SECRET

TOWARD NEW HORIZONS

A Report to

GENERAL OF THE ARMY H. H. ARNOLD

Submitted on behalf of the

A.A.F. SCIENTIFIC ADVISORY GROUP

by

TH. VON KARMAN

SCIENCE, the Key to Air Supremacy

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REPLY REFER TO

HEADQUARTERS, ARMY AIR FORCES
WASHINGTON

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.

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 napalm 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.

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

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 preapred 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. Kármán

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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TO

"TOWARD NEW HORIZONS"

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

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By

Theodore von Karman

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WHERE WE STAND

By

Theodore von Karman

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Part III — AIRCRAFT MATERIALS AND STRUCTURES

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Chapter I

• SCIENCE AND AERIAL WARFARE

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.

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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 wareſare 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.

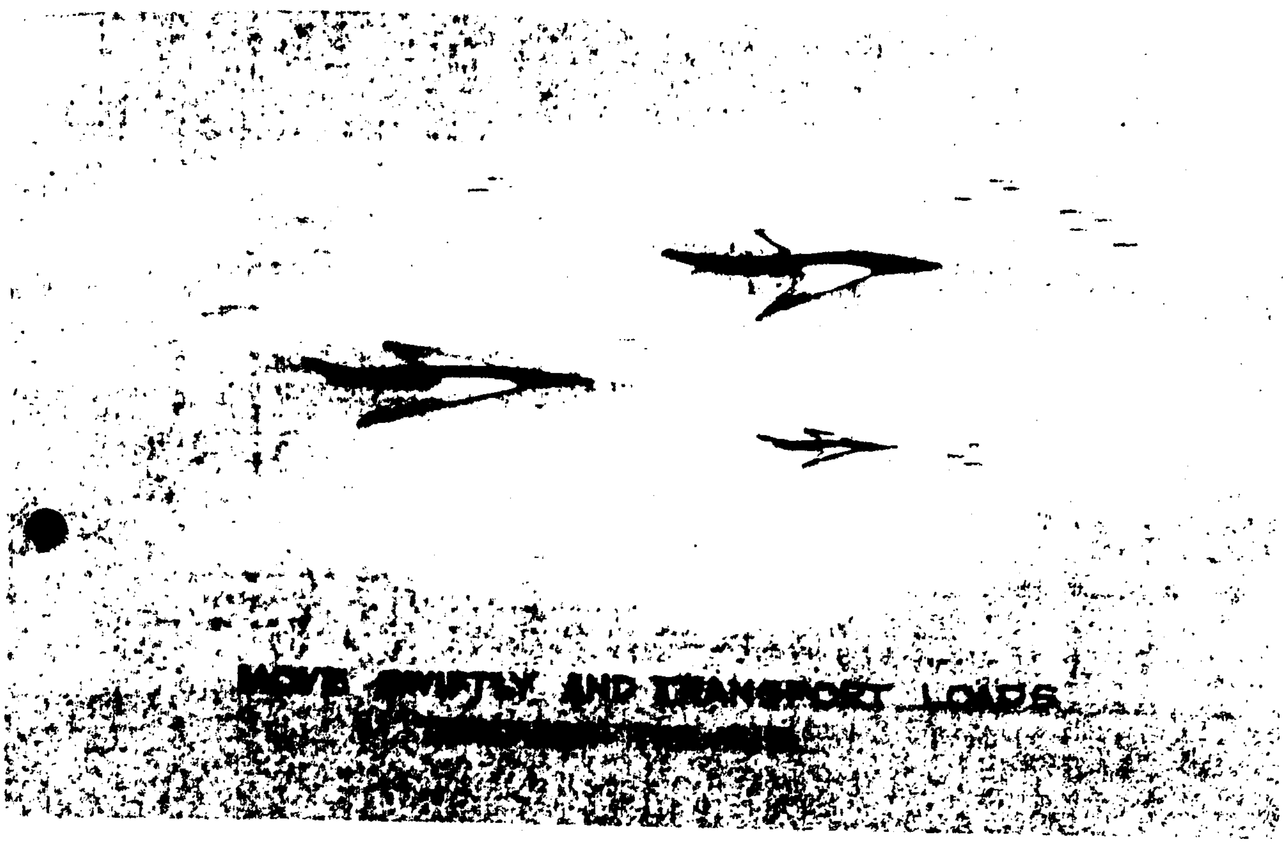
f. Scientific and technological training of Air Forces personnel.

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

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 carry-