# *Prophecy Fulfilled: "Toward New Horizons" and Its Legacy*

*Edited and with an Introduction by*
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*Where We Stand* was written in 1945 and issued as an AAF Report in 1946. *Science, the Key to Air Supremacy*, originally published in 1945 as part of the multi-volume *Toward New Horizons*, was reprinted by the Air Force Systems Command History Office in 1992. Many of the illustrations in this version of *Science, the Key to Air Supremacy* were adapted from the 1992 edition.

# Foreword

Since the days of ancient warfare, commanders have relied on science and technology for success in war. Their use in military affairs increased dramatically after the Scientific and Industrial Revolutions, particularly in the nineteenth century. For example, chemists and metallurgists contributed greatly to World War I, while World War II is sometimes referred to as the physicists' war. During the fifty-year conflict known as the Cold War, scientists from diverse disciplines collaborated to multiply the effectiveness of military force and meet national security needs.

Of all the federal organizations devoted to science and technology, none has been more important or influential than the U.S. Air Force's Scientific Advisory Board. In the midst of World War II the Commanding General of the Army Air Forces, Henry H. "Hap" Arnold grasped the absolutely essential relationship between post-war science and national security. To realize his objective of inextricably linking science to air power, he called upon his friend, the brilliant Hungarian physicist Theodore von Kármân, to assess and predict the future of military aeronautics. In *Where We Stand* and in *Science, the Key to Air Supremacy*, Kármân and his hand-picked staff devised a multi-disciplinary approach to preserving the technical advantage gained by U.S. air power during the war. Both of these seminal reports are herein reprinted.

Although the Cold War has ended and the imperatives of national security have changed radically, the basic technological conditions which informed both Arnold and Kármân remain the same. Now as then, the capacity exists for sudden and devastating attack on the American continent. Now as then, a large commitment must be made to research which renders the skies safe from aggressors and enables the national command structure to project air power at great distances. Now as then, the boldness and imagination of the nation's scientists and engineers must be harnessed to defend American security. The history of the Scientific Advisory Board's first half century offers the encouragement and example that such needs can be met and that the future of democracy can be secured in large measure by the mobilization of American science and technology in service to the global air and space power of the United States Air Force.

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# Introduction

## The Marriage of Science to Air Power

Dr. Michael H. Gorn

The scene repeated itself countless times. An elderly man, slowed by arthritis, painfully descended the mobile stairway connecting the airliner to the ground. When he finally reached the tarmac, a small knot of people pushed forward and surrounded him, offering warm greetings, hugs, and handshakes. As the old visitor turned to face the well-wishers, they heard the heavily accented baritone and saw the familiar graces: a flash of smile, the grey eyes, a black beret, and an ill-concealed hearing aid. Whether in Montevideo or Moscow, they gathered to see their old professor, colleague, and friend. Indeed, the Hungarian Dr. Theodore von Kármán, perhaps the world's leading theorist of flight and certainly its leading personality, always attracted attention. Priests, actresses, baseball players, and, of course, scientists, found themselves captivated by his Rabelaisian wit and gallant charms.

Strangely, many military figures also entered his circle, attracted first by his professional eminence; later, by his charismatic manner; and finally, by his success as a science administrator. None of his friends in uniform understood and valued the physicist quite like Commanding General of the Army Air Forces Henry H. Arnold. At the end of the Second World War Arnold faced a dilemma: how to introduce the most advanced scientific ideas into peacetime long-range planning. During the war many of the finest researchers from industry and academia rallied to the nation's defense, working for the government directly or undertaking research in university laboratories. Their discoveries had proven invaluable to U.S. air power, adding to the speed, range, payload, and accuracy of strategic bombing, and multiplying the destructiveness of armament. Advances in propulsion, materials, fuels, radar, and explosives transformed the air war.

After Allied victory appeared certain, however, Arnold realized these men and women would soon return to civilian life. At the same time, the postwar peace in no way guaranteed that the new weapons of sudden and mass destruction would not be aimed by hostile powers at U.S. targets. Only technological superiority in the skies could prevent surprise attack. To do so, some method had to be found to tap at least part of the enormous reservoir of civilian talent, persuading them to continue to serve the Army Air Forces. The answer suggested itself piecemeal. Before the war ended and the scientists returned to civilian pursuits, Arnold decided to assemble some of the leading figures and initiate a comprehensive review of future technologies useful to the Army Air Forces.

* * *

The process of predicting scientific and technical developments for the Air Force began on a cloudless, breezy day early in September 1944, when two men sat alone in an automobile parked at the end of a runway at La Guardia Field, New York. The older man, in his mid 60s, appeared small in stature and pale from recent surgery. The younger, by just a few years, was stocky and broad shouldered, but tired-looking. They conferred for some time, discussing the course of the war, the role of air power in it, and the future of the Army Air Forces in the postwar world. As aircraft roared overhead and cool winds rocked the car, they chatted about a preoccupation of the younger man: harnessing science to assure technological superiority in the skies in the decades to come. Before this talk between Kármán and Arnold ended, an informal understanding had been reached which would exert a profound influence on American military aviation. The friendship and trust they had developed over a decade stood them in good stead: the general asked the scientist to assemble a group of his most eminent colleagues in the Pentagon, study such things as jet propulsion, atomic energy, and electronics, and "make me a report."

Kármán raised some objections. A gentle, warm-hearted man, he had no desire to give, or take, orders in a military hierarchy. He did not really want to work in the Pentagon. But Arnold assured him he would be his only boss, and that he would give all the necessary commands. Moreover, the general set no time limit for completing the report. Kármán would undertake the study at his own pace, using his own methods. Arnold asked him to consider not merely the next generation of air power, or the one after that; but project years into the future. He and his associates were free to travel anywhere they chose—including Germany, Russia, and Japan—to learn from their colleagues abroad. More than this, Arnold wanted the scientists assembled at the Pentagon to "forget the past; regard the equipment now available only as the basis for [the] boldest predictions." He told them to imagine air war decades in the future, concentrating on supersonic aircraft, crewless airplanes, advances in bomb lethality, defenses against future aircraft, air-to-air and air-to-ground communications, television, weather, medical research, atomic energy, and all other likely and appropriate avenues of research. Forced for four years to think in incremental terms, General Arnold now sought the best people in the scientific community to spur air power technology far beyond present limitations.

The chance to share Arnold's dream of aviation progress, more than the promises of his own institutional autonomy, inspired Kármán. It also persuaded him to accept the offer to act as the link between civilian science and the Air Force. He later admitted that as Arnold made these proposals on the La Guardia air strip, he became fascinated by the possibilities. Although the end of the war remained well in the future, the general argued that U.S. air power would fail to maintain its dominant position in the postwar world by relying only on in-house experts; the genius of civilian science, he said, must be enlisted to assure superiority in the years to come.

Whom had Arnold asked to be the matchmaker between science and military aviation? Theodore von Kármán was born in Budapest, Hungary on May 11, 1881, in a middle class Jewish family, the son of Maurice von Kármán, a distinguished professor of education at the University of Budapest. Past generations of Kármáns were less illustrious; his paternal grandfather worked as a tailor for Hungarian noblemen. Maurice von Kármán received his title of nobility for sweeping reforms instituted in the secondary education system of his country, and for overseeing the curriculum of the Archduke Albrecht. Although Todor showed a genius for mathematics at a very early age, his father insisted he receive a liberal education before narrowing his sights on the sciences. After several years of home tutoring and matriculation at an elite gymnasium, he studied at the Budapest Royal Polytechnic Institute, and in 1902 took a degree with honors in mechanical engineering. The young Kármán then pursued the study of aerodynamics under one of the discipline's founding giants, Professor Ludwig Prandtl of Gottingen University, Germany, and received the doctor of philosophy degree there in 1908. His research at Gottingen on aerodynamic drag had profound implications for aircraft, ship, and bridge design. With a reputation second only to his mentor's, he accepted a chair as Director of the Aachen Aerodynamics Institute and taught there until World War I. Between 1914 and 1918, he served as the chief aircraft designer for the Austrian Air Service. From the end of the war until 1929, he returned to Aachen and pursued research in fluid mechanics. By the end of the decade he rivalled Prandtl's international stature.

Kármán's fame spread to America, where formal aeronautical research had not yet reached the degree of sophistication it had in Europe. To remedy the situation, the Guggenheim Fund for the Promotion of Aeronautics provided a large grant to establish the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT). Cal Tech's President Robert A. Millikan, anxious to persuade Kármán to become GALCIT's first director, invited him to lecture at Pasadena. The 1926 trip confirmed Millikan in this thought. Millikan and Harry Guggenheim were deeply impressed by Kármán's intellectual capacity, practical insight, and organizational finesse. His charm and warmth also won converts. After three years of negotiation, in October 1929, he accepted the Cal Tech offer. He left Europe for two reasons: Nazi influence had begun to intensify on the Aachen campus; and Millikan had offered a very handsome salary and wide autonomy.

During the 1930s, Kármán exerted a powerful influence over aeronautical research and development in the United States. Due largely to his efforts, Cal Tech came to rival the best of the world's centers of aeronautical research. Indeed, Southern California became the hub of the nation's aircraft industry, in part the result of the faculty, students, and laboratory assembled by Kármán in Pasadena. As war loomed over Europe, Arnold invited the scientist to sit on a special committee of the National Academy of Sciences reviewing technical projects of interest to the Army Air Corps. At the general's suggestion, Kármán and his staff undertook a research project to develop small liquid and solid propellant rocket engines to boost aircraft performance. The motors proved so successful that in 1942 Kármán and his group formed the Aerojet Engineering Corporation (forerunner of the Aerojet General Corporation) to fabricate them. Two years later, Cal Tech received a contract from the Army Ordnance Department to develop tactical ballistic missiles. In response, the Jet Propulsion Laboratory, formed from the sinews of GALCIT, was organized to research the fundamental problems of rocketry.

Undoubtedly, Kármán's crowning service to the nation began in fall 1944, just after he agreed to act as General Arnold's scientific adviser. Appointed on October 23, 1944, he proceeded immediately to Eglin Field, Florida, where he and a few colleagues spent a month laying the groundwork for the long-range study requested by Arnold. On his return to Washington, Kármán drafted a list of candidates and, luckily for the project, many had not yet returned to civilian work. He finally enlisted three dozen eminent persons, including Dr. Hugh L. Dryden, a leading aerodynamicist with the National Bureau Standards; Drs. Lee A. DuBridge, Frank C. Wattendorf, and Hsue-shen Tsien from Cal Tech; George E. Valley, Ivan Getting, E. M. Purcell, and Vladymir K. Zworykin from the Massachusetts Institute of Technology (MIT) Radiation Laboratories; and Norman Ramsey of Harvard University, a pioneer in nuclear physics. Despite resistance from some Air Forces officials, Arnold also permitted Kármán to select able men from industry, including George Schairer of Boeing Aircraft Company.

Thanks to Arnold's sense of urgency, official recognition and structuring of Kármán's office came quickly. On November 10, 1944, Lt. Gen. Barney M. Giles, Deputy Commander of the Army Air Forces, announced a new Long Range Development Program. As "expert consultant to . . . Arnold," the Hungarian would receive "full cooperation and expeditious action" in carrying out the general's mandate. The new office received the designation "Army Air Forces Consulting Board for Future Research" and won official status on the Air Staff. Its members would report directly to Arnold on the latest developments and would prepare on demand special reports pertaining to "scientific thought, technical research, and air power." Subjects of pressing interest included propeller- and jet-powered aircraft, guided missiles, fuels, and explosives. Finally, effective the first day of December 1944, the Board for Future Research was renamed the Army Air Forces Scientific Advisory Group (SAG), "an office attached to the Commanding General." Hugh Dryden served as Kármán's scientific deputy, and Colonel Frederic E. Glantzberg his military deputy.

Once the SAG office had been organized and established on the Air Staff, one task became paramount: researching and writing for Arnold the report on long-range science. The general set forth clear guidelines for the study, based on his understanding of the experiences of World Wars I and II. He argued that during both conflicts, aggressor nations had sought to maintain American neutrality, only to find U.S. power arrayed decisively against them. The lesson for the next war, Arnold wrote, "is too plain for the next aggressor to miss: *the United States will be the first target.*" Consequently, American air power would have no grace time to mobilize, and must, from the very first engagement, be the leading force in the skies. He concluded that research should be the bulwark of an Air Force capable of defending the country. The imagination and genius of the whole nation—in industry, academia, and the armed forces—"must have free play, incentive, and every encouragement." Arnold demanded comprehensive and continuing programs of research both inside and outside the Army Air Forces in order to achieve rapid advances in aerodynamics, physics, chemistry, electronics, rocket-related sciences, jet propulsion, and radar.

Finally, the general ask Kármán to rely on the current war only as a "baseline" for understanding existing aeronautical science, and in all other respects to "divorce yoursel[f] from the present war." He also wanted the scientists to pose organizational questions. To what extent should government underwrite peacetime scientific research in universities and industry? Should scientists be asked by the government to donate a small portion of their time to do research in the interests of national security? How should the Army Air Forces go about acquiring modern testing and support equipment? How much of the air power budget should be invested in R&D?

Theodore von Kármán now knew how formidable a task lay ahead. He and Arnold agreed that a team of scientists should travel immediately to the European war zone and interview their counterparts both in the allied and enemy nations. Early in December 1944 Dr. Frank Wattendorf, a former Kármán student and one of his closest aides, drafted a comprehensive itinerary of eleven countries. Perhaps most promising were the British national laboratories at Teddington and Farnborough for review of jet propulsion, missiles, radar, television guidance systems, fuels, materials, and explosives. Plans were also made to visit the French National Aeronautical Laboratories and the Belgian launch sites of robot bombs. The tour of Holland would center on the Phillips Corporation, engaged in advanced radar research. Aachen, Metz, Strasbourg, Germany; Zurich, Switzerland; and Swedish, Finnish, Polish, and Italian aeronautical centers all offered the fruits of German science. Kármán and Wattendorf considered it "very important" to see Russian developments at Moscow's Central Aero-Hydrodynamic Institute, hoping for reciprocation by Soviet visitors to U.S. research installations.

The work of the Scientific Advisory Group in Europe proved to be more successful than anyone could have guessed. Once the arrangements were in hand, "Major General" Kármán and his associates stepped aboard a C-54 transport bound for London. They arrived on April 28, 1945, under the unusual code name Operation Lusty, which the Hungarian called "unlikely but pleasant." After a few days of rest in the British capital, his contingent journeyed to Paris. Since the war continued to rage in its last stages in Germany, their plans had to be adapted to battlefield circumstances. While awaiting orders in France, Kármán received an urgent message describing the existence of a clandestine, top secret scientific institute, uncovered by U.S. soldiers in a forest near Braunschweig, northern Germany. The group arrived at Headquarters United States Strategic Air Forces in Europe on May 4 and traveled immediately to the hitherto unknown site. They found the laboratories reduced to shambles by the surging American forces. But even the ruins deeply impressed Kármán. His former assistant, Adolph Bauemker, had camouflaged the facility's many buildings as farmhouses and concealed them behind thick groves of trees. Here, advanced work had progressed on ballistics, aerodynamics, and jet propulsion.

Kármán set about collecting documentary and microfilm data scattered about the premises, and interviewed German scientists "who had not the time or the inclination to flee." Between the various sources he was able to discover most of the projects undertaken at the clandestine location. He came to an ominous conclusion. Had the Germans further developed their discoveries and better organized their scientific research, they might have prolonged or even won the war. Even though Bauemker and his staff enjoyed all the necessary funding and were allowed to pursue whatever inquiries they chose, they lacked influence over the military establishment, which regarded them merely as unrealistic intellectuals who failed to grasp military realities.

Excitedly, Kármán cabled General Arnold and described the enormous cache of materials quite literally unearthed at Braunschweig. About 3,000,000 documents weighing 1,500 tons had been amassed, microfilmed in Europe, and returned to the United States to form the backbone of the War Department Documentation Center. Information on swept-wing aircraft, ejection seats, and high speed human physiology led the list of crucial research subjects gleaned from the Braunschweig laboratories.

Once he had finished there, Kármán visited the devastated city of Aachen, the seat of the aeronautical institute he had once directed, and Gottingen University, where his mentor, Dr. Ludwig Prandtl, still presided over long-range research. While Kármán interviewed Prandtl about his wartime experiments in nuclear power, Wattendorf and Dryden traveled south to Munich, where they met over 400 engineers and technicians who had been evacuated from the Peenemunde rocket facility. Chief among them were Dr. Wernher von Braun and Gen. Walter Dornberger. From these two men Dryden and Wattendorf learned much about the technical aspects of the V-1 buzz bomb and the V-2 long-range rocket. Once the interviews at Gottingen and Aachen had been completed, on May 27 Kármán boarded an aircraft bound for Paris, then flew to London where Royal Air Force officials briefed him on progress in jet propulsion and missiles.

While several more weeks of exhausting travel lay ahead for the buoyant Kármán, his younger colleagues had begun to conclude their work. Tsien, Wattendorf, and Dryden prepared to return to America around mid-June, but not before arrangements had been made to ship to the United States a great prize: a complete, uncrated Swiss-made wind tunnel, destined originally for Germany. Despite the great pressure on the military air transport system, Hugh Dryden insisted upon "immediate action" to transship this invaluable machine from its hangar at Orly Field to Wright Field, and late in the month a B-17 was made available for the purpose. The Swiss wind tunnel, the interviews with the European scientists, the boxes of documents and laboratory equipment, and the technical intelligence reports assembled by the SAG group, all added luster to the mission's reputation.

The next portion of the Hungarian's odyssey took him to the U.S.S.R. Invited to attend the 220th anniversary of the founding of the Soviet Academy of Sciences, General Arnold urged him to "look around and let us know what you see." The departure occurred in mid June 1945 thanks to the efforts of Ambassador Averell Harriman, who secured the necessary clearances. Kármán arrived in Moscow aboard a lend-lease DC-3 dispatched by the Soviets to pick him up. On landing, he found the Russian capital alive with victory, and to his delight, received an invitation to share the reviewing stand at Red Square with Premier Josef Stalin. There he saw a massive military parade, followed later by a sumptuous Kremlin banquet hosted by the Soviet Marshal himself. In spite of the elation of the moment, the trip revealed more about the manner in which the Russians organized science than about Russian science itself. Unlike wartime conditions in Germany, Soviet researchers received both ample salaries and the highest military honors for their service in the war. Indeed, Kármán remarked with approval that several of the leading Soviet professors wore generals uniforms and enjoyed direct access to the armed forces elite. The Hungarian also admired the extent of the Soviet laboratory system. "The supreme scientific organization," it ranged from the Ural Mountains to the eastern Ukraine. He toured laboratories in Moscow and Leningrad which specialized in chemistry, propulsion, semiconductors, and nuclear research. However, he saw no equipment or installations related directly to military technology and found incredible his hosts disclaimers that they had no control over these facilities. "This struck me as surprising," he would later recall, "since they were all in generals uniforms." More telling, he found it difficult to meet scholars or students informally to discuss their work since most contacts had been arranged in advance.

Tired by a whirlwind of parties and meetings, he happily journeyed back to Paris early in July. As General Arnold had arrived in nearby St. Germaine (en route with President Truman to the Potsdam Conference for meetings with Stalin and Churchill), Kármán visited him and described the bonanza of knowledge yielded by his travels. Arnold expressed genuine delight, praised the scientist for persuading many of his German counterparts to emigrate to the U.S., and recognized the immense value of the documents and equipment retrieved for the Army Air Forces. The general asked him to prepare a formal interim report summarizing his European experiences.

Accordingly, Kármán returned to the Pentagon and, with the aid of his staff, feverishly wrote down his impressions. Six weeks later—on August 22, 1945—he submitted the product of his labors to Arnold in a seminal volume entitled *Where We Stand*, a summary of the existing state of aeronautical knowledge. In listing eight "fundamental realities" characterizing postwar aerial combat, he reached several astonishing conclusions:

> Aircraft, manned or pilotless, will move with speeds far beyond the velocity of sound.
>
> Due to improvements in aerodynamics, propulsion, and electronic control, unmanned devices will transport means of destruction to targets at distances up to several thousands of miles.
>
> Small amounts of explosive materials will cause destruction over several square miles.
>
> Defense against present-day aircraft will be perfected by target-seeking missiles.
>
> Only aircraft or missiles moving at extreme speeds will be able to penetrate enemy territory protected by such defenses.
>
> A perfect communication system between fighter command and each individual aircraft will be established.
>
> Location and observation of targets, take-off, navigation and landing of aircraft, and communication will be independent of visibility and weather.
>
> Fully equipped airborne task forces will be able to strike at far distant points and will be supplied by air.

But *Where We Stand* provided only a mid-term assessment of the future; much hard work remained on Arnold's comprehensive report. Kármán realized his investigations of some subjects were not yet complete. In particular, he sought more technical data on the German V-2 rocket in order to give General Arnold the fullest possible picture of future aerial warfare. Questions about supersonic flight also awaited further study. To satisfy these and other particulars, he decided to organize a second trip to Europe.

Before embarking, the framework for Arnold's long-range study had to be erected. In an August 1945 SAG meeting, Kármán exhorted his staff and assembled consultants to research and write the study with all possible speed. Pressures to complete it had begun to amount. The Japanese surrendered in August and the War Department announced plans to amalgamate under civilian control all long-range defense research. Hoping to publish his study in time to thwart the movement towards scientific centralization, he persuaded his colleagues to abandon the idea of producing a lengthy, textbook-style report organized by academic discipline (e.g., physics, chemistry, engineering, etc.). Instead, each agreed to write a brief monograph relating his scientific specialty to subjects of specific interest to air power—missiles, propulsion, radar, and so on. They set a year-end deadline for themselves. While Kármán prepared for his second European sojourn, the SAG members and consultants, led by Deputy Director Dryden, gathered their thoughts and began the hard task of committing their conclusions to paper.

As the Hungarian's September 1945 departure neared, he selected his traveling companions: Wattendorf, Tsien, Colonel Glantzberg, Colonel McHugh, and Lt. Col. Frank W. Williams of Wright Field. The civilians would again enjoy the privileges of temporary military rank. Their passports would take them once again to Europe, including the United Kingdom, France, Holland, Switzerland, Sweden, and Italy. In mid-October they would fly to the Pacific Theater, stopping in Australia, India, and China. In a verbal directive of August 25, General Arnold also asked the group to visit Japan, for which von Kármán scheduled two weeks at the end of the trip. This final leg of the journey did involve some risks; the chaotic situation in Japan might "entail delicate involvements," but General Arnold nonetheless felt the opportunity to "observe, correlate, and draw deductions" from Japanese science had to be seized. These aims would be furthered by Kármán's friendship with several Japanese scientists, dating back to his pre-war lectures at the Imperial University of Japan. Placing General Arnold's own C-54 transport at the group's disposal for the duration of the trip, Lt. Gen. Ira C. Eaker asked officials of the Far East Air Forces to organize first-hand inspections of research centers for the Kármán party in order for them to exercise "imagination and scientific acuity in recognizing important scientific trends."

The European portion of the journey enjoyed mixed success. Late in September Kármán held useful discussions with Professor Jacob Ackeret of Zurich on new techniques in laminar flow control. Back in Germany, he attended to a number of problems. He negotiated with British representatives to avoid an unseemly competition for German scientists. He discussed with Colonels Glantzberg and McHugh the format of the long-range study summary volume, which he himself would write for General Arnold. But privately, Kármán agonized over the report. In what direction should it go? Should he suggest a total restructuring of air forces research, or emphasize just one or two aspects of R&D? Nothing seemed to jell in his mind.

Misfortune suggested his course of action. In mid-October General Arnold suffered a serious heart attack and from his sickbed in Washington, D.C., called Kármán, urging him to hasten the drafting of his report. When the scientist offered to have it finished on New Years 1946, Arnold said he would "greatly appreciate" an earlier completion. The general wanted to devote his full prestige to Kármán's study, but knew his time was limited due to ill-health. A December 15 deadline was agreed upon. Facing a short schedule and exhausted after months of traveling, interviewing, and writing, Kármán now rearranged his schedule. He cabled Arnold on October 29 saying he was "much worried" about concluding his work on time, especially in light of the upcoming trip to Japan. He decided to send his group to the Orient immediately, while he remained in Paris "about twenty days . . . using the time for writing up my ideas conceived in recent months. I feel this is the best way to accomplish the job," he told the general, and "am very anxious not to disappoint you." Working undisturbed, he hoped for mental concentration and physical rest.

During the whole of November 1945, Kármán concentrated exclusively on this crucial project. Comfortably lodged at the Prince of Wales Hotel in Paris with excellent secretarial assistance and the Sorbonne's fine scientific library close at hand, he wrote the first draft of the summary volume, expecting to polish it between his return to Washington on November 28 and the mid-December deadline. Meanwhile, Hugh Dryden acted as his Pentagon surrogate. As Kármán finished portions of the text, he cabled them to Dryden for review. Indeed, Dryden bore the heaviest load, not only editing Kármán's copy, but sending his chief a number of collateral studies, writing sections on guided missiles, and shepherding production of all the technical volumes. Despite the crush, Kármán insisted the present undertaking be equal in stature to *Where We Stand*, which had been "very well received." By the third week in November his report was well in hand and the others were taking form. The Hungarian then added a discussion on the air forces and the atomic bomb. Finally, he scrutinized each draft volume himself, but relied heavily on the judgement of Dryden, DuBridge, and Wattendorf. At the end of November Kármán arrived in Washington, in time to help integrate the findings on the returning Tokyo group.

Just days before the deadline a draft lay on the table. What should it be called? An officer suggested "Toward New Horizons." Some on the SAG criticized the title, arguing it implied the present scientific horizons lacked vision. But the weary Kármán, in no mood for debate, insisted that they had, in fact, looked "at the basic scientific potential which could change the future. The name remained." His introductory essay, entitled *Science, the Key to Air Supremacy*, arrived on General Arnold's desk as promised, on December 15. The remaining twelve volumes (which included *Where We Stand*) were distributed on a limited basis to the Air Staff and to Wright Field. A truly comprehensive work, its twenty-five authors produced thirty-two separate monographs grouped by subject matter in these volumes: Technical Intelligence; Aerodynamics and Aircraft Design; Future Airborne Armies; Aircraft Power Plants; Aircraft Fuels and Propellants; Guided Missiles and Pilotless Aircraft; Guidance and Homing of Missiles and Pilotless Aircraft; Explosives and Terminal Ballistics; Radar; Communications; Weather; and Aviation Medicine and Psychology.

When he presented *Science, the Key to Air Supremacy* to General Arnold, the Hungarian attached a memorandum in which he summarized the essential findings of the entire study. He emphasized in particular a question posed by Arnold in his November 7, 1944, letter empowering the study: "What proportion of available money should be allocated to research and development?" To answer it, he consulted American industry for a model. U.S. corporations invested roughly five percent of annual profits in research. Hence, he proposed peacetime air forces budgets equal to five percent of the recent annual wartime budgets. If outlays after 1945 declined 80 percent, Kármán's formula actually yielded R&D support of one-quarter to one-third of total expenditures.

A share of such size exceeded the wildest expectations of all but a few. How could von Kármán justify it? He argued that in an age of atomic weaponry, the security of the nation demanded a powerful Air Force for offensive and defensive purposes. He proposed a large proportion of the increased R&D funding be invested in a ten-year program of scientific exploration leading to supersonic flight, pilotless aircraft, all-weather flying, perfected navigation and communication, remote controlled fighter and bomber forces, and air transport capable of moving whole armies. All research, he warned, must be directed toward these goals, not diverted toward abstract inquiry for its own sake. The establishment of interdisciplinary development centers, rather than laboratories, would help scientists focus on the practical solutions.

To complement the sharp upswing in R&D expenditures, Army Air Forces personnel, training, and organizational practices had to undergo significant change. Kármán suggested the service develop a global strategy for applying such new technologies as pilotless aircraft, and institute a three-tiered typology of weaponry: human directed, electronically assisted, and purely automatic. Finally, the scientist asked Arnold to always keep an open mind toward potential scientific breakthroughs. "Problems never have final or universal solutions," he wrote, "and only a constant inquisitive attitude toward science and a ceaseless and swift adaptation to new developments can maintain the security of this nation . . . ."

He based these conclusions partly on the experiences of the two world wars, and partly on the global review he had just completed of science and aerial warfare. The twentieth century transformed war from a drama of human endurance to a technological contest for control of the air. Aided as never before by scientists in the last war, military leaders needed to realize that the future hinged on cultivating the closest cooperation with the nation's laboratories and researchers. His first-hand observations of Communism in World War I and Nazism before World War II taught that acts of international aggression could never again be dismissed. Atomic explosives only heightened the danger of and underscored the crucial role of air power in modern warfare. Surprise attacks using such weapons were not unthinkable, and science offered no sure umbrella against this eventuality; the impact of even a single nuclear warhead threatened immense destruction. Kármán found the answer in a powerful offense to deter aggression. Only offensive aerial systems provided the capacity to reach remote targets quickly and strike them with maximum impact; attain air superiority over any region of the world; and land large contingents of men and equipment wherever required. In addition, Kármán urged that America establish total air superiority over its own territory by erecting a network of highly sophisticated warning and homing devices to detect incoming enemy forces. To achieve these objectives, "only an Air Force which fully exploits all the knowledge . . .science has available now and . . . in the future, will have a chance of accomplishing these tasks."

The science of aircraft design and construction progressed immeasurably during the war, and pointed toward continued improvements in the decades ahead. Since 1939 a string of breakthroughs in aerodynamics brought the velocity of aircraft nearer and nearer the speed of sound. Flying wing shapes and laminar flow devices on wings greatly reduced drag, leaving engineers on the threshold of aircraft designs capable of piercing the sonic barrier. New propulsion systems, particularly jets, had the potential for very high speed because of their light weight and their tendency to become more efficient with greater velocity. Improvements in reciprocating engine design also resulted in spectacular increases in the economy, range, and cargo capacity of transport aircraft. Kármán believed nuclear power offered the potential for continuous flight over immense distances, eliminating the problems typically encountered with the more combustible fuels.

Great progress had also taken place in navigation and instrument flying. Radio transmissions, as well as pulse and echo radars, had begun to penetrate weather, clouds, and darkness, the main inhibitors of aviation. In the years ahead, developments in communications and electronics would result in highly accurate blind bombing and landing, location of remote and invisible objects, pinpoint ground control of tactical aircraft, and the conquest of night and inclement weather. Likewise, Kármán predicted great strides in gyroscopic and servo-motor devices, whose main impact would be on automatic piloting and remote control mechanisms for pilotless aircraft and guided missiles. Electromagnetic radiation techniques—especially infrared, radio, and radar—would make "possible and effective" automatic bomb target seeking and fire control. By combining automatic and remote control systems with homing apparatuses, drone aircraft would be developed with "tremendous speed, extraordinary range, and ability to hit targets accurately." As such, they would augment manned forces in appropriate missions.

A major portion of *Science, the Key to Air Supremacy* addressed itself to organizational changes to ensure the preeminence of science in the future Army Air Forces. Kármán insisted upon an institutional alignment in which science permeated the entire military structure. "Scientific results," he observed, "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." How did he suggest bringing about this revolution? First, person to person contacts between scientists and the uniformed leadership needed to be strengthened. The Hungarian wished to encourage this atmosphere by exchanges of personnel among military officers and civilian laboratories, employment of scientific consultants, and the establishment at major universities of laboratories dedicated to research facilities in fields related to air power. Second, industry and the air forces required greater unity of effort. This Kármán would undertake by separating the management of R&D from weapons procurement, opening large applied research centers at which industries would work on a contract basis on large projects, and underwriting pilot programs at aerospace plants with an option to expand to full production should the products prove useful.

Kármán's organizational reforms also included a reorientation of the R&D structure to combine complementary technologies in unified research centers. He proposed separate facilities for supersonic and pilotless aircraft, operational aircraft, nuclear aircraft, a conventional armament center at Eglin Field, and a new site at which aerodynamics, propulsion, control, and electronics would be studied on an integrated basis. Kármán also addressed himself to the complicated question of infusing scientific ideas and methods into command and staff work. He offered Arnold a number of alternatives, including the permanent establishment of the Scientific Advisory Group on the Air Staff; the creation of liaison offices on the Air Staff to coordinate air power science with other government agencies; the inclusion of scientific personnel in intelligence services; and the peacetime employment of scientists for operational analyses and target studies. Moreover, officers commanding laboratories required long tenure without jeopardy to promotion, and rank commensurate with the importance of their research, not the size of their organizations. To obtain for government service the finest scientists available, Kármán urged their salaries and conditions of work be exempted from civil service regulations.

Finally, there remained the vital question of providing scientific and technical education for Army Air Forces personnel. Kármán recommended special training at technical institutes for young officers and broad scientific schooling at the master's degree level for those recruited through the ROTC. He even proposed that twenty percent of officers with baccalaureates in the sciences undertake doctorates in their chosen disciplines.

*Science, the Key to Air Supremacy*—indeed, the whole of *Toward New Horizons*—received an enthusiastic reception. This resulted, in part, from months of discussion among Kármán and Arnold's staff prior to the publication of the report. Indeed, as early as November 1944, Kármán and his colleagues had drafted an outline similar to that adopted in *Toward New Horizons*. By spring 1945, Kármán told Arnold that to flourish, air power science must have its own facilities, staff, and funding; hence his plea to the general to continue the research laboratories established during the war. Staffed by civilian scientists, these labs represented the germ of the research center concept found in *Science, the Key to Air Supremacy*. Indeed, almost as soon as the German experimental facilities had been examined, SAG members reported that the foreign labs were "more ambitious and forward looking than our own," and asked Army Air Forces leaders to consider construction of a development complex featuring a cluster of large wind tunnels for aeronautical research. Thus, the circulation of many of the ideas in *Science, the Key to Air Supremacy* during the months of its gestation prepared the ground for its eventual acceptance.

No one praised the report more vigorously than General Arnold. He called it "the first of its kind ever produced" and a boon to research and development planning in the years ahead. Lt. Gen. Nathan F. Twining, Commander of the Air Materiel Command, endorsed its recommendations and said the implementation of the first volume alone would provide a sound foundation for the future of the Army Air Forces. Years later, Gen. Jimmy Doolittle—Chairman of the SAG's successor, the Scientific Advisory Board (SAB)—described *Toward New Horizons* as "the most important thing" the group ever accomplished. In later years, even the modest Kármán admitted the report did make a significant contribution to U.S. air power.

*Science, the Key to Air Supremacy* and the other volumes of *Toward New Horizons* represented the first exhaustive review of science as it related to the military services. Both made plain the preeminence of air power in protecting the nation and asserted that its success rested in large part on technological progress. Both influenced profoundly the approach and content of all future military aviation forecasts. Most important, Theodore von Kármán won the point that long-range science research must not become the captive of civilian or military control. It must, he argued, be "dispersed among all the people and their institutions."

# Where We Stand

**Theodore von Kármán**

**1945**

# Where We Stand

## Supersonic Flight

Supersonic flight appeared before 1940 as a remote possibility. Supersonic motion was considered as characteristic of artillery shells; level flight supported by wings was thought to be confined to the subsonic speed range. Some people talked of the stone wall against which we were running by trying to fly faster than sound.

One of the main results of bolder and more accurate thinking, and more experimentation in the last few years, is the fact that this stone wall disappeared, at least in our planning, and will disappear in actual practice if efforts are continued.

I believe the first engineering analysis presented in this country was contained in a report by myself and my collaborators early in 1944. It was shown in this report that an airplane of 10,000 lb gross weight, and 80 lb/sq ft wing loading, can climb to 40,000 ft altitude, reach a speed of 1000 mph, and fly at this speed for five minutes. As the propulsion device, a ramjet was considered.

The two main requisites of supersonic flight are the development of air frames which are aerodynamically efficient in the supersonic range and the development of lightweight efficient propulsion units.

The German contribution to the problem of supersonic flight is mainly on the aerodynamic side. No particular advance has been made by them in power plants such as the ramjet and turbojet for extremely high speeds. The Germans tested these power plants only at subsonic speeds Their main contributions to aerodynamics were as follows:

1. By wind-tunnel testing and by firing of winged missiles, it was shown that the passing of sonic velocity does not entail any stability difficulties if the transition is made in a relatively short time by rapid acceleration.

2. By wind-tunnel testing, it was found that efficient wing forms with high lift over drag ratio and effective control surfaces could be designed for supersonic flight.

These German achievements are not the result of any superiority in their technical and scientific personnel, however, but rather due to the very substantial support enjoyed by their research institutions in obtaining expensive research equipment, such as large supersonic wind tunnels, many years before such equipment was planned in this country.

## Supersonic Wind Tunnels

There is no doubt that we were slow in recognizing the necessity of supersonic wind-tunnel research. I myself tried to persuade the Chief of Ordnance, after my return from a trip to Europe in 1937, to install a supersonic tunnel at Pasadena. General Barnes decided in 1942 to build such a tunnel at Aberdeen Proving Ground. The design was based on model studies carried out between 1940 and 1942 at the California Institute of Technology. Wright Field and NACA are building supersonic wind tunnels but until recently only one small tunnel with a cross section of 7.5 x 7.5 in was available. As the missile program made the need for supersonic aerodynamic data urgent, the Budget Bureau of the Government ordered hearings with the idea rather of restricting than encouraging the construction of such vital instruments of research under the slogan of "avoid duplications."

The picture of the situation on the other side is given by Figs. 1 and 2, which cover German supersonic wind tunnels in operation and under construction.

It seems to me that the Air Forces have to recognize the fact that the science of supersonic aerodynamics is no longer a part of exterior ballistics but represents the basic knowledge necessary for design of manned and unmanned supersonic aircraft. The Air Forces have to provide facilities and include this field in their research, development, and training programs.

## Arrowhead Wing

The main difficulty of flying at speeds near and beyond the velocity of sound is, of course, the extremely low lift-drag ratio of the airplane due to excessive drag. The range of an airplane, for example, is directly proportional to this ratio. Wing theory and wing design for subsonic airplanes were worked out with rather surprising success in this country and we

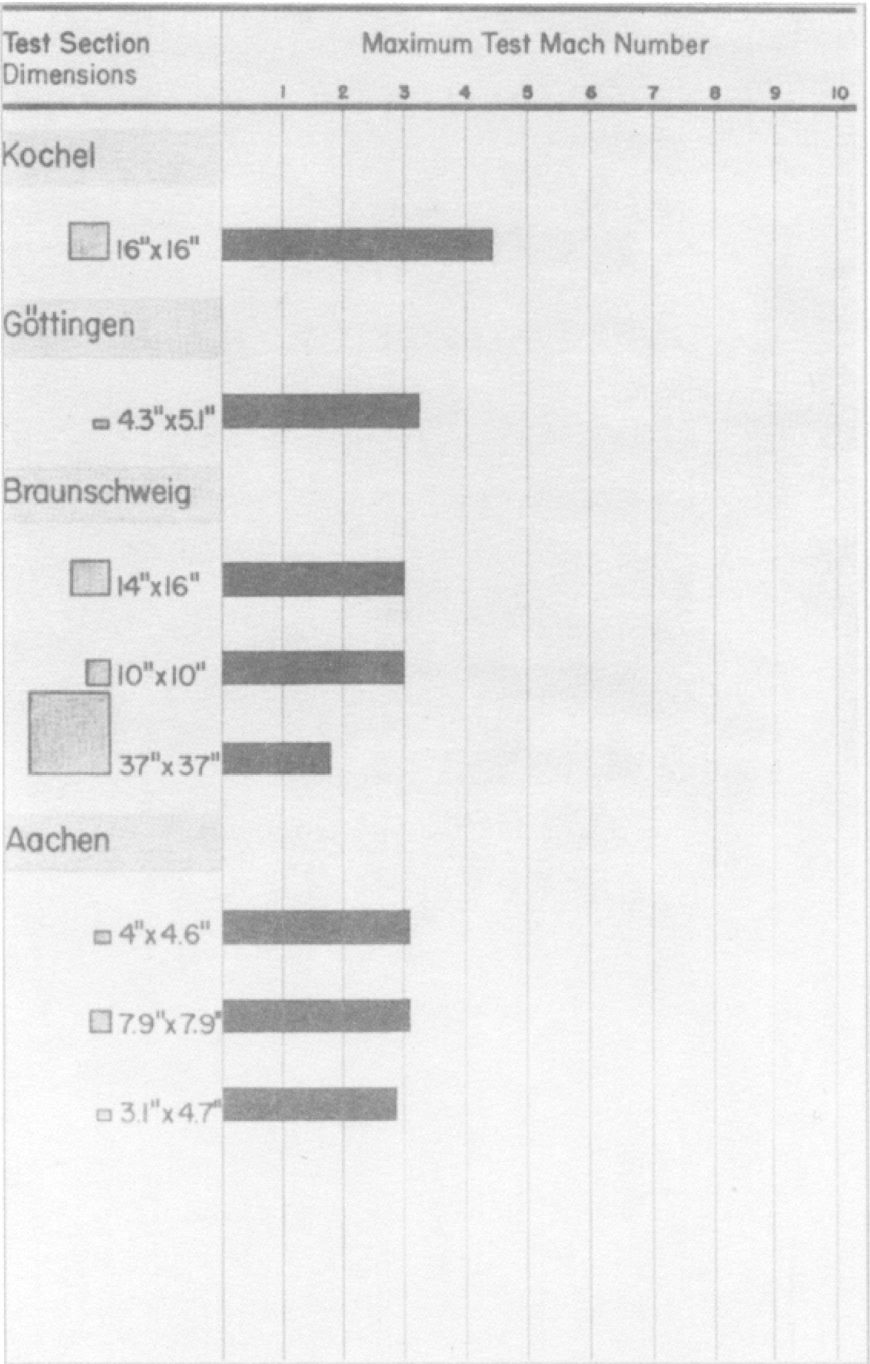


*Figure 1–German Supersonic Wind Tunnels (operation 1945)*

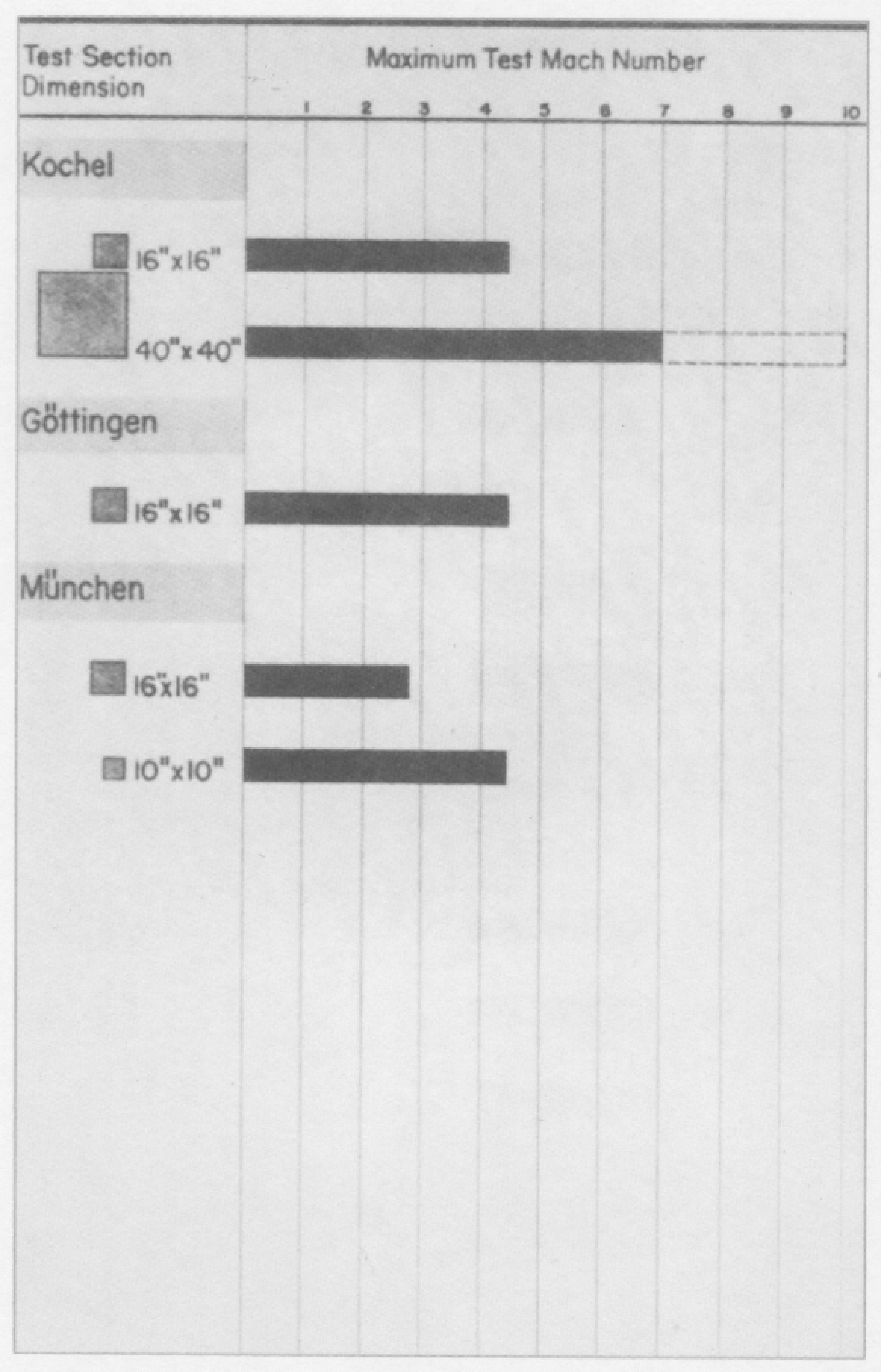


*Figure 2–German Supersonic Wind Tunnels (Construction 1945)*

were ahead of the Germans in this field. However, in the field of transonic and supersonic wing design, the Germans developed to the point of practical application ideas which were only in the discussion stage here.

The optimum lift-drag ratio of the wing of a very well designed subsonic airplane, the Mustang, is shown in Fig. 3. It is seen from the same figure that the lift-drag ratio for a rectangular supersonic wing at a Mach number of 2 is less than that of an old-fashioned biplane cell. This is the point where new ideas must step in.

One such idea is that of the arrowhead wing (Pfeilflügel), first suggested in a scientific paper by A. Busemann in 1935. This was a dormant idea until revived with success by German scientists and designers in the period 1942-1945.

The arrowhead wing is based on the thought that sweeping back the wings reduces considerably the effective Mach number of the wing and so lowers the resistance. As a matter of fact, if the sweepback is sufficiently large, the shock wave can be eliminated even at supersonic speeds over the greater part of the wing. I include here two photographs (Fig. 4) which belong to a series of experiments carried out at my suggestion in the Aberdeen supersonic wind tunnel in April, 1945, before I went abroad. These experiments were made at a Mach number of 1.72. It is seen that the straight wing produces a strong shock wave at the leading edge which fails to appear in the case of the swept-back wing. Robert Jones of the NACA announced similar suggestions in a report in June, 1945. The German scientists carried out comprehensive investigations on the problem. The two longer illustrations in Fig. 3 show the improvements of lift-drag ratio which can be realized by proper wing shapes. The Germans found that the reduction of the effective Mach number by sweepback applies also to the transonic range. They found that the critical Mach number at which the compressibility effects increase the drag and cause stability troubles, can be pushed to higher values by large sweepback of the wings. This result was utilized in several of their last airplanes, for example, the Messerschmitt-Lippisch design of their rocket interceptor, the e-163.

## Suggestions for Research

I believe that for the realization of supersonic flight the following engineering researches are indicated:

1. Complete airplane models with actual operating power plant should be tested for performance and detailed improvements in super-

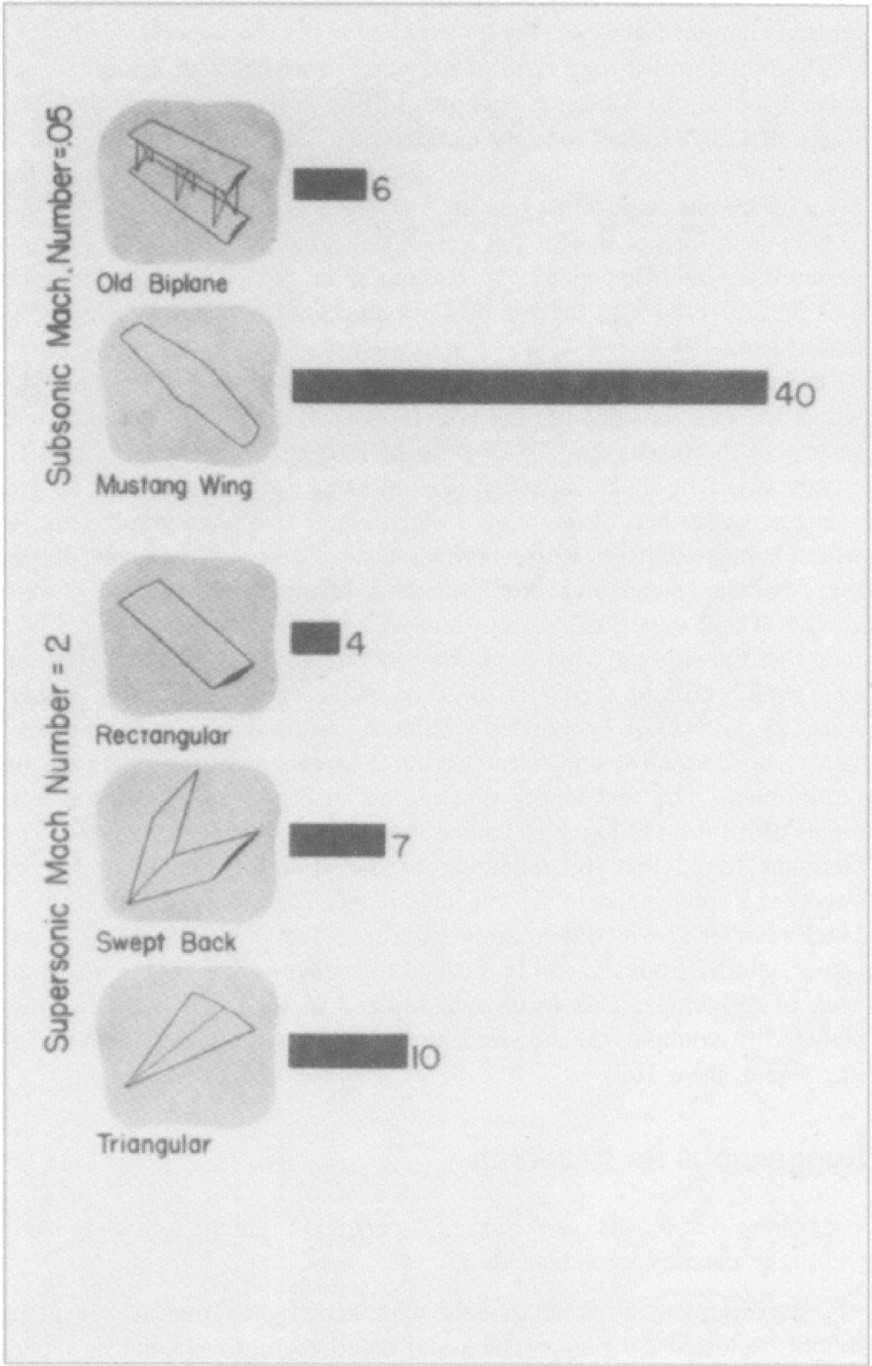


*Figure 3–Optimum Lift-Drag Ratios*

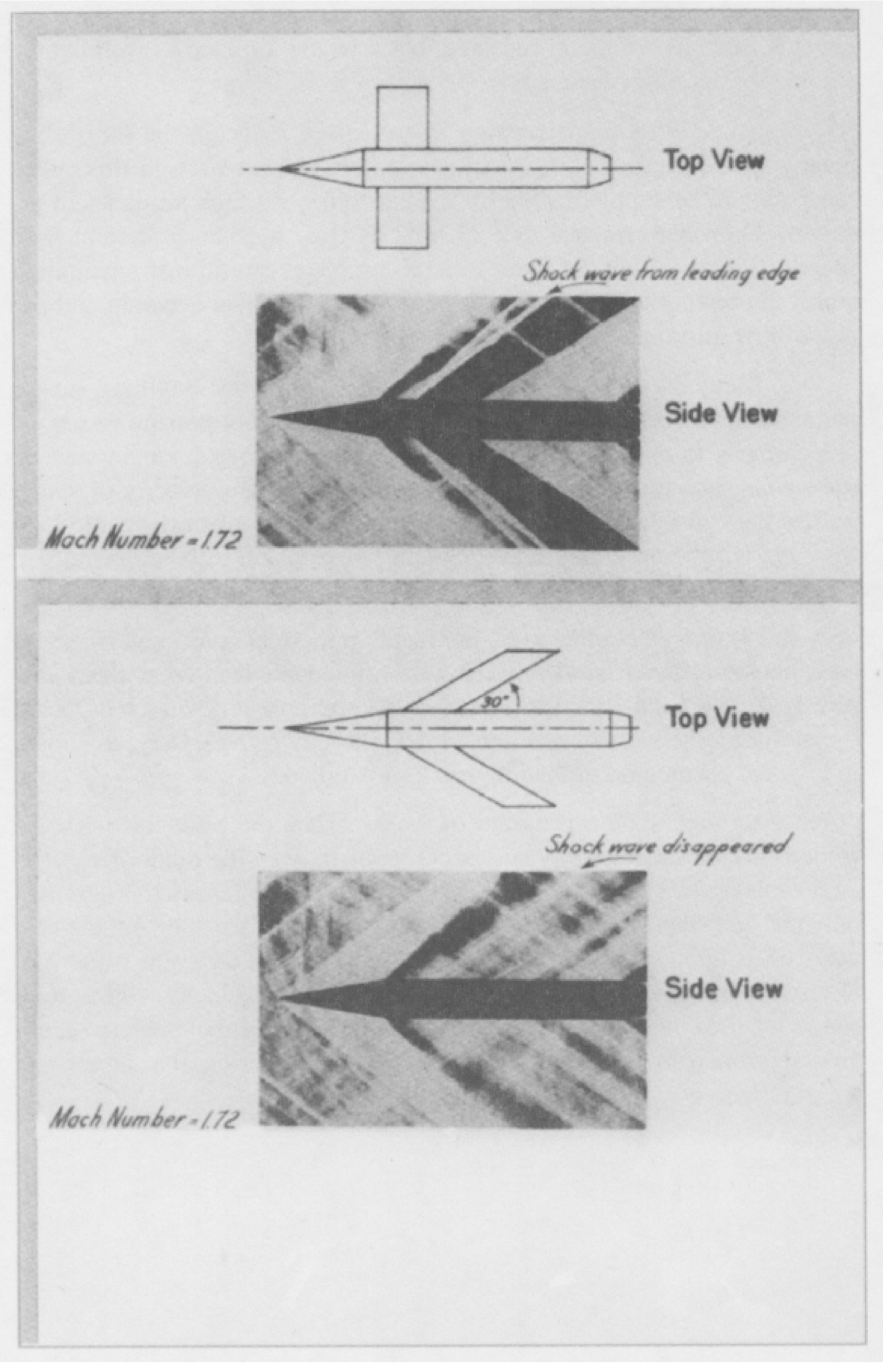


*Figure 4–Sweepback Effect on Shock Waves*

sonic wind tunnels at supersonic speeds. For this purpose supersonic wind tunnels of large test sections are necessary so that not only the components, such as wing and fuselage, but a whole airplane as well can be studied for optimum design.

2. Since wind-tunnel testing in the speed range in the immediate neighborhood of the sonic velocity is unreliable, research in this speed range should be supplemented by special flying research airplanes in order to obtain performance data as well as flow mechanics data at high speeds. For the success of these tests, a complete, careful instrumentation and flight-testing technique has to be developed so that accurate and detailed flow information can be obtained.

3. Methods of launching the airplane by various auxiliary power plants such as rockets, should be investigated. One promising means of launching is to combine the take-off and climb into one single step by rockets as shown in Fig. 5. The transition through the velocity of sound will be then very fast and the rockets can be dropped when spent. No long runways will be necessary and the main power plant, turbojet, or ramjet, can be designed most efficiently for supersonic operation only.

4. Landing is facilitated by the fact that the fuel consumed is a large percentage of the initial weight. However, to enable landing at a safe low speed, deceleration and lift increase by appropriately directed rocket thrust during the last few seconds of descent may be necessary, as shown in Fig. 5. This method of landing has to be studied.

Only through such a program of research can the problem of supersonic flight be satisfactorily solved. Of course, from the point of view of tactical usage of supersonic aircraft, the result of this research program is only the first step. There still remains the question of working out the best ways of using an aircraft of supersonic speed for the different situations. However, the very new horizon opened up by a velocity higher than sound justifies the intensive research indicated. We cannot hope to secure air superiority in any future conflict without entering the supersonic speed range.

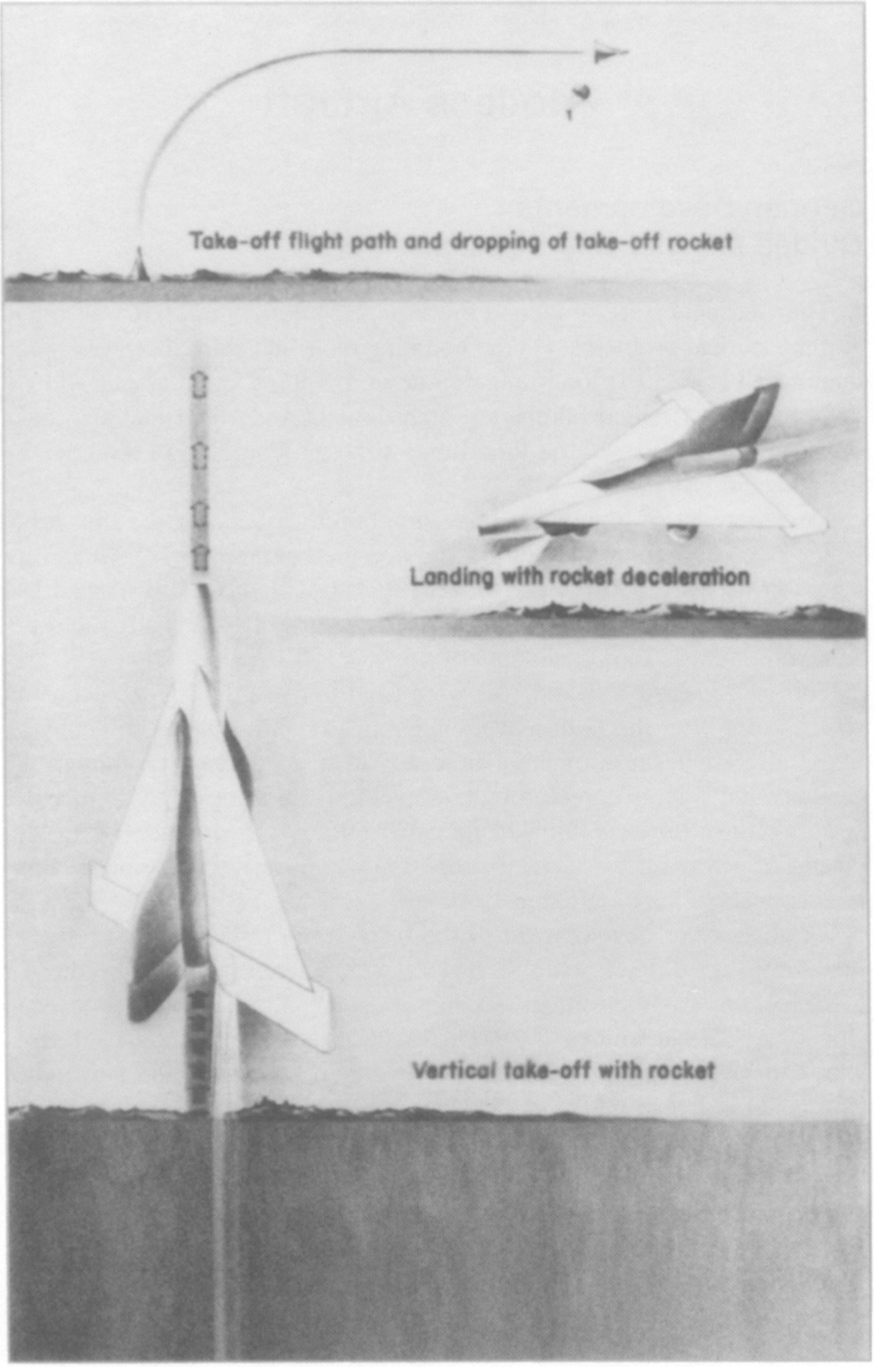


*Figure 5–Supersonic Airplane: Take-off and Landing*

# Pilotless Aircraft

## German Development of Guided Missiles and Pilotless Aircraft

The German effort on guided missiles and pilotless aircraft was aimed at three tactical problems: (1) the bombing of Allied ships, both naval and merchant vessels; (2) long-range strategic bombing of England; and (3) defense against Allied bombers. Some thought and effort had also been given to the problem of the long-range strategic bombing of America by unmanned missiles.

Development of high-angle and glide bombs to answer the first problem was started about the end of 1939 or the beginning of 1940 and resulted in the PC-1400-FX and Hs-293 missiles, first used in August and October, 1943. Both missiles were direct-sight radio-controlled and became unusable as soon as air superiority was lost.

The well-known V-1 and V-2 were used to meet the second problem, which arose after the failure of the attempt to bomb England by conventional aircraft because of the efficient British air defense. Although the fundamental scientific research and development work on these missiles had its root in projects initiated for other purposes early as 1935, the focusing of effort on the tactical problem of long-range bombing of England appears to have started in 1941.

The history of development of the buzz-bomb (V-1) is quite interesting. An inventor, Paul Schmidt, had a development contract from the Air Ministry for an intermittent jet motor in 1935. The work proceeded slowly. About November, 1939, Diedrich, of the Argus Motor Company, who had been working for the Air Ministry on exhaust pipe jet-propulsion nozzles, began work on intermittent combustion in an open pipe. In 1940, the Air Ministry brought Schmidt to the Argus Company and combined the developments. The first successful motor was completed in 1941. This motor development itself was intended for use in aircraft. About that time the ground forces development of the large V-2 rocket, which was started at a very early date, was delayed. Since this weapon was considered extremely important for the outcome of the war, an official of the Air Ministry proposed the use of a combination of small airplane with intermittent jet motor as a substitute for the same purpose. The V-l was thus conceived and became a development of the air forces. Its code name was originally Kirschkern (cherry pit) because it was merely to be spit out against England.

Fieseler Aircraft Company was selected to build the air frame. The development tests were made at the Air Ministry laboratory at the Luftfahrtforschungsanstalt Hermann Göring, Braunschweig, in the 2.8-m high-speed wind tunnel. The original model of the V-1 was not very good, the net thrust of the motor being zero at 380 mph. About 60% of the operating time of this wind tunnel was needed for nearly a year to bring the development to its present stage.

The first reconnaissance photograph of the V-l was taken by the British at Peenemünde in April, 1943, and bombing made Peenemünde uninhabitable by August, 1943. The first operational use of the V-l was on 12 June 1944.

The V-2 or long-range rocket was known as A-4 or Apparat 4. The first of the series, A-1, was fired in 1935 at Kummersdorf. It was a small rocket of aluminum construction, 100-kg thrust, intended for use on aircraft.

Dr. von Braun, leader of the Peenemünde group which developed the V-2, was a student of Professor Hermann Oberth, a well-known inventor and writer in the field of rockets, who had published books on interplanetary rocket travel. A group of Oberth's students became interested in rockets and organized an amateur rocket group. All were well-trained scientists. In 1935, Dr. von Braun was employed by the German War Department and sent to Peenemünde. In 1941, von Braun brought Oberth there as head of the Patent Section. By 1941, Peenemünde was an active test station. The Me-163 was brought there in September, 1941 and in October, 1941 flew at a speed of 1,003 km hr (about 623 mph). In October, 1941, the first supersonic wind-tunnel tests were made on a projectile at a Mach number of 4.4. After the bombing of Peenemünde in August, 1943, the activities were decentralized. The wind-tunnel group went to Kochel, where it was in operation in January, 1944. The first use of the V-2 was on 8 September 1944.

Development of guided missile defense against bombers began early in 1943. The missiles were all rocket-propelled and, in their final development, many were to be automatically controlled with homing devices and equipped with proximity fuses. Many of these missiles (X-4, Hs-298, Schmetterling, Rheintochter, Enzian, and Wasserfall) reached their final testing and early production stage but with direct-sight radiocontrol only.

The electronic developments, homing devices, and proximity fuses lagged behind the vehicle and propulsion unit developments. The X-4 air-to-air missile was provided with an interesting direct wire control to avoid the possibility of jamming, present with radio control. Two of the wings carry at the tips spools of fine wire long enough to permit a range of three miles while maintaining direct wire connection between the missile and the control aircraft. The wires can be fed out at speeds of more than 400 mph. None of these missiles were used against our bombers. The German situation became so critical indeed that development of complicated guided rockets was stopped in February, 1945, in favor of concentrating on small, unguided rockets to be used in large numbers.

The German military agencies, research institutions, and industrial designers devoted a large effort to guided missiles and considered them very promising weapons. In August, 1944, there were some 25 projects for homing devices under developments. The major research laboratories of the air and ground forces made many wind-tunnel and flight tests, some at high supersonic speeds, and made many theoretical studies of problems related to guided missiles and pilotless aircraft.

Perhaps the most important result of the German effort in this field was to show that winged missiles are superior in performance to finned missiles. Thus, the next stage in the development of the V-2 rocket was to have been the addition of wing. The necessary wind-tunnel tests had been made in connection with the development of the winged ground-to air rocket Wasserfall and ballistic computations had shown that this change alone would increase the range of the V-2 rocket from about 250 to about 400 miles. Wind-tunnel models of the winged V-2, known as A-9, are shown in Fig. 7.

The German scientists believed, although some German engineers in industry disagreed, that the ultimate guided missile would be completely automatic in its operation. Although for quick development and for test purposes they favored the use of manual radio control, their long-range plans contemplated first automatic blind tracking of the missile and target, then the connection of the two tracking devices through a computer to the radio control channels, and finally the use of a homing device for the last part of the trajectory and a proximity fuse.

Looking over the great variety of projects one finds that the V-2 rocket was the most outstanding technical achievement and that the Peenemünde group of scientists, working for the ground forces, was the most capable missile research group in Germany. It is important for us to note that one element in their success was the fact that they had under a single leadership in one organization, experts in aerodynamics, structural design, elec-

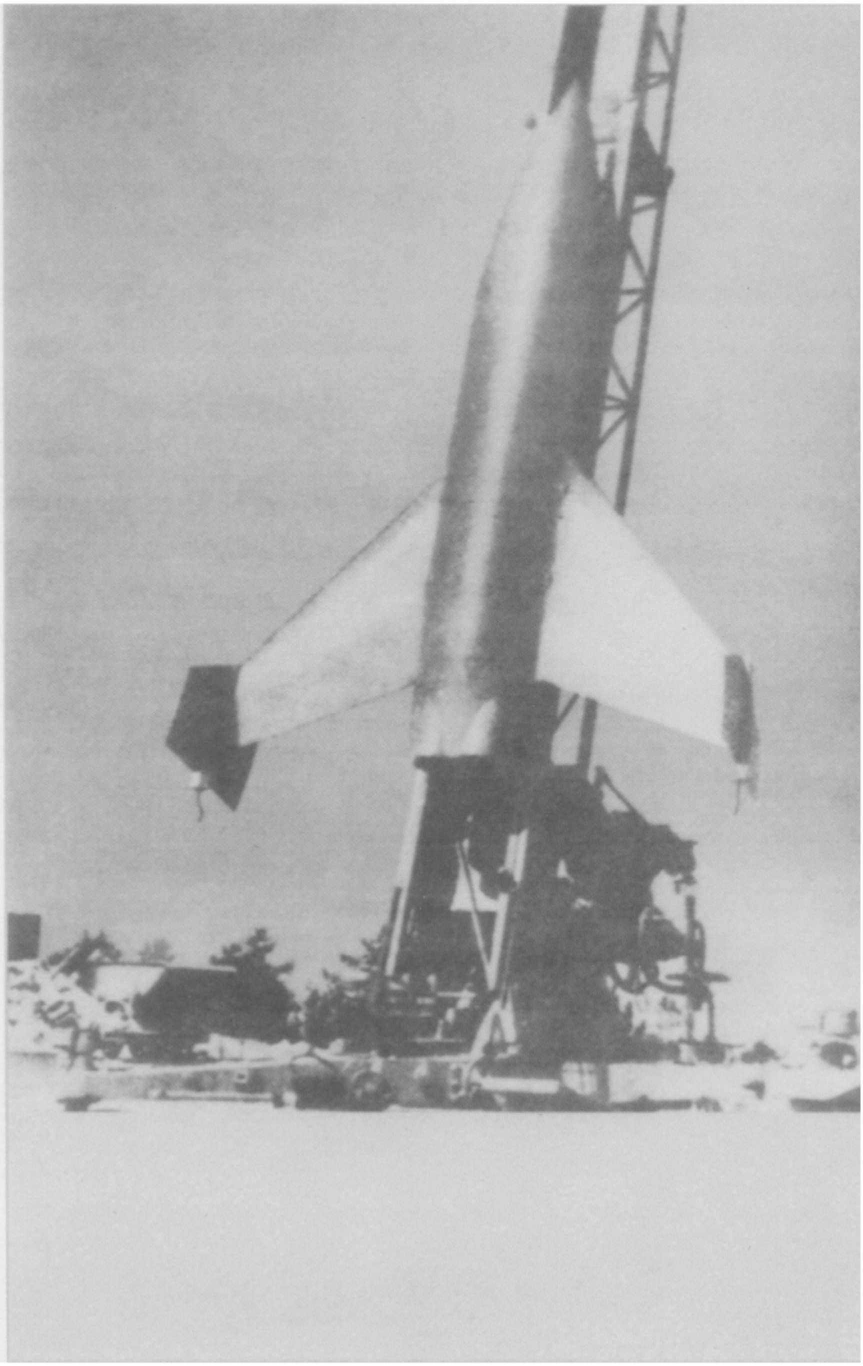
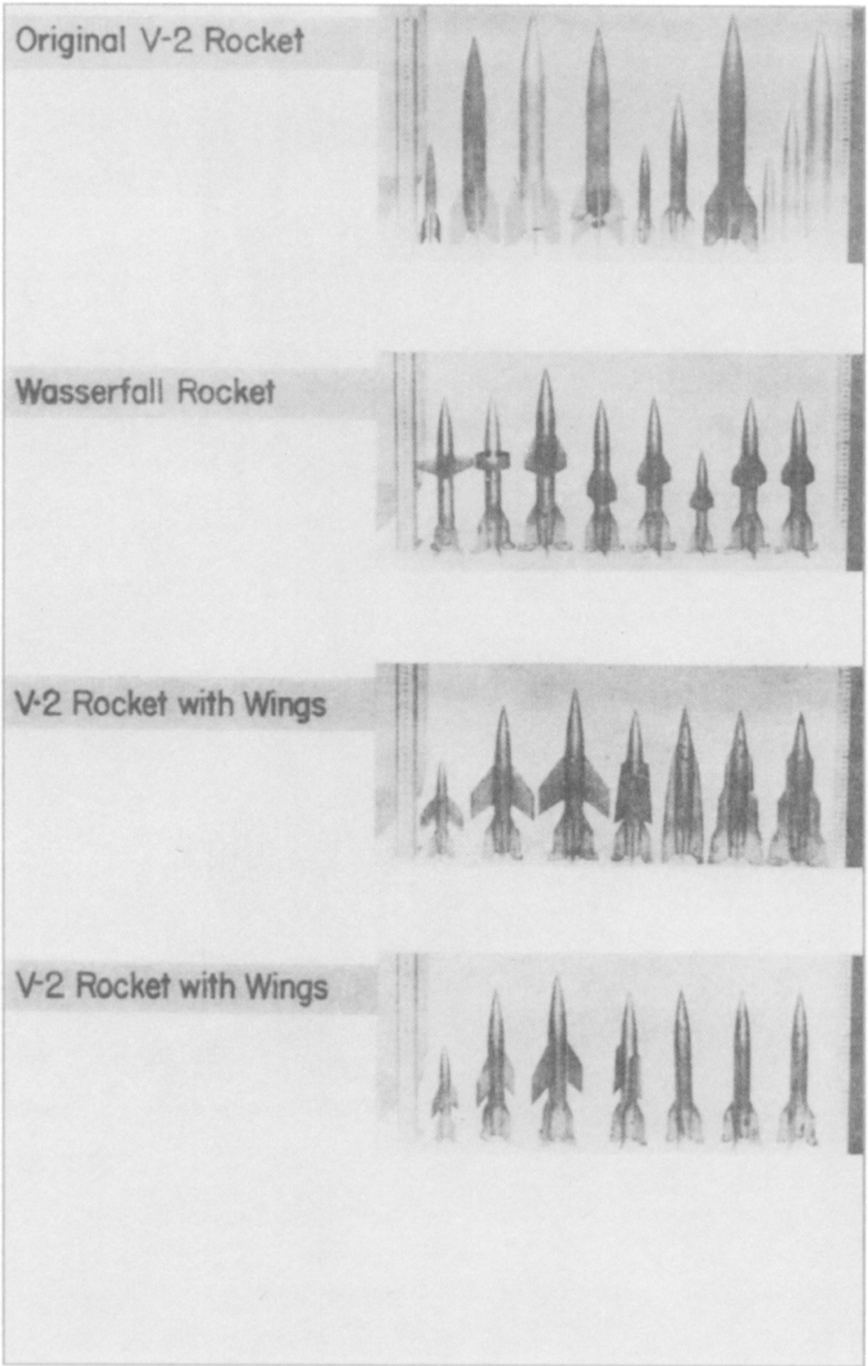


*Figure 6–German "Feuerlilie" Rocket*



Original V-2 Rocket

Wasserfall Rocket

V-2 Rocket with Wings

V-2 Rocket with Wings

*Figure 7–Rocket Models for Supersonic Wind-Tunnel Tests*

tronics. servomechanisms, gyros and control devices, and propulsion; in fact, every group required for the development of a complete missile. The letters and papers in the files of industrial groups, like Messerschmitt, show rapid progress in the field of vehicle and propulsion, the fields in which the firm itself had qualified people, but delay after delay on controls and electronic devices which had to be secured elsewhere. The Luftwaffe research laboratories made little progress in the actual development of specific weapons, largely because of the absence of electronics experts and their lack of facilities for the construction of experimental missiles.

In addition to the German view that the final guided missile would be completelyautomatic in operation, the possibilities of long-range strategic bombing were fully understood. There is no question but that the diversion of the efforts of the Peenemünde scientists in 1943 to the development of an antiaircraft guided rocket delayed the introduction of the winged V-2 rocket (A-9) and its successor, the transoceanic rocket (A-9 plus A-10. Drawings and computations had been completed for the A-10, a rocket weighing 85 T with a thrust of 200 T to be used as a launching rocket for the A-9, accelerating it to a speed of 3,600 ft/sec. The motor of the A-9 would accelerate it further to a speed of 8,600 ft/sec, giving it a range of about 3,000 miles. Some consideration was given to the design of one version of the A-9 carrying a pilot. The Scientific Advisory Group agrees that the German results of wind-tunnel tests, ballistic computation, and experience with the V-2 justify the conclusion that a transoceanic rocket can be developed.

The principal German advantage in the field of guided missiles was the lead in time in the development of rockets. which were considered to have serious military applications as early as 1935. Much effort was put into this field and as a result the supporting industrial developments were ready as a foundation for missile designers. They could buy rocket motors and rocket fuels from commercial sources. In this respect they lead us. The V-2 development was successful not so much because of striking scientific developments as because of an early start, military support, and a boldness of execution. In the electronic field, radar in particular, we are definitely one or two years in the lead, although we have not put as much effort in the experimental determination of the limits of application of acoustic and infrared devices.

## Pilotless Aircraft from Viewpoint of the Air Forces

The Air Forces have rather thoroughly explored the field of guided high-angle and glide bombs released from aircraft. This program is un-

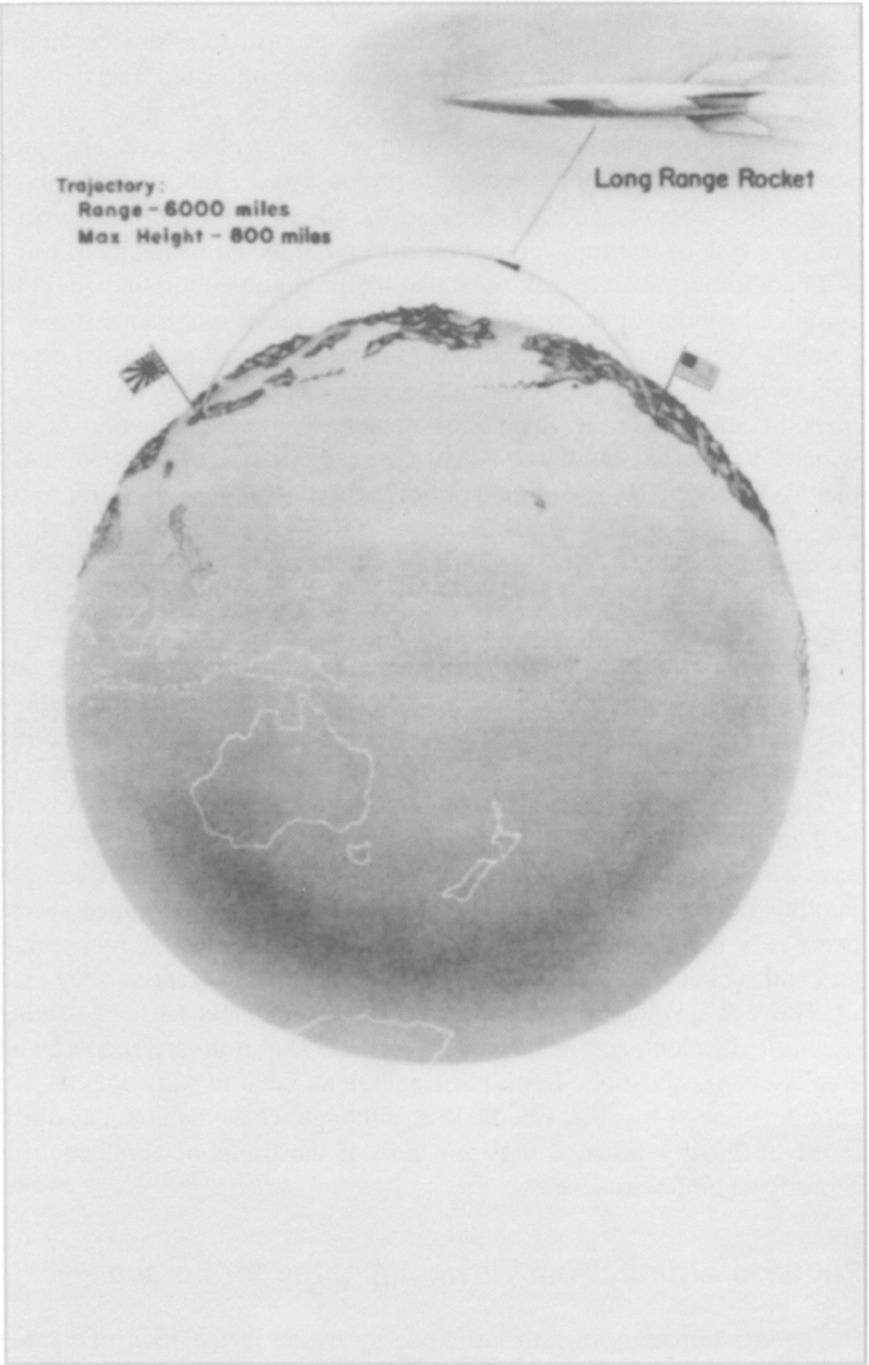


*Figure 8–6000-Mile Rocket*

doubtedly well known to the Commanding General through the AMC progress reports It includes preset glide bombs controlled by an automatic pilot, high-angle and glide bombs remotely controlled by radio with and without television repeat-back equipment, and high-angle and glide bombs homing by light, heat, and radar. During the war period there were many projects and the number tended to grow continually. In this early stage of development there was not much possibility for real systematic planning. It should be possible now to reduce the number of projects to those meeting definite military requirements and to standardize on a small number of missiles. These standardized missiles should be used to continue research and development on homing devices.

Our endeavors in pilotless aircraft in the proper sense include, in addition to the successful reproductions of the V-1 type, a few promising beginnings. However, the Air Forces should realize that the task is far beyond the scope of inventing gadgets and trying to make them work. There is urgent need of a systematic analysis of the various tasks which manned airplanes equipped with bombs, guns, and rockets perform, and which now may be performed by pilotless craft.

In other words, two developments have to meet for successful solutions of the problems: The tactical viewpoint must lead to the choice of the types of pilotless aircraft; on the other hand, physical science will proceed to offer more and more extended ranges and improved accuracy.

However, beyond that the implications of the accomplishments of the German Pennemunde group and of the recent development of the atomic bomb by United States and British scientists, future methods of aerial warfare call for a reconsideration of all present plans. A part, if not all, of the functions of the manned strategic bomber in destroying the key industries, the communication and transportation systems, and military installations at ranges of from 1,000 to 10,000 miles will be taken over by the pilotless aircraft of extreme velocity. The use of supersonic speeds greatly reduces errors due to wind drift and other atmospheric conditions and the tremendous zone of damage of the atomic bomb diminishes the required precision. Hence, the difficult control problem is made easier.

For the future long-range strategic bomber, the Scientific Advisory Group foresees two types of pilotless aircraft, both with wings, one with a high trajectory reaching far into the outer atmosphere, and the other designed for level flight at high altitudes. The first one can be considered as a further development of the V-2 rocket. In fact, this was planned by the German scientists. By using two or more step-rockets for the acceleration, a very high speed is imparted to a missile, perhaps as high as 17,000 mph or more, to give ranges of several thousand miles. In this case, the

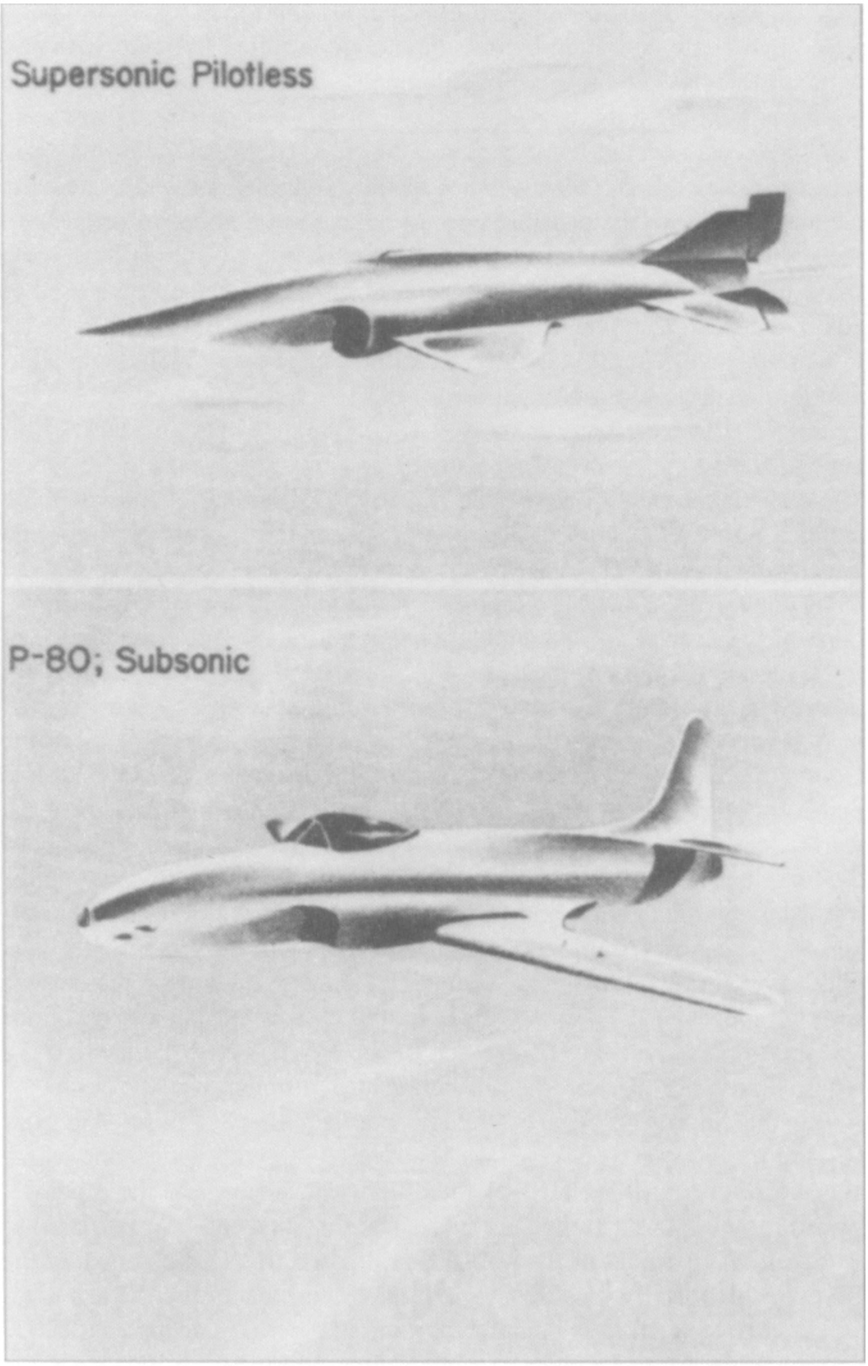


*Figure 9–Supersonic and Subsonic Airplanes*

wings are required mainly for control purposes, but they also serve to extend the glide path in the lower atmosphere. The German scientists have suggested a second type of trajectory requiring less initial energy, in which the wings are caused to curve the path of the missile when it returns to the region of increasing air density so that it rebounds to great heights. After a number of rebounds the winged missile settles down to a steady glide. Such a trajectory would seem difficult to control accurately.

The second future strategic bomber is a supersonic pilotless aircraft, flying at altitudes of from 20,000 to say, 60,000 ft. It appears to us now that the speed will be about twice the speed of sound and that the aircraft will be powered by a turbojet motor. An intermediate step might be a pilotless aircraft traveling at high subsonic speeds with a Mach number of about 0.9 about 600 mph at 40,000 ft.

For the future defense against hostile aircraft, it seems clear that supersonic guided missiles will be used, propelled either by rockets or more probably by a ramjet. The fully automatic radar beam guiding methods of control of the type suggested but not experimentally tried, by the Germans will probably be used for guiding, supplemented by simplified heat-homing devices and proximity fuses.

The present facilities and organization for research and development of pilotless aircraft appear inadequate. It cannot be expected that such complex problems can be successfully solved by any group which is specialized in only one of the several fields which are involved.

Leadership in the development of these new weapons of the future can be assured only by uniting experts in aerodynamics, structural design, electronics, servomechanisms, gyros, control devices, propulsion, and warhead under one leadership, and providing them with facilities for laboratory and model shop production in their specialties and with facilities for field tests. Such a center must be adequately supported by the highest ranking military and civilian leadership and must be adequately financed, including the support of related work on special aspects of various problems at other laboratories and the support of special industrial developments. It seems to us that this is the lesson to be learned from the activities of the German Peenemünde group.

# PROPULSION METHODS IN THE MAKING

## Introduction

The following classification embraces the most important novel methods of propulsion emerging from the war years, utilizing atmospheric oxygen:

| | *Suggested Designations* | *German Designations* |
|---|---|---|
| Reciprocating engine + ducted fan | Motorjet | ML |
| Gas turbine + propeller | Turboprop | PTL |
| Gas turbine + ducted fan | Turbofan | ZTL |
| Gas turbine + jet | Turbojet | TL |
| Continuous jet, compression by aerodynamic ram | Ramjet | L |
| Intermittent jet | Pulsojet | IL |

These systems are shown schematically in Figs. 10a and 10b.

The motorjet is widely known as the Campini system. As a matter of fact such a propulsion system was used in the first jet-propelled airplane which was flown in Italy a few years before the war. Probably it will be found heavier and less efficient than some other systems. All elements of the various systems were known long before the war in the patent literature. The fact that they succeeded in becoming practical realities is due to several causes:

1. Fast airplanes and missiles required propulsion systems independent of the use of propellers.

2. Military use justified the design of engines with relatively poor fuel economy, if they are lighter and less bulky than conventional recip-

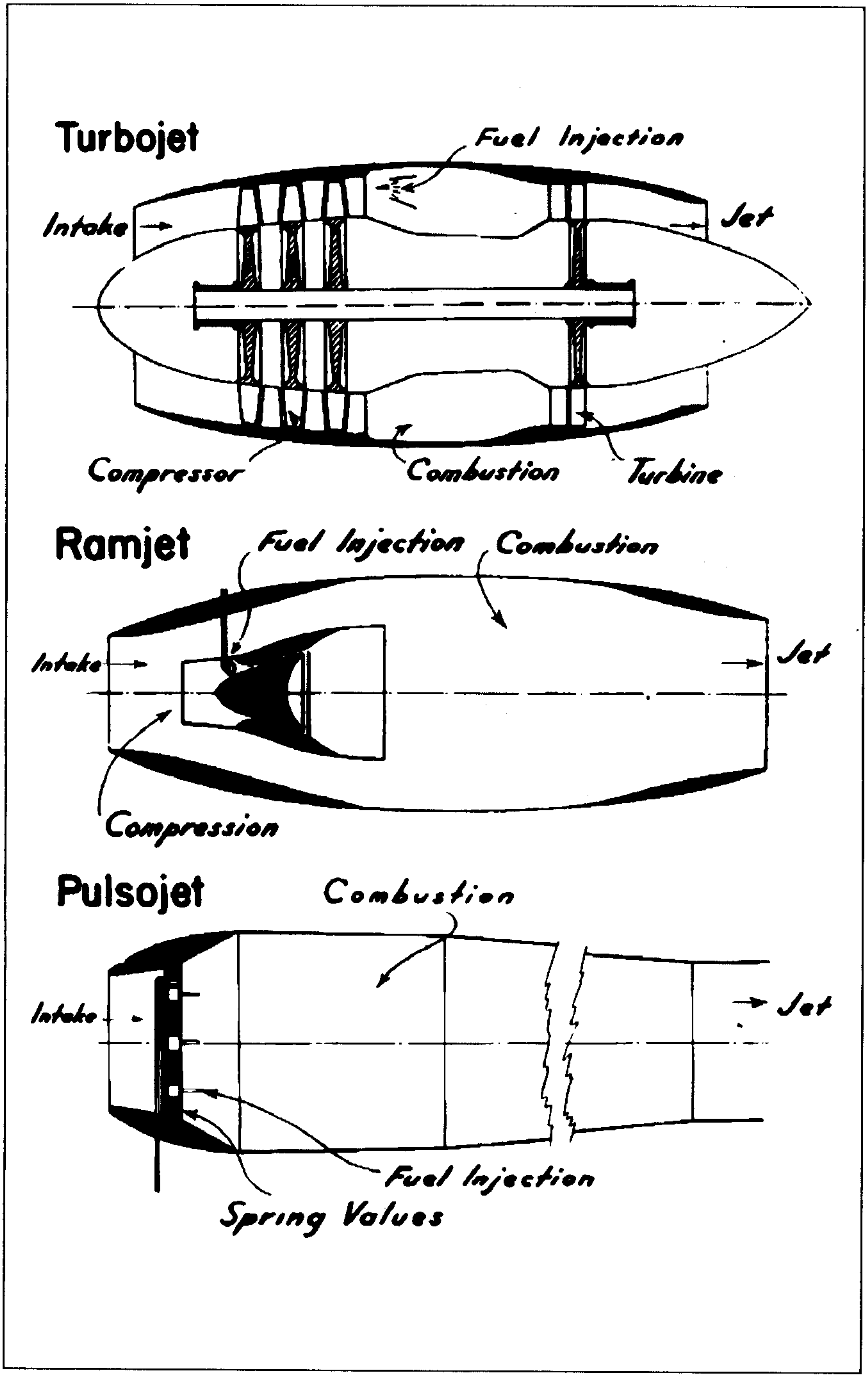


*Figure 10-B–Various Propulsion Systems*

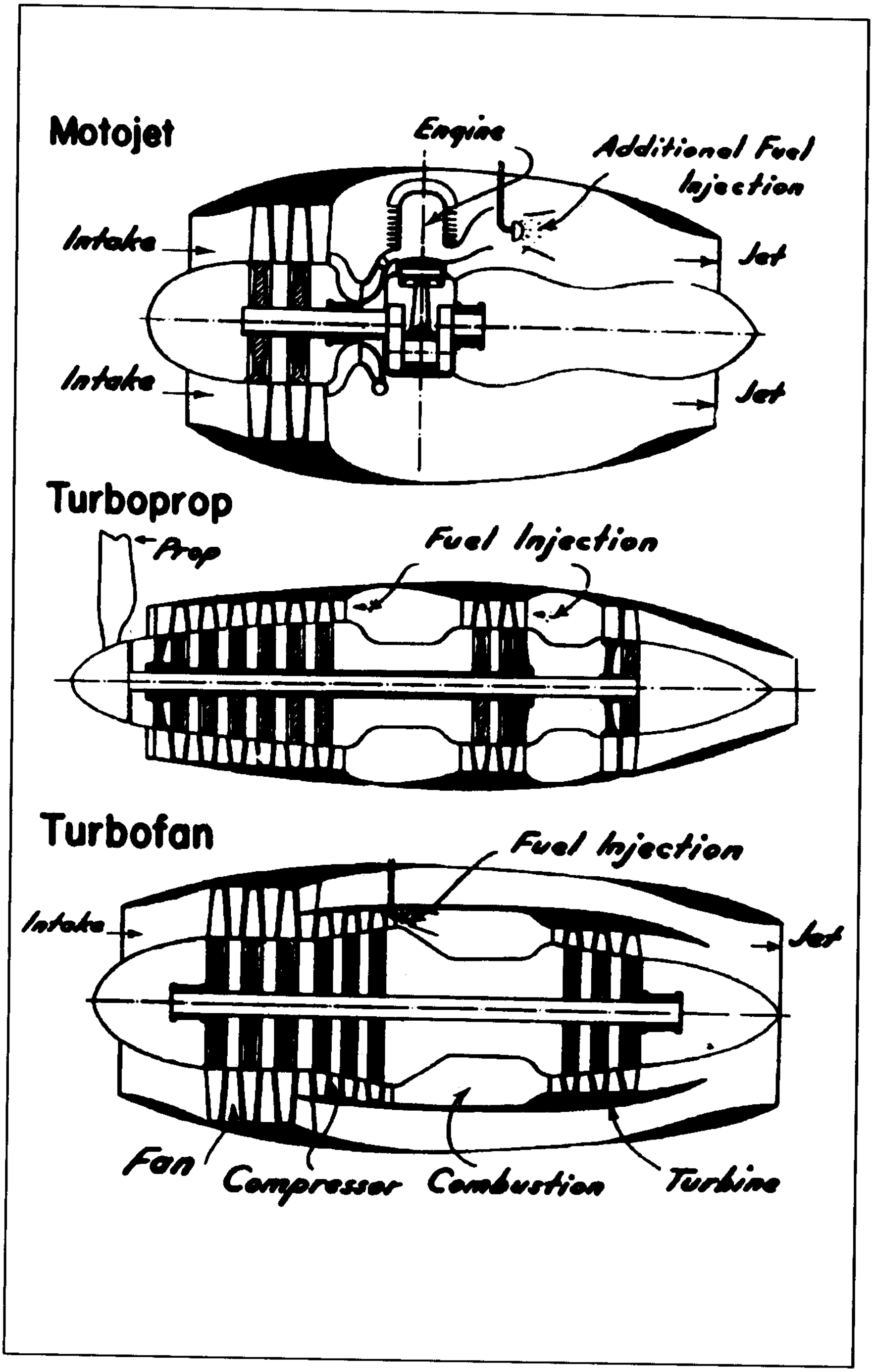


*Figure 10-A–Various Propulsion Systems*

rocating engines and/or could offer themselves to simpler manufacturing methods.

3. The science of aerothermodynamics, especially research on combustion in high-speed airflow made great progress in the war years.

4. Metallurgy found new high-temperature-resisting materials.

5. Bold and progressive designers created prototypes of turbines and compressors which conventional engineering considered impossible.

The progress made in combustion technique, lightweight construction, and materials is here to stay and development will continue. In addition, proper scientific study and further research will make at least some of the new propulsion systems equally or more economical than the conventional engines are now. On the other hand it may also happen that the competition of the novel ideas will induce designers of reciprocating engines to produce some radical improvements in their own field. In the following pages, Allied and German developments in the new propulsive devices are compared in some detail. Before discussing the most important types, I include here as a matter of interest a 12-year plan for the period 1938-1950, which the man responsible for engine research in the German Air Ministry published in a secret document in July, 1943, although it does not appear to me as a very well-balanced and far-seeing project.

**First 4-Year Program (1938-1942).** The aim of the first 4-year program was the development of simple turbojet engines for mass production, without particular regard for quality, utilizing readily available material, simple manufacturing methods, and generous tolerances. At the same time studies were to be initiated in preparation for the second period. Results of the first period are shown in mass production of turbojets such as the BMW 003, the Jumo 004, and the Heinkel-Hirth 011.

**Second 4-Year Program (1942-1946).** This period had the objective of developing the following items:

1. Improved turbojets of higher power, capable of operation at higher altitudes. (Example: BMW 018 for 7700-lb thrust.)

2. Gas turbine + ducted fan units.

3. Gas turbine + propeller combination. (Example: BMW 028 for 12,000 hp at 500 mph at sea level.)

4. Ramjet.

5. Research and design studies on a gas turbine with heat exchanger for long distance flights. This has the German designation GTW.

6. Reciprocating engine + ducted fan units.

7. Research and development on the explosion-type gas turbine. One of the ideas on this subject was the use of a pulsojet, such as the V-1 motor, as a source of gas for operating a turbine.

**Third 4-Year Program (1946-1950).** Development to a working state of the following items was visualized for this period:

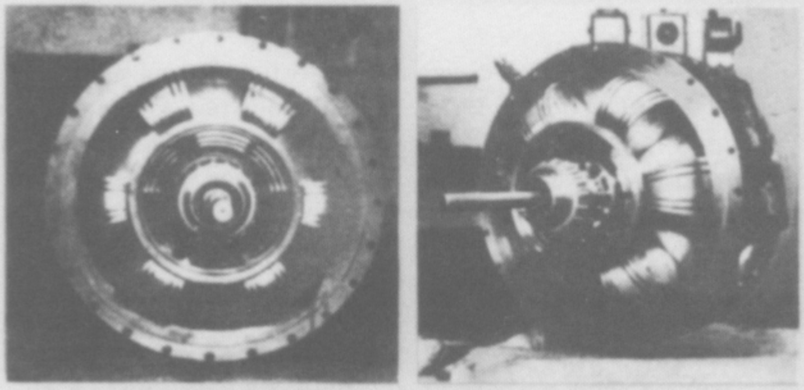
1. Gas turbine with heat exchanger (GTW system).
2. Reciprocating engine + ducted fan units.
3. The intermittent or explosion-type gas turbine.

## TURBOPROPELLER AND TURBOFAN

It is general opinion that simultaneously with the development of the jet reaction principle for fast airplanes the gas turbine with propeller or fan drive will have wide applications for airplanes of moderate speed. Jet propulsion has intrinsically low efficiency at low and moderate speeds so that the propeller is superior. On the other hand, it is expected that further research will help the gas turbine attain at least the same efficiency as reciprocating engines now have. It will then have the additional advantages of lighter weight, simpler construction, and absence of the vibrations inherent in reciprocating engines.

The thermal efficiency of existing gas turbines is still considerably lower than that of reciprocating engines at their optimum operating conditions. However, many methods not yet completely developed are available for improvement of the efficiency and associated reduction of fuel consumption of the gas turbine. Heat exchangers help to recover the energy of hot exhaust gases; intercooling between compressor stages and reheating between turbine stages increase the cycle efficiency. Finally, the replacement of the rotating compressor and combustion chamber by a reciprocating system, for example, a free-piston gas generator, allows the use of high pressures and materially lowers the fuel consumption. It is extremely desirable that all of these avenues of further development be thoroughly investigated. An interesting German suggestion, a free-piston gas generator with doughnut-shaped housing for the pistons, is shown in Fig. 11. The arrowhead wing principle applied to the design of high-speed propellers for reducing compressibility effects and increasing effi-

Free-Piston Engine



Swept-Back Propeller

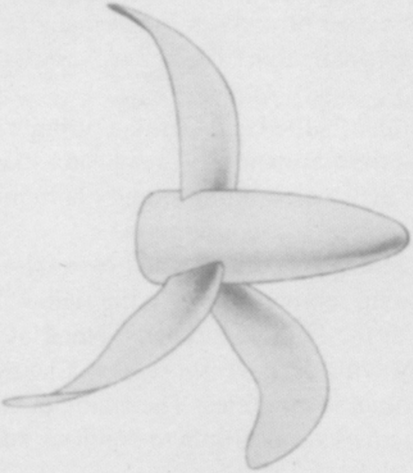


*Figure 11–German Engine and Propeller Developments*

ciency is also shown in Fig.11. Table I outlines German and Allied turboprop and turbofan, and high-speed propeller developments.

## Turbojet

The principles and main design characteristics of turbojet engines for airplanes were known before the war in all countries. Endeavors in private industry in England and Germany started at about the same time, in 1935. Our own industry was somewhat discouraged by official studies which were certainly much too conservative, especially concerning the weight of gas turbines and compressors. The German government was perhaps more alert in subsidizing this development than was the English government. The American development started with directives from General Arnold. As far as the centrifugal type of compressor is concerned, the U.S. units were based on Whittle's design, utilizing our own experience with turbosuperchargers. The independent development of the axial-type compressor started about the same time. In the German designs, both centrifugal and axial types are used; with emphasis on the axial. The progress of the actual prototypes in Germany is illustrated by a timetable taken from a German report, dated 2 November 1944, shown in Fig. 12.

The comparative merits of Allied and German turbojet units are shown in Fig. 13. It is seen that the Germans of were ahead as far as the sizes of units are concerned; but they were trailing slightly both in specific weight of the engine and in its specific fuel consumption.

In Table II, I am including a list of detailed research problems which may be helpful for planning future research in the field of gas-turbine and jet engines, as well as in the field of turbojets. None of these problems was solved in Germany with decisive success; but most of them were carefully studied in German laboratories. The status of German research is indicated with some remarks concerning the outlook and recommendations.

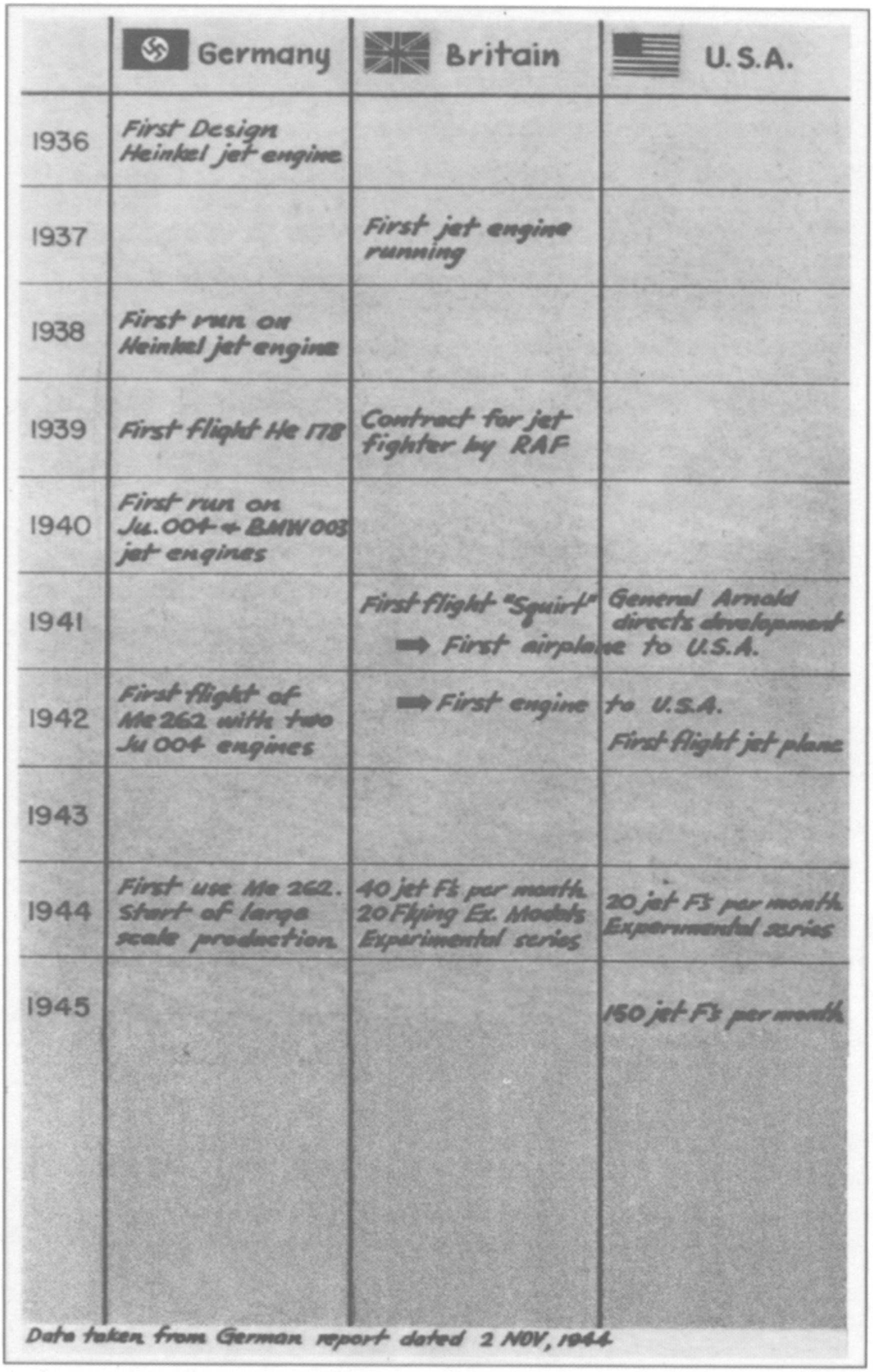
The present application of turbojet engines is for propelling airplanes at the upper end of the subsonic range. Although the propulsion efficiency of the jet is relatively low at such flying speeds, its application is justified by lightness of weight and simplicity of construction of the jet engine in comparison with reciprocating engines, and because the efficiency of propeller drive decreases somewhat at flight speeds approaching sonic velocity. On the other hand, the propulsive efficiency of jet drive is increasing with increasing velocity; hence, we have to consider

# TABLE I

## Turbopropeller and Turbofan Development

**NOTE:** No detailed list of allied projects is presented since most of the active projects are Classified.

| *Item* | *German Projects* | *Remarks* |
|---|---|---|
| Turboprop | BMW 028; Adaptation of BMW 018, 12,000 hp at 500 mph at sea level, wt 7700 lb. Design stage.<br>Jumo 022; Adaptation of 012, 8000 hp at sea level. Preliminary design only.<br>Daimler - Benz 021; Adaptation of Heinkel-Hirth Oll, 4000 hp at 500 mph at 25,000 ft. Design stage only. | U.S. leads Germany in having a low-powered turboprop in experimental operation, namely, the TG-100. Germany leads U.S. in development of high-powered unit, namely the BMW 028. Recommend U.S. push development of larger powered units. U.S. needs greater capacity in compressor and turbine test facilities, and wind tunnels for testing large gas turbine nacelles. |
| High-Speed Propellers | Tests of swept-back propeller blades at DVL, Berlin, and AVA Göttingen, show improved efficiency at high-flight speeds. | Intensive investigation of swept-back propellers in high-speed wind tunnels recommended for U.S., since it shows possibility of increasing top speed of propeller-driven aircraft. |
| Turbofan | Design studies by Junkers, Heinkel, BMW. | Recommend immediate evaluation of this drive for application to U.S. aircraft. |
| Free-Piston Gas Generator | Junkers reciprocating free piston and LFA rotating free piston. | Rotating free piston shows promise of decreased weight and size over reciprocating free piston. Recommend German development be evaluated whether advantageous for applications in U.S. |



| | Germany | Britain | U.S.A. |
|---|---|---|---|
| 1936 | First Design Heinkel jet engine | | |
| 1937 | | First jet engine running | |
| 1938 | First run on Heinkel jet engine | | |
| 1939 | First flight He 178 | Contract for jet fighter by RAF | |
| 1940 | First run on Ju. 004 + BMW 003 jet engines | | |
| 1941 | | First flight "Squirt"<br>➡ First airplane to U.S.A. | General Arnold directs development |
| 1942 | First flight of Me 262 with two Ju 004 engines | ➡ First engine to U.S.A. | First flight jet plane |
| 1943 | | | |
| 1944 | First use Me 262. Start of large scale production | 40 jet F's per month<br>20 Flying Ex. Models<br>Experimental series | 20 jet F's per month<br>Experimental series |
| 1945 | | | 150 jet F's per month |

Data taken from German report dated 2 NOV, 1944

Figure 12–Timetable of Turbojet Development

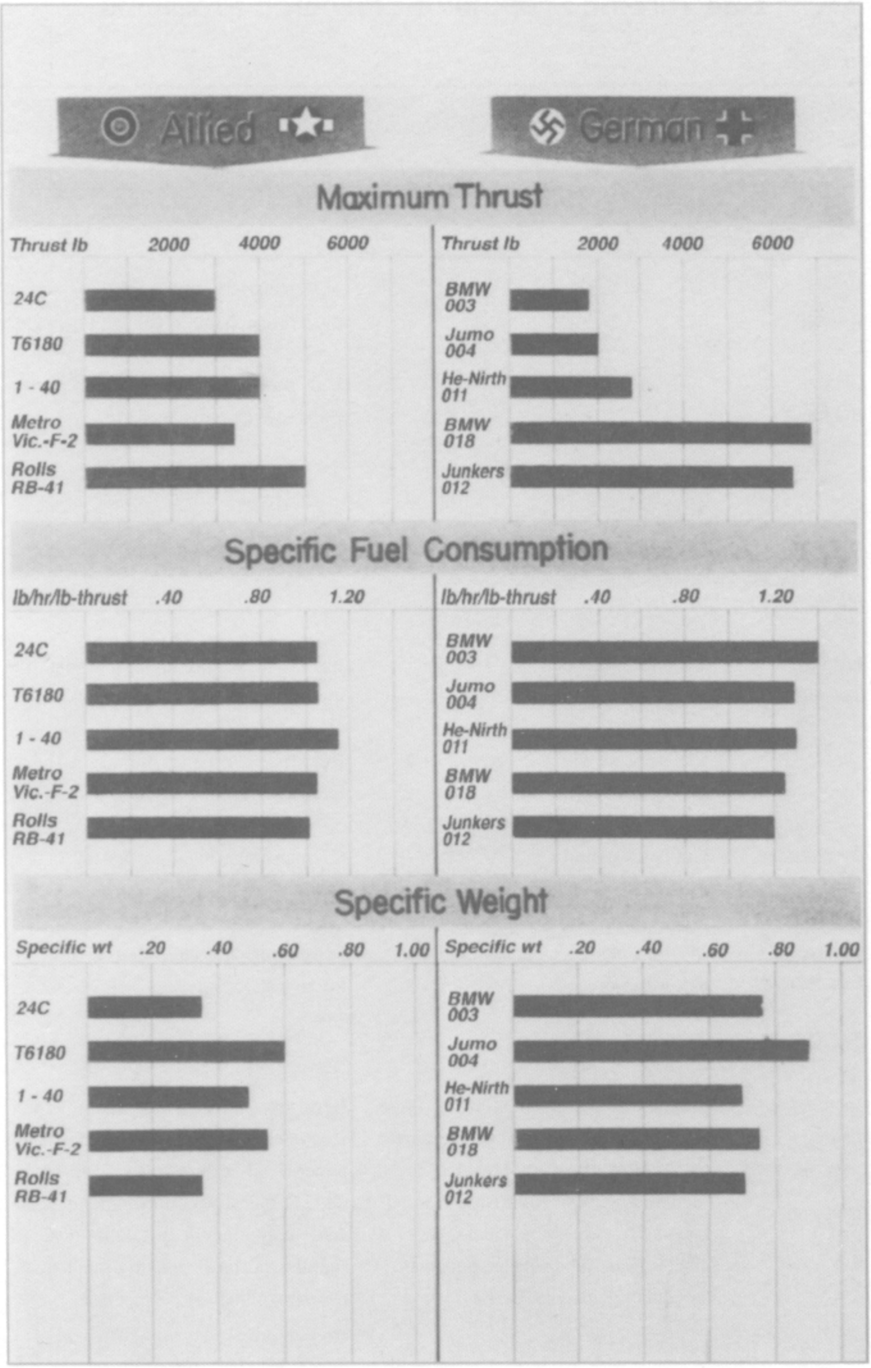


*Figure 13–Characteristics of Turbojets*

# TABLE II

## Gas Turbine Propulsion Research Problems

| *Problem* | *German Projects* | *Remarks, Outlook and Recommendations* |
|---|---|---|
| ***Higher Temperatures*** | | |
| High Temp. Alloys | DVL and Industry | U.S. materials superior, but we should push research on fatigue improvement. |
| Ceramic Blades | LFA and AVA. | U.S. not behind, but research on improving brittleness needed. |
| Cooled Turbine Blades | Air-cooled; BMW et al.<br>Water-cooled; Schmidt, LFA.<br>Sodium-cooled; Rietz, AVA. | Evaluation of German water-cooled and sodium-cooled technique recommended. |
| ***Higher Take-Off Thrust*** | | |
| Tail Pipe Burning | Used in Jumo 004. | Increased take-off thrust important for turbojets. |
| Liquid Injection | Experiments with $H_20$, $HN0_3$, $N_20$ | Results promising but more thrust increase needed. |
| Overspeed at Take-off | Not much done. | German units handicapped by materials. |
| Variable-Area Nozzles | Most German jet engines have adjustable tail cones. | Development should also include adjustable stator vanes. |
| ***Aerodynamic Improvements*** | | |
| Compressor Blading | Research at Göttingen, Stuttgart. Little research on increasing stage pressure rise by slots, flaps, and boundary layer suction. Extensive plans for test equipment at Braunschweig, Göttingen, 30,000-hp aerodynamic components laboratory planned at Ötztal. | Germany slightly ahead due to earlier start. German's 30,000-hp Ötztal components laboratory exceeds in scope all U.S. plans. Recommend a *full-scale* AAF components test laboratory to supplement basic research of NACA, which should also be expedited. |

## TABLE II - Continued

## Gas Turbine Propulsion Research Problems - Continued

| *Problem* | *German Projects* | *Remarks, Outlook and Recommendations* |
|---|---|---|
| ***Aerodynamic Improvements (Continued)*** | | |
| Nacelle Aerodynamics | Wind-tunnel tests on jet-engine nacelles at Braunschweig, Stuttgart. Ötztal 100,000-hp, 27-ft diam, M=1.0 wind tunnel for testing full-scale jet nacelles (80% complete). | Present German and U.S. wind tunnels inadequate in size and speed for jet nacelle tests. Germans had 100,000-hp tunnel under construction, Recommend large high-speed tunnel of similar size be included in plans for AAF equipment. |
| ***Cycle Improvement*** | | |
| Intercooling and Reheat | Design studies by industry. | German emphasis on mass production of turbojets postponed applied work on cycle improvement. U.S. work should be encouraged. |
| Regeneration | Design studies by industry; AVA ceramic heat exchanger | Recommend systematic research on efficient, light weight, heat exchangers. |
| Closed Cycle | No evidence of serious consideration. | Recommend Ackeret-Keller system at Escher Wyss, Zurich, be evaluated in terms of aircraft application, especially with use of helium. |
| ***Application to Missiles*** | | |
| Subsonic Missiles | Design studies of expendable turbojets to replace Argus tube of V-1. | Recommend development of expendable, simply constructed turbojet for missile application. |
| Supersonic Missiles | No indication of German thought on supersonic turbojet application. | Recommend further studies of supersonic turbojet and construction of experimental model. Supersonic wind-tunnel facilities for testing propulsion units at supersonic speeds urgently needed. |

the possibility of using the turbojet as a propulsion unit for very high speeds, for example, speeds well beyond the velocity of sound.

Due to the importance of this subject, I initiated a Scientific Advisory Group study of estimated turbojet performance at speeds extending beyond the speed of sound. The results showed that even with the present-day limitations of operating temperatures imposed by materials, the turbojet should outperform the ramjet up to a speed of 1.5 times the speed of sound, and that with increased temperatures still better performance would be obtained. This is in direct contradiction to a widespread belief existing at the present time that a compressor is useless for supersonic speeds, and that the simple ramjet becomes the logical propulsion system. Many other engineers seem to believe that neither the turbojet nor the ramjet is capable of functioning above the speed of sound, and that rocket propulsion is the only possible drive for supersonic flight. We do not believe that this is correct. Our analysis has definitely shown the feasibility of using turbojets for supersonic flying speeds. If the turbojet should be used for supersonic missiles, an expendable type turbojet must be designed in such a way that the manufacturing costs do not become prohibitive. The Scientific Advisory Group several times emphasized the importance of a study of expendable turbojet designs. German reports also include suggestions for the same type of development and at least one project was under way.

The divergence of opinions among various experts on this subject shows the necessity of further fundamental investigations which best can be done in supersonic wind tunnels.

It is our belief that the use of higher speeds will also affect the aerodynamic design of turbines and compressors. The rotational speed of turbomachines is today often restricted by our lack of knowledge of supersonic flow patterns. The development of supersonic turbomachinery may lead to further reduction of the weight and frontal area of jet propulsion units, and materially improve the performance of manned and unmanned airplanes.

## Ramjet

Ramjets and rodsets are the simplest and lightest propulsive devices for aircraft and missiles. The fuel consumption of the ramjet is rather high and, therefore, in the whole field of jet propulsion, it occupies a place between the rocket and the turbojet. Unlike the turbojet, it does not use any mechanical compressor, the compression being obtained only by ram. Therefore, it is indeed a pure aerothermodynamic engine, without mechanical moving parts. Its maximum efficiency occurs naturally at very high flight speed. Hence, it is most suitable for propulsion of aircraft and missiles at transonic and supersonic speeds, especially for short flight durations. This is the reason why the idea of using ramjets, although it was suggested decades ago, lay undeveloped until today, the age of high-speed flight.

For maximum ram efficiency, the design of the entrance diffusers for transonic and for supersonic speeds is somewhat different as shown in Fig. 14.

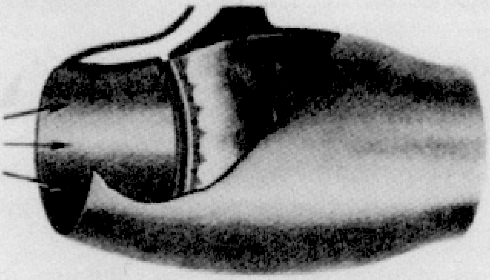
Due to its promising future, the ramjet is being intensively developed by the Allies; it was earlier developed by the Germans. The situation is outlined in Table III.

A comparison of efforts shows that, although the Germans have run some wind-tunnel tests on their designs, we are not far behind in this initial phase of ramjet development. In fact, part of our effort is wisely directed toward the basic problem of combustion, thus insuring rapid future progress.

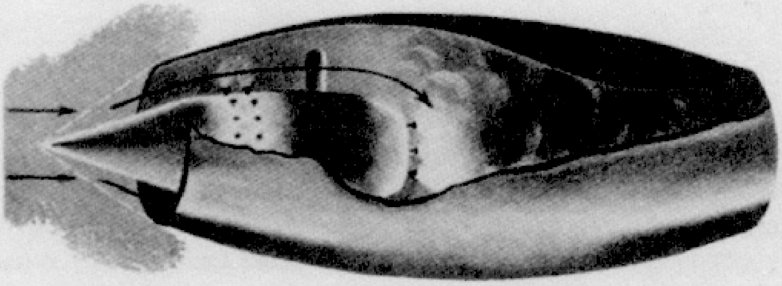
## Pulsojet

The engine used for the German V-1 flying bombs was the first successful example of a pulsojet. The difference between the pulsojet and the ramjet is that the former utilizes the resonance effect of the duct to obtain higher combustion pressures; therefore, a better fuel economy is realized in the pulsojet than in the ramjet, which operates without resonance effect and depends on ram compression only. Also, due to this difference in operating principle, the pulsojet can produce a static thrust while the ramjet cannot. However, it is the general belief, substantiated by theoretical analysis, that the advantages of a pulsojet over a ramjet gradually disappear as the speed of flight increases. For supersonic speeds, the ramjet may be the lighter power plant, with the possible further advantage of smooth thrust. However, it seems to me that it is too early to say which power plant is the better one, and this decision should be postponed until more test data on both types of engine are available.

German development of the pulsojet was started by Paul Schmidt, the inventor, as early as 1935. As previously mentioned, its application to the flying bomb, V-1, must be considered as a temporary expedient, used only when the development of the V-2 rocket missile was delayed. The history of the pulsojet is shown schematically in Table IV. It is seen that, although the Germans were the first to have a working pulsojet, their more recent efforts have produced only limited success. The development



For Transsonic Speeds



For Supersonic Speeds

*Figure 14–Ramjets*

# TABLE III

## Ramjet Development

| Germany | Allies |
|---|---|
| 1943 Fa. Walter Co. of Kiel designed a ramjet which was tested at the LFA up to M= 0.85. Fuel consumption 7 lb/hr/lb of thrust. | 1943 Combustion research was started at National Bur. of Standards and MIT. |
| 1944 Focke-Wulf Co. designed a short ramjet which was tested at the LFA up to M= 0.90. The fuel was first vaporized before burning. Fuel consumption lower than Walter ramjet. | Further Allied development data classified CONFIDENTIAL |
| 1944 W. Trommsdorf designed a ramjet projectile stabilized by spin. Few initial trials not successful. | |
| 1944 E. Sanger and A. Lippisch suggested use of coal in ramjet as fuel. Combustion research done at Göttingen. | |
| 1944 Supersonic diffuser for ramjet was studied both at Göttingen and LFA. | |

# TABLE IV

## Pulsojet Development

| | *Germany* | *United States* |
|---|---|---|
| 1935 | P. Schmidt started to develop the pulsojet under the auspices of GAF. Perfected an ignition device for 50 cyc/sec but found ignition unnecessary once engine was running. Complicated fuel injection. | U.S. projects still classified SECRET |
| 1939 | Argus Motor Co., Berlin, also started to work on the pulsojet. They had a cumbersome intake valve shaped like a spiral, but simple fuel injection. | |
| 1940 | The simple injection system of Argus was combined with the Schmidt spring air valve. Flight tests made. | |
| 1941 | Decision made to apply the Argus engine to V-1. | |
| 1941 to 1944 | Continued research to increase the thrust of V-1 engine, both by static and wind-tunnel tests. By removing part of the obstruction to the air flow, DFS Group has increased the thrust from 660 to 880 lb. A conical inlet for more air flow by P. Schmidt increased the static thrust to 1500 lb. | |

program in the U.S., while started late, is more thorough and should yield reliable data for judging the comparative merits of the pulsojet and the ramjet in the near future.

## Rockets

Rocket propulsion differs from the jet-propulsion devices hitherto mentioned in that the rocket does not utilize atmospheric oxygen. Its performance is, therefore, practically independent of altitude; in fact, the thrust produced increases somewhat when the outside pressure decreases. It functions best outside of the dense part of the atmosphere. As a matter of fact, it is the only propulsion device for the upper stratosphere and the stellar interspace.

Rocket propellants are either liquids or solid mixtures with moderate or slow rates of burning. Gaseous propellants require bulky containers and are, therefore, impractical. One class of the liquid propellants is called monopropellants; i.e., liquids which under action of igniters or catalyzers decompose and generate a large volume of hot gases. The expansion of the hot gas through the rocket nozzle accelerates the gas and generates the thrust. The bipropellants or the multipropellants are propellants consisting of two or more components. One component is the oxidizer which, when brought together with the other components in the rocket motor, sustains a vigorous combustion reaction and generates a large quantity of hot gas. The hot gas, in turn, produces the thrust by expansion through the nozzle. The combustion for some propellants has to be started by igniters or catalyzers. But there is a class of bipropellants, such as the combination of nitric acid and aniline, which is spontaneously inflammable when the components are brought into contact in the rocket motor.

One of the important findings of the study on rockets carried out by the Scientific Advisory Group is the fact that, barring the use of atomic energy, the optimum performance of all possible combinations of chemicals used as rocket propellants is not greatly different. Two methods of comparison can be used; comparison can be made on a constant weight-of-propellant basis or on a constant volume-of propellant basis. The propellant which has the highest impulse per unit weight is the liquid oxygen and liquid hydrogen combination. But the propellant which has the highest impulse per unit volume is the nitric acid and aniline combination. The extremely low density of liquid hydrogen makes very large tanks necessary for its storage and, thus, practically rules out its use in the liquid oxygen and liquid hydrogen propellant. High impulse per unit volume (and, hence, small body and low drag) is very important in guided antiaircraft missiles which have to travel at high speeds in relatively dense atmosphere. The German choice of a nitric acid propellant for such missiles is believed to have been prompted by this advantage.

As a matter of interest, I shall include here the definitions of a few novel terms in German rocket engineering.

| | |
|---|---|
| Monergol: | Monopropellant |
| Hypergol: | Bipropellant or multipropellant that is spontaneously inflammable when the components are brought together in the motor. |
| Ergol: | The inert part of the fuel component in the "Hypergol." For instance, the aromatic gasoline in the mixture with aniline for nitric acid. |
| Initiator: | The active pan of the fuel component of the "Hypergol." For instance, the aniline in the mixture with aromatic gasoline for nitric acid. |
| Katagol: | Monopropellant which is decomposed by catalyzer charged in the motor. |

Liquid propellants are generally stored in tanks in the body of a missile and have to be forced into the rocket motor by one of the following methods:

1. Gas, under pressure, acting on the liquid surface in the propellant tanks. The gas can be obtained either from high-pressure storage tanks or from a gas generator, using part of the main propellant itself or a separate solid propellant for this purpose.

2. Liquid pumps. The pump has to be driven by a gas turbine using hot gas from a small combustion "pot" fed by a part of the main propellant supply or by an auxiliary propellant.

At present, the gas-fed systems are generally heavier than the pump-fed systems for durations longer than 30 sec and thrusts larger than 4,000 lb. The gas generator system is, of course, lighter than the gas-under-pressure system due to the saving of the gas-bottle weight. On the other hand, the simplicity of the gas-fed system over the turbine-pump system has many advantages when really large-scale production for expendable weapons is considered.

Rockets as means of propulsion have been developed in the United States with two main applications in mind. The first application is the artillery rocket and the second application is the assisted take-off of heavily loaded airplanes from small airfields and possible short-duration boost to achieve high performance. As actual operational experience was accumulated, it became evident that the requirement for large airfields, for landings by battle-weary pilots, and the power boost of conventional engines by water injection, practically eliminated the necessity for assisted take-off as far as land based bombers are concerned. However, some recent developments indicate a renewed interest in rockets. These developments are:

1. Long-range winged missiles, rising to extreme heights where the rocket is the only power plant which can operate without the assistance of atmospheric oxygen.

2. Guided antiaircraft missiles with a rocket as the main propulsive unit or as the launching device.

3. Launching of supersonic, long-range, pilotless or manned airplanes.

The task of the rocket in launching and take-off of supersonic airplanes and winged missiles is not fully covered by the term assisted take-off. In fact, the rocket will in many cases be the main source of power for take-off of such aircraft.

Both in the U.S. and in Germany, after rocket engineers had succeeded in constructing liquid-fuel rocket motors of several minutes endurance, the idea came up to use rockets as sole power plants on manned airplanes capable of short duration flights. In Germany, such an airplane (the Me-163B) actually was used in combat as an interceptor. However, it is doubtful whether such an airplane will be justified after power plants of almost similar light weight as the rocket motor but with much lower fuel consumption, like the ramjet, become available, and after perfected target-seeking missiles have taken over the task of short duration manned interceptors.

The historical development of rockets by the Germans is summarized in Table V. It is seen that the Germans were forced by the requirements of the war to develop cheap and easily manufactured propellants and to accept the difficulties of handling such propellants as nitric acid and hydrogen peroxide.

There is no doubt that the various applications for rocket motors mentioned above fully justify the statement that rocket research and development have become one of the most important responsibilities of the Air Forces for the future. It is true, of course, that many applications of the rocket concern the ground and naval forces. However, the Air Forces should maintain leadership in rocket development as a main and an auxiliary source of power for manned and pilotless aircraft; they should develop their own facilities for testing rocket propulsion devices; and they should secure a free hand in maintaining the collaboration of the best scientific personnel and the best equipped laboratories in the Nation. Our early perfection of long-duration solid-propellant rockets, and the promis-

# TABLE V

## Development of Rockets

| Germany | United States |
|---|---|
| 1. The German solid propellant for artillery rockets has a wide operating temperature range of from -40° to 140°F. | U.S. projects still classified SECRET |
| 2. To obtain smooth burning at pressures below the critical pressure of the solid propellant, a spring-loaded regulator valve is fitted to the motor. | |
| 3. The handling of 80% concentration of $H_2O_2$ was made relatively safe. Long duration $H_2O_2$ and methyl alcohol and hydrozine hydrate rocket was perfected for Me-163B. Turbine-pump system functioned well. | |
| 4. The difficulty of producing enough $H_2O_2$ and the advantage of high density of nitric acid-aniline propellant for guided missile application forces the Germans to use the latter. Improvements are made to shorten ignition lag, even after the addition of inert component to the fuel. | |
| 5. Film cooling and evaporative cooling was developed, particularly for high performance propellants such as liquid oxygen and alcohol. | |
| 6. Early trial on monopropellant not successful. The Schmidding propellant, a mixture of methyl nitrate and methyl alcohol, was not reliable. | |

ing results obtained with nitric-acid aniline and nitro-methane liquid propellants should be further exploited. The propulsion of long-range winged missiles and antiaircraft missiles, and the take-off of supersonic aircraft are important Air Forces applications which call for powerful progress in rocket engineering.

# ATOMIC ENERGY FOR JET PROPULSION

Based upon the published values of the measured heat of fission of $U^{235}$, it is calculated that the available energy of this material is 3.120 x $10^{10}$ BTU per pound. This is more than 1,500,000 times the lower heat value of gasoline, the most powerful fuel generally used today. The study of chemicals suitable for fuels or rocket propellants indicates that no really radical improvements in the BTU per pound ratio can be expected within the frontiers of molecular reaction. It will be possible to produce fuels and propellants more suitable for certain types of engines, increase their safety, improve their handling quality, and lower their costs of production. Nevertheless, no hope for spectacular improvements in range and speed performance of aircraft can be derived from further development of conventional fuels. Use of atomic energy as fuel, however, will radically change this situation.

The question of whether or not and how atomic power can be produced continuously and at a constant rate suitable for propulsion cannot be discussed in this report. Let us transfer our thoughts to an era in which the fundamental aspect of the problem already has been solved.

It appears to me that the application of atomic, energy to transportation will probably precede the application to power generation for stationary purposes. In the latter case the cost is the governing factor; in transportation, it is the cost and the weight of the fuel to be carried. In high-speed aerial transportation the importance of weight transcends the importance of cost. Hence, it may be concluded that the extremely expensive atomic agent, now having been developed as an explosive, will be used for propulsion and probably jet propulsion.

In speculating on the possible use of atomic energy for this purpose we have to change our usual concepts. For example, the weight of the fuel proper is certainly negligible. In other words, the available energy is almost unlimited. The problem is how much of this energy we shall be able to utilize in an engine of limited size and limited weight, where the weight of the engine includes all materials which have to be carried in the vehicle besides the atomic fuel proper.

Let us consider, for example, the case of rockets. We shall exclude the use of the disintegration products as working fluid for the rocket. The temperature of the disintegration products alone without dilution would be too high for any known or possible engineering materials to resist. Since temperature is the limit, the most efficient expansion process for the fluid is the isothermal expansion, with the temperature of the gas kept at the maximum allowable value by constant reheating. Inasmuch as one obtains the highest exhaust velocity by using a working fluid with the least possible molecular weight, hydrogen should be used. Then assuming a maximum temperature of 8,000°F, which would require cooling, of course, and a chamber pressure of 100 times atmospheric pressure, we can obtain a specific impulse of 1,365 lb-sec/lb of hydrogen carried in the vehicle. This means that the specific propellant consumption of rockets would be reduced from the present day value of 18 lb/hr/lb of thrust to 2.6 lb/hr/lb of thrust. This is a great reduction, even though the ratio is far below the spectacular figures for the ratio of the effectiveness of atomic and conventional bombs. However, the use of atomic energy would certainly allow the construction of rocket-driven pilotless aircraft which could reach any point of the globe without stop. Even interstellar navigation appears feasible.

As to jet-propulsion devices using atomic energy with atmospheric air as working fluid, the fuel consumption itself again would be negligible. The size and performance of the craft driven by atomic power would depend mainly on the weight of the auxiliary materials like moderators, and devices for cooling and for controlling the rate of energy production. Of course it is difficult today to make any estimate of the bulk and weight of such equipment.

The most interesting feature of such a propulsion system is that the overwhelming part of the weight to be carried by the vehicle is independent of the endurance and only a very small portion of the weight is proportional to the flying time or the range desired. In other words, if one succeeds in reducing the engine weight to the limiting value which makes flight at a certain speed possible, very small further reduction of the weight would increase the range almost without limit.

It seems to me that there are possibilities in the development of nuclear energy for jet propulsion which deserve immediate attention of the Air Forces. To be sure there are problems still to be solved requiring inventive activity of specialists in nuclear physics. However, the main problems are engineering problems requiring inventive genius of the same order but different kind. We have to convert the energy liberated by the nuclear reaction into heat of such temperatures as needed for our propulsive devices. Important problems to be solved are in the nature of heat transfer, resistance of materials to heat, corrosion, etc. It appears necessary to find a way, within the limits of necessary security, for engineering talent which could be used to accelerate the progress in the field of propulsion. It would secure us the conquest of the air over the entire globe without range limitations.

It is my feeling that the Air Forces should, as soon as possible, take the lead in investigating the possibilities of using nuclear energy for jet propulsion.

# JET PROPELLED AIRCRAFT

Of the novel power plants mentioned in this report, only the turbojet and the liquid-fuel rocket motor have been successfully used on aircraft.

Our Bell P-59 (turbojet), Lockheed P-80 (turbojet), and Ryan FR-1 (reciprocating engine and propeller plus turbojet) are all well known to the Commanding General.

The Germans had developed and used some jet-propelled aircraft in combat and had others under development. This is shown in Table VI.

For future fundamental planning, a very careful choice of propulsion systems is necessary. It is possible to make a basic analysis, computing for various systems the sum of the specific weight of power plant and fuel required to travel at a given speed for a certain endurance. Then the optimum power plant is the one for which this sum has a minimum value. However, it is impossible to decide rigidly from such a simple study which type of propulsive system is best for a certain purpose. Beside the minimum specific weight of the power plant and fuel, many other aspects enter the picture. One important factor is the frontal area of the engine. Then also the structural weight of the airplane is influenced by the choice of power plant. The jet-propelled airplane has the advantages of not requiring a minimum ground clearance for the propeller, and of being comparatively easy to maintain. On the other hand, jet propulsion introduces aerodynamically difficult problems such as the intake and ducting of very large quantities of air.

No one has doubts about the great future propulsion in military aircraft. However, such general statements as "one or two years from now all fighters and bombers will be jet propelled" should be replaced by careful, scientific analysis which secures jet propulsion its proper place, but does not exclude other combinations such as the turboprop or, in the case of extreme ranges, the reciprocating engine and propeller. The choice of the most efficient power plant must nor be influenced by any general feeling that the propeller appears obsolete.

I believe that German high-speed wind-tunnel results will prove to be very helpful in our designs in connection with aerodynamic and vibration problems originating from interference between the jet system and the air

## *Table VI*

# CHARACTERISTICS OF GERMAN JET AIRPLANES

| AIRPLANE | HE-162 | ME-262 | ARADO-234 | ME-163 B | HORTON-229 | JU-287 | 8P-20 'NATTER' |
|---|---|---|---|---|---|---|---|
| USE | FIGHTER | FIGHTER | BOMBER | TAILLESS FIGHTER | FLYING WING FIGHTER | BOMBER | FIGHTER |
| ENGINE-NAME & TYPE | BMW-003 E-1 OR E-2 | JUMO T-J UNITS TL 109.004 B-1 | JUMO-004 | BI-FUEL ROCKET MOTOR HWK 509 A-1 | JUMO-004 | JUMO-004 | BI-FUEL ROCKET MOTOR HWK 509 A-2 |
| NUMBER OF ENGINES | ONE | TWO | TWO | ONE | TWO | FOUR | ONE |
| MAXIMUM THRUST | 1,760 LB @ S.L. STATIC | 4,000 LB @ S.L. STATIC | 3,900 LB @ S.L. STATIC | 3,650 LB S.L. STATIC |  | 8,000 LB @ S.L. STATIC | 3,750 LB |
| GROSS WEIGHT | 5,940 LB | 11,000 LB | 20,900 LB NORMAL LOAD | 11,500 LB NORMAL LOAD |  | 50,600 LB | 4,920 LB |
| WING LOADING | 49.5 LB /SQ FT | 40.7 LB /SQ FT | 72 LB /SQ FT |  |  | 81.6 LB /SQ FT | 95.5 LB /SQ FT @ TAKE-OFF |
| MAXIMUM SPEED | 522 MPH @ 19,700 FT | 550 MPH @ 30,000 FT | 500 MPH | 590 MPH. @ 25,000 FT | 550 MPH @ 20,000-25,000 FT | 485 MPH @ 16,400 FT (35,400 LB MEAN WT) | 620 MPH @ 16,400 FT |
| MAX. RANGE OR ENDURANCE | 620 MI @ 36,000 FT<br>85 MIN @ 36,000 FT | 845 MI @ 30,000 FT<br>90 MIN | 680 MI-WITH 1100 LB BOMBS<br>900 MI —NO BOMBS | 10-12 MIN FULL POWER | 1 HR @ 22 500 FT |  | 36 MI AFTER CLIMB<br>436 MIN-500 MPH-9800 FT |
| TAKE-OFF DISTANCE | 2,625 FT-NO ASSIST<br>1,245 FT-WITH ASSIST | 3300 FT HARD SURFACE<br>6000 FT TURF | 4200-4,500 FT | 3,600 FT ± |  |  | VERTICAL |
| RATE OF CLIMB | 4,230 FT/MIN @ S.L. | 4,600 FT/MIN @ S.L. |  | 10,000 FT ±/MIN @ 40,000 FT ALT |  |  | 37,400 FT/MIN @ S.L. |
| LANDING SPEED | 102 MPH | 112-124 MPH | APPROX. 110 MPH |  | 81 MPH |  |  |
| STATUS | FLYING EXPERIMENTAL | IN COMBAT | FIGHTER VERSION IN COMBAT | IN COMBAT | DESIGNED | DESIGN STAGE | FLYING EXPERIMENTAL |

frame. However, the Air Forces should, in cooperation with aircraft designers, initiate a comprehensive high-speed wind-tunnel test program in order to obtain further information in this field. The ATSC took the first step in such a program by holding a meeting between NACA, industry, the Navy and the ATSC in late summer, 1945. However, any program which is undertaken will be severely restricted and handicapped for a long time by the lack of high-speed wind tunnels of sufficiently large size.

The two rocket airplanes mentioned in Table VI, the Me-163B and the Natter, are of special interest because pure rocket motors were their sole source of power. The Me-163B was more or less conventional in that take-off and climb were accomplished under its own power. However, the Natter was intended to be launched nearly vertically by means of two or four solid-propellant launching rockets. It was to be aimed at a point 2 km behind the point of collision so that attack on a bomber could be made from the rear. This rocket-propelled interceptor was armed with 24 rockets of 7.3-cm caliber. After the rocket ammunition is exhausted, the airplane is caused to disintegrate; the nose section is allowed to fall freely and be expended but the air frame with rocket propulsion motor and the pilot are saved by parachutes. A former Luftwaffe pilot, who had been convicted of some crime. acted as test pilot in the first flight of the Natter and was killed.

Rocket airplanes have, at the present time, intrinsically, only a few minutes of endurance. Their use as interceptors in the future may be made unnecessary by the development of more economical propulsive devices of light weight, and perfection of target-seeking electronic or heat devices which would eliminate the need for a pilot. However, I highly recommend that the rocket-type of airplane be developed at the present time for research purposes. One advantage of rocket drive in this case is the possibility of exact thrust measurement, which is extremely difficult for any other propulsive system. These research airplanes would be very useful for studying performance, flow conditions. and flight mechanics.

# TAILLESS AIRCRAFT

In Germany, tailless aircraft were intensively developed by A. Lippisch and by the Horten brothers. The Junkers' designers did a considerable amount of engineering study on large tailless airplanes but none were actually constructed.

Lippisch worked on the design of tailless airplanes at DFS beginning in 1936. He designed a series of about eight aircraft, before the time when he came in contact with Messerschmitt and developed the Me-163A and Me-163B. Stability problems were encountered at high speeds and the Me-163B was "redlined" at a Mach number of 0.80 (590 mph at 25,000 ft). Satisfactory stalling characteristics were obtained by a special low-drag fixed slot at the wing tips. A vertical tail was found necessary for satisfactory directional stability. Lippisch's latest design was the P-11, a tailless aircraft with two turbojet engines. The critical Mach number was estimated to be 0.92 (about 680 mph at 25,000 ft); wind-tunnel tests indicated a drag coefficient as low as 0.0063.

The Horten brothers flew their first tailless aircraft in 1935. They received no support from the Air Ministry until February, 1945, following the publication of a photograph of a Northrop tailless airplane in "Interavia." Their design was to be powered with two Jumo 004 turbojet engines. Computed high speed was about 600 mph.

The development program for tailless aircraft has been more extensive in the United States than any place abroad.

The Northrop XP-56 was a pusher-type, flying-wing fighter. This airplane was flown only a few times and indications were, from these tests, that the performance was short of expectations and that difficulties in control were encountered. Unfortunately, wind-tunnel tests necessary to trace the basic reasons for these difficulties could not be carried out, because no high priority could be attached to merely experimental projects.

Theoretical studies here and abroad show significant advantages (for example, longer ranges) for tailless aircraft over tailed aircraft. especially in the case of gross weights of 150,000 lb and more. Of course it must be assumed that the tailless aircraft is made stable and maneuverable without measures which would compromise the performance. The recent recognition of the advantage of swept-back wings for very high speeds makes the tailless airplane particularly attractive also for transonic airplanes. It is the opinion of the Scientific Advisory Group that the development of tailless aircraft should be encouraged; however, actual construction should be supplemented by extensive wind-tunnel investigations of methods for improving stability and control at high speeds.

# AERODYNAMIC MISCELLANEA

By aerodynamic miscellanea, I mean auxiliary items which contribute to the advance of the aerodynamic art. The items which I now consider are:

1. Flow Measurement Techniques,
2. Laminar Flow Wings, and
3. Boundary Layer Control.

A discussion of these miscellanea follows, with a brief review of German developments and comparison with our own.

## FLOW MEASUREMENT TECHNIQUES

The average level of German development in wind-tunnel instrumentation appeared somewhat below our own, although in some instances they had surpassed us especially in fields such as supersonic aerodynamics where their basic facilities were more advanced. On the other hand, their electronic equipment was generally inferior to ours.

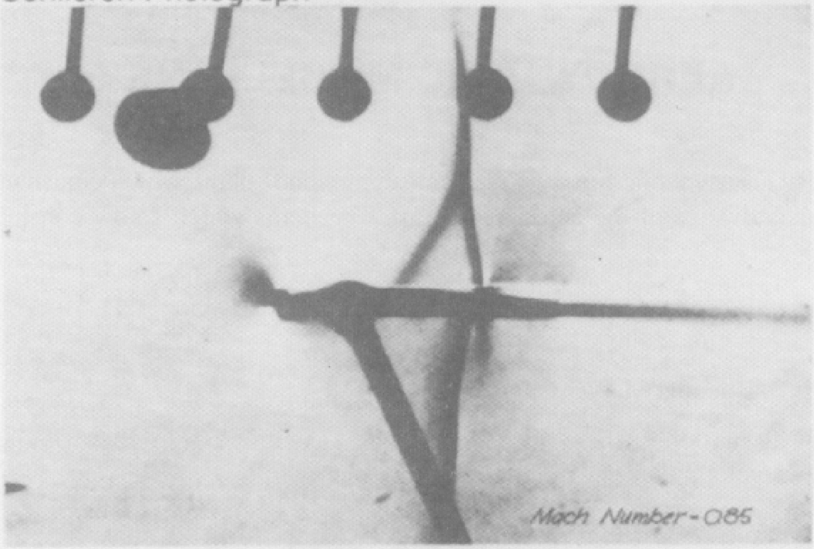
In high speed air flow, in both the transonic and supersonic range, instrument which project into the air stream cause excessive disturbance of the flow. For this reason, both German and Allied aerodynamic instrument development work was concentrated largely on methods of studying air flow by methods which do not disturb the flow pattern.

Several interesting German developments were:

1. Combination Schlieren and interference methods which show both density gradients and lines of constant density on the same observation screen or photo graphic plate, as shown in Fig. 15.

2. A novel X-ray method of measuring density, which makes use of the fact that the absorption of an X-ray beam is dependent on the density of the medium through which it passes.

Schlieren Photograph



Interferometer Photograph

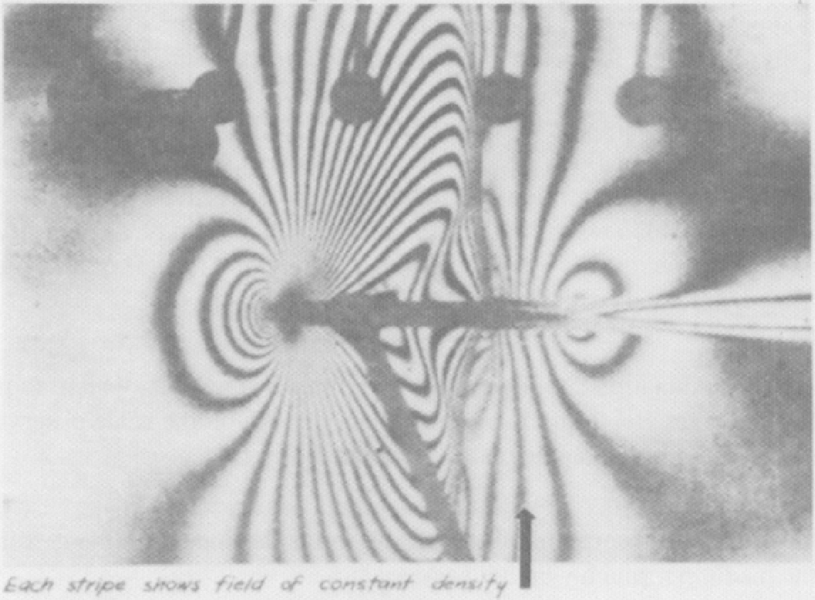


*Figure 15–High-Speed Airflow Photographs*

3. A corona method of measuring velocity, which utilizes the fact that the potential of a corona discharge varies with the speed of the air passing by.

4. A spark method of determining local temperature, by measuring the local speed of sound, at which the disturbance, caused by a spark discharge, travels.

A brief comparison of German and Allied developments in measurement technique is given in Table VII.

## LAMINAR FLOW WINGS

In this field we were far ahead of the Germans. In the following paragraphs, the German development status will first be given, followed by our own.

### *German Developments.*

According to the German dynamicist Schlichting, German work on laminar flow airfoils did not start until about the end of 1938. By 1940, Schlichting considered that the fundamentals were known. Drag coefficients as low as 0.0027 were reached at a Reynolds Number of $5 \times 10^6$, but the German scientists were unable to retain the low drag at higher Reynolds Numbers. They were handicapped by lack of suitable low-turbulence wind tunnels. On one occasion, Prandtl reported: "Suitable wind tunnels for the conduct of airfoil investigations at sufficiently high Reynolds Number and at low turbulence are lacking in Germany. On the other hand, it is known that in the U.S.A. particular installations created for this purpose are working exceptionally vigorously in this field."

Tests were made on a Japanese laminar flow airfoil, on three airfoils derived from one member of an obsolete NACA Series 27215 (which was described in a captured French secret report), and on a few airfoils designed by Schlichting. The Germans also had some information on a Russian laminar flow airfoil obtained from a captured report.

The Germans never used laminar flow airfoils on aircraft. They were astonished and mystified by the performance of the Mustang and made many wind-tunnel and flight tests. They gave the following tabulation of wing profile drag coefficients (obtained by momentum method) for a number of airplanes at lift coefficient of 0.2:

| | | | | | |
|---|---|---|---|---|---|
| He-177 | 0.0109 | Ju-288 | 0.0102 | Me-109B | 0.0101 |
| FW-190 | 0.0089 | Mustang | 0.0072 | | |

# TABLE VII

## Flow Measurement Techniques

| *Item* | *German Development* | *Allied Development* |
|---|---|---|
| Interferometer | Extensive development at LFA, AVA, WVA for measuring density in high-speed air flow; nothing new in principle but considerable development of details. LFA has system whereby simultaneous Schlieren and interfence pictures are recorded on the same photographic plate. | U.S. development by Ladenburg, Princeton. Also small project by Dr. Williams, Pasadena. U.S. application lagging German. |
| X-Ray Method | This method used at Kochel utilizes principle that absorption of X-ray beam is a funciton of density of the medium through which it passes. Ionization meter is calibrated in terms of density. | Unkown to Allies. |
| Schlieren Method | All supersonic wind tunnels have associated Schlieren equipment. Largest mirrors are 1.2 m in diam, under construction for Kochel 1 m by 1 m Mach number 7.0 tunnel. | Used in the few existing Allied supersonic wind tunnels. |
| Spark Method | A spark creates a disturbance travelling at the speed of sound. Measurement of the local speed of sound determines the local temperature. developed for WVA. | Application to temperature determination unknown to Allies. |
| Ultrasonic Waves | Generation of high-frequency waves affords another method of determining temperature by means of measuring the local velocity of sound. | Application to temperature determination unknown to Allies. |
| Hot Wire | Some work at Göttingen but not very advanced. | U.S. developments, especially by Dryden, Bur. of Standards; also by Liepmann, CIT; superior to Germans. British work also more advanced than Germans. |
| Corona | Aachen development of corona for velocity measurement. | Experimental development by Lindvall, CIT, in 1935. Not continued. Some work at MIT. |

## TABLE VII - Continued

## Flow Measurement Techniques - Continued

| *Item* | *German Development* | *Allied Development* |
|---|---|---|
| Doppler Method | Method developed at Fassberg for measuring speed in the jet of rocket by means of the Doppler effect. | This method not used by Allies for measuring speed of rocket discharge. |
| Electro-Magnetic Balances | Used in many of the intermittent wind tunnels, such as LFA, AVA, WVA, to measure transient forces. | In common use in U.S. wind tunnels. Electronic technique in general superior to German. |
| Piezo Elec. Capsules | Used at LFA for measuring transient forces. | This method is also in use by Allies for special purposes. |
| Half Models | This technique used at WVA; convenient for meauring pressures, hinge moments, etc. | This technique also used at CIT. |
| Cavitation | Similarity between cavitation and compressibility phenomena used for qualitative work in water channels on simulated critical compressibility conditions. | Water channels not used by Allies for simulated compressibility effects. |
| Simulated Turbojets | For wind-tunnel models, small high-speed compressors are used to simulate internal flow, and alcohol is burned to introduce heat. | Not used as yet by Allies for wind-tunnel models of jet aircraft. |
| Flexible Walls | In some supersonic wind tunnels, continuous flexible walls of the test section are used to change Mach number. Some tunnels used fixed nozzles and variable diffuser. | Flexible walls have been ordered for Aberdeen, Wright Field, and Ames supersonic wind tunnels. Flexible walls have been in use for several years by NACA and in England. |
| Half-Open Jets | In some supersonic tunnels the test section is partly closed and partly open. This is said to decrease wall interference, especially through transonic range. | This technique not as yet used by the the Allies for supersonic flow. |

The German comment is: "The drag of this only foreign original airfoil tested up till now is far below the drag of all German wings tested in which it should be remembered that it was tested without any smoothing layer."

Another writer says: "A comparison of flight measurements shows quite unmistakably that the Mustang is far superior aerodynamically to all other airplanes and that it maintains this superiority in spite of its considerably greater wing area."

### *Allied Developments*

The NACA began investigations of laminar flow airfoils in a low-turbulence wind tunnel in the spring of 1938, and the encouraging nature of the results obtained (without details) were described in the Wilbur Wright Lecture of the Royal Aeronautical Society on 25 May 1939, and in the NACA Annual Report for 1939. In June, 1939, an advance confidential report by Jacobs was released. A summary was published in March, 1942 in confidential form. The most recent summary was released in March, 1945, and this summary has been kept up to date by supplementary sheets.

As indicated in the summary of German developments, the Allies are far ahead in low-turbulence wind-tunnel equipment and in knowledge of laminar flow airfoils and their application to aircraft. Drag coefficients as low as 0.003 at a Reynolds Number of $20 \times 10^6$ have been obtained.

A summary of the present state of knowledge is given in the NACA restricted report L5C05, "Summary of Airfoil Data," by Abbott, von Doenhoff, and Stivers, March, 1945.

## BOUNDARY LAYER CONTROL

In this field the Germans had an advanced start and had just about reached a practical state. A discussion of German and Allied developments follows.

German Developments. Considerable work was done on boundary layer control at AVA, Göttingen, starting in 1925. The first airplane with boundary layer control was built and flown in 1932.

From about 1942 on, work was intensified. Schwier obtained a maximum lift coefficient of 4.3. using pressure jet boundary layer control in wind tunnel tests. In July, 1943, Stüper obtained a maximum lift coefficient 3.8 in full-scale flight tests with boundary layer control by suction. The maximum lift coefficient on his airplane without boundary layer control was 1.9. About the same time, a maximum lift coefficient of 3.4 with boundary layer control was reported in wind-tunnel tests of a four-motored airplane which was to be developed by Junkers. A unique suction and pressure-jet boundary layer control system was used. Air was sucked in over the inboard portion of the wing, just ahead of the flaps, and blown out over the outboard portion of the wing, just ahead of the ailerons. In November, 1943, Wagner outlined work which was done at Arado, shoving a maximum lift coefficient of 4.0 to be possible.

All German investigators noted that the internal wing ducting required and the power required to drive the boundary layer control equipment constituted serious obstacles to the successful, practical application of boundary layer control. However, it was felt that these obstacles could be successfully met. At the end of the war, an Arado transport airplane, having low landing and take-off speeds because of boundary layer control, was in service in the German Air Force.

### *United States Developments.*

An L-1 airplane was equipped with boundary layer control by suction. The maximum lift coefficient was 3.5 without boundary layer control and 3.6 with boundary layer control. The landing speed of the modified L-1 was considerably higher than that of the original airplane due to the weight of the boundary layer control equipment.

Boundary layer control has an important application in making low landing speeds possible on high-speed aircraft. It also appears that the potentialities of boundary layer control in the transonic speed range have never been systematically evaluated. We found that some interesting work was done by Ackeret at the Institute of Technology in Zurich, Switzerland. The Scientific Advisory Group recommends that an intensive research program on boundary layer control be undertaken by the Army Air Forces.

# THE ART OF RADAR

## INTRODUCTION

The last four years of war-stimulated research have resulted in the development of equipment and techniques in the radar and electronics field which offer possibilities of profoundly affecting the whole concept of future air force operations. These devices have already passed the laboratory stage, and nearly $3,000,000,000 worth of radar equipment is now in actual combat use in the Army, the Navy, and the Air Forces. Thus, the fundamental ideas in the field have been thoroughly proven and are definitely here to stay.

In spite of the rapid progress made in a relatively short time, the technique in this field is still in its infancy. Enormous possibilities lie ahead, and additional research, both on the technical and on the operational side, will pay huge dividends in more effective air force operations.

At the same time, the rapid introduction of new and miraculous devices has led to the feeling among the uninitiated that anything is possible by the use of electronics. It is, therefore, of greatest importance to understand thoroughly the limitations as well as the possibilities of radio, radar, and electronic equipment in order to avoid raising impossible hopes and in order to eliminate unnecessary and ill-conceived research and development programs.

Fundamentally, radar is a device which enormously extends the range, power, capabilities, and accuracy of human vision. For example:

1. The human eye cannot see in darkness or through fog, clouds, and rain. Radar is not at all limited by darkness or by fog, and to only a slight extent by heavy clouds and rain.

2. The human eye determines only roughly and with difficulty the distance to an object which it sees. Radar determines the distance rapidly, accurately, and continuously.

3. The human eye can pick up or see objects such as airplanes only at distances of a few miles. Suitable radar can see airplanes at distances up to 200 miles.

4. The human eye, aided by optical instruments, can get accurate data on bearing, elevation, and range of only one distant object at a time, and considerable time is required for such determinations. Radar can determine and display these data within a few seconds for all objects in view over an enormous area, in the best cases up to a radius of 200 miles.

These features of radar open up many possibilities, such as: all-weather day and night air operations; an increase in accuracy and versatility of bombing, gunfire, and navigation; the control from the ground or from the air of major air force operations; provision of information and controls to relieve the overburdened pilot, both in navigation and in combat; and, the accurate remote control of pilotless aircraft.

Furthermore, it must be realized that radar is not a facility or attachment which will occasionally be used under bad conditions. Rather, the air force of the future will be operated so that radar is the primary facility, and visual methods will be only occasionally used. Bad weather or darkness are normally prevalent from 60 to 90% of the time, and predictions of good weather at remote points fail to be realized from about 25 to 50% of the time. Hence, in an all-weather air force, radar must be the universally used tool for bombing, gunfire, navigation, landing, and control. The whole structure of the air force, the planning of its operations, its training program, and its organization must be based on this premise. The development and perfection of radar and the techniques for using it effectively are as important as the development of the jet-propelled plane.

## GERMAN RADAR DEVELOPMENTS

Broadly speaking, the radar art in Germany at the end of the war was in about the same state as it was in this country and England in early 1942. The Germans did not realize the possibilities of microwave radar, for example, until they inspected equipment shot down in British and American airplanes. Furthermore, they were forced, during the latter years of the war to concentrate their efforts on defensive measures and hence, never developed a concept of the offensive use of radar. Finally, the British and American jamming and countermeasures techniques were so effective that over half of the German radar development talent was forced into the task of developing antijamming measures, to protect their own existing radar equipment. This did much to stop progress in the development of new radar techniques.

The beginnings of German radar took place at as early a date (1936) as the corresponding developments in the United States and England. By the beginning of the war the Germans had an early warning system of good design and were making progress on equipment for control of fighter aircraft and for antiaircraft artillery. The German scientists felt that 50 to 60 cm was about the shortest wavelength that could be practically employed in radar and concentrated very considerable engineering talent on the development of a variety of equipments at this wavelength. Their engineers considered the development of microwave techniques, but discarded this possibility as impractical because no adequate transmitter at such frequencies was known to them. The equipment they had in use at 50 to 60-cm wavelengths, however, was excellent in its engineering design and very large quantities were in actual use.

Germany suffered seriously through the lack of a good organization of their radar and electronics development effort. Most of the development took place in industrial laboratories such as those of Teietunken, but the very brilliant group of German physicists in universities were never called in to participate. Consequently, while engineering design was good, imaginative thinking was lacking. The industrial engineers complained that they received no intelligent and understanding cooperation from any of the military agencies. They believed that the top military commands had no conception of the importance of radar and electronic equipment. On the other hand, the university scientists did not take the initiative to mobilize their efforts themselves as was done in the United States and England. The close coordination which existed in this country between both technical and operational military officers, the industrial laboratories, and the university scientists was completely lacking in Germany. Some attempt to remedy this situation was made in late 1944, but the effort never got going before the end of the war. The development work was scattered widely throughout the country, largely due to the disruptive effects of Allied bombing, and the various agencies and laboratories worked independently and without adequate coordination.

The only German radar put into extensive tactical use was that designed for air warning and air defense. Early warning stations, ground-controlled interception stations, antiaircraft fire control equipment, and airborne aircraft interception equipment were all in effective use. The techniques used by the Germans for navigational assistance to bombers on offensive missions during the Battle of Britain did not utilize radar, but employed elaborations of the United States airway navigational aids. Ingenious radio beam techniques were employed and in some cases these were made to operate bomb computing devices in the aircraft. However, the British jamming of these radio beams was very effective, in spite of strenuous efforts continuously made by the Germans to change frequencies and otherwise alter their techniques to avoid jamming. The concept of using microwave airborne radar for bombing and attack on shipping apparently did not come until British and American planes carrying such equipment were shot down over German-occupied territory. The capture of this equipment created a considerable sensation among German scientists and military experts. A large effort was immediately undertaken to copy this equipment. However, no sooner had a start been made on copying 10-cm equipment than 3-cm equipment appeared in American planes. Rumors that even shorter wavelengths were being developed by the Allies caused the Germans to start work on 1-cm and shorter wavelength devices. Their efforts became so scattered thereby that apparently no microwave equipment at all was ever put into production. In addition, the efforts of the engineers were also diverted to improving their air-defense equipment and to finding methods of avoiding Allied countermeasures, so that the positive efforts to develop radar for new offensive uses were greatly retarded. The concept of using radar for the ground control of tactical and strategic air operations, so successfully employed by the U. S. 8th and 9th Air Forces, apparently never occurred to the Germans, even though some of their ground equipment could have been adapted to this purpose.

The development of rockets and other unmanned missiles was far more actively pursued in Germany than the development of electronic equipment. As a result, apparently no advanced electronic or radio control methods for their missiles comparable with Allied developments ever got beyond the paper or laboratory stage. Had the Germans had an active coordinated electronic development program comparable to that built up by the Allies and had this been combined with their missile work, some dangerous weapons might have resulted. Various ideas were reported by individual workers for the control of missiles but the aerodynamics laboratories apparently did not have adequate electronic talent and the electronic engineers were largely cut off from contact with the aerodynamic work. Only the most successful missile development organization, the Peenemünde group, had a qualified electronic engineering section.

## RADAR FROM THE VIEWPOINT OF THE AIR FORCES

The ability to achieve air force operations under all conditions of darkness and weather contributes more than any other single factor to increasing the military effectiveness of the air forces. Hence, any research program designed to overcome the limitations to flight at night and in bad weather will pay big dividends.

Radar has already done much to overcome visibility limitations, and is of the greatest importance in the problems of traffic control in and near airports and of landing under conditions of bad or zero visibility. Although there is room for great technical development of the radio and radar aids to landing and traffic control, one of the chief problems is the development of a system in which all conceivable aids will be properly integrated and used together. This can only come as a result of extensive experience and a comprehensive program of trials.

Radar has revolutionized methods of air navigation. The development of microwave radar, which permits the use of narrow beams, enables the continuous presentation to the navigator of a more or less recognizable map of the surrounding country. In its earliest and crude form little more than cities, towns, and coastlines could be distinguished; but modern developments give sufficient resolution to identify many features of the landscape such as rivers, streams, bridges, and rail lines and make feasible the use of ordinary maps. In addition, heavy storm clouds make themselves evident on the radar screen. Over the sea, radar contact flying is restricted to areas within sight of identifiable land, but radar "sees" at distances up to 50 or 100 miles.

The possibilities of direct radar navigation are greatly extended by the use of strong, readily identifiable, artificial echoes provided by radar beacons, the radar equivalent of optical beacons or lighthouses. Radar permits the measurement of distance to the beacon and its bearing within the inherent accuracy of the radar equipment carried on the aircraft. By measurements on two beacons, the position of the aircraft can be determined.

Microwave systems give essentially short-range navigation. For long ranges the pulse techniques of radar are applied to longer waves, for example, in the Loran system. Here two pairs of ground stations emit synchronized pulses. In the aircraft the pulses are received and the time difference between the arrival of the pulses from the members of a pair is measured. This locates the aircraft on a hyperbolic line of position and two such lines give a fix. The airplane carries only a receiver and the traffic capacity is unlimited.

The use of radar in strategic bombing operations has proven itself in this war. Suitable radar equipment can allow the carrying on of such operations under the many conditions where visual bombing is not possible. Only a beginning has been made in the development of radar bombsights and much remains to be done to improve their precision, their versatility, and over-all operational usefulness.

Tremendous improvement in the control and marshalling of air forces appears possible through the medium of airborne radar. Control of air operations includes military functions, involving radar surveillance of movements of friendly and enemy aircraft, and the guidance of our own planes on their missions.

The future development of control radar falls into two categories: radar for the defense of this country, and radar for attack. It is not necessary to say more about the defensive possibilities of ground control radar. The problem of the future is chiefly an economic one; to install sufficient stations to surround the country completely is possible and necessary. Since these stations can be easily integrated into the airlines navigational net, the investment will be of great peacetime value. While in peacetime the network will be extremely valuable, in war it will be our protection against sneak attacks and against air raids of all descriptions. Control radar for offensive warfare will undoubtedly develop to the point where a unified command of air operations is possible throughout the whole operation. The commanding general will see the disposition of his own and enemy forces, whether piloted or pilotless, and be able to instantly modify his plans.

Radar also has been used in aerial fighting for aircraft interception, for range finding, for tail warning, and for fire control, particularly in the defense of heavy bombers. Future developments of radar equipment for fighters are largely dependent on the extent to which it is found desirable to control fighters by ground equipment of increased range and resolving power. Fire control and associated radar equipment for heavy bombers can be made indefinitely more and more complex. An analysis to determine whether one should abandon such air battleships seems in order, before developing more complicated equipment which may only slow down the airplane to the point where still more and more complexity and fire power is needed.

The radically altered military situation produced by the development of guided missiles has been discussed previously. The development of radar and other detection and navigation devices has provided a wealth of technical means for locating and guiding missiles. The essential problems which radar can solve are those of locating the missile, locating the target, and transferring intelligence to and from the missile. The present fundamental limitation is that the missile cannot be followed over the horizon. This limitation has to be circumvented by providing one or more relay stations, putting the controlling radar in an aircraft, or by shifting the location problem to the missile itself. Long-range guidance will be combined with homing devices for attack against certain targets, for example, ships.

The application of radar to guided missiles brings in new problems because of the large scale on which missile warfare must be planned. Radar components of much simpler design must be developed.

Most of the problems mentioned above require, before all, engineering skill and talents for clever adaptation and combination of recently developed principles and methods. However, the art of radar is so new that limitations which appear today may soon disappear because of novel discoveries. The Air Forces must be alert in swiftly utilizing any new developments.

# INFRARED DEVELOPMENTS

The military applications of infrared and heat radiation are for (1) signalling, (2) identification, 3) detection, (4) communication, and (5) guiding of heat-homing missiles.

## GERMAN DEVELOPMENTS

At the onset of the war, the Germans assumed that the Allies would employ infrared equipment and consequently produced in limited quantity a simple phosphor infrared detector as a countermeasure. These instruments were very insensitive compared with the U.S. phosphor developed somewhat later in the war. Although work continued in Germany, apparently it did not lead to improved instruments.

Very intensive work was done in Germany on the development of electron image tubes. However, this work was not unified and there appears to have been considerable duplication of effort and lost motion due to a lack of full interchange of information. The performance of the tubes was quite good but none of the designs was suitable for large quantity production. Furthermore, instead of concentrating on the manufacture of one type, they attempted to produce four or five different types. The telescopes used with the image tubes were elaborate and complex in the extreme; for example, one driving and gunsighting telescope had 17 glass elements mounted in a structure weighing more than 25 pounds. Because of this, German production was only just getting started at the close of the war. A total of 1,000 to 3,000 units was built, but almost none of these ever saw combat duty.

The Germans appeared not to have developed a signalling and identification system using tholofode cells. In the field of infrared communication equipment (optiphones), the Germans were somewhat ahead of the Allies in that they had at least 3,000 units in field service. These units are not technically superior to the developmental model built in the United States.

The German work in the far-infrared field (heat) was not very extensive, the only work reported so far being a number of ship-detecting units for detecting and determining the range of ships off shore.

## ALLIED DEVELOPMENTS

The British concentrated work on a simple electron image tube suited primarily for signaling and identification, although it was used experimentally for such purposes as driving, gun aiming, etc. Production started about 1941 and the instruments were used on the British Isles throughout the war. For security reasons, few were used on the Continent but some, together with a few U.S. instruments, were used in North Africa.

U.S. production of image tubes and telescopes was not started until 1942 and they were not produced in quantity until a year later. Their first use in large numbers was by the Navy for signal communications. Later the Army put into the field a gun-sighting and reconnaissance unit. These were used almost exclusively in the Pacific.

Airborne applications have been found practical but the various technical difficulties were overcome too late for field use. Detection of aircraft by infrared telescopes was found not to be feasible.

No communication systems for speech transmission were put into production.

Very intensive work has been done on heat sensitive elements for guided missiles, the production in some instances running into fairly large figures. Recent tests of the VB6, a heat-homing missile developed by NDRC Division 5 in collaboration with ATSC, have been very successful.

The possibilities of infrared and heat-seeking devices are certainly not yet fully explored. It will be one of the important research fields of the Air Forces. The importance of this branch of physical research will be enhanced by the fact that many industrial and military establishments still try to obtain relative safety by going under ground.

# Science,
# the Key to
# Air Supremacy

AAF Scientific Advisory Group

1945

General of the Army Henry H. "Hap" Arnold

# 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. 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. Counter-measures are of secondary importance.

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

g. Peace time 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 possi-

ble 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?

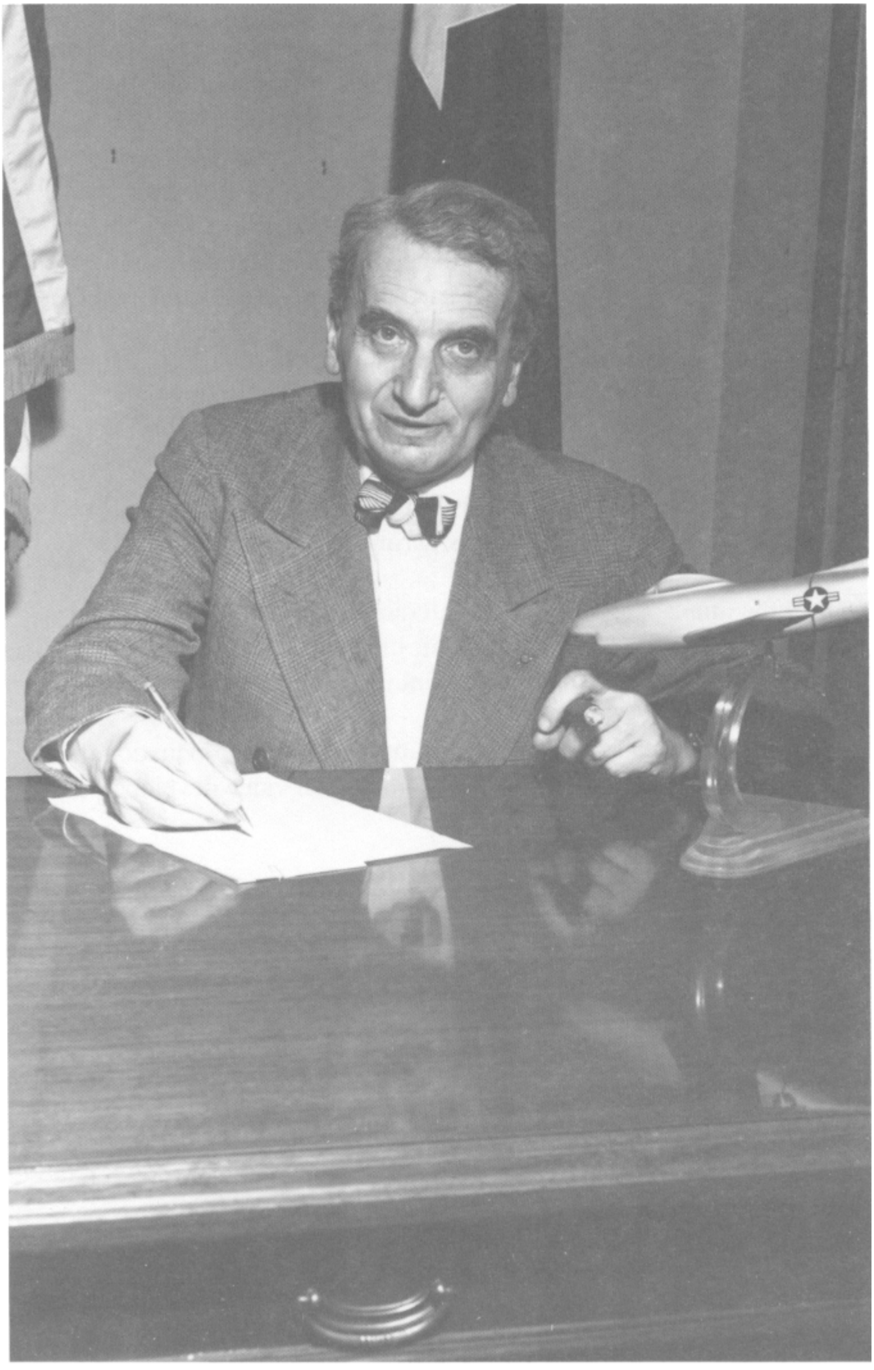
c. What are the best methods of instituting the pilot production of requited nonrevenue equipments of no commercial value developed exclusively for the postwar period?

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.

Signed

H. H. Arnold



Director of the Army Air Forces Scientific Advisory Group
Dr. Theodore von Kármán

**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 I 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 center's 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. 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. VON KARMAN
Director
AAF Scientific Advisory Group

# 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 Kármán, renowned scientist and consultant in aeronautics, who agreed to organize and direct the group.

Dr. von Kármán 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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# Chapter I

# 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 appar 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 warfare on land and on sea. Today's strategic considerations refer to the three-dimensional space surrounding the globe. They must bc 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 is 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 percent safe defense is impossible. It is easier to make offensive action efficient by scientific means that 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.

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 attitudes 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 gyro and servomotor 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 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 a only 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.

## Chapter II

# Analysis of Research Problem

## 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 airplane, 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 1,500-2,000 miles in the substratosphere and 3,000-3,500 miles in the stratosphere.

2.8 In the example represented by the diagram, the ranges are shown fortwo values of the ratio between fuel and initial weight, 0.5 and 0.7. For the lift-drag ratio and the thermal propulsive efficiency of the 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 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.

## Air Plane Types

2.10 No attempt is made to write the specifications for the aircraft 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.

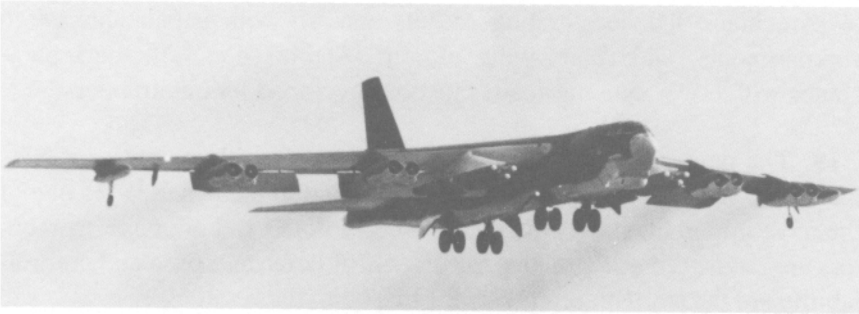
2.13 In the field of pilotless bombers the goal is the intercontinental missile. We assume a system of bases distributed in such a way that all possible target areas in the world can be reached by such missiles. Two types of pilotless bombers should be developed for this purpose. The first type should 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 attitude by piloted airplanes, it will be capable of level flight up to a range of 2,500 to 3,000 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 takeoff, 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



A prime example of an aircraft which could swiftly, and with great destructive power, hit remote targets was the B-52 Stratofortress, which wasd designed and tested during the period following this study.

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.

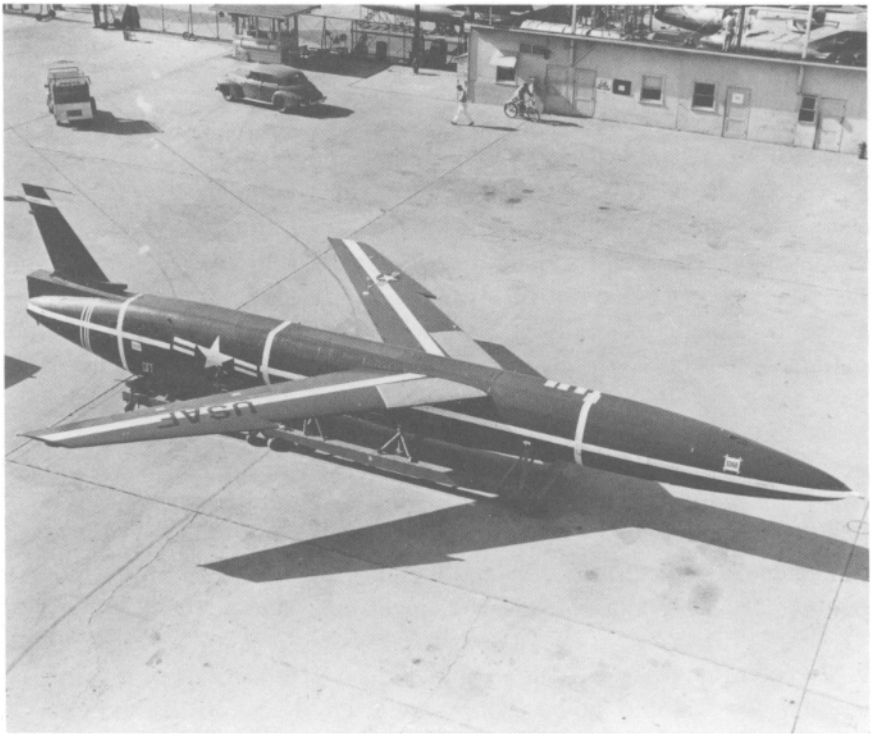
2.19 The possibility of attacks by single aircraft with disastrous effects makes the defense of our frontiers, industrial equipment, and bases one of the most important tasks of the Air Forces. Piloted and pilotless interceptors are envisaged as the main instruments of defense. Speed and controllability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

Examples of pilotless bombers envisioned by Karman and developed during lthe 1950s were the Matador (above) and Snark missile (below).



Long-range intercontinental ballistic missile development was predicted for the future in *Toward New Horizons.* Here, Gen. Bernard A. Schriever, Commander, Air Force Systems Command, is shown with models of the many missiles developed by AFSC and predecessor organizations during the twenty years following Kármán's report.

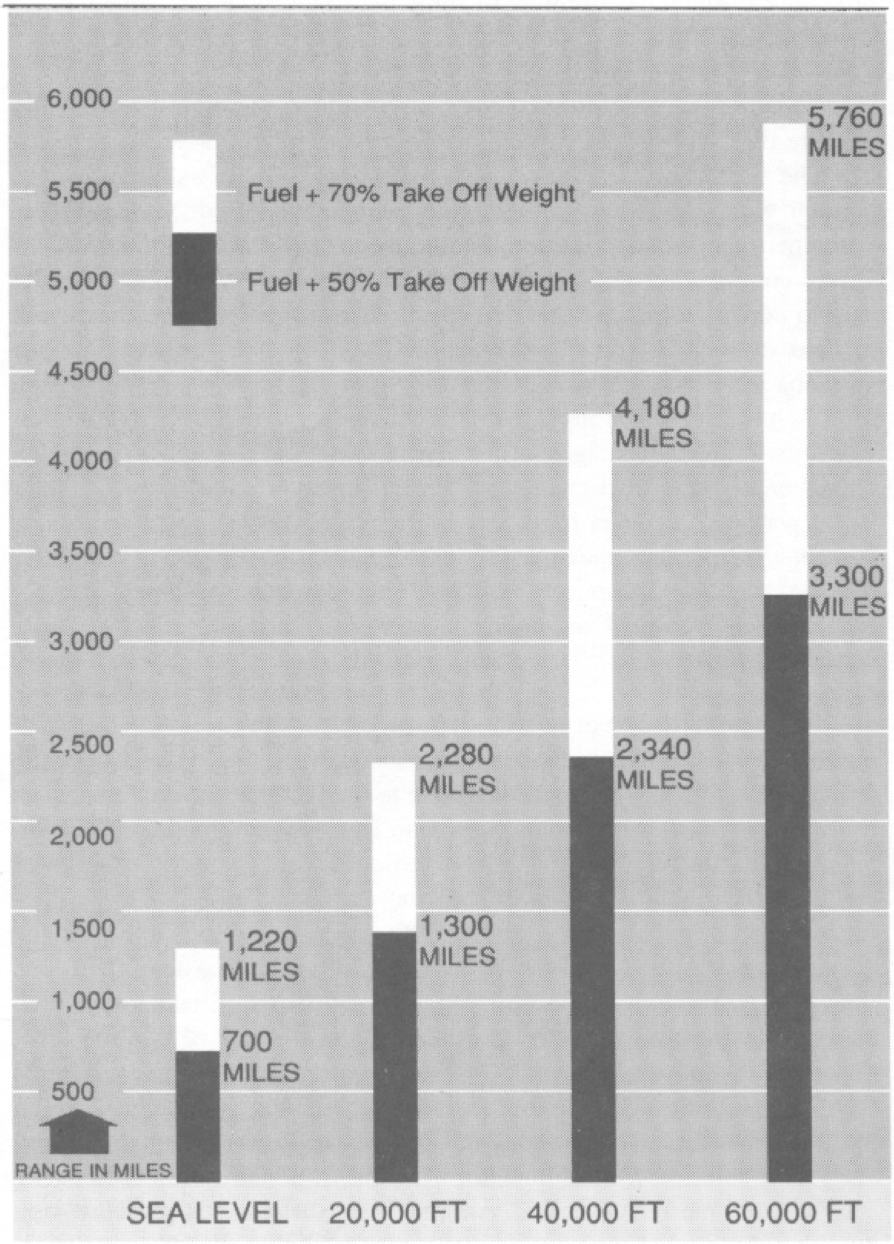
i.e., to try to secure laminar flow in the boundary layer by positive measures along the entire wing and in a large range of angles of attack. It is known that theoretically this aim can be attained by the so-called boundary layer control. Results along this line are already available, for example, in 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 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 w hich are different from those occur ring 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 the 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 highspeed 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.

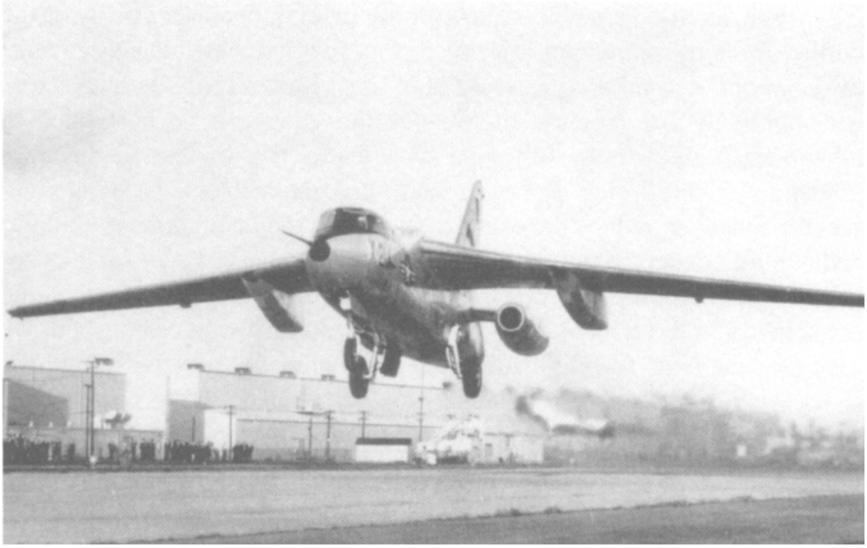
## Ranges Attainable at 1,000 MPH at Various Altitudes



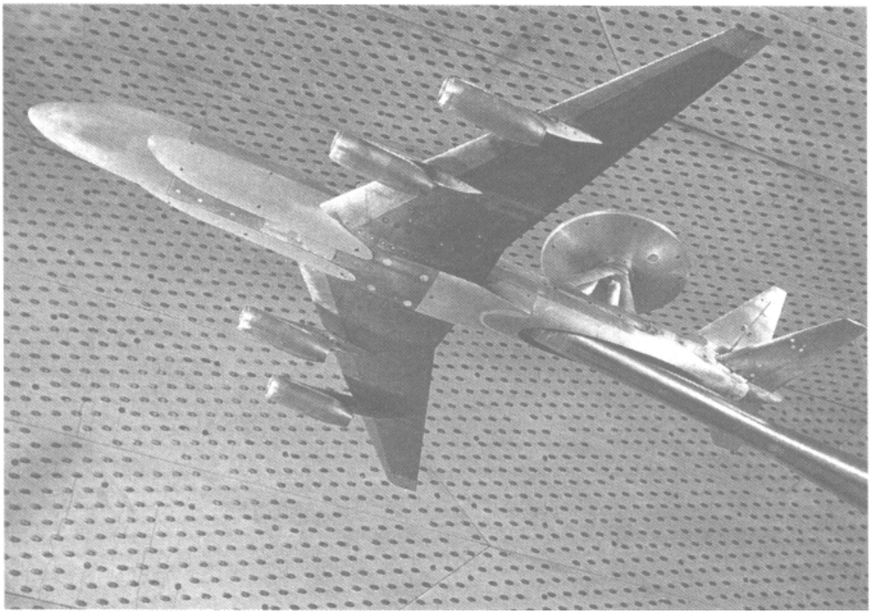
2.25 Fighters and interceptors now in the making operate actually at the border of the transonic range. Hence, every method which is able to raise the limit of the rapid drag increase is of great importance. German scientists observed that increase of drag of the wing can be postponed to higher Mach 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 112, 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



One aerodynamic concept addressed by Kármán concerned development of the larminar wing. The Northrop X-21(above) used this concept.



Developing wind tunnels and testing aircraft design models was important to Kármán's vision of aircraft development and testing methods. Above is an E-3A Airborne Warning and Control (AWAC) model undergoing wind tests at the Arnold Engineering and development Center (AEDC), Tullahoma, Tennessee.

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 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 turbine 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.

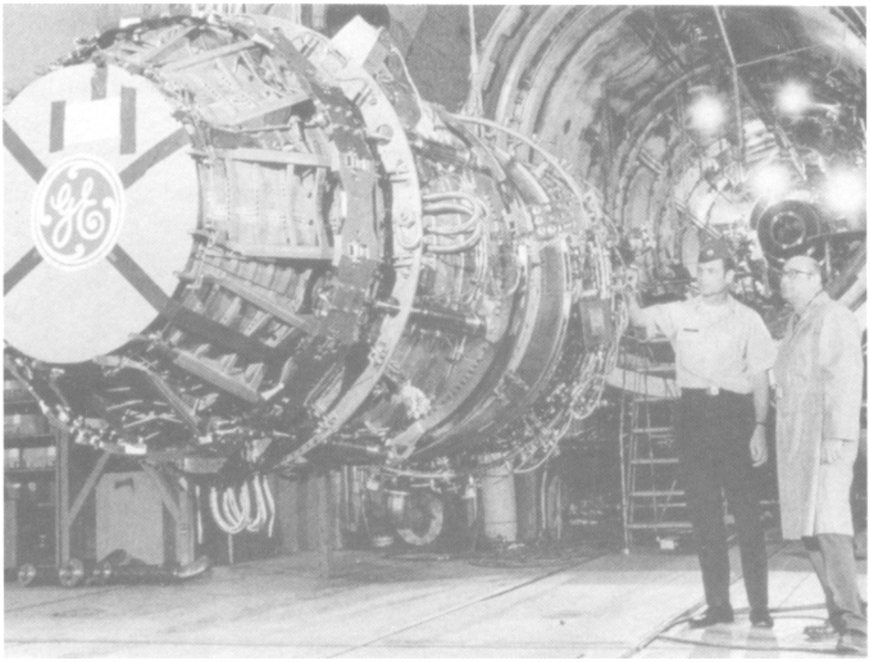
2.35 With the practical realization of the gas turbine, the entire field of propulsion, aerial, maritime, and ground transportation came into a revolutionary stage. Science and industry are feverishly working on the analysis of related aerodynamic and thermodynamic phenomena, improvement of materials 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, ie., 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 Kármán, 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 |

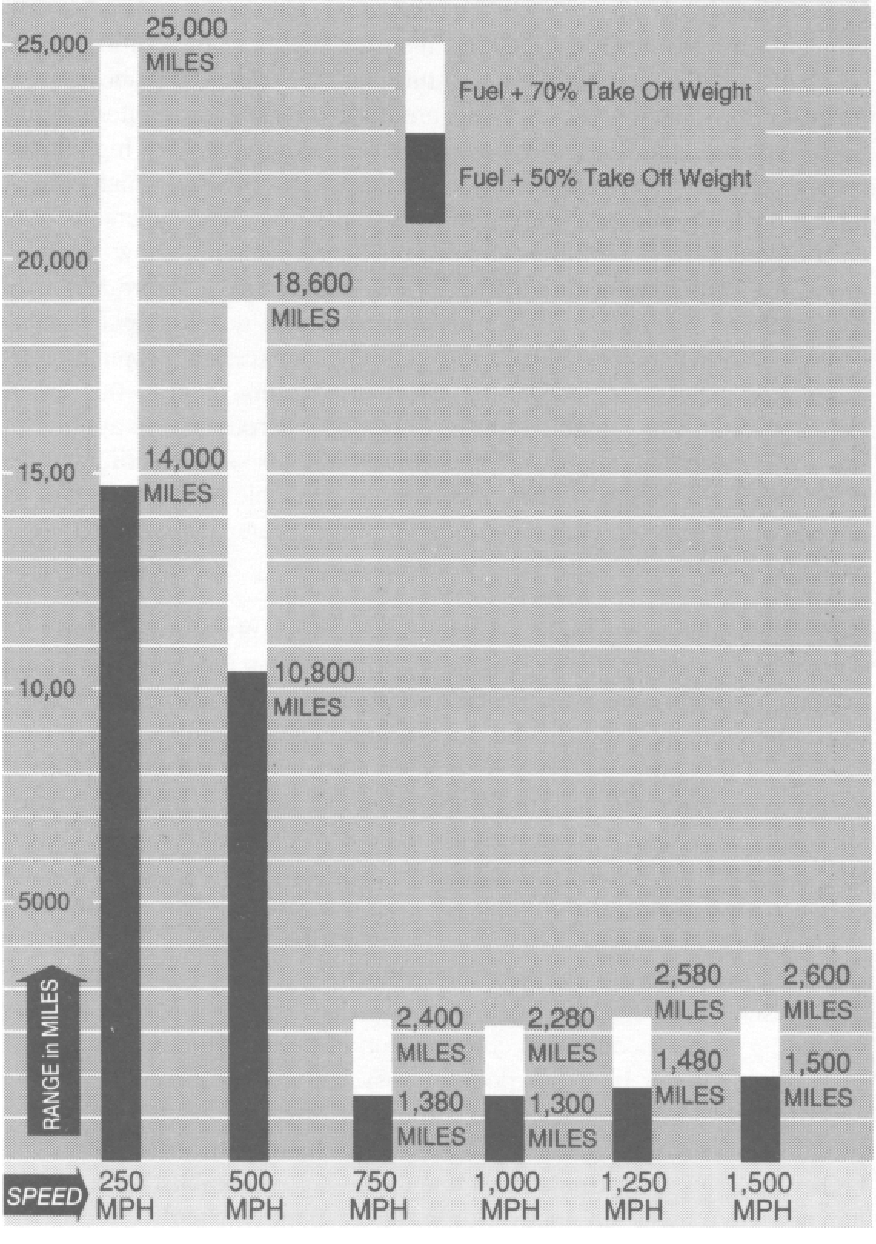
2.38 The chief limitations of the motorjet are those associated with the reciprocating engine. Since the reciprocating engine has a large frontal area in comparison with the gas turbine, units of large power become difficult



This seminal study also highlights the need for aircraft propulsion and engine design testing and development. Above, AEDC engineers check on a General Electric engine undergoing testing at the Tullhoma facility.

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.



Ranges Attainable at Various Speeds

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 worthwhile 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 astrospheric pressure and we can well dispense with the mechanical compressor and hence the turbine of the turbojet. The unit will then consist 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.

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 atmosphere 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 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 atomic 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 altitude beyond the stratosphere. The "satellite" is a definite possibility.

2.56 If the substitution of nuclear reaction chambers for fuel combustion chamber 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. Nevertheless, 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 essential 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 high 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 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 temperate 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 machinability 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 b 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

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 undoubtedly 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 photographs , 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

Five U-2s on the ramp at Edwards AFB. This aircraft was designed and perfected for reconnaissance, following the study's recommendations.

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 suitable 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 coordinations. 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 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 thickness 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 1,200 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 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 Before radar, 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 10 at ranges up to 1,000 or 2,000 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 echoes. 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 1,400 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 1,200 miles by day and 2,000 by night with errors of from one to two miles at 1,000 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 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 attitude would be controlled independently and the dive to the ground would be initiated 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 targetseeking 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

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 1,000 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 farther 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 groundbased 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 greater 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 tag 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 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 impaired. 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 arts 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.

## Ability to Cause Destruction

5.1 The war which just ended was the first one in which aerial 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 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 tasks 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 tanks. A scientific curiosity of the first decades of this century, the so-called Monroe 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 Terminal and Ballistics*.)

## Function Independently 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 h 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 Communication.*) 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 collision. Any airborne radar with 360 degree 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 occurring 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 aid 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 mode scale, with various control methods.

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

## 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 black out 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 initial 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 Right 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.

The Ryan X-13, an experimental tail-sitting testbed, represented an interesting, if unsatisfactory, attempt to develop a practical vertical take-off and landing concept.

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 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 2,000 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 (6in. 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 flights and becomes increasingly significant above 30,000 ft. For one hour's exposure 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, exercises 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

At the time of this report, the rocket-powered Bell X-1 neared readiness for its first flights on January 19, 1946. Many references to the expected results of supersonic flight centered on the knowledge of this aircraft's engineering design and potential performance characteristics. It first exceeded Mach 1 on October 14, 1947.

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 counter-measures 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 counter-measures 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 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 reliability 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 depend 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 communication must be very highly organized in order to economize the needed channels.

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 begins 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 available 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 the 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

## 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 given 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.

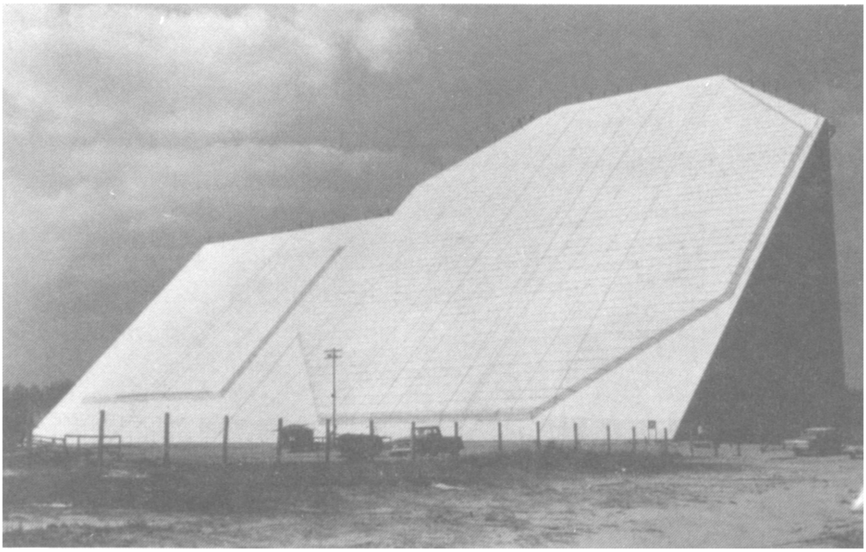
## Countermeasures Against Missiles

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.

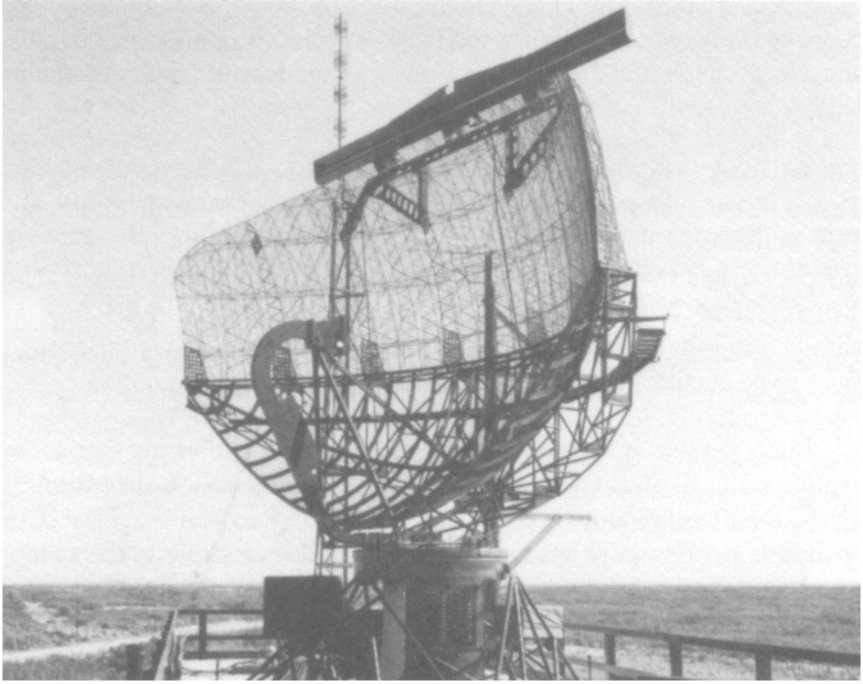
9.7 Any missile using remote radio control, electronic homing devices, or proximity fuses, can in theory be jammed. In practice it is necessary to know something of the method of operation and to adapt jamming equipment to the particular enemy device. The information may be obtained either by intelligence 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 decayed 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



The report asserted the need to defend home territory based upon enhanced radar development, including both radar for early warning in case of attack and warning networks integrated with control of fighter and missile squadrons. Among the systems developed to meet the detection and warning requirements were the AN/FPS-85 Spacetrack Radar (above) and the CPS-5 Surveillance Radar with the Collins Squirrel-Cage Antenna (below).



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.

## Chapter III

# 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 11 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.

## 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 contacts 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 Force 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.

## 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 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

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 becomes 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 aeronautical 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 bc 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 allweather 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 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.

# 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 effect 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 discussion 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 missiles and atomic energy involve radical changes. and bombers will be different; 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 advance 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 Service. 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

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 these 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 judgement 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 eturn 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 scientific 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.

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.

# Toward New Horizons and Its Contributors

**Science, the Key to Air Supremacy**
A Report to General of the Army H. H. Arnold
by the AAF Scientific Advisory Group
By Theodore von Kármán

**Where We Stand**
By Theodore von Kármán

**Technical Intelligence Supplement**

**Aerodynamics and Aircraft Design**
Part I: High Speed Aerodyamics
By H. S. Tsien

Part II: The Airplane — Prospects and Problems
By W. R. Sears, I. L. Ashkenas and C. N. Hasert

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**Future Airborne Armies**
By T. F. Walkowicz

**Aircraft Power Plants**
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Part IV: Future Trends in the Design and Development of Solid and Liquid Fuel Rockets
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Part V: High Temperature Materials
By Pol Duwez

## Aircraft Fuels and Propellants

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By W. J. Sweeney

Part II: Petroleum — Its Use for Motive Power
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Part III: The Airplane — Prospects and Problems
By W. R. Sears, I. K. Ashkenas and C. N. Hasert

Solid Propellants for Rockets and Other Jet Propelled Devices
By L. P. Hammett

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

## Guided Missiles and Pilotless Aircraft

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Part III: The Launching of a Winged Missile for Supersonic Flight
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Part IV: Properties of Long Range Rocket Trajectories in Vacuo
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## Guidance and Homing of Missiles and Pilotless Aircraft

Part I: Selected Guided Missiles Now Developed or Under Development
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By G. A. Morton

Part III: Radar Aids for the Guidance of Missiles
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By H. L. Dryden

## Explosives and Terminal Ballistics

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By G. Gamow

Part II: Properties of High Explosives
By D. P. McDougall

Part III: Terminal Ballistics and Destructive Effects
By N. M. Newmark

**Radar and Communications**
Part I: The Use of Radar in Air Forces Operations
By L. A. DuBridge, E. M. Percell and G. E. Valley

Part II: RADAR — A Discussion of Future Trends of Interest to the Army Air Forces
Supplement — Defense Against the Atomic Bomb
By L. A. DuBridge, E. M. Purcell, and G. E. Valley

Part III: Aircraft Radio Communication Equipment
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**Weather**
By I. P. Krick

**Aviation Medicine and Psychology**
Part I: Future Trends of Research in Aviation Medicine
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Part II: Psychological Research in the Army Air Forces
By C. W. Bray

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