrouded propellers located in the stern of the ship. Boundary layer control, of course, would probably require a construction material suitable for forming a smooth surface with sufficient local strength.



LOCATE TARGETS AND RECOGNIZE THEM

LOCATE TARGETS AND RECOGNIZE THEM

3.1 In order to accomplish its mission the Air Forces must not only be able to move swiftly and transport loads through the air but the movement must be directed to bring the aircraft or missile and its means of destruction from a base to the vicinity of a military target which may be anywhere on the globe. The target must then be recognized. The technical problem is one of locating two objects, the aircraft or missile, and the target, with respect to some frame of reference and of bringing the two locations in coincidence by guiding the aircraft or missile. It is convenient to consider the problem in three successive phases: (1) Reconnaissance, or obtaining advance knowledge of where targets are to be found so that an attack may be planned; (2) navigation, or guiding the aircraft or missile from the base of operations to the vicinity of the target; and (3) recognition of the target immediately prior to its attack.

RECONNAISSANCE

3.2 The basic frame of reference for locating targets is an accurate and precise survey map of the earth's surface, but before targets can be located on a map, we must first know that they exist. The first procedure will undoubtdely be to make factual surveys of enemy industry, transportation systems, and military installations by the usual methods involving agents traveling within enemy territory, study of prewar economic data, and similar methods. The next step is to obtain information by reconnaissance flights of aircraft or missiles using every known method of aiding the senses of man, including aerial photography, radar, heat detectors, detectors of radioactive materials, etc. The enemy will try to disguise his main factories and other installations by camouflage and decoy targets and will try to interfere with the operation of our scientific aids, for example, by providing smoke screens and by electronic jamming. We must, therefore, employ a variety of means, comparing the results of one against the others. This problem of determining precisely where the target is located in the first place requires the judgment which can only be supplied by the human brain, and cannot be entrusted wholly to any single mechanism as may perhaps be possible in the navigation and attack problems.

AERIAL PHOTOGRAPHY

3.3 If accurate maps of the enemy's territory are not already available they must be provided by our own forces and the most feasible method is by means of aerial photography. Methods of aerial photography have been highly developed and will continue to be useful even if aircraft fly faster and higher. It may happen that difficulty is experienced with clouds and haze in which case radar methods can be used as discussed in the next section. Maps made from aerial photographs may or may not show the actual location of all possible targets but they will show the shape and location of cities, important rivers, coastlines, mountains, and other natural features and they will serve as the basic frame of reference for location of strategic and other fixed targets.

3.4 Aerial photography is also used for detailed surveillance of enemy territory and for the detection of specific military targets. The long period of time which is available for the study of reconnaissance data usually enables the detection of decoys and camouflage and permits exact location of the target. Concealment by camouflage can generally be defeated by color photography or stereoscopic photography, both of which have been highly developed. Few pigments useful for optical camouflage match the colors of the surrounding territory so perfectly that they cannot be detected by color photography with suitably selected filters. Stereoscopic photography enables the detection of the relative heights of objects in the field of view which cannot be changed by application of paint.

RADAR SURVEYS

3.5 Useful maps can be made by photographing the indicator scope of an airborne radar and the detail is greater the narrower the radar beam, i.e., the shorter the wave length for a given antenna size. It is, in fact, desirable to provide special reconnaissance radar equipment in a special aircraft whose express function is to provide large and clear map-like presentations of the terrain suitable for photographing. Such records are useful not only for making the usual line maps but as guides to bombardiers when radar methods of bombing are used. Radar reconnaissance can be made at night and through clouds. It penetrates the nets and cloths commonly used as camouflage materials, and may even penetrate natural cover like forests under certain conditions.

3.6 Cities and large industrial installations are usually easily detected in radar photographs. Smaller targets can be detected under suitable background conditions. Objects surrounded on one or more sides by water such as bridges, piers, ships, etc., are easily detected by modern radar equipment.

HEAT SURVEYS

3.7 Underground installations cannot be detected either by aerial photography or by radar, and other means must be sought. Any large industrial plant uses considerable amounts of power which is eventually turned into heat by friction in the machines, losses in electric motors, electric lights, air compressors, etc. In an underground plant the heat must be conveyed to the surface through a suitable ventilating system except in very unusual circumstances. The hot air exhaust pipe may be detected by sensitive heat meters carried in reconnaissance aircraft. The same equipment is effective in detecting optically camouflaged industrial plants and in differentiating between real and decoy targets.

ACOUSTIC METHODS

3.8 The present war saw the development of sonobuoys for detecting the presence of submarines. These devices dropped from aircraft into the sea contain microphones

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to pick up underwater noise and a radio transmitter to relay the information to the reconnaissance aircraft. It is practicable to use similar devices against surface and underground targets which give off considerable noise as is the case for many types of industrial plants.

MAGNETIC METHODS

3.9 The present war has also brought the development of magnetic methods of detecting submerged submarines. In principle the same methods should be applicable to the detection of underground factories. Because of their short range of detection these devices are not at present highly practicable for this purpose.

ATOMIC POWER PLANTS

3.10 Plants engaged in the manufacture of materials for atomic bombs or atomic power plants may be detected not only by the heat given off but by the special types of radiation from them which penetrates considerable thicknesses of earth. Suitable airborne equipment can probably be designed for the detection of such radiation.

NAVIGATION

3.11 Having fixed the geographical location of the enemy targets the next step is to bring the aircraft or missile to the vicinity. The central problem of navigation is to determine quickly and accurately the geographical position of an aircraft. The ideal situation is to have available continuously the position of the aircraft regardless of weather conditions, preferably in the form of a plot on a map showing the history of the flight up to the present moment. As the speed of the aircraft increases, the time required to obtain the position must be reduced. For example, an aircraft flying at 1200 miles per hour traverses 20 miles in one minute, and it would be necessary to reduce the time to less than three seconds if an accuracy of one mile were desired. It is obvious that automatic observing and computing devices are required.

POSITION FINDING

3.12 The methods available for locating the position of an aircraft may be classified in various ways. They will be discussed here under the headings visual methods, dead reckoning, and radio and radar methods, the greatest emphasis being placed on the radar methods because they seem to offer the greatest possibilities of attaining the ideal.

VISUAL METHODS

3.13 When the ground is visible, the position of the aircraft may be obtained by referring to visible landmarks such as cities, railroads, rivers, mountains, lakes, lighthouses, etc., and comparing them with a map. This simplest method of navigation, known as air pilotage or piloting, is useful primarily over land in clear weather and over territory for which maps are available.

3.14 Over the oceans, also over land and above clouds when celestial objects are visible, the methods of celestial navigation may be used. This procedure amounts fundamentally to a determination of the position of the aircraft relative to the geographical position of one or more celestial bodies which is known if the time is known. Much ingenuity has been exercised in developing aids for converting the observed data into position of the aircraft in the shortest possible time. Attention should be given to the problem of automatic celestial navigation of pilotless aircraft.

DEAD RECKONING

3.15 Dead reckoning is the method of estimating position by keeping an account, or reckoning, of the course and distance from a previously known position. The basic observed data are the air speed and the compass course, but suitable corrections must be made for air temperature and pressure to give true air speed, for declination and deviation to give the true heading, and for the wind.

3.16 Much of the human labor involved in this method has been removed by the development of the flux-gate compass and of instruments for measuring true air speed in conjunction with a device known as an air position indicator. In this device, the compass heading is combined with true air speed automatically to give latitude and longitude, starting from an initial setting at a known position. The mechanism takes account of the fact that a degree of longitude is of varying length at different latitudes and functions accurately except at very high latitudes. The compass corrections may be set in manually from time to time.

3.17 When science has perfected a satisfactory ground speed indicator not dependent on ground stations, the mechanized dead-reckoning system, or ground position indicator, will be a most effective navigational aid. Its weakness is that the errors are cumulative and that it must have been in operation continuously from some known position. Its advantage is that the equipment is all on the aircraft and operation is not dependent on receiving radio transmission over long distances. The method of dead reckoning is the one method that is always available.

3.18 The navigation employed in the V-1 and V-2 long-range missiles was essentially that of dead reckoning. In the case of V-1, the altitude was automatically controlled, the heading was determined by a magnetic compass which monitored the directional gyro of the autopilot, and the distance was measured by an air log. At the preset distance the bomb was made to dive on the target. In the case of V-2, the navigation occurred during the burning period of the rocket motor. The vertical heading was controlled by an elevation gyro, the azimuth by a radio beam, and the propulsion was cut off when a fixed speed was reached as determined by an integrating accelerometer.

3.19 The accuracy obtainable by dead-reckoning methods is of the order of from two to five percent of the range from the last known position, the exact value depending not only on the type of measuring instruments and computers but also on atmospheric conditions. For example, the accuracy of current air position indicators is

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such that the error infrequently exceeds four percent and averages about two percent. The errors of measurement and computation can probably be reduced below one percent with continued improvement in instrument design. The principal source of error is the variability and uncertainty of the wind. This error decreases as the speed of the missile or aircraft increases.

RADIO AND RADAR METHODS

3.20 Prior to the introduction of radar techniques, many radio aids to navigation had been developed. Two-way radio telephone communication and the broadcasting of meteorological information are of incalculable assistance to navigators. For regular air routes the system of radio beams radiating from radio-range beacons and the radio marker beacons enable navigation under conditions of zero visibility. This system has been highly developed for commercial air transport in the United States. The beam defines a specific track in space, enabling correction to be made for wind drift. The information is independent of any transmission from the aircraft and the number of aircraft which can receive the information simultaneously is unlimited. However, there are technical difficulties at the radio frequencies used by the present system associated with the effects of the terrain and of the ionosphere on radio transmission at those frequencies. The trend is toward the use of higher frequencies and to methods dependent on microwaves and pulse transmission.

3.21 In the preradar period there was extensive development of aircraft radio direction finders, and homing devices, and of systems of aircraft location by direction finding from ground stations. Information so obtained was used for occasional computation of position as a fix in connection with navigation by dead reckoning. The most highly developed form of radio direction finder is the automatic radio compass which gives direct readings of the bearing relative to the axis of the aircraft of any radio station to which it is tuned. Indicators are available which combine this indication with that of a flux-gate magnetic compass. The same technical difficulties are encountered as for the radio-range system at the frequencies commonly used because of the effects of terrain and ionosphere on the transmission giving rise to night effects, multiple and bent courses, etc. In any system based on direction finding the errors increase with the range. Perhaps the most elegant beam system is the modern German "Sonne" system which allows an observer to determine his bearing relative to a land station with an accuracy of the order of 1° at ranges up to 1000 or 2000 miles.

3.22 Radar has developed many new techniques which are described in greater detail in the reports of the radar consultants, *Radar and Communications.* The development of microwave radar makes it possible for the navigator to "see" the terrain under blind-flying conditions and to use the simplest of all methods, air pilotage. In X-band and shorter wavelengths, the resolution is sufficient for identification of rivers, streams, bridges, rail lines, and other surface features. In addition, the range of radar vision is greater than that of the eye, so that over the sea, land may be "seen" at ranges of from 50 to 100 miles. When over land, or at sea with the aid of radar buoys, drift may be determined and combined with an air position indicator to give a ground position indication. An accuracy of the order of two percent of the distance traveled since the last fix is attainable. This method of radar navigation requires no ground stations.

3.23 The pulse techniques of radar have given rise to the development of a new technique of position finding based on measuring distances rather than directions to known points, hence called telemetric. The known points may be marked by radar beacons which provide strong identifiable artificial echos. When "interrogated" by receiving a signal from a microwave transmitter in the aircraft, the beacon transmits an echo, and the time interval from pulse emission to receipt of echo is a measure of the distance. Even a single beacon enables a fix within the accuracy set by the width of the radar beam. Much greater precision is obtained by measuring simultaneously the distance from two beacons, the procedure used in the British "H" system and Shoran. The traffic capacity of this type of system is limited.

3.24 Another telemetric method is the hyperbolic method in which pairs of ground stations emit synchronized pulses. The pulses are received in the aircraft and the time difference between the arrival of pulses from the member of a pair is measured. This locates the aircraft on a hyperbola and two such hyperbolas give a fix. The aircraft requires only a receiver and the traffic capacity is unlimited.

3.25 The range of microwave systems extends to the optical horizon or only slightly beyond. For long ranges a relatively low radio frequency must be used. The hyperbolic system of navigation operating at frequencies of two megacycles per second or lower is known as Loran. The standard system now in use has a range over water of 700 nautical miles by day and 1400 miles by night with errors of from 0.1 to 10 miles depending on the geometry of the lines of position. A system under development is expected to have a range of 1200 miles by day and 2000 by night with errors of from one to two miles at 1000 miles. Laboratory techniques of pulse comparison indicate the possibility of improving the accuracy by an order of magnitude.

3.26 The process of hyperbolic navigation may be compared with that of celestial navigation. The determination of lines of position is essentially similar except that the mathematics is more complicated. However, the unchanging character of the lines of position obtained from fixed reference stations in contrast to the moving stars permits precomputation. Charts may be prepared in advance for pairs of stations and the results are permanently useful so long as the stations are maintained because the lines of equal time difference are fixed with respect to the surface of the earth.

3.27 There is no technical obstacle to a complete mechanization of the receiver so that the output is either in the form of dial counters giving Loran coordinates or a plotting board which will plot the position continuously on a Loran chart. It is then a short step to connect the output to the rudder so that a predetermined track may be followed automatically.

3.28 Since hyperbolic navigation requires only a receiver on the aircraft or missile, and the traffic capacity is unlimited, it is the most promising system for the control of large numbers of long-range ground-to-ground pilotless aircraft. As now visualized, special ground stations would be adjusted so that the hyperbolic line of position corresponding to a fixed time difference for which the missile receivers are set passes through the target. Aircraft could be launched from many points in a large area; all following a preset course until they intercepted the line of position through the target. They would then change course and follow the line of position to the target. The altitude would be controlled independently and the dive to the ground would be initiated

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by reaching the appropriate position line of a second pair of ground stations. This type of attack could be operated without close coordination between control group and launching crews; their operations would be practically independent.

MAGNETIC METHODS

3.29 The use of the compass for determining direction on the earth's surface is well known. It has been repeatedly suggested that additional measurements on the earth's magnetic field may yield another method of navigation. Thus, in theory, measurements of the magnetic dip and of magnetic field strength give two numbers which could serve as coordinates of position to be related to ordinary geographic coordinates by suitable surveys. The principal weakness of the method is that a recent survey over the territory to be traversed is necessitated by the secular variation of magnetic properties. In addition, the accuracy would be severely limited by diurnal variations and magnetic storms as well as by the lack of suitable airborne instruments. The method may be worthy of some further study.

3.30 It is probable that no single method will answer all of the navigation problems of piloted and pilotless aircraft. However, there are available scientific methods and techniques in rich variety which make possible continuous knowledge of position independent of adverse meteorological conditions.

RECOGNITION OF THE TARGET

3.31 As the aircraft or missile approaches the general vicinity of the target, the bombardier, gunner, operator, or the mechanism of the pilotless missile (if of the target-seeking type) must find and recognize the target preparatory to the attack. Most of the methods useful for reconnaissance are also useful for recognition with the exception of photography which takes too much time.

3.32 In the case of large and extended targets such as cities, factories, or other major installations above ground, when the visibility is adequate, there is no difficulty. The eye may be aided by a suitable telescope, and the mind may be assisted by suitable aerial photographs and maps. The photographs, maps, or sketches may be constructed in relief to show the appearance when approached at the normal approach altitude and thus facilitate recognition.

3.33 Photographs of radar indicator scopes obtained on reconnaissance missions may be used in the same manner as aerial photographs as an aid to recognition.

3.34 Skilled operators have no difficulty in recognizing many types of targets directly on the radar indicator. Cities, bridges, piers, ships, islands, beaches at the coast line, and aircraft can all be recognized without difficulty. Special techniques are available for detecting moving targets which are especially useful for aircraft detection but which are also applicable to ground targets under some conditions.

3.35 If agents are available in the enemy territory, they may mark targets otherwise invisible by portable radar beacons or, in special cases, such marking beacons may be dropped from the air.

3.36 Radar methods may be used to follow the aircraft or missile from ground control stations and to direct the pilot or actually remotely control the aircraft to a target whose map location is known by previous reconnaissance.

3.37 The reconnaissance methods using heat detectors, detectors of special types of radiation from radioactive materials, magnetic measurements, or acoustic radiosondes dropped on the ground may find application in recognition of special targets. These methods as well as radar are applicable to the homing control of missiles. In fact any target possessing any peculiarity as to physical properties which set it off from its background can be recognized by a suitable homing intelligence device.

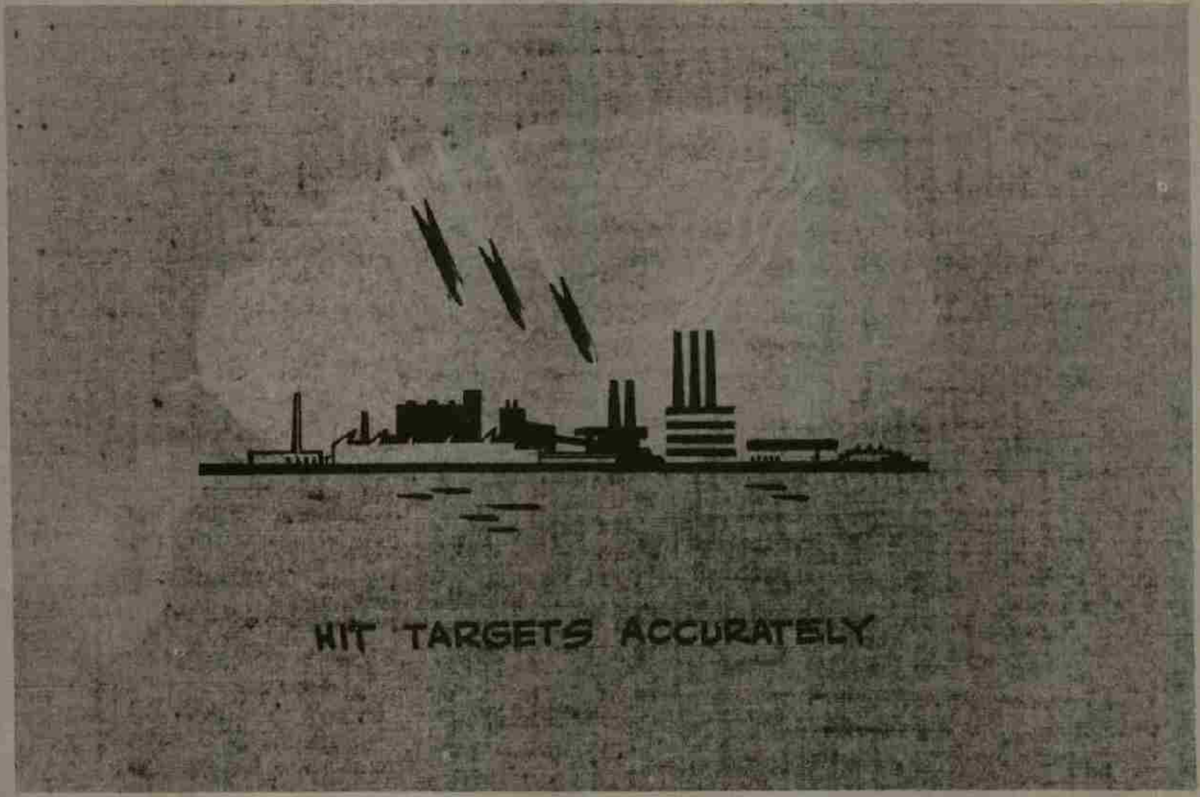
3.38 Especially in the case of pilotless aircraft, the operation of recognition and control may be carried out at a remote point by the aid of radio repeat-back of information from a television camera or a radar search set.

See further reports of the Scientific Advisory Group:

Guided Missiles and Pilotless Aircraft

Guidance and Homing of Missiles and Pilotless Aircraft

Radar and Communications


HIT TARGETS ACCURATELY

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4.1 The degree of accuracy required for successful strategic bombing is one of the most discussed topics of aerial warfare. Visual bombsights were designed for so-called pin-point bombing. However, war experiences show that this type of bombing is applicable only to a limited extent, because of weather and enemy interference. Hence, in most cases pin-point bombing has to be replaced by area-bombing, i.e., by bombing with an accuracy obtainable by radar blind aiming, by dropping the bombs simultaneously from a large formation, or by missiles equipped with automatic pilot. In the future, bombing in large formations will probably be prevented by improved antiaircraft devices. It will be necessary to revise bombing equipment in the light of future methods of strategy, including the use of atomic bombs.

4.2 The ability to hit targets accurately is dependent on the aerodynamic performance of the bombs, meteorological conditions, the accuracy of the bombsight, and the abilities of the bombardier. The study of the aerodynamic characteristics of bombs at low speeds has been well developed, but further research is needed in the transonic region. A considerable loss in accuracy of bombing from high altitude, originally attributed to the effect of high speed on the aerodynamic characteristics, was finally traced to structural failure of the fins. However, there is some evidence of an adverse effect of high speed on stability for certain types of bombs.

4.3 Bombers require bombsights in order to hit the target. In general, it can be said that the faster an airplane travels the less accurately it can drop its bombs. If bombers are actually going to fly at speeds around 1000 mph it cannot be said with certainty that present bombing precision can be improved upon or even maintained in spite of ever increasing complexity of the bombsights. Errors in the release mechanism and ballistic trajectories become important at high speeds. The reaction time of the bombardier will have a significant effect on precision.

4.4 Any self-contained bombsight has two parts, the sighting means and the computer. In optical bombsights the sighting means is a telescope; in radar bombsights it is a radar. There are only trivial differences in computer design in the two cases.

4.5 The faster the bomber flies, the farther ahead the sighting means must see; above 400 or 500 mph only radar can see far enough and there is no sense in trying to develop optical bombsights for such aircraft.

4.6 But a fundamental difficulty with radar is that in order for it to see far and also clearly, its antenna must be wide; this is a tendency in flat contradiction to aerodynamical trends for high-speed aircraft.

4.7 The design of bombsight computers aims not only at accuracy but at decreasing the time required for manipulation after the target is recognized. This has a profound effect on what is required of the associated radar since the more time required to adjust the computer the father away the target has to be recognized, and there is a practical limit to this. The recent war has seen the beginning of the development of computers suitable for use in dive and glide bombing as well as for offset bombing, i.e., sighting at some more easily recognizable point whose position relative to the target is known. These developments give greater freedom of flight path to the bomber.

4.8 Pilotless bombers whose range is limited to less than approximately 100 miles may be entirely directed by means of precision ground-based devices employing radar principles. Extensions of the Shoran equipment to automatically control such aircraft can be perfected.

4.9 For longer ranges, studies should be made of the use of airborne relay stations such as airplanes, rotary-wing aircraft, or missiles, and of combinations of ground-based directors with a homing device in the vehicle. In order to achieve long range the ground stations must operate on relatively long wavelengths such as are employed by the Loran system; this connotes low precision. Such means must thereby be employed to bring the missile to the vicinity of the target, whereupon the homing device may take over control.

4.10 Studies of the optimum locations of Loran stations for this purpose should be undertaken; the possibility of mounting such stations on submarines should be explored. The possibility of long-range guiding by automatic celestial navigation should also be investigated.

4.11 The homing devices used may react to any radiation emitted from the target or may, radar-like, themselves illuminate it. Radio waves, thermal radiation, light, and certain of the high-energy radiations from nuclear reactions may be considered as practical for homing purposes; if the device homes on radiation emitted from the target, then to a certain extent it can automatically recognize the target. Thus, a device made to home only on gamma rays would only home on unshielded atomic power plants, whereas one made to home on radio waves would neglect atomic power plants in favor of radio transmitters. This advantage is not so favorable as it sounds however, since the possibility of erecting decoy targets always exists, even for atomic energy plants.

4.12 For extremely high-speed missiles like V-2 the homing problem is made very difficult by the extremely long range required of the detecting device.

4.13 Magnetic airborne devices are not regarded as offering good prospects for guiding pilotless aircraft. It is to be doubted whether devices sensitive to sound will be of any use either.

4.14 Means for guiding missiles may be ground-based or air-based regardless of whether the missile itself is launched from ground or air. The particular tactical need will determine which of the four possible combinations should be used. It may prove upon further study that the guiding and launching means should be similarly based.

4.15 The most difficult problem in launching missiles from the air is to launch them in the proper direction, if the target is nearby, so that they will require a minimum time of flight. The proposed defense of very heavy aircraft by this means may prove particularly difficult for this reason.

4.16 While use is made of all available aerodynamic knowledge in the design of pilotless bombers, especially in the field of transonic and supersonic aerodynamics, there are many special problems introduced by the use of homing devices which must be solved if high accuracy is to be attained. For greatest accuracy the missile should look in the direction of travel of its center of gravity except as corrections for wind and target motion are introduced by a course computer. An aircraft of conventional design operates at a variable angle of attack dependent on load and speed, and boresight errors would arise as discussed by Dr. H. L. Dryden in "Present State of the Guided Missile Art," Part I of the SAG report *Guided Missiles and Pilotless Aircraft.*

4.17 Perhaps the major problem in the design of a pilotless bomber is the coordination of all elements to give stable operation without excessive hunting, i.e., systems coordination. The lag characteristics of the intelligence device and of the autopilot and associated servomechanisms are perhaps the most important factors, but the stability and accuracy are dependent on many other factors including the aerodynamic characteristics of the missile.

4.18 In addition to bombs released from manned airplanes or carried by guided pilotless bombers, guns and rockets play an important role in aerial warfare. Rockets, stabilized either by tail fins like a bomb or by spin like a shell, are one of the important new developments of the present war. Comparatively large missiles may be fired with no recoil on the airplane from very simple launching devices. Their accuracy has been continually improved with better knowledge of the aerodynamics of rockets and with the development of rocket-sighting devices. Their effectiveness by the application of proximity fuses has greatly increased.

4.19 The development of fire-control equipment has had little difficulty in keeping ahead of the development of guns. The range, accuracy, and rate of fire of the guns are not at all of a magnitude commensurate with the needs of aircraft traveling at supersonic speeds. Problems which must receive increased attention are the adaptation of guns and aircraft so that neither the aerodynamic performance of the aircraft nor the effectiveness of the gun is imparied. One typical engineering problem is the elimination of vibration which impairs the accuracy. It will do very little good to make superior gunsights if the guns are not also improved.

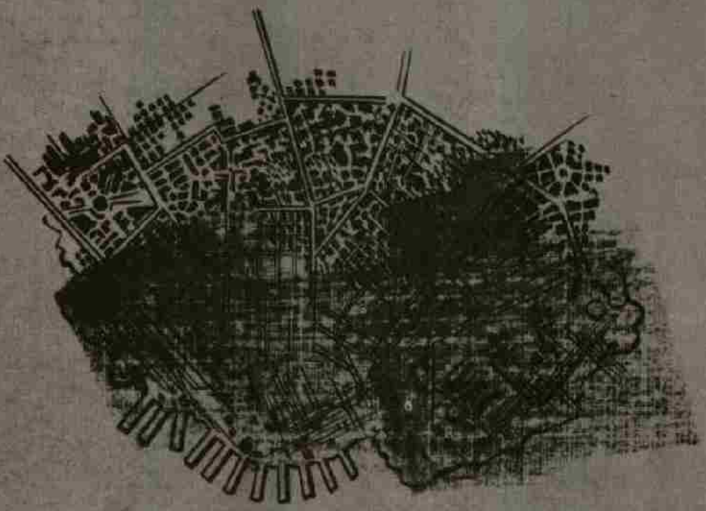
4.20 Many of the present computers for antiaircraft fire are based on the assumption that the two aircraft are traveling in straight lines. This assumption does not give sufficient accuracy. A fundamental study should be made of the types of paths usually followed by aircraft in combat and gunsights should be redesigned on the basis of the results of the study.

4.21 As the speed of airplanes increases to the supersonic range, a further limit on accuracy is imposed by the unalterable reaction time of the human operator. In principle, this difficulty can be overcome by making machines which are more and more automatic. Some progress had been made in this direction in the experimental radar-controlled guns which could be locked on any desired aerial target and thereafter would automatically keep the guns pointed at it. If such devices can be developed of sufficiently low weight, the man would be called upon only for the will to fight, a trait which so far has not been built into any automatic device.

4.22 It is certain that instruments of control will become more complicated in structure as they are required to perform more and more functions formerly carried out by men. The problem of instrumental reliability and satisfactory operation then becomes urgent.

4.23 Reliability can only be assured by a continuing program of development not only of the instruments themselves but also, and equally important, of the component parts of which they are made. Such development of improved components may not be adequately supported by the ordinary economic forces of peacetime competition and heavy financial support by the Air Forces may be necessary.

4.24 Satisfactory operation can only be assured by careful selection and training of personnel and above all by careful designing of instruments in accordance with the psychological and physiological needs of the men who are supposed to operate them. A special staff of persons trained both in engineering and psychology may be needed to carry out this kind of development. It would be the prime purpose of this group to insure that the design of aircraft, of the offensive armament, and of the instruments meant to control them are coordinated so that one integrated fighting machine comes out. The present tendency to design an airplane and then hang on guns, rockets, bombs, radar, and sighting devices as a multitude of accessories must cease.



CAUSE DESTRUCTION

ABILITY TO CAUSE DESTRUCTION

5.1 The war which just ended was the first one in which areial bombing played a decisive role. An immense amount of work was put into the development of bombs, bombing instruments, and bombing tables. Much of the present knowledge of the results of bombing and the effectiveness of bombs was obtained by systematic observation and analysis. A new branch of terminal ballistics developed, dealing with the effect of bombs on their targets. Since the heat released by our present molecular explosives is near the possible upper limit, great attention was paid to the most efficient use of the limited amount of energy. Then with the appearance of the atomic bomb, the destructive power of one bomb was made equal to the effect of 20,000 tons of explosive. The question arises, should the efforts for further improvement in construction and use of conventional bombs be continued, or should the whole material available be worked up for the archives and further study be concentrated on the atomic phase of the problem.

5.2 It is true that after the discovery of the gun, archery gradually became a sport instead of a military art. This process of substitution was slow; however, analogous processes in our age may become very rapid. Hence, we might argue that atomic bombs are the future means of destruction and we may forget about conventional bombs. The arguments against this theory are the following:

(1) Production facilities of atomic bombs may be limited, so that their use will be restricted to the most important actions. (2) In many cases of future warfare we shall not be willing to use means of utter destruction. (3) Economic and political reasons may suggest the use of conventional explosives as an alternative to atomic explosives.

5.3 Fundamental features of nuclear processes involved in the functioning of the present atomic bomb do not permit making them of considerably smaller power than those which have been used against Japan. The answer to the question whether the development of conventional bombs should be continued depends to a great extent on whether the developments of nuclear science will produce a variety of bombs in a range of sizes, adaptable to various missions. The gap between the effect of the largest conventional and the present atomic bomb is immense. Warfare is directed primarily to securing the safety of our nation and not to the indiscriminate destruction of others. Hence, it appears that the most reasonable channel for development of atomic weapons is to investigate the possibility of smaller capacities. No one can tell today whether and to what extent this is possible. Since there is no guarantee that atomic bombs can be substituted completely for conventional bombs, the work on development and improvement of conventional weapons must be continued.

5.4 I believe the Air Forces should concentrate its effort upon: (1) getting full information about the destructive power of the present atomic bombs; (2) studying the possibilities of the adaptation of atomic bombs to various missions which proved to be effective against the war potential of the enemy in the last war; (3) studying the possibilities of developing smaller size nuclear bombs perhaps by using nuclear reactions other than fission; and (4) making comparative studies of efficiency and costs of past methods of strategic bombing and future methods using pilotless bombers loaded with either atomic or conventional explosives.

5.5 Special study should be made of the problem of destruction of underground establishments. In the last war submarine berths were attacked with bombs, but with practically no success. It must be anticipated that a considerable portion of the key industries of possible enemies will be located underground in order to escape bombardment. Probably attack on communications leading to the underground factories and depots gives the best possibility of successful neutralization of such underground establishments.

5.6 The destruction of air targets, i.e., aircraft and missiles, has received comparatively little scientific study. Recent tests by the War Department have shown that one pound of high explosives exploding within the wing of an airplane will cause sufficient damage to produce a crash or at least make return from a mission improbable. However, additional study is needed of the damage from blast and fragmentation at distances within the range of proximity fuses. In this application of fragmentation as a means of destruction, considerable progress has already been made by the application of scientific principles to develop controlled fragmentation, controlled both as to size and general direction of travel of the fragments. The theory of blast is now well developed; from this theory, for example, it has been estimated that 20,000 tons of TNT, which is said to be the equivalent as regards blast, of the atomic bomb, will destroy an aircraft one to two miles away. The efficient design of warheads for air to air missiles and ground to air missiles is dependent on accurate information on the destructive effects of both ordinary and atomic explosives when used either for blast or for hurling fragments.

5.7 The destruction of ships offers many new problems in terminal ballistics. The penetration of the armor of battleships and other men-of-war is essentially the same problem as penetration of the armor of tanks. A scientific curiosity of the first decades of this century, the so-called Munroe effect, has been applied in this last war to the development of hollow or shaped charges which have remarkable powers of penetration. Ships are more easily destroyed by underwater explosions.

5.8 "Terminal Ballistics and Destructive Effects," by Dr. N. M. Newmark (Part III of *Explosives and Terminal Ballistics*) describes the present state of knowledge of destructive effects of explosives. This report also contributes suggestions for completing our information on the subject. It is believed that such a program should be carried out because (1) in a transition period such information is certainly needed, and (2) the final picture concerning the relation between the atomic and the conventional explosive is yet uncertain.

5.9 The following conclusions regarding the selection of conventional weapons for attack of various ground targets appear to be generally accepted:

a. The most effective high explosive bomb for attack of light industrial buildings is a GP bomb fused to burst between the roof and the floor. Greater damage is produced to the building and to its contents with this fusing than with instantaneous fusings, or with cratering bombs.

b. Against heavy industrial buildings and heavy machinery, large cratering bombs or penetrating bombs are required to produce severe damage.

c. Against relatively combustible construction, either residential or industrial, incendiary bombs were several times as effective, weight for weight, as any other type of bomb, except possibly air burst of very large blast bombs.

d. Small bombs, blast bombs, and incendiary bombs had virtually no effect on submarine pens and heavy fortifications. Penetrating bombs or large general purpose bombs are required.

e. Against brick wall-bearing construction and against light wood-frame construction, blast bombs are most effective, and air burst at the proper height produces more damage than ground burst or cratering bombs.

5.10 Improvements needed in present conventional weapons depend on the availability in quantity and size of atomic bombs. Since it must be assumed, in the immediate future at least, that only a relatively small quantity of present-type atomic bombs will be available, conventional bombs must be capable of being used effectively against all possible types of targets.

5.11 The following requirements seem to be most urgently needed:

a. Bombs designed specifically for the attack of massive underground installations including shaped-charge bombs, rocket-assisted bombs, and follow-through bombs. Possibly the required improvement in penetration performance can be obtained by developing bomb cases of increased strength.

b. Development of large blast bombs with extremely light cases, to be used with proximity fuses for air burst, as a weapon against targets vulnerable to blast.

c. Development of fragmentation bombs with more adequately controlled fragmentation.

d. Development of fuses with more accurate control of timing, to permit bombs to burst after penetrating the roof of a building and before striking the floor or penetrating the earth beneath. (See SAG report *Explosives and Terminal Ballistics.*)

FUNCTION INDEPENDENTLY OF WEATHER AND DARKNESS

FUNCTION INDEPENTLY OF WEATHER AND DARKNESS

6.1 The goal of the Air Forces is an all-weather air force, i.e., complete independence of weather, both for flying and carrying out offensive and defensive missions. Flying independently of weather includes take-off, landing, and traffic operations without visibility, navigation without contact and minimum influence of the weather situation and wind on the flight path and flying time. The main requirement for carrying out offensive missions in any weather is the replacement of visual bombing and visual fire control by radar methods. The same methods and equipment which are needed to carry out flight bombing and combat operations in cloudy weather serve the same purposes on dark nights.

BLIND LANDING

6.2 There are two aspects to the problem of blind landing, the actual blind landing or blind approach of a single aircraft, and the problem of traffic control in the neighborhood of a landing area, which is in many ways more difficult than traffic control along cross-country airways. The first problem mentioned has been attacked from two different directions, represented by the glide-path-localizer system, and the more recent GCA (ground-controlled-approach) system. In the glide-path-localizer system a direction of approach, and a glide path, are defined in space by fixed radio beams. Through a suitable receiver and indicator the pilot is apprised automatically of his position relative to this path. In the GCA system the position of the aircraft is determined by a precision radar set on the ground and instructions are given to the pilot over any available communication channel. Each system has its advantages and disadvantages and both are certainly susceptible to technical improvement. The radar method is inherently flexible, and it requires no special equipment in the aircraft; however, its traffic handling capacity is now rather restricted and it does require fairly elaborate ground equipment and a highly trained crew. We cannot regard either method as a universal solution of the problem. There may be in fact several future systems, or combinations of systems for different types of airports, ranging from permanent commercial air bases to temporary landing strips at advanced military bases. What is needed, in addition to technical improvements, is extensive experience and a comprehensive program of trials aimed at an integrated combination of all useful aids.

TRAFFIC CONTROL

6.3 Traffic control near an airfield is peculiarly difficult because of the congestion which exists at such a focal point and the necessity of orderly approach to the landing path. Microwave search radar, on the ground, is a powerful aid and is an essential adjunct of the GCA system. It does not, however, solve all the critical problems, which include communication and identification. It ought to be possible for a ground controller not only to know the position and altitude of any aircraft in the vicinity, but to talk directly to any selected one. This requires a multiplicity of channels, and a degree of flexibility and reliability not approached by any existing communication equipment. However, the voice communication techniques available at microwave frequencies are very promising and should be exploited. Incidentally the heavy investment in existing types of equipment is exerting a retarding influence on this development, which we consider extremely important for the future Air Forces.

6.4 Going even further, one can envisage means by which some of the information available on the ground could be relayed to each pilot in the vicinity, almost completely breaking down the barriers of overcast and darkness.

INSTRUMENT FLYING

6.5 Navigation without contact involves, first, instrument flying, that is, controlling the aircraft in a condition of reasonably steady flight on a given course, and second, determining as frequently as necessary the position of the aircraft in ground coordinates. We have to consider also obstacle detection or collision prevention.

6.6 Automatic pilots have been in use since about 1933. In the present form one or more gyroscopes are used to detect rotations of the aircraft, the resulting relative motion is translated into a signal which is amplified and operates the controls. Means are provided to make various adjustments of sensitivity and to prevent self-oscillation. The automatic pilot must be adjusted to the particular type of aircraft and the best adjustment often depends on the roughness of the air. Automatic pilots for pilotless aircraft must be designed to operate without the necessity of manual adjustments in the air.

6.7 Instrument flying in all weather conditions requires a solution of the icing problem which is still a great obstacle to continuous operation of pilotless as well as piloted aircraft.

6.8 An aircraft flying blind can keep track of its position by the sort of aided dead reckoning provided by the ground-position-indicator for some time after a fix in ground coordinates has been obtained. Even with further improvements in instrumentation there will remain the inherent limitation due to lack of precise knowledge of the wind. Airborne radar of reasonably high resolution permits, over land at least, contact flying or direct radar pilotage, which may be used on occasion as the sole means of navigation or may more usually serve to establish frequent fixes for an automatic dead-reckoning instrument. Not all aircraft will be able to afford the space for this facility, and, since the radar picture must be interpreted by a human observer, pilotless aircraft would be required to relay such a picture back to the controlling base.

6.9 A very important means of blind navigation is provided by the long range hyperbolic system, Loran, which has come into wide use. A detailed discussion of the future possibilities of this and related systems is included in the report of the consultants on radar. (See the SAG report *Radar and Communications.*) We should call particular attention to the possibility of increasing the accuracy of such systems at very long range, which has an important bearing on the problem of guiding pilotless aircraft far beyond the horizon.

OBSTACLE DETECTION

6.10 Military operations require the simultaneous operation of large numbers of aircraft under blind conditions. The problem arises of avoiding collission. Any airborne radar with 360° view is capable of performing this function within the limitations imposed by its minimum range and resolving power. The minimum range is fundamentally limited by the pulse length; it is about 125 feet for a 1-microsecond pulse. Hence, while the airborne radar search set suffices to warn of the approach of other aircraft, it cannot be used to guide formation flying in blind conditions in the tight formations employed in clear weather. However, there seems to be no good reason for close formations in bad weather.

6.11 It would be possible to devise systems smaller and less elaborate than a complete search radar to perform solely the function of warning of obstacles. Whether these would be worth while in themselves depends on the type of formation flying, and the type of aircraft, which develop in the future.

WEATHER

6.12 Long range flights in general will be carried out at altitudes "over the weather" thus avoiding most disturbances caused by the weather situation. For this purpose it is generally sufficient to fly at 40,000 feet altitude at moderate latitude and at 50,000 feet altitude in the equatorial zone. Altitude flying involves certain equipment, especially supercharged engines and supercharged cabins. Problems occuring at high altitudes in gas turbine and jet engine operation have to be solved. Furthermore, problems of aeromedicine related to high altitude flying have to be pursued. (Cf. 7.11 to 7.15.) The influence of wind will be automatically minimized by the high speed of future aircraft.

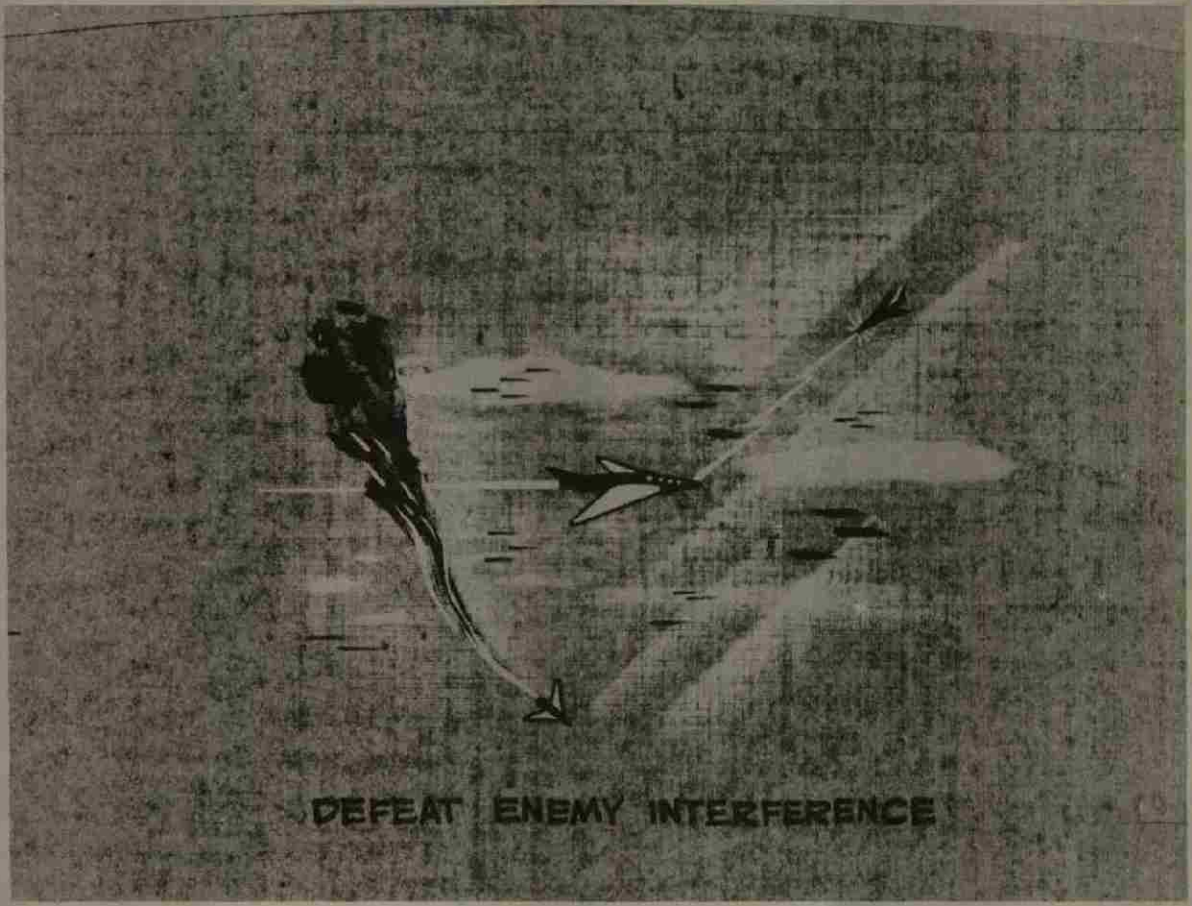
6.13 The age of the "All-Weather Air Force" is drawing nearer. However, it will never be possible to ignore the forces of weather. The key to all-weather flying lies in knowing what the weather will be, understanding its dangers, and circumventing them. Circumvention can be achieved through the development of special equipment (radar, new electronic aids, television) and through careful selection of flight paths. Use of equipment, choice of procedures, and determination of flight paths must be based on the weather forecast. The weather forecast is vital also to ground force operations. Fire control necessitates corrections for atmospheric conditions, chemical warfare cannot be conducted with precision when a weather forecast is lacking, soil trafficability is a function of the weather, and tactics and planning demand an evaluation of what future weather will be. No military operation is wholly freed from the weather; many are bound closely to it.

6.14 Wartime researches led to marked advances in upper air analysis, weather forecasting, weather observation, and the application of weather information to military problems. Particularly noteworthy progress was made in upper air researches. Unprecedented quantities of upper air observations from all over the world provided the fundamental data. Researches led to the formulation of new methods of upper air analysis and to the extension and development of fundamental theories concerning the dynamics and structure of the upper air. Major advances were also made in long-range forecasting. Several long-range forecasting methods were developed and submitted to rigorous trial, using specially devised mathematical techniques to test their validity. The best methods were then utilized to prepare weather advice for pending military operations. The development of new scientific devices, for example, radar, made possible the development of new and improved instruments which extended the range and accuracy of meteorological measurements. In turn, the effective use of radar required additional meteorological studies.

6.15 Future research must be directed towards improving weather forecasting, obtaining vital knowledge concerning the upper atmosphere and ionosphere, and achieving all-weather flight. The theories and data obtained during the war must be carefully checked and sifted to develop new forecast tools. The advent of new weapons, such as the atomic bomb, guided missiles, robot planes, and very high ceiling aircraft makes it necessary to obtain observational data for the upper atmosphere and ionosphere and to develop theories that will make forecasting practicable for these high regions. This involves research in highly specialized branches of physics and meteorology, for such factors as cosmic rays, terrestrial magnetism, ionization, and special radiation effects become important in the high atmosphere. In the achievement of all-weather flight, the weather obstacles to be overcome in flight must be described and measured in detail if equipment and procedures to overcome the weather are to be successfully devised. The atmosphere is of ever-increasing importance as the medium through which the instruments of war are launched. Meteorology, the science of the atmosphere, is of ever-increasing importance to the military. To keep abreast of modern military developments, research in meteorology must be vigorously pursued.

6.16 The conditioning of weather over large territories has not been seriously considered in the past; however, the progress of meteorological science and the possibility of introducing in the air large amounts of energy by nuclear methods, might bring this aim into the realm of possibility. For example, the amount of energy required for forced local release of atmospheric instability in the case of convective storms and for the dissipation of fog should be within the limits of available energy from atomic sources. The general problem consists essentially of three parts: (1) exact knowledge of the weather parameters in the domain in which we want to produce changes, including both instantaneous values and their tendency of variation; (2) methods of computing the future weather, as dependent on the presence or absence of available control measures; and (3) means of applying the controls, such as adding energy in certain regions, modifying the reflection coefficient of certain areas, etc. It seems possible, with the aid of electronic computers, to produce a model of a certain region of the earth's surface and the existing weather situation, which can be used not only for fast weather prediction, but also for direct rapid experimentation, on a model scale, with various control methods.

See the SAG report *Weather*, by I. P. Krick.



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DEFEAT ENEMY INTERFERENCE

7.1 The fight for air superiority includes the annihilation of all the means the enemy has to take the air and the neutralization of his ground defenses. Hence, strategic bombing and the fight for air superiority are intimately interwoven; bombing missions promote air superiority, and the gain of air superiority increases the effectiveness of bombing missions. However, the possibility has to be envisaged that concentrated battles of air power against air power will be fought for control of the air, as battles were fought for superiority on land and on sea. Then, of course, superior experience, superior skill, and superior equipment will decide the outcome.

ARMAMENT VS. SPEED

7.2 It is possible to develop large battleships of the air which would depend for protection on powerful, defensive armament including target-seeking missiles. It must be kept in mind, however, that they will be opposed by fighter airplanes with superior speed and maneuverability, of both the piloted and remotely-controlled variety. This suggests that a more effective method of defense against such attacks will be obtained by increasing the speed, the ceiling, and the maneuverability of the bomber to avoid the inevitable decrease in performance inherent in reliance on complex and necessarily heavy defensive armament. The problems are somewhat similar to those encountered in the past in building up sea power, and the future strategists of the air will have to decide on the relative merits of the different schools of thought which will probably develop.

7.3 As far as the technical problems are concerned, speed, maneuverability, rate of climb, and altitude, appear as the main requirements. Improvements in speed and rate of climb are determined by improvements in aerodynamics, propulsion, and lightweight construction. One particular difficulty with jet-propelled airplanes occurs when fast climbing from the ground is required. Although the rate of climb is excellent, the total time of reaching a certain altitude is handicapped by the fact that the best speed of climbing is relatively high, near the maximum speed. Consequently, considerable time is needed for acceleration of the plane near the ground. Probably means of assisted take-off will be needed to reduce the time of acceleration.

7.4 Present jet-propelled, fast airplanes lack, in some respects, the maneuverability of earlier fighter airplanes. This is a natural consequence of higher flying speeds, but steps must be taken to counteract it insofar as possible, in order to produce interceptors capable of pursuing successfully the fastest and most maneuverable enemy bombers. This requires the maintenance of lift to as large angles of attack as possible, without stalling, particularly at high Mach numbers, and the use of as low wing loadings as are consistent with the requirements of high speed and range. In piloted aircraft this problem also involves the blackout limit of the pilot, which must be maintained as high as possible by use of pressure suits and other aero-medical techniques, and probably by use of the prone position in very fast interceptors.

HIGH ALTITUDE

7.5 To secure air superiority it is necessary to reach equal or higher altitudes than the enemy. Rocket-driven airplanes are especially suitable for extreme altitudes, because their propulsion is independent of atmospheric air, although their flight duration is inherently limited. Hence, it will be necessary to use every possible means to adapt other types of jet propulsion to high altitudes. Improvements in combustion and improvements in compressor design are the main requirements, especially the elimination of difficulties which are encountered in compressor efficiency when supersonic flow occurs in the machine.

HUMAN LIMITATIONS AND CAPABILITIES

7.6 The human element, both on the ground and in flight, is of paramount importance in global operations directed toward attaining air supremacy. The study of this element is the concern of aviation medicine which includes: (1) the intial selection of personnel on the basis of those human qualities which make for efficient combat airmen with emphasis on vision, hearing, reaction time, neuropsychiatric normality, cardio-respiratory efficiency, physical prowess and psychologic adaptability; (2) the training of aircrews in the technique which will enable them to perform efficiently, independently of weather and darkness, under the unusual stresses produced by high speed, high altitude, great maneuverability, rapid changes in barometric pressure with changing altitude, and instrument flight and contact with the enemy; (3) the effect of flight on the human organism; (4) the maintenance of health, efficiency, and safety of flying personnel under all environmental conditions; and (5) a detailed consideration of human requirements and limitations in the design of aircraft, so that the airman-aircraft complex will be made into an efficient fighting element.

7.7 Inasmuch as human tolerance does not change, the steadily progressive increase in speed, ceiling, and potential maneuverability of aircraft has resulted in a progressively smaller margin between psycho-physiological requirements and human tolerance. Once supersonic speed is exceeded, this margin will be of paramount importance in the operation of the aircraft. Hence, it is essential to determine under all conditions of flight the human tolerance as given by nature and the limits which can be attained as the result of selection, training, and the use of special protective devices, such as a G-suit, in order to utilize fully new aircraft in combat operations. Of necessity, the performance of present and future aircraft will be based in part on human limitations and capabilities.

7.8 An additional human factor is that once an aircraft is damaged and must be abandoned, the aeronautical engineer's problem is over but the problem of survival of the crew, wherever they may happen to be in the world, is just beginning.

7.9 High-speed flight and maneuverability result in certain hazards and stresses on the flyer. At the comparatively slow speed of 600 mph, 880 ft are traversed every

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second. Between the time the pilot receives an impulse to act and action by the pilot 0.2 sec elapses for simple reactions and he has traveled 176 ft without anything happening. For discriminative reactions the reaction time may be 0.4 sec or more. These times require that the controls be immediately at hand and that the flyer be alert. If the situation requires a change in the course of the airplane, aiming and firing a gun or carrying out other mechanical tasks, the total time lag increases (reaction time and mechanical lag). To keep this reactionless period at a minimum requires that pilots be selected who have the shortest possible reaction time. When two aircraft are approaching head on at a speed of 2000 mph there will be an extremely short interval of time from the instant when the crews of the two aircraft first see the other aircraft until the aircraft are passing. Obviously radar aids are essential. Danger of collision will be a real possibility.

7.10 When flying at very high speed quick turns with resultant high acceleration of short duration may be a method of eluding guided missiles. Therefore, studies to determine the effects of comparatively high acceleration of from 1 to 5 sec duration on flying personnel is of vital importance. Also the effects of exposure to negative acceleration immediately after exposure to positive acceleration and vice versa should be carefully investigated. The effect on acceleration tolerance of such factors as anoxia, cold, heat, febrile and post-febrile state and intake of food and fluids is virtually unknown. All acceleration suits should be incorporated into the flying suit. Determination of the maximum acceleration that can be tolerated when the pilot is in the prone position (approximately 10-12 g from the chest to the back) and still allow manipulation of the controls will allow the aeronautical engineer to design such aircraft to withstand higher acceleration than ever designed before. However, the tolerance of a man in the prone position to acceleration from the head to feet on take-off and feet to head on landing is known to be quite low.

7.11 Flight at high altitudes requires the use of oxygen by the crew. The oxygen equipment, now used by the Army Air Forces, gives flyers complete protection against anoxia up to altitudes of 37,000 ft. For continued flying efficiency above 37,000 ft, some form of added pressure must be used to protect the flyer. Pressure breathing (6-in. water pressure) can increase the ceiling 2,000-3,000 ft. Pressure breathing used in connection with counterpressure pneumatic clothing can give protection for a few minutes as high as 60,000 ft. Pressure suits and pressure cabins, however, give the only complete protection at extreme altitude.

7.12 Aeroembolism (or bends) is a serious human limitation in high altitude flight and becomes increasingly significant above 30,000 ft. For one hour's exposure at 35,000 ft, one person in ten would be incapacitated; one in four at 40,000 ft. Very few individuals can stay more than 20 min above 40,000 ft without suffering from aeroembolism. Prebreathing of oxygen for from 1/2 to 1 hr before flight can delay very considerably the onset of aeroembolism. On the other hand, exercise at altitude increases the danger of its onset.

7.13 Of the mechanical effects of altitude, the most serious is the rapid expansion of body gases, especially above 30,000 ft, which, if they exist, can cause painful abdominal discomfort. Extreme rates of decompression are well tolerated but compression rates above 1 psi/min are increasingly difficult to withstand except for specially trained and selected personnel.

7.14 All aircraft designed for extreme high-altitude flights (ten miles and up) must be equipped with pressure cabins and ideally should be maintained at an absolute pressure of 4.4 psi or over. Pressure suits have been built that satisfy this requirement but have proved to be extremely cumbersome and awkward.

7.15 Experiments on human subjects have shown that the human body can tolerate a relative expansion of internal gases of 2.3 during any explosive decompression of a pressure cabin or a pressure suit. Above 50,000 ft, however, it is virtually impossible to protect a pilot by proper choice of cabin pressure condition from both the dangers of anoxia and expanding internal gases. Loss of cabin pressure at any altitude above 50,000 ft will place the pilot in sufficient danger to require emergency protection from some form of pneumatic clothing, a practical version of which has yet to be developed.

7.16 Emergency escape from an aircraft, while traveling at extremely high speeds (transonic and supersonic), and at high altitudes (10-50 miles) will require many special considerations. A parachute must be developed that will relieve the very high expected opening shock and will be free of oscillation. For this purpose, the Germans developed the ribbon parachute. Emergency oxygen must be carried, probably in the parachute, and for bailouts above 50,000 ft, some protection must be provided against severe anoxia and aeroembolism. Methods must be provided to eject the flyer free of his damaged ship. Ejection seats as an escape method are only practical for subsonic speeds. Full-face oxygen masks will protect the face from wind blast and cold. The concept of an ejectable cockpit, properly pressurized, is at present the best probable solution to escape at extreme altitudes. For such a cockpit, a stabilizing parachute is required as the speed drops through the transonic range. Larger parachutes free of severe opening shocks will be required to reduce descent to a safe value for striking the ground. Alternately, the cockpit could be unsealed automatically below 50,000 ft and allow a conventional parachute descent. Automatic opening devices should be used throughout the sequence of events.

7.17 The high skin temperature of supersonic aircraft will require special protection for the pilot against heat prostration. Air-cooled flying clothing will be a requirement. Proper choice of insulation on the cabin will be a factor. As the speed of the aircraft drops to subsonic levels, protection against the cold for the pilot must be considered.

7.18 Since some rocket-propelled aircraft may use liquid oxygen as one of the fuel components, this liquid could be used as a source of cabin pressurization, as a source of oxygen for the pilot, and as a method of cooling an air ventilated duct for protection against excessive cabin heat. For rocket propulsion, using toxic liquids or atomic energy sources, protection must be given the pilot against noxious gases or radiation.

COUNTERMEASURES

7.19 High speed, maneuverability, and high altitude are the means of escaping interference from ground defenses. However, we must attribute to the enemy the same highly developed weapons of defense which we try to develop. Hence, it appears imperative to have in our airplanes means for detection and deflection of target-seeking devices aimed at them. This is one of the many problems which concern countermeasures against new remote-controlled or homing devices.

7.20 A technically competent enemy will try to thwart our operations by countermeasures directed at our own electronic devices for the collection of information and the transmission of intelligence and control. The vulnerability of a target-finding radar to jamming is no less important than the vulnerability to fighter attack of the vehicle which carries the radar and the bomb. We have seen in the war just past a lively battle of weapon and counterweapon in the fields of radio and radar. At certain times we enjoyed the advantage of a new technique, temporarily unknown to the enemy, and hence, of a period when a new device (for example, microwave ASV radar) could be used with impunity. It would not be wise to count on many such advantages in the future, and it is, therefore, important to assess the vulnerability of new devices at an early stage of their development. In the reports of the individual consultants on radar, communications, infrared, and guided missiles, the specific problems of countermeasures are taken up. It is worth while to present here certain broad conclusions which emerge from these studies:

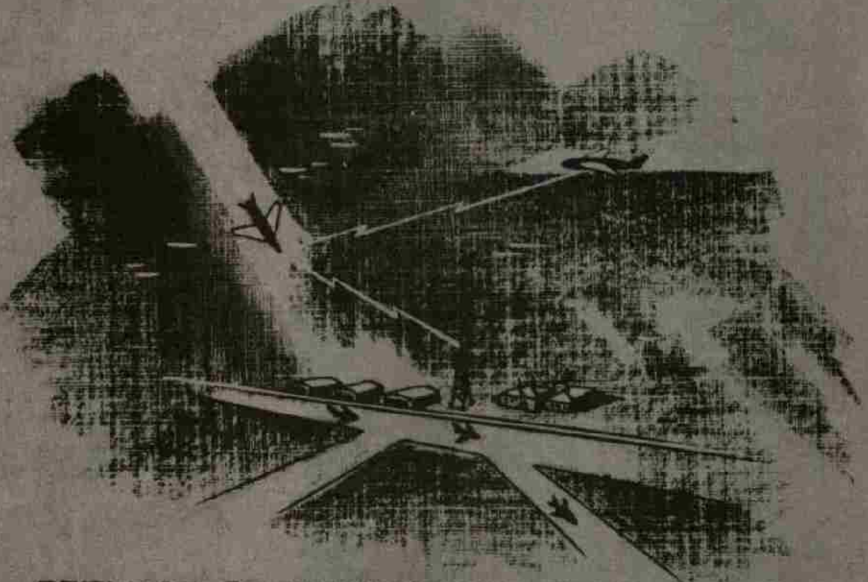
a. The fact that an electronic device can, in principle, be jammed (and most of them can) does not necessarily mean that it will be jammed so as to impair seriously its military value. The problem of jamming, realistically considered, is not merely one of ingenuity, of which we must assume that the enemy has an unlimited supply, but of electric power and energy and well-known physical laws. It may be made uneconomical for the enemy to interfere with some device of ours, even though he regards it as a serious threat.

b. The developments in radar and related fields which promise the most in freedom from enemy interference are the use of a diversity of frequency channels, rapid tuning from one channel to another, higher power, and where consistent with other requirements, more directive beams of radiation. The opening up of the microwave region of the spectrum has, on the whole, made the task of the would-be jammer much more formidable.

c. Radio links used for remote guiding and control, or for transfer of intelligence from and to unmanned aircraft, will probably make more and more use of the "combination-lock" type of security, exemplified by electronic pulse coding and decoding, in contrast to the "concealed-button" type of security, which involves the dangerous assumption that the enemy cannot readily discover what we are doing.

d. Concealment and camouflage against detection by radar and other means have been developed vigorously and will continue to develop. We must keep active and alert in this field, if only to be able to anticipate the countermeasures to which our devices may fall victim.

e. In general, electronic warfare puts a premium on ingenuity, speed, adaptability, and alertness. Against the countermeasures of a determined and technically advanced enemy our only permanent military assets are well-informed, resourceful, scientific personnel, and a flexible production organization.



PERFECT COMMUNICATIONS FROM GROUND TO AIR AND FROM AIR TO AIR

PERFECT COMMUNICATION FROM GROUND TO AIR AND FROM AIR TO AIR

8.1 The preceding discussion has assumed accurate and reliable communication between the airplanes involved, and between the airplanes and their base. Present aviation communication, while fairly satisfactory, still lacks a good deal in realibility and ability to make contact. However, if the present rate of development continues, the requirements of the projected Air Forces can be met in a relatively few years.

8.2 At present the communication problem is divided into two parts:

a. Liaison communication for the long-range transfer of information between individual airplanes or flights of airplanes and their base, distances from a few hundred miles to several thousand miles.

b. Command communication between the members of a group or formation of planes.

8.3 Future aviation communication will undoubtedly retain these two subdivisions, and will probably include a third, namely short-range communication between air bases and airplanes, for the purpose of guiding offensive operations, traffic direction, and landing control. This may include visual presentation by television and instrument indication, as well as voice communication.

8.4 The liaison system must operate on frequencies between one and ten megacycles. This is because radiations at higher frequencies follow essentially line-of-sight paths, while lower frequencies, such as are used for transoceanic communication, require antenna lengths which cannot be accommodated, even in the largest bombers. In order to obtain communication at a distance in the frequency range available for liaison work, it is necessary to deepnd upon ionospheric reflection, and to obtain reliability it is essential to select from among eight or ten bands in this region. Because of these limitations, liaison communication is limited to between five and ten speech channels. This means that the communication must be very highly organized in order to economize in the channels needed.

8.5 The use of teletype systems and special voice coding can greatly reduce the frequency bandwidth required for a communication channel. By adopting these means, a great many more channels become available. This may become an important part of liaison.

8.6 Long-distance communication of the liaison type may be supplemented by a high-frequency relay system. This will make available a large number of channels, which can be used for liaison. However, the longer wavelength direct liaison channels must be retained in the event the relay chain is broken.

8.7 Command communication allows a much greater latitude in the selection of the frequency at which it can operate, since only line-of-sight is required. In practice it will be carried on at as high a frequency as possible, in order to make available a maximum of communication channels, limited only by the state of technical development, antenna considerations, and the molecular absorption of the air.

8.8 At present, command systems operate at frequencies around a hundred megacycles. In the immediate future the frequency should be increased by a factor of at least ten, and perhaps much more. There will be available a large number of communication channels at these upper frequencies, so that each airplane in the group or formation can be assigned individual channels, in addition to general and emergency channels shared by the whole group.

8.9 The channel space available can be used not only to give a large number of bands, but also to protect the system from jamming, interference, and interception, by using special forms of modulation, multiple channels, or other refinements.

8.10 With the large number of channels to be employed in this type of operation. it is imperative that the individual units be integrated into a closely knit practical system. This can be done following practices similar to those employed in ordinary telephone systems. Each airplane in the formation would be assigned a frequency or pair of frequencies on which he would communicate with anyone calling him. In order to call another airplane, the calling transmitter and receiver would be tuned to the frequency of the station being called, simply by manipulating a numbered dial similar to a telephone dial. While certain problems connected with frequency stability remain, steps have already been taken toward their solution in the use of a single stabilized oscillator to control the frequency of both transmitter and receiver, various feedback systems, and similar measures. In such a network it would be essential that certain master channels be kept open at all times for the reception of general commands and emergency instruction. Since these channels must be available whether or not a station is calling another airplane, this arrangement may require some duplication of equipment. This will not be seriously objectionable, because short-range, high-frequency radio equipment can be made relatively small.

8.11 Certain command operations may be aided by highly directional transmission. Communication of this type can be carried out very efficiently in the microwave portions of the radio spectrum. Laboratory models of receivers and transmitters are at present in existence, and the technical availability of this equipment is assured.

8.12 The extremely high-frequency portion of the radio spectrum, that is 60,000 megacycles or more, has certain properties which may be of value for short-range command systems. Here the molecular absorption of the atmosphere beigns to be important. This means that the signal is attenuated very rapidly with distance. Thus, it would be possible to carry on communication between airplanes in a formation and yet maintain radio silence as far as ground detector or more distant airplanes are concerned. However, before such equipment becomes avilable for practical aviation application, it must go through a long period of research and development.

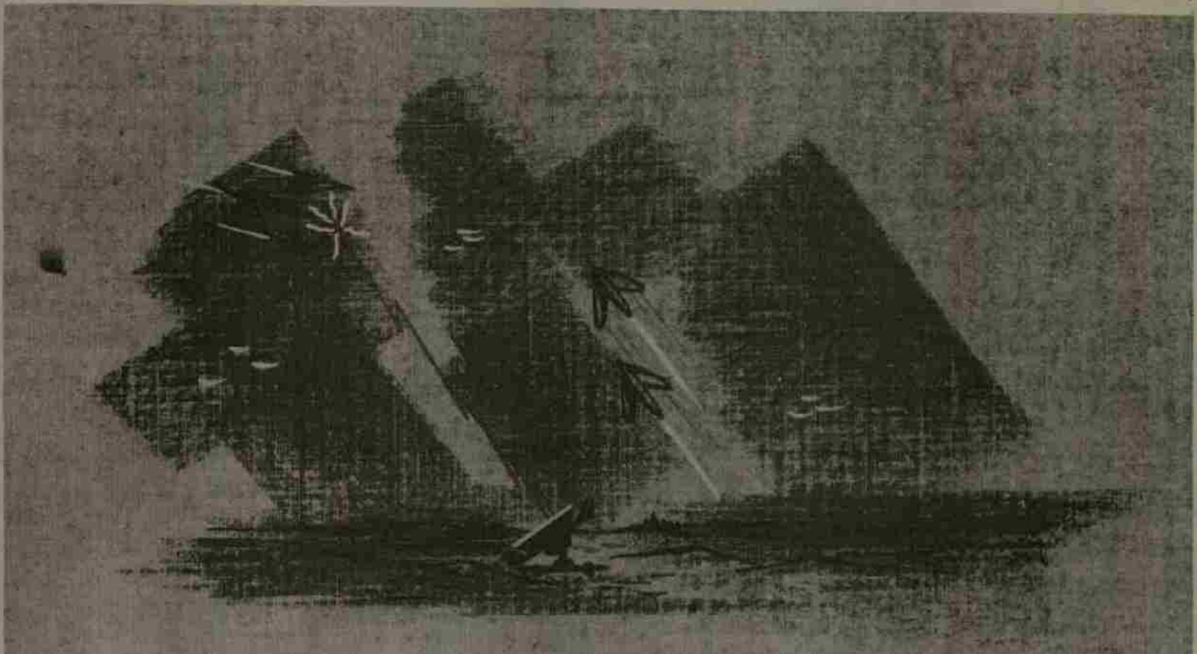
8.13 For single-seater fighters and other aircraft where one man must perform a great many operations, as well as act as radio operator, it may be necessary to supplement voice communication with an indicating system, with a semipermanent record of the message. Developmental equipment of this type has already been produced in the form of the British "Beechnut" and American "Volflag." These units not only give an annunciator presentation of the message, to be read by the pilot, but also give an automatic answer-back when the equipment correctly records the signal. This type of equipment can be made highly selective and jam-proof.

8.14 Facsimile may also serve as an adjunct to voice communication. It allows the transmission of large amounts of information over a relatively narrow channel. Furthermore, this information is in the form of a permanent record. The information which can be transmitted may be in the form of maps, pictures, or charts, in addition to written words, which in itself can be of considerable value. Because the bandwidth required is somewhat greater than is needed for speech transmission, it probably will not be used as liaison equipment, but will be operated at command frequencies and on radio relay chains.

8.15 In order to carry out successfully large-scale aerial operations under all weather conditions, it is necessary to provide very complete contact between the air base and airplanes leaving or approaching the base. When large numbers of airplanes are involved, voice communication will not be adequate, but must be supplemented by some form of visual aid. A modification of the "Teleran" system can provide the required contact. With this system, the location and altitude of all airplanes in the neighborhood of the base are determined by radar equipment at the ground station. This information is electronically plotted on maps of the terrain, dividing the space above the air base into a predetermined number of levels. A picture of the map and the airplanes at a given level is transmitted by television to the airplanes at that level. Thus, the pilot of every airplane at each level knows the whereabouts of every other airplane at his altitude, and the danger of collision is greatly reduced. The transmitted map carries with it appropriate meteorological information and any instructions that may be necessary. Blind landing and take-off aids are also provided for airplanes at the lowest level.

8.16 This system gives the ground station complete control of the airplanes in the vicinity and makes possible the concentration of large numbers of aircraft with relatively little danger. It also makes it possible for the air station to direct the grouping of large airplane formations and perform other functions necessary in carrying out air activities on a large scale.

8.17 The three classes of communication described will provide for the interchange of information required for integrated air activity on a large scale. In its present state of development, the radio art is in a position to supply most of the technical means for liaison, command, and air-base control. However, radio research should be encouraged in order to improve present means and develop new equipment giving better performance. (See the report "Aircraft Radio Communication Equipment," Part III of the SAG report *Radar and Communications.*)



DEFEND HOME TERRITORY

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DEFEND HOME TERRITORY

DETECTION AND WARNING

9.1 The first problem of defense is detection and warning. The successful defense of England was attributed largely to long-wavelength, early warning radar, installed at the time of the Munich agreement. This equipment could detect aircraft at a range of 150 miles at normal cruising altitudes, although its resolution was so low that it could not separate as distinct indications two aircraft 10 or 15 miles apart. Aircraft at low altitudes could not be detected. Had the Germans known the limitations of the equipment, they could have defeated its use.

9.2 These early types of equipment, operating on wavelengths of ten and three meters, were succeeded by microwave equipment of much greater resolution. The range of all types is essentially limited by the optical horizon. It is possible to build equipment capable of detecting all aircraft flying below any give altitude and above the optical horizon with a resolution and position accuracy of the order of 150 feet, under normal atmospheric conditions. It is possible to eliminate from the indicator all targets which are not moving. Hence, the area covered will be determined by the height of the set and the screening by surrounding hills. The height can be increased by using airborne sets, but the size of the available aircraft limits such equipment to lower weight and power, which in turn limits the range to about 200 miles.

9.3 Identification of the detected aircraft as friendly or hostile is a major problem. Identification beacons have been found to be only a partial solution. Reliance has to be placed in large measure on knowledge of the flight plan and of the progress of the flights of all friendly aircraft, identifying unfriendly aircraft by a process of elimination. Advances in communication techniques will probably supply additional aid in identification.

9.4 Unsolved problems in detection and warning are the ability of aircraft to fly low, so that they remain below the optical horizon until very close, and the problem of detecting missiles like V-2, coming in from the stratosphere at steep angles outside the angles covered by present radar warning sets. The first may be solved by the use of airborne search radar sensitive only to moving targets. The second requires only additional engineering development to improve the high-altitude coverage.

9.5 The provision of warning alone, without methods of defeating the attack, is useless. The warning network must be integrated with the control of fighter and missile squadrons.

COUNTERMEASURES AGAINST MISSILES

9.6 The second great problem of defense of home territory is countermeasures against missiles. We shall not here discuss passive measures, such as dispersion of industry, underground location of key targets, etc., but only the active measures against the missile in flight. So far as known at present, the possible active measures against atomic bombs do not differ from those against missiles carrying ordinary explosives. Such measures will be directed to deflect the attack by electronic disturbances, to produce premature explosion, and finally to hit or destroy the missiles by blast or fragmentation from warheads of defensive missiles.

9.7 Any missile using remote radio control, electronic homing devices, or proximity fuses, can in theory be jammed. In practice it is necessary to know something of the method of operation and to adapt jamming equipment to the particular enemy device. This information may be obtained either by intelligence methods, by continuous search of the electromagnetic spectrum, or by examination of captured equipment. There is no blanket over-all method of jamming which would defeat any and all types of electronic apparatus. This method of defense requires extremely close cooperation between intelligence officers, special reconnaissance patrols, and electronics specialists engaged in development of jamming equipment.

9.8 Missiles using homing devices may be deceived by decoy targets. Thus a missile using heat radiation could be decoyed by artificial targets. This device is of limited application, since techniques of target selection are known, and the enemy must be assumed to possess them. It would be difficult, if not impossible, to locate a decoy target within the field of view if a missile were directed toward the real target and yet far enough away to be outside the radius of destruction of an atomic bomb.

9.9 Many persons have suggested the possibility of producing premature explosion or otherwise incapacitating missiles by means of some form of ray. If the missile carries a proximity fuse, it may indeed be possible to operate it by a suitable electronic jammer and thus explode the bomb, whether it consists of atomic or ordinary explosive. In the absence of a proximity fuse or of a system for remote electronic control of detonation, science offers no prospect of detonation at a distance. The interaction of electromagnetic radiation with matter has been thoroughly investigated from long radio waves through microwaves, infrared, visible light, ultraviolet, X rays, gamma rays, to cosmic rays. Our ability to concentrate radiant energy at a distant point is limited by a fundamental property of wave motion in an unbounded medium, i.e., the tendency of the waves to spread. Even if twice the total electric power of the United States were placed in a single beam from a reflector 50 feet in diameter, the intensity at one mile would just reach the sparking voltage in air. Furthermore, shielding is relatively easy, because of the high inductivity of metals. The very shortest rays cannot be focused, and the energy decreases as the inverse square of the distance. Thus, present scientific knowledge offers no hope for, but on the contrary distinct evidence against, the possibility of detonating bombs at a distance.

9.10 No serious attempt has yet been made to hit a projectile or missile moving with, say, twice the velocity of sound. However, by adapting the target-seeking principle to winged rocket projectiles, it should be possible to accomplish this aim, provided location and warning occur sufficiently in advance. Another principle would be that of a barrage of aerial mines; however, it does not appear possible to increase the density of the barrage to such an extent that the missile would not slip through. Certainly both methods should be studied.

9.11 Against aircraft, manned or unmanned, moving with sonic or slightly higher velocity, target-seeking automatic interceptors seem to give most promise. The German project Wasserfall, the British CAP project, and some of our own undertakings move in this direction. Ramjet propulsion seems to be the most efficient way to reach the necessary speed and flight duration.

9.12 Manned interceptors will be developed, as well as automatic devices. For this purpose both rocket and jet propulsion drive should be considered. For extreme altitudes, the rocket may be the only method of propulsion which promises success. Because of human limitations, manned interceptors probably cannot be used against extremely high-speed unmanned missiles.

OFFENSE IS BEST DEFENSE

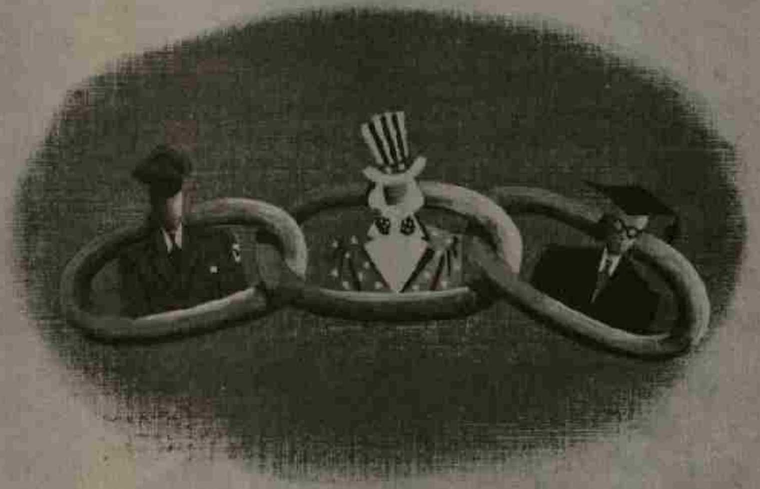
9.13 One possibility in the future may be the rocket barrage with atomic warhead. This could be used against aircraft or missiles traveling at high altitude. If the range of the effect of the atomic explosion is exactly known (estimated as about two miles for the present atomic bomb) and atomic explosion is possible in devices of reduced size, damage on our own territory can be avoided. Especially, attack from the high seas could be prevented by projecting the barrage at a sufficient distance out to sea.

9.14 While it is profitable to develop as effective means as possible for both active and passive defense against enemy action, it must be remembered that a purely defensive attitude is defeatist. A nation which relies solely on defense for its security is inviting disaster. England might well have become untenable if only defensive measures had been relief on to stop the V-2 attacks. These attacks were only stopped after use of the launching sites had been denied the enemy. Japan's defeat was assured when she failed to deny us access to air bases from which we could attack the homeland itself. *The best defense is adequate preparation for a strong offense.*

SCIENCE- THE KEY TO AIR SUPREMACY

Chapter II

• PROBLEMS OF ORGANIZATION WITH RECOMMENDATIONS



FUNDAMENTAL PRINCIPLES FOR ORGANIZATION OF RESEARCH

PROBLEMS OF ORGANIZATION WITH RECOMMENDATIONS

FUNDAMENTAL PRINCIPLES FOR ORGANIZATION OF RESEARCH

10.1 The spectacular innovations in technological warfare which appeared with ever-increasing momentum in World War II have made us extremely conscious of the necessity for continuous scientific research to insure maintenance of our national security. The legislative and executive branches of the government, industry, and science are now intensively engaged in finding the best form of organization and the most efficient scheme for uniting all efforts to create the best facilities and utilize all the available scientific talents. Many of the fundamental questions of organization will be decided after the legislative work has been done. However, it is of the utmost importance that the Air Forces lay down the leading principles of their own policy and establish the foundation of organized research in their own realm.

10.2 The basic principles of the responsibilities of the Air Forces in the scientific domain may be formulated as follows:

a. The Air Forces have the fundamental responsibility for insuring that the nation is prepared to wage effective air warfare. This responsibility cannot be delegated to any other government agency or scientific body.

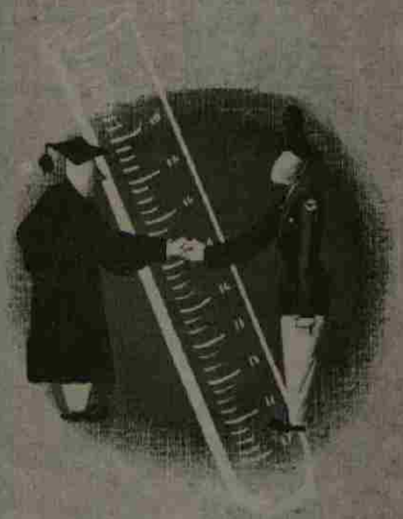
b. The Air Forces must be able to call on all talents and facilities existing in the nation and sponsor further development of facilities and creative work of scientists and industry.

c. The Air Forces must have the means of recruiting and training personnel who will have full understanding of the scientific facts necessary to procure and use equipment which is more advanced than that used by any other nation.

d. The Air Forces must be authorized to expand existing AAF research facilities and create new ones to do their own research and also to make such facilities available to scientists and industrial concerns working on problems of the Air Forces.

10.3 During World War II, the Air Forces enjoyed the fruits of research work being done by several scientific bodies organized or called upon for the duration of the war. Moreover, the whole scientific manpower of the nation was available to the services, and a great portion of it to the Army Air Forces. How to secure the cooperation of science and industry during peacetime is a very difficult problem.

10.4 Unfortunately it is not possible to establish the necessary link between science and industry on one side and the Air Forces on the other, by establishing contact and agreement at the top level only. It would be simple to establish an office of organized science and agree to allot scientific problems to such an office and military problems to the Air Forces. However, scientific results cannot be used efficiently by soldiers who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations. The following sections present certain recommendations which may have some value for the solution of the problem.



CO-OPERATION BETWEEN SCIENCE AND THE AIR FORCES

COOPERATION BETWEEN SCIENCE AND THE AIR FORCES

11.1 It is generally recognized that an adequate national program for extending the frontiers of knowledge in various fields of basic science is a necessary adjunct to the maintenance of military security of the nation. Every scientific development eventually finds its way into the field of military applications. However, basic research requires time. Wars are fought with weapons based on fundamentals discovered during the preceding years of peace. Discovery of fundamental results is dependent on an atmosphere of freedom from immediate specific goals and time tables.

11.2 For these reasons government authorities, military or civilian, should foster, but not dictate, basic research. The successful conduct of such research requires freedom and continuity of effort and cannot be accomplished by intermittent contracts for small tasks. Research staffs cannot be assembled and dispersed at short intervals. In addition, parallel competitive attacks on research problems do not constitute wasteful duplication. Coordination should take the form of exchange of information, rather than centralized dictatorial control of projects, funds, and facilities.

11.3 The Air Forces do not desire to do basic scientific research in their own organizations; however, they wish to encourage and sponsor such research as they deem necessary for the defense of the nation.

11.4 At the present time there is a tendency to concentrate the direction of scientific research activities in one controlling organization and make this organization responsible for the production of scientific results needed by the services, for the development of new weapons and equipment. Such centralization can be detrimental to American science, if it means exclusion of independent individuals and small groups of research men whose contributions are vital to the maintenance of an abundant scientific life within a nation.

11.5 Generally it may be said that the conception and initial development of new ideas often come from men and groups which are widely dispersed and not directly connected with central organizations and planned research. Jet propulsion and atomic energy are good examples of this thesis. In both fields individual initiative, not dictated by any preconceived plan, played an important part, both in this country and abroad. If free enterprise and initiative are necessary for maintaining a sound economy within a nation, certainly they are even more necessary in scientific life.

11.6 It is imperative from this point of view that the Air Forces continue and expand their present direct relations, spiritual and contractual, with various universities, research laboratories, and individual scientists. None of the central organizations existing now and to be established should be the only source of information and the sole intermediary agency between science and the Air Forces. The Air Forces should have the freedom to call on institutions and individuals whose assistance they deem to be of the greatest benefit for their program.

11.7 The ideal goal is, on one side, the creation of a scientific atmosphere in the Air Forces, on the other side, the maintaining of a permanent interest of scientific workers in problems of the Air Forces. The handling of research on applications of nuclear physics by some military authorities gives an interesting example of how scientific people can be antagonized by too much command.

11.8 The physical attributes of scientific life are libraries, laboratories, publications, society meetings. The main impediment to high-grade cooperative scientific activity in the past has been the conflicting philosophy of scientists and soldiers in handling scientific matters. An unavoidable difficulty is introduced, of course, by the security restrictions necessitated by the character of military research. However, it is believed that this problem can be successfully solved.

11.9 The first requirement for successful scientific collaboration is an efficient method of making the material contained in the archives of the Air Forces and other military bodies accessible to those scientific workers who are cleared for classified information and whose cooperation is desired. The lack of such an organized library service has in the past been one of the great impediments to scientific work. The Air Documents Division, established recently at Wright Field, may be the nucleus for the development of an efficient library and information service.

11.10 Concerning the laboratory work, it is recommended that Army Air Forces personnel be assigned to civilian laboratories, in order to acquire an intimate knowledge of scientific research to permit them to evaluate correctly scientific facts and effectively direct and supervise research in the Air Forces laboratories. However, the personnel assigned to civilian laboratories should not be there as supervising or liaison officers, but merely to learn. On the other hand, it is recommended that the Air Forces develop a scientific reserve corps familiar with current military problems, as a pool for active service in wartime. Younger scientists, who were working on projects in various civilian organizations during the war, would constitute admirably fit candidates for this reserve corps.

11.11 The employment of civilian consultants, which was authorized for the duration of the emergency, should be continued in peacetime. The wide variety of research and development problems facing the Air Forces definitely requires that the Air Forces be able to call upon specialists from time to time and for limited periods, in order to obtain the best advice and comprehensive reports on selected topics of current interest.

11.12 During the war several laboratories, established by the services and the NDRC, in close connection with universities and directed by scientists belonging to the universities, made important contributions. This favorable result suggests the establishment of cooperative laboratories, in which the administrative and financial responsibility and management would remain with the government, and the scientific direction would be undertaken by faculty members. This method would solve the security problem and yet have the advantages of the geographical and spiritual connection with a place of scientific learning.

11.13 In the field of publications and meetings, it is recommended that the interest of scientists in military problems be cultivated by sponsoring a society for military sciences, whose membership and publications would be restricted in conformity with security regulations. Air Forces personnel should be given membership in this society and permission to discuss and publish the results of their endeavors in the classified publications of the society.

11.14 The following recommendations are therefore made:

a. Direct research contracts between the Air Forces and scientific institutions.

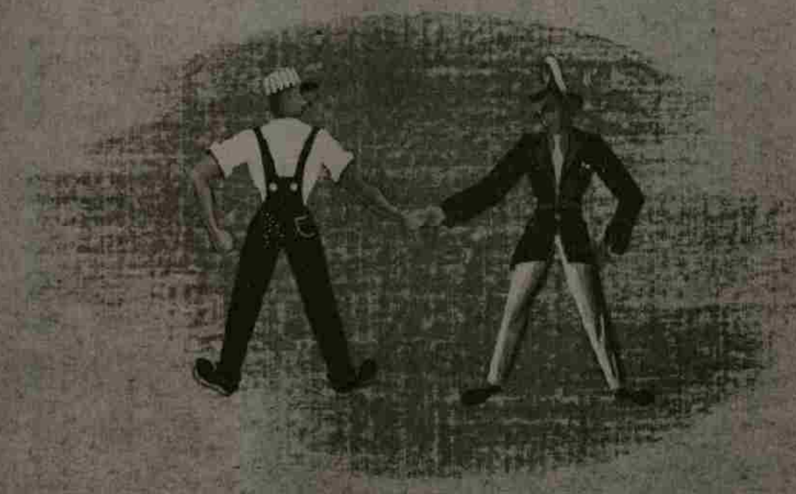
b. Library of classified material, to be made available to scientists who have been cleared.

c. Exchange of personnel between the Air Forces and civilian laboratories.

d. Authorization for temporary employment of scientific consultants.

e. Cooperative laboratories in close connection with universities.

f. Scientific society for military sciences, with membership requiring clearance, and classified publications.



CO-OPERATION BETWEEN INDUSTRY AND THE AIR FORCES

COOPERATION BETWEEN INDUSTRY AND THE AIR FORCES

12.1 This report does not deal with problems of procurement. Thus the analysis and recommendations are restricted to the problems of research and development to be done cooperatively by the Air Forces and industry.

12.2 The main field in which industry and the Air Forces will work in close cooperation is applied research and development. It is imperative that the Air Forces separate funds and management of development contracts from procurement contracts. In the past, much time and effort have been wasted by lack of a clear line between procurement and development. Development contracts should also be based on competition, since the competitive spirit probably produces the best solution in the shortest time. However, competition in scientific and development work is different in its nature from pure commercial competition.

12.3 The main objective in separating research and development from procurement is to make it possible for industry and the talent available in the industry to carry on applied research, which is absolutely necessary for rapid progress in the articles to be produced. Some industrial companies own facilities and funds for this purpose, as for example, the large companies producing electrical equipment, automobiles, and chemical products. These companies practice mass production and have a wide market for their products; therefore, they are able to do applied (in some cases even basic) research for the purpose of improving their products or of reducing the cost of production. In the case of the aircraft industry, it is generally recognized that the government must at least partially support the costs of applied research, because many of the problems refer solely to military applications and the costs of development cannot be recovered by the sale of the product. It is believed that it is more advantageous for the Air Forces to pay for the research needed than to pay higher prices for the products which would include the costs of development.

12.4 Supersonic flight and pilotless airplanes will undoubtedly create a gap between aircraft used in civilian life and in aerial warfare. Consequently certain parts of the aircraft industry will be engaged in developments which have no commercial value and will not result in large orders from the government during peacetime. It is then necessary that promising developments of this type be carried through the pilot-plant stage with the financial support of the Air Forces. These pilot plants should be able to furnish the quantity necessary for tactical evaluation of the equipment. In addition, all preparations must be made for securing a rapid expansion of production of both materials (such as special fuels and propellants) and devices (like missiles, electronic equipment, etc.).

12.5 Many problems require facilities which are only available to the government. In the past the NACA, at the request of the armed services, carried out most of the tests necessary to improve the characteristics of experimental airplane types. It is believed that it would be more advantageous for the general progress if the NACA were relieved of the duty of testing and improving experimental types and could concentrate on forward-looking investigations on questions of basic and applied science. The testing and research for immediate improvement of experimental types should be taken over by the Air Forces and new facilities should be created which allow the carrying out of such tests on a large scale. The design of new facilities should take into account the probable development in the next decades.

12.6 The air lines will be an important factor in any future warfare, since their equipment and experienced personnel constitute a valuable reserve for organized transportation between the mainland and bases distributed over the world. Hence, a close connection between the air lines and the Air Forces is necessary. In the operational field, as in the field of airplane and engine development, the natural development is that the facilities of the Air Forces should be used for perfecting operational methods, such as traffic control, landing aids, etc.

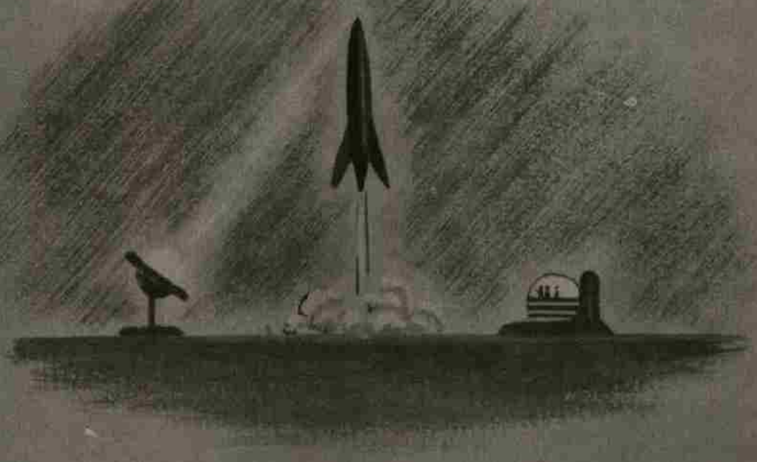
12.7 The following recommendations are therefore made:

a. Separation of funds and management of research and development contracts from procurement contracts.

b. Design of Air Forces facilities for applied research and development, both in the field of technology and operations, on such a scale that they can be made available to the industry producing equipment and the companies engaged in air transportation, to carry out the research necessary for the development desired by the Air Forces.

c. Promising developments of the nonrevenue-producing type should be placed in pilot-plant production to such an extent that the Air Forces can obtain a sufficient number for tactical evaluation of the special equipment and devices to be used in case of war.

d. Rapid expansion of production facilities for such items should be adequately provided for by the development contracts.



ADEQUATE FACILITIES IN THE AIR FORCES FOR RESEARCH AND DEVELOPMENT

ADEQUATE FACILITIES IN THE AIR FORCES FOR RESEARCH AND DEVELOPMENT

13.1 Scientific research in the Air Forces embraces not only the application of the physical sciences for production of efficient equipment, but should refer to all phases of aerial warfare which require scientific thought and analysis. For example, it should include problems of a physiological and psychological nature, as well as the scientific analysis of operations and methods of prognosis of the effects of planned operations.

13.2 In the past, especially in the last prewar years and during the war, the Air Forces developed research and testing equipment at Wright Field for aircraft, engines, armament and other equipment, materials, and also for aeromedicine and physiology. At Eglin Field a proving ground was established for equipment to be tested under field conditions and for the study of effects of means of destruction. These facilities, in the light of future development, appear definitely inadequate, even from the purely technical viewpoint of producing and testing efficient equipment.

13.3 There is no doubt that electronic devices will play an increasingly important part in all future Air Forces operations. In the past, the history of electronic applications has usually been that a device was developed for ground use, and then, some time later, its value to the Air Forces was realized, and after suffering severe and prolonged redesigning, it finally became useable in the air. Almost invariably this process of redesign was carried out by engineers with no real knowledge of the special problems of aircraft. In other words, the areonautical engineers have had no appreciation of the possible value of electronics in solving their problems, and the electronic engineers have had no knowledge of the difficulties their equipment would experience on aircraft. Electronic equipment has been added to planes as an afterthought, with consequent difficulties of installation and operation. Even in the case of radar, it was not until 1944 that a group of radar scientists and aeronautical engineers conferred for the purpose of studying the uses of radar and discussing the problems of installing radar equipment in planes.

13.4 Future controlled missiles are completely dependent on electronic devices. They must be designed by electronic and aeronautical engineers working in close cooperation. Instrument flying requires that the electronic equipment be designed by persons familiar with aeronautical problems.

13.5 In the age of moderate speed airplanes with conventional engine-propeller drive, it was possible to carry out development work on separate components. Supersonic airplanes and pilotless aircraft cannot be developed successfully by such methods. Questions of aerodynamics, structures, propulsion, and control are closely interconnected. The component parts of a guided missile cannot be made to function independently any more than can any one organ of the human body. Based on these considerations, it is proposed that the Air Forces create new facilities, under one command, entirely separated from procurement and supply, with the objective of developing supersonic and pilotless aircraft.

13.6 The Center for Supersonic and Pilotless Aircraft Development (SPAD) should be equipped with adequate wind-tunnel facilities to attain speeds up to three times the velocity of sound, with large enough test sections to accommodate models of reasonable size, including jet propulsion units, and one ultrasonic wind tunnel for exploration of the upper frontier of the supersonic speed range. Ample facilities for the study of combustion and other characteristics of propulsion systems at very high altitudes should be provided. Electronic engineers should be given the necessary facilities to study control methods, servomechanisms, and homing devices in close cooperation with aerodynamicists and propulsion experts. The Development Center should also provide facilities for investigations of the human aspects of flight at supersonic speed and extreme altitudes. The facilities for experimental launching, flight research, and flight analysis should be integral parts of the Development Center.

13.7 It is believed that the Air Forces program in the field of supersonic and pilotless aircraft urgently needs the establishment of such a central organization to lead the activities of the scientific institutions and industrial companies to new horizons; and, to make facilities available for research and development work, necessary, beyond a doubt, for maintaining our supremacy in the air.

13.8 It is proposed that research and development in the field of aircraft operations, communications, and weather service be consolidated into a Center for Operational Aircraft Development (OAD), with the objective of approaching the ideal of the all-weather Air Forces, solving the problems of traffic control, fighter control, and of warning and location. This Center should be equipped with adequate laboratory facilities for applications of radar and television technique. Experimental bases for testing control and communication devices should be integral parts of this Center. It should cooperate closely with the air lines and the weather service.

13.9 It is believed that the proving ground at Eglin Field should be put in charge of development of bombing devices and procedures, and study of bombing survey and analysis methods.

13.10 It is proposed that a Center for Nuclear Aircraft Development (NAD) be initiated, dealing with problems arising in connection with atomic bombs and the use of atomic energy for aircraft propulsion.

13.11 The organizations and facilities suggested in this chapter cannot be created in one year, but must be developed gradually in coordination with the work of other interested military and civilian agencies. On the other hand, it is my conviction that unless the Air Forces begin systematically building up development centers with competent personnel and adequate testing facilities, they will unavoidably lose the lead and initiative in fields which in a few years will constitute the domains of their most vital responsibilities.

SUMMARY OF RECOMMENDATIONS

13.12 The following recommendations are therefore made:

a. Research and development in the field of aerodynamics, propulsion, control, and electronics should function as one entity.

b. A Center for Supersonic and Pilotless Aircraft Development (SPAD) should be established, with adequate wind-tunnel, propulsion, control, and electronic research facilities.

c. A Center for Operational Aircraft Development (OAD) should be established for research and development in the operational field, such as all-weather flight problems, communications, and fighter control.

d. A Center for Nuclear Aircraft Development (NAD) should be initiated.

e. Eglin Field should be developed into a research and development center for bombing technique, research on blast effects, and bombing survey and analysis methods.

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INDUCTION OF SCIENTIFIC IDEAS IN STAFF AND COMMAND WORK

INDUCTION OF SCIENTIFIC IDEAS IN STAFF AND COMMAND WORK

LONG-RANGE PLANNING

14.1 Scientific planning must be years ahead of the actual research and development work. Long-range planning should be the responsibility of the Commanding General of the Air Forces. I believe there is general agreement throughout the nation that in the past decades the direct interest of the Commanding General in long-range planning has been one of the most important assets of the former Air Corps and the present Air Forces. This philosophy should be preserved in the future. From this point of view, it is advisable that a permanent Scientific Advisory Group, consisting of qualified officers and eminent civilian scientists, should be available to the Commanding General, reporting directly to him on important new developments and advising him on the planning of scientific research. It is considered that the advice and contributions of persons who, although thoroughly familiar with the work and the needs of the Air Forces, have their main activity outside of the Army, would be of considerable value. This group should contain experts with broad experience in the various branches of science involved, who would represent a cross section of our scientific thought. Their reports to the Commanding General would be used to ffeect continuous revision of the Air Forces research and development program.

MANAGEMENT OF RESEARCH AND DEVELOPMENT

14.2 The problem of the best organization of management and development is a very difficult one. It cannot be expected that unanimous agreement can be reached on this question. The plan for management of research and development is a sore point in all large organizations or companies. It mostly undergoes periodic changes, which emphasize one or the other side of the question, ranging from separate and almost independent research laboratories to decentralization of research and development into the operating units. In the special case of the Air Forces, two solutions have been proposed: (1) the establishment of one Air Staff section for research and development; and (2) a supervising and directing agency attached to the office of the Chief of Air Staff. Both solutions have advantages and disadvantages. Obviously it would be extremely difficult to remove the actual operation of all research and development facilities from all the various existing staff sections and concentrate them in one new section. On the other hand, the central supervising and directing agency would have a hard task introducing new ideas into the operation of a large number of dispersed sections and commands engaged in research and development.

14.3 Independently of the special form of management of research and development, the office in charge of direction and supervision of research should establish panels consisting of representatives of other agencies engaged in aeronautical and related research, for example, the National Advisory Committee for Aeronautics, the National Bureau of Standards, the Civil Aeronautics Administration, the aircraft industry, the air lines, scientific institutions, and individual scientists. These panels should assist in formulation of the detailed research program and the choice of the agency, institution, or individual best fitted and available to carry out the desired research work.

SCIENTIFIC INTELLIGENCE

14.4 Scientific intelligence is one of the important requirements for the future Air Forces. In the recent past the necessity for an organized scientific intelligence service became more and more evident as the war proceeded, and it became an urgent necessity as Germany collapsed. Fortunately, at that time a great number of scientists and technicians could be made available to the Air Forces on a voluntary basis. In this way the information gained from Germany could be worked up in an appropriate manner. However, at the present time, only a few months later, no more such personnel is available. The supervision of future German scientific work, for example, is still lacking scientific help.

14.5 Scientific intelligence starts at home. The example of the atomic bomb show that scientific discoveries of prominent military importance were made by pure scientists who had no connection with any military office or establishment; as a matter of fact, they were not interested in military applications. Hence, it will be necessary for the Intelligence Service to employ scientific personnel with broad interest and knowledge, who have the ability to recognize the military aspects in the scientific production of our theoretical and experimental scientists, university, and industrial laboratories. The screening of patents and inventive ideas presented to the military agencies, as it has been done in the past, will not be sufficient. The Intelligence Service needs permanent collaborators who pursue the scientific literature, attend meetings, visit scientific establishments, and report their findings and suggestions periodically. In peacetime much tact will be necessary to accomplish such efficient intelligence service, because of the commercial interests involved and the natural inclination of scientific men not to talk about their results before the final rounding up of their work.

14.6 Scientific intelligence in foreign countries is, of course, a much more difficult matter. One can distinguish between scientific intelligence on subjects which are open to duscussion and on subjects which are classified. I believe that all knowledge of scientific life in a foreign country is of great importance since, after all, the same scientific personalities who create the peacetime science of a country will be called upon to help their country in wartime. Therefore, it is strongly recommended that the Air Forces: (1) have scientific attaches in embassies and legations in various countries; (2) send scientifically trained officers, engineers, or consultants of the Air Forces to scientific meetings and congresses abroad; and (3) send personnel connected with the Air Forces for longer periods to study at foreign institutions.

14.7 The intelligence services concerned with subjects which a foreign country does not want us to know, will use the methods which were successful in general military intelligence. However, it is imperative to have a scientific section in the Intelligence Service which will direct the search for and exploit the results of scientific data. It is imperative that we have knowledge, in advance, of all potential targets which could be of importance in scientific warfare, unless a complete exchange of scientific and technical data, as proposed recently by Great Britain, extends over the whole world.

SCIENCE IN PLANS AND OPERATIONS

14.8 The Air Forces entered into World War II with quite inadequate preparation as far as the prognosis and analysis of the results of missions were concerned. Analysis groups were assembled during the war, and opinions concerning the relative importance of targets were widely different. We now have the experience of a long war. The work done by organizations such as the U.S. Strategic Bombing Survey gives material for discussion and for planning future applications. Of course, in a future war bombs and bombers will be different; missiles and atomic energy involve radical changes. However, it cannot be sufficiently emphasized that it would be a great mistake, after dissolving the groups which worked on analysis of operations, to discontinue the analytical work itself. It is believed that the staff sections dealing with planning and operations should be equipped with adequate scientific personnel to be able to continue studies on methods of target analysis, operational analysis, and the like. It is necessary to have in peacetime a nucleus for scientific groups such as those which successfully assisted in the command and staff work in the field during the war. In these studies experts in statistical, technical, economic and political science must cooperate.

PERSONNEL POLICY

14.9 It is believed that many shortcomings of research and development in the Air Forces originate from a lack of appreciation, at higher levels, of the qualifications necessary for successful direction of a laboratory or a proving ground. The theory that an intelligent officer is able to direct any organization, military, technical, or scientific, is certainly obsolete. An officer in charge of a laboratory or proving ground can be really useful only if he holds the position for a sufficient time to become thoroughly acquainted with the subject matter and personnel. Officers with engineering training on engineering duty must not be handicapped, as regards promotion, because of long tenure of the same assignment or time spent in acquiring advanced education.

14.10 The position and rank of officers responsible for research and development must be made commensurate with the importance of their work and achievement and must not depend on the size of the organizations under their command.

14.11 The level of civilian personnel engaged in research and development work must be raised by authorizing the Air Forces to hire or dismiss civilian scientific personnel outside of the Civil Serivce. Also, methods of appointment, compensation, and management of civilian scientific personnel under the Civil Service must be freed from those restrictions of the Civil Service regulations which make the government service unattractive to first-rate scientists. In this connection, a separate branch of the Civil Service for scientific personnel would be of value.

SUMMARY OF RECOMMENDATIONS

14.12 The following recommendations are therefore made:

a. A permanent Scientific Advisory Group should be available to the Commanding General, to advise him on questions of long-range scientific planning.

b. The office in charge of research and development should establish research panels for coordination of Air Forces research with that of government agencies and other scientific institutions.

c. Scientific intelligence at home and abroad should be strengthened by including scientific personnel in the Intelligence Service, appointing scientific attaches abroad, and frequently sending scientifically-trained officers or civilians to meetings and for study in foreign countries.

d. Operational analysis and target studies should be continued in peacetime, with adequate scientific personnel.

e. Officers in charge of laboratories should keep such positions long enough to be really useful, without being handicapped in promotion by long tenure of such assignments.

f. Position and rank of officers responsible for research should be determined by the importance of their work and not by the size of the organizations under their command.

g. Appointment and compensation of civilian scientific personnel should be freed from Civil Service regulations, to enable the Air Forces to employ first-class scientists and engineers.

SCIENTIFIC AND TECHNOLOGICAL TRAINING OF AIR FORCES PERSONNEL

SCIENTIFIC AND TECHNOLOGICAL TRAINING OF AIR FORCES PERSONNEL

15.1 The discussion in this section refers only to the scientific and technological training of Air Forces officers. The specific training of mechanics, radio operators, electronics technicians, and the like, is not considered. It is believed that in addition to utilizing civilian consultants in various advisory capacities and civilian scientists and engineers in the Civil Service, the Air Forces must organize a broad training program for officers in various fields of science and engineering. New scientific discoveries will continually have a profound influence on the concepts of air warfare, and the Air Forces must be flexible and capable of adjusting themselves to thse new concepts. This requires, above all, that the Air Forces be permeated by officers who have the training which will make them capable of evaluating scientific facts with good technical judgment and vision.

TRAINING FOR AIR STAFF WORK

15.2 Practically all sections of the Air Staff are confronted with problems involving the application of science. Therefore, it is desirable that future Air Staff officers have an understanding of the capabilities of science and an appreciation of scientific thought. Therefore, it is proposed that a certain number of young officers be selected and given scientific training for future Air Staff work. Two years of special training at scientific institutions should be given these officers, in a branch of science chosen by them. The aim of this education should be training of the mind and acquaintance with scientific results, rather than specialized knowledge and routine skill. At intervals of about five years, one-year refresher courses should be inserted. The scientific training would be in addition to military training for staff duties, which is given at such places as the Army War College, the Command and General Staff School.

TRAINING FOR RESEARCH AND DEVELOPMENT

15.3 A certain number of officers should be given specialized scientific technological training in the branches of mathematics, physical sciences, and engineering, which are of vital interest for development of equipment and operational methods. This training should be accomplished at scientific institutions. Its main objective should be not so much the education of research men in the proper sense, as to give future officers engaged in, or in charge of, research and development an intimate knowledge of the capabilities and limitations of science and accustom them to working in cooperation with scientists and scientific institutions. It is very important that in the future scientific training, a broad variety of sciences which have applications to Air Forces problems be taken into account. A proper balance must be established between aeronautics proper, thermodynamics, electronics, nuclear physics, meteorology, aeromedicine, economics, etc. These officers can best be recruited through the Air Forces ROTC. Exceptionally brilliant students (about 20 percent of the total number taken) should be permitted to continue their scholastic training until they have an M.S. degree and then be put on active duty for about three years. This will give them an opportunity to orient themselves in the type of work they are best suited for in the Air Forces. After that, they should return to college for a period of two years, or long enough to get a Ph.D. degree. This would produce a supply of officers with an intimate knowledge of several fields of science. This is essential to finding the best compromises when military requirements produce conflicting design problems involving more than one field of science. The remaining 80 percent of those students selected through ROTC would go on active service after obtaining a B.S. degree and would return to college, after about three years of active service, long enough to obtain an M.S. degree.

15.4 All officers engaged in research and development must be given repeat scientific training for a period of one year at intervals of about five years. This training can be given at scientific institutions, or by assigning the officer to work as an engineer at one of the research laboratories working on Air Forces problems.

15.5 Every effort should be made to retain in the Air Forces those research and development officers who have already received added scholastic training at government expense during the war. Flying training in grade should be provided for those who are not pilots at the present time, but who desire flight training and can qualify for it. Training a pilot is a much simpler job than training an engineer. It does not appear reasonable to concentrate on trying to make engineers out of pilots at the Air Forces Engineering School, while at the same time refusing to give good engineers a chance to become pilots because they have not been members of combat aircrews.

TECHNICAL SCHOOLS IN THE AIR FORCES

15.6 The main objective of the technical schools in existence or to be established in the Air Forces should be training for procurement, maintenance, and operation of equipment. While these schools should give a short review of the fundamentals of the sciences involved, they should concentrate their efforts on the transmittal of practical knowledge and skill. Exceptionally brilliant graduates of the Air Forces technical schools should be selected for further scientific training in civilian schools.

SUMMARY OF RECOMMENDATIONS

15.7 The following recommendations are therefore made:

a. A certain number of young officers should be selected and given special training at scientific institutions in preparation for future Air Staff work.

b. Technical officers recruited throughout the Air Forces ROTC should be given advanced scientific training up to the level required for an M.S. degree, in a broad variety of sciences which have applications to Air Forces problems.

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c. Additional training should be given 20 percent of the officers referred to in the preceding recommendation, to qualify them for a Ph.D. degree.

d. All future Air Staff and technical officers who receive scientific training should be given one-year refresher courses at intervals of five years.

e. Every effort should be made to retain in the Air Forces those research and development officers who received scholastic training at government expense during the war.

f. Flying training should be opened immediately to those officers with scientific training who, regardless of combat experience, otherwise qualify.

g. The AAF Engineering School shall be built up in such a way, that fundamentals of the sciences involved in AAF problems shall be included in the curriculum. Exceptionally able graduates shall be selected for further scientific training in civilian educational institutions.

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