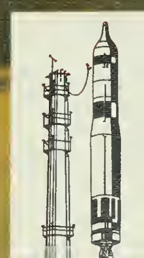
fundamentals of AVIATION AND SPACE TECHNOLOGY



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Foreword

In 1945 Mr. Edwin A. Link, inventor of the Link flight trainer and electronic simulators, and his company, Link Aviation, Inc., sponsored the publication of a book written by Norman Potter and William J. Konicek of the Link staff. The book was called "Fundamentals of Aviation" and was an immediate success. Since that first publication, Mr. Link has signally benefited aviation by establishing The Link Foundation, which is dedicated to the advancement of education and training in aeronautics.

In 1955 the staff of the Institute of Aviation of the University of Illinois revised the book. It was completely rewritten and enlarged in 1959 by those members of the University staff whose names appear as co-authors on the title page and the title was changed to "Fundamentals of Aviation and Space Technology."

The interest of The Link Foundation and Dr. Frank E. Sorenson, then Executive Secretary of the Foundation, and of Miss Marilyn C. Link, made the 1959 edition possible. However, the authors had complete freedom in the selection of materials and assume sole responsibility therefor.

Mr. James M. Hancock acted as coordinator. Mr. Robert L. Ayers, Mr. Thomas H. Bailey, Mr. Hale C. Bartlett, Mrs. Gertrude A. Becker, and Mr. Thomas H. Gordon, also of the Institute of Aviation staff, contributed materially to the manuscript.

The reception accorded the first edition of this book under its present title was very gratifying. It appealed especially to teachers and students, as well as to the air transportation industry for orientation courses.

The book was reprinted in 1962, with a few revisions being made to update and clarify the content, and a chapter added on developments in space exploration. The continued success of the book has again exhausted the supply, and a new printing is necessary only two years after the previous revision. Statistics and other items have been updated and the glossary expanded. Also, the chapters on the Federal Aviation Agency and Space Exploration have been revised to reflect recent changes and developments. For the benefit of libraries and others who wish hard covers, the book is available in such covers.

It is a pleasure to acknowledge again the cooperation of The Link Foundation, particularly of Miss Marilyn Link, Executive Secretary, and Dr. Frank E. Sorenson, Chairman of the Technical Assistance Board. Mr. James M. Hancock, who is now Executive Director of the Chicago Planetarium Society, has acted as coordinator of the revision. Their assistance has been invaluable.

As Mr. Link wrote in the first edition of the book, "With a full realization of the wide influence of aviation on the peoples of the world; with an understanding of the problems which youth will face growing up in the air age; and with a profound belief in, and respect for, the processes of education meeting this challenge, we respectfully dedicate this aviation publication to all American youth."

Urbana, Illinois
June 1964

Leslie A. Bryan
Director, Institute of Aviation
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Contents

Illustrations

Chapter 1 Living in the Aerospace Age

No other mode of transportation has had greater impact on the world than aviation. None has so changed the economic, political, and social traditions of the world in such a short period of time. The phenomenal growth of the aerospace industry, the rapid expansion of commercial air travel, the tremendous influence of aviation on military concepts and international affairs, all have had inescapable and overwhelming effects on day-to-day living.

The youth of today must have an appreciation and awareness of the history, practical effect, and future potential of this transportation giant. Only through an understanding and application of aeronautical principles, by both the present and future generations, will the United States be able to maintain its air-power position. Many young Americans have already realized the value of a technical aviation education, including flight and engineering, and are well on the way to participation in the Aerospace Age. Space travel and the space frontier are absorbing and vital problems.

But just as important is an awareness of the advantages and disadvantages, the privileges and restrictions, and the rewards and consequences of expanding aviation in the world of today and tomorrow. The impacts of aviation are economic, social, and political.

The Economic Aspect

Aviation in the United States directly influences the economic activities of millions of individuals. Several hundred thousand persons are industrially employed in the field of aviation. Millions of passengers fly on the commercial airlines each year for both business and pleasure. Both the production and the distribution of goods and services are facilitated by the airplane. Mass-production firms use air freight when production line stoppages are threatened. Increasing quantities of goods are being flown direct from factory to retail outlets, providing more rapid delivery and eliminating the need for warehouses in a firm's distribution system. Air-mail letters move across the United States, non-stop, in approximately five hours. Even live lobsters are flown from Maine to air-conditioned supermarkets in Texas. The use of helicopters for air taxi and industrial work is rapidly increasing. Businessmen are now aware of the economic value of owning and operating private aircraft for business purposes. Corporate flying is growing in tremendous strides. As consumer incomes continue to grow, more and more people will own personal aircraft.

Categorically speaking, there are three basic areas in aviation: (1) the aerospace manufacturing industry, both civil and military; (2) the air transport industry; and (3) general aviation.

Table 1. Aerospace Industry Classification

- Aerospace Manufacturing Industry:
  - Aircraft
  - Aircraft Engines
  - Aircraft Parts and Accessories
  - Missiles
  - Spacecraft
- Air Transport Industry:
  - Domestic Scheduled Airlines
    - Trunk Lines
    - Local Service Lines
    - Helicopter Airlines
    - Supplemental Air Carriers
  - International and Overseas Lines
  - Alaskan Carriers
  - Intra-Hawaiian Carriers
  - All-cargo Airlines
- General Aviation:
  - Business Flying
  - Commercial Flying
  - Instructional Flying
  - Personal Flying

The aerospace manufacturing industry includes all research, development, fabrication, assembly, and sales operations relating to airplanes, missiles, parts, accessories, and equipment. The industry also includes major overhaul, maintenance, and modification facilities.

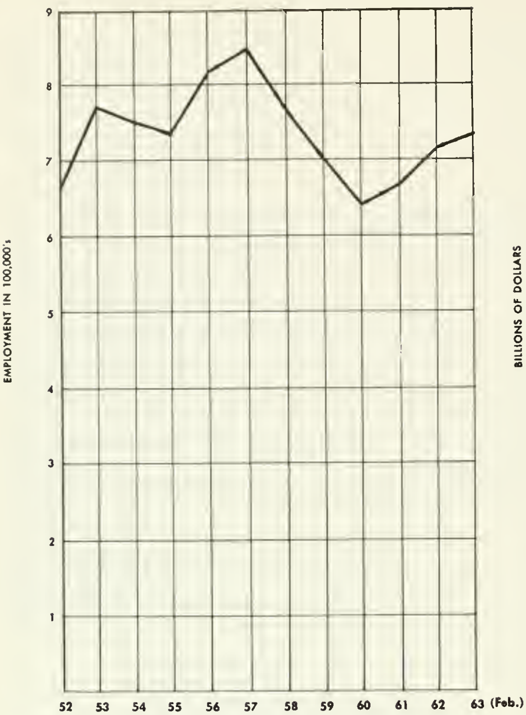


Figure 1—Average Annual Employment in the Aircraft and Parts Mfg. Industry (1952-1963). Source: *Aerospace Facts and Figures*, 1963 Edition, p. 69.

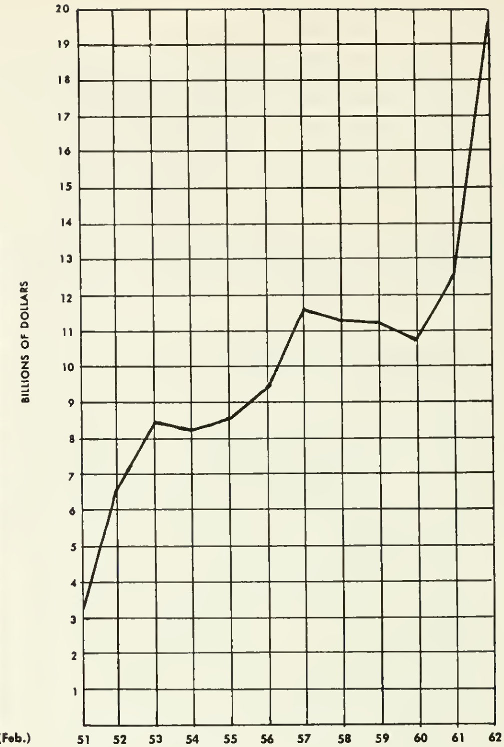


Figure 2—Aircraft Manufacturing Industry Sales (1951-1962).

In contrast, the air transport industry encompasses only scheduled flying activities performed by commercial airlines and air freight carriers. The routes flown, the rates charged for services, and all items pertaining to safety are carefully regulated by the federal government.

General aviation consists of all other aviation activities except those of the air transport industry and the military services.

THE AEROSPACE MANUFACTURING INDUSTRY

During World War II, the United States aircraft manufacturing industry became a large industrial complex capable of producing 100,000 planes per year. Employment soared to over 1.3 million persons. However, after the war ended and enough civilian aircraft had been produced to satisfy the immediate postwar demand, the industry dropped to a point where it was producing at a rate of only 6 per cent of its wartime capacity. With the onset of the Korean War, the industry began to expand again, and, since 1950, has grown to be one of the most important industries in the United States. In 1962, aircraft and allied manufacturing represented a $19.5 billion industry. (Figure 2.) This growth is economically significant because in ten years the industry created several hundred thousand new job openings—employment rose from 670,000 in 1952 to over 726,000 in 1963. (Figure 1.)

The foundation for this employment increase and growth of the industry is the national defense program. In recent years, over 50 per cent of the federal government's budget has been allocated to national defense; of this, a significant portion has been diverted to the aerospace manufacturing industry for research, development, and production work on airplanes, missiles, and spacecraft. During the 15-year period 1947-1961, 89 per cent of the total sales of 51 of the largest aerospace companies was to the federal government.

Not only is a vast number of jobs created by the industry, but a wide variety of skills is also needed.

Aircraft, missile, and spacecraft manufacturing all emphasize research and development activities. Because there are constant changes in design and production methods, the research and development field is an important source of employment for engineers, scientists, technicians, and craftsmen. In 1956, the amount of money spent for research and development in the aerospace industry exceeded that of all other industries. Since 1957 the industry has had a higher proportion of scientists and engineers involved in research and development work than has any other industry. In addition, these scientists have more craftsmen assisting them than is the case in any other industry.

Even though professional and technical personnel are necessary, there are also many job openings for skilled and semi-skilled production workers. Approximately 50 per cent of the industry's working force are tool and die makers, sheet metal workers, machine tool operators, welders, inspectors, assembly line production workers, and maintenance men.

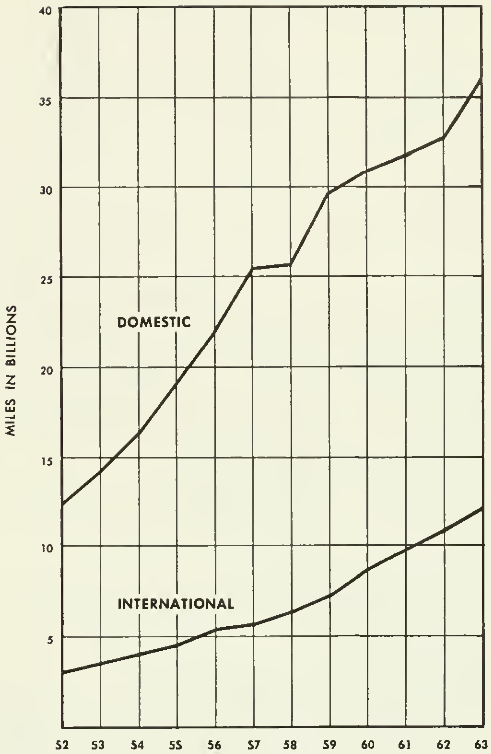


Figure 3—Revenue Passenger Miles Flown (1952-1963). Source: *Aerospace Facts and Figures*, 1963 Edition, p. 126, and *Aviation Week and Space Technology*, March 16, 1964, p. 164.

AIR TRANSPORT INDUSTRY

October, 1958, marked the beginning of a new era in the history of commercial air transportation in the United States. During this month, a United States international carrier inaugurated the first regularly-scheduled commercial jet airliner service from New York City to Paris and soon after to London and Rome. Likewise, a major domestic airliner initiated non-stop transcontinental jet service in January, 1959. In February, jets began flying between Chicago and the West Coast with jet service soon following for all major cities in the United States.

The development of commercial jet airliners represents the highest degree of mechanical perfection yet achieved by man in the field of public transportation. The giant four-engine turbojet aircraft are capable of carrying 100 to 150 passengers, in silent, vibration-free flight, between 500 and 600 miles per hour, at altitudes of 40,000 feet, for distances up to 5,000 miles.

The magnitude of progress in air transportation achieved since World War II becomes apparent when it is remembered that as late as 1941, air travelers were crossing the United States in two-engine, 21-passenger airliners at 165 miles per hour, requiring 16 hours to make the trip. Even when comparing the jet with its predecessor, the highly-perfected, conventionally-powered DC-7C commercial airliner, the difference is noticeable. On the average, the modern commercial jet airliners reduce flying time between cities by approximately 42 per cent.

Table 2. Flying Times of Modern Jets vs. Douglas DC-7C

Cities	Miles	DC-7C (hours)	Jets (hours)
New York to London	3,250	12.0	6.5
New York to Paris	3,680	13.0	7.0
New York to Rio de Janeiro	5,020	18.5	10.0
San Francisco to Honolulu	2,420	8.0	5.5
Los Angeles to New York	2,458	7.5	4.5
New York to Los Angeles	2,458	8.5	5.5

Economically speaking, since a jet transport can carry more people at higher speeds, it accomplishes more work in the same period of time than the conventional airliner. A jet transport carries twice as many passengers as a DC-7C at 1.5 times the speed; therefore, its productive capacity is three times that of the DC-7C. Another illustration of the economic importance of the jet airliner is the ability of one jet

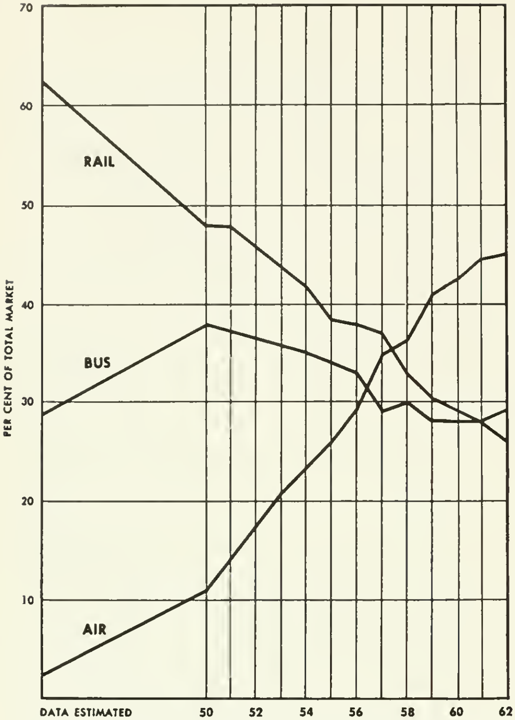


Figure 4—Airline, Railroad and Bus as Per Cent of Domestic Passenger Mile Market (1950-1962). Source: *Aerospace Facts and Figures*, 1963, p. 129.

airliner to fly the North Atlantic route and carry the same number of passengers annually as a 40,000-ton ocean liner such as the Queen Mary.

Three factors which indicate the economic value of air transportation are: (1) revenue passengers carried; (2) revenue passenger-miles flown; and (3) the dollar volume of sales revenue. Since 1949, the number of revenue passengers carried by both domestic and international airlines has more than quadrupled. In 1949, the domestic airlines carried over 12 million revenue passengers. In 1962, over 62 million were flown. Similarly, international airlines increased from 1.5 million revenue passengers flown in 1949 to over seven million in 1963.

During this same period, revenue passenger-miles flown by the domestic trunk carriers quintupled, while the international carriers quadrupled their mileage. In 1962, the domestic trunk airlines flew nearly 44 billion passenger-miles and in 1963 the international carriers flew 13.3 billion passenger-miles. The total revenue passenger-miles flown by these two carriers is equivalent to ten persons each making 10,396 round trips to the moon during a single year, or more than 28 round trips each day.

In 1962, sales revenue in the air transport industry climbed to a volume of $3.4 billion.

In 1938, the airlines accounted for only 1.7 per cent of the total passenger volume, while railroads received 65.5 per cent, and buses 32.8 per cent, but twenty-five years later, air travel had increased about 25 times, while rail travel had declined over 51 per cent in relative importance. By 1962, the domestic airlines received 45 per cent of the total passenger volume; railroads, 26 per cent; and buses, 29 per cent. (Figure 4.)

The demand for scheduled airline passenger service in the U. S. domestic market is projected to rise from about 36 billion revenue passenger-miles in 1962 to 43 billion in 1965 and to 57 billion in 1970. The trip-length distribution of this demand is expected to shift modestly toward the long haul. The coach-economy share of this demand is projected to increase markedly, from more than 55 per cent in 1962 to about 85 per cent by 1970. The development of new all-cargo aircraft and new cargo-handling systems, together with more efficient carrier operating practices and keener competitive situations, should enable domestic aircargo prices to drop about 45 per cent during the 1960's. This factor, plus the projected expansion of the gross national product and the increased demand for airmail which seems likely, is expected to stimulate a combined demand increasing from about 510 million ton-miles in 1963 to about 2⅓ billion ton-miles in 1970.

The free world demand for international air passenger transportation is projected to rise from about 26 billion revenue passenger-miles in 1960 to 38 billion in 1965 and 54 billion in 1970. The U. S. flag carriers' revenue passenger-miles are projected to increase from 8⅓ billion in 1960 to 13.3 billion in 1963 and to about 17 billion in 1970. The coach-economy share of this demand is projected to increase from an already high share of about 75 per cent in 1960 to 90 per cent by 1965 and to 94 per cent by 1970. Predicated on the forecast that rates in the free world international aircargo market will be reduced by 60 per cent between 1960 and 1970, the free world effective demand for international aircargo and airmail transportation is projected to increase to more than 5 billion ton-miles in 1970. The U. S. flag carriers' share of this demand is projected to increase from about 1.8 billion ton-miles in 1963 to about 2 billion ton-miles in 1970.

Considering the fact that only 30 per cent of the people in the United States have ever flown, the above estimates do not seem unreasonable. A vast market of potential air travelers is still available and, further, a growing population indicates that the market potential is expanding, not contracting.

In summary, the economic effects of the present air transport industry are: (1) a sharp shrinkage of distance in terms of time; (2) a greatly expanded transport capacity of the new jet in comparison to propeller-driven aircraft; (3) a tremendous increase in the number of people using air transportation for business and pleasure; and (4) a major shifting of traffic volume from the railroads to the airlines.

What economic significance will the air transport industry have on employment? In 1963, about 175,000 persons were employed in this industry, and more than 40,500 worked for the Federal Aviation Agency. In 1952, the industry employed about 98,000 people. Therefore, non-governmental employment increased about 70 per cent in an eight-year period.

Airline operations require many skilled workers to fly and maintain aircraft, provide passenger and terminal service, and perform long-range planning for management purposes. Pilots, navigators, flight engineers, mechanics, traffic agents, dispatchers, meteorologists, engineers, and administrators, all combine their talents to provide a properly functioning, efficient airline. In addition, Federal Aviation Agency personnel are concerned with air traffic control, airways communications and navigational facilities, flying safety, and research and development activities. A very important and growing field within the FAA is the development of the air route traffic control system which will create new positions for radar controllers, technicians, and dispatchers.

Of the people working for an airline, about 14 per cent are flight personnel, 20 per cent are mechanics, and 2 per cent are communications specialists. The remaining 64 per cent are concerned with ticket sales, reservations control, ground servicing of aircraft, sales management, personnel administration, economic research, legal counsel, and executive duties.

Air Cargo

The aircargo business is conducted by two groups: (1) the all-cargo airlines, and (2) the regular domestic and international airlines. The all-cargo airlines were established to carry aircargo exclusively.

The volume of aircargo—freight, mail, and express—has been increasing over the years. In 1962 the total volume of cargo carried by the certificated airlines totaled nearly 1.3 billion ton miles of which 898.1 million ton-miles was freight, over 251.4 million ton-miles was mail, and 70 million ton-miles was

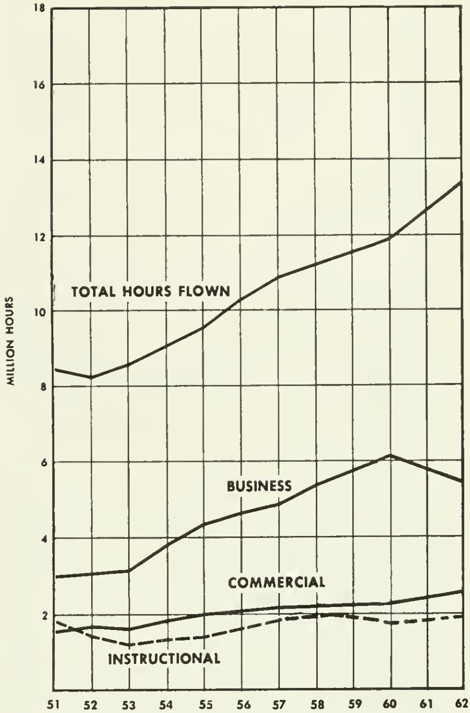


Figure 5—Hours Flown in General Aviation (1951-1962). Source: *Aerospace Facts and Figures*, 1963 Edition, pp. 133-4.

express. While the percentage of volume of cargo carried by air is less than one per cent of the total intercity ton-miles moved by all forms of transportation, the airlines are planning on carrying much greater quantities in the future.

Air transportation costs still are high when compared solely with the *costs per mile* of water, rail, or truck transport. Today, however, by carefully analyzing total distribution costs, the airlines are often able to show manufacturers that standard production-line items may be shipped more profitably by air. Savings result primarily from the ability of the manufacturer to eliminate large inventories, cut warehousing requirements, and reduce the number of times the product must be handled. Moreover, good will is established between the manufacturer and his customer through rapid attention to and delivery of the customer's orders.

Helicopters

The helicopter is a relatively uneconomical form of transportation. It requires several hours of ground maintenance time for every hour of flight time. It is slow and difficult to fly. Only now is it beginning to achieve all-weather operation. Further, its payload is limited when compared to that of an airplane. Yet the helicopter fulfills a very important need in commercial air transportation because of its small-field versatility.

Scheduled helicopter airlines carry passengers between downtown locations and airport terminals. In 1959, three cities had scheduled helicopter service—New York, Chicago, and Los Angeles. A St. Louis firm has inaugurated metered helicopter service similar to that provided by taxicabs. Even though helicopter transportation is still in its infancy, its growth record is phenomenal. Operations began in 1953. During that year 1,000 passengers were carried. In 1962, 359,000 passengers were carried—a 359-fold increase!

GENERAL AVIATION

The major divisions of flying within the general aviation classification are (1) business, (2) commercial, including agricultural and charter flying, (3) instructional, and (4) personal. In terms of number of aircraft operated and number of hours flown annually, general aviation leads all other segments of civil aviation. In 1962, over 82,000 aircraft were engaged in general aviation flying. This contrasts with approximately 2,200 commercial airliners in domestic use. Moreover, these 82,000 airplanes flew an estimated 13.3 million hours that year, over three times the number of hours flown by the commercial airlines.

After World War II many people thought the airplane would become as commonplace as the automobile, with millions owning and operating small, personal aircraft. Flight training was stimulated by federal government educational benefits granted to veterans. Enrollment in flight schools soared. In 1947, general aviation reached its all-time high in number of hours flown. This 1947 record of 16.3 million hours quickly dropped to an average level of 8.9 million hours during the period 1950-1955. (Figure 5.) Limited utility and high operating and ownership costs of aircraft proved detrimental to the widespread growth of private flying.

Since 1946, however, an important trend has materialized. Businessmen have discovered that the airplane is a valuable tool in the operation of their enterprises. The total hours flown for business purposes increased from 2.6 million hours in 1949 to 5.5 million hours in 1962. In eleven years, the increase was two-fold and accounted for over 40 per cent of the total number of hours flown in general aviation in 1962.

The use of business aircraft permits a company to expand its sales volume by increasing its market coverage without necessarily increasing the number of salesmen on its staff. For example, a 200-mph company plane can fly from Dallas to Houston in one hour and 12 minutes; from New York to Boston in 55 minutes; from Los Angeles to San Francisco in one hour and 42 minutes. The advantages of covering a regional sales territory by aircraft instead of by automobile are obvious.

General aviation aircraft also have many uses in addition to that of transportation. Farmers, ranchers, and others engaged in agriculture have found the airplane valuable for aerial application of chemicals or seed to land, crops, and forests. Control of insect invasion is a most important aspect of this work.

Chartered passenger and cargo transportation is a significant part of general aviation. Commercial flying accounts for about 18 per cent of the total number of hours flown in general aviation activities. Included in this category are pipeline control, forestry patrol, mapping, aerial photography, mineral prospecting, and advertising, as well as agricultural flying.

Instructional flying, including dual and solo flight, is responsible for about 15 per cent of general aviation flying. Immediately following World War II instructional flying accounted for over 60 per cent of general aviation activity. As veterans' benefits diminshed, instruction also diminished, so that it soon represented the smallest portion of general aviation annual flying hours. Since 1955, this trend has reversed sharply, with instructional flying increasing from 1.3 million hours in 1955 to 1.9 million hours in 1962—an increase of 49 per cent. With the ever-increasing popularity of the airplane in business flying, the present increase in flight training promises to continue.

Personal flying tends to remain a fairly constant percentage (approximately 27 per cent) of the total hours flown in general aviation. The level of consumer income is a determining factor in the number of hours of pleasure flying.

It is estimated that the current value of the general aviation fleet exceeds $700 million. Add to this a $500 million per year sales volume of fixed-base operators serving over 200,000 active pilots, and it is evident that general aviation now has a firm foundation in the economy. In view of the great potential for increased business flying, this segment of aviation is expected to experience remarkable growth during the next decade.

The Social Aspect

In order to judge comprehensively aviation's effect on the "social man," it is necessary to review certain aspects of everyday life and determine how the airplane has contributed to a re-appraisal, if not a re-evaluation, of social concepts.

POPULATION DISTRIBUTION

Any important means of transportation moves populations. Ships brought people to America; the railroads stimulated the growth of cities; the automobile dispersed city people outward and drew rural inhabitants in toward the outskirts of the cities.

Aviation has a similar significance in the distribution of population. The out-of-the-way locality, where minerals, chemicals, and other natural resources may be exploited, can be brought into contact with other population centers by the speed of air transportation. Similarly, the sparsely populated regions lying adjacent to or on air routes, between densely populated centers, will tend to increase in population.

A closely related factor to future population distribution is the ability of the airplane to promote new business and trade activities in areas not now served by railroads or highways, but which, though undeveloped, are potentially rich in resources. The 49th state, Alaska, is an excellent example of a potential population growth area.

EDUCATION

In an over-all sense, the influence of aviation on education is synonymous with its influence upon civilization and culture. Speaking of education in a narrower sense, i.e., a formal classroom-laboratory, teaching-learning process, aviation has had a tremendous impact on elementary, secondary, and university instruction.

Recently, a survey was completed which indicated that 47 institutions of higher learning conferred degrees in aeronautical engineering on the basis of a four-year curriculum; 22 others conferred such degrees on the basis of a five-year curriculum; while 25 schools offered a program of studies in either aeronautical administration or other aviation service fields.

Aviation trade schools have been established in every state. There are 69 airframe and aircraft powerplant mechanics schools. Of the 843 flight schools, 216 teach flight and related subjects, and the other 627 teach flight only. In addition, many airlines, aircraft assembly factories, and aircraft engine plants maintain schools or apprentice training programs.

The social sciences not only tell the history of powered flight, but also relate its social, economic, and political effects. The physical sciences include the theory of the airfoil, the physics of airframe construction, the chemistry of fuel and metals, the mathematics of missiles and rockets, astronomy, celestial navigation and geography, and flight engineering development.

FAMILY LIFE

The habits and living conditions of the family have also been affected by the introduction of the airplane. The most noticeable change has occurred in the family's choice of vacation sites. Within the usual two-week vacation period, it is now possible to visit scenic and historic locations which are thousands of miles away. Relatives who have moved to distant places are only hours away. Because of this, there has been a tendency for family members to feel a greater freedom of choice in choosing to relocate without necessarily weakening family ties.

Eating habits have been changed by the increased use of aircargo facilities. Foods from distant areas are now more readily available. New products are quickly distributed to the consumer and new markets created and expanded.

Widespread influence of privately-owned aircraft on family life is contingent upon the further development of low-cost, high-efficiency, light airplanes. Privately-owned aircraft will provide a higher degree of personal mobility and influence sports activities—specifically camping, hunting, and fishing—of families in higher income brackets. Big spectacle sporting events can be more easily attended, and increased sporting activity in more widely separated areas is possible.

The Political Aspect

Just as aviation has a social and economic impact upon persons and nations so, too, it has an effect in the realm of politics. In the fields of total air power, military strength, and international relations, the impact of aviation is noticeable.

MILITARY OPERATIONS

World War I indicated to military strategists that fundamental changes would be required in planning offensive-defensive actions in all wars. At first planes were employed only as mobile observation posts which could quickly and accurately report concentrations of enemy troops and fire power. As this activity increased, the next logical step to occur was an attempt to deny this activity to the opposition. Airplanes not only carried a pilot or a pilot and observer, but also a rifle and hand grenades. Soon, machine guns were mounted on the nose of the plane, and later bombs were also carried. During World War I, a new aviation jargon came into being and new tactics were evolved, but the full potential of aerial warfare was neither understood nor employed.

In the period between the two great wars, some nations did more to incorporate aviation into their military forces than did others. There was, however, a general lack of comprehension of the support, reconnaissance, fighter, bombing, and transport abilities of a modern air force. Although the first powered flight occurred in the United States in 1903, this country was one of the last major powers to become fully aware of the significance of the airplane.

The most famous of the early advocates of aviation, particularly in the military field, was General "Billy" Mitchell. He proved the superiority of the airplane over the battleship, but his strategical victory ended in his personal defeat. He was court-martialed and resigned from the Army, although he continued his fight for the recognition of a strong military air fleet. Today, the United States has implemented many of the ideas which General Mitchell attempted to promulgate in the 1920's.

During World War II, the aviation industry "grew up," commercial air transportation was vastly expanded, and military commanders not only recognized the value of an air force, but assigned to it an equal area of responsibility with the Army and Navy. The importance of this partnership role of the Air Force was confirmed when the Congress decreed in 1947 that a new Cabinet-level post should be created, i.e., the Department of Defense, in which the Army, Navy, and Air Force had equal status.

Since World War II, the greatest demonstration of the use to which air power could be put was given during the "Berlin Airlift." Thousands of tons of food, clothing, coal, and other necessities of life were airlifted into beleaguered Berlin. This accomplishment was carried out without the loss of a life or the loss of an aircraft and was completed during all kinds of weather and on a 24-hour schedule.

Figure 6—A North Pole-Centered map, or a polar projection, shows the new world geographic relationships created by the airplane.

Air power today includes the military air force, commercial air transportation, the aircraft industry, and general aviation. It is not the size of the fleet of military aircraft alone which determines air supremacy.

INTERNATIONAL AFFAIRS

Until the beginning of World War II, it had been the American tradition to be isolationist—to "go it alone"—to avoid being involved in "foreign entanglements." Only a terrifying event, such as the bombing of Pearl Harbor, could change the thinking of the public for any length of time. There was, of course, a more liberal trend of thought—one which reflected a strong tie with Europe. This feeling of internationalism was, for the most part, concentrated on the Atlantic Coast. This was logical, of course, because New York was closer to London, Paris, Rome, and Berlin than was Chicago.

It has only been since the end of World War II that many midwesterners and westerners discovered that they had been looking at the wrong map. The well-known Mercator Map did not give an accurate picture. The Polar Map clearly pointed out that the distances from Europe to Chicago, Denver, and Seattle were approximately the same as the distance from New York to these same places in Europe. (Figure 6.)

Commercial airlines, in 1957, began flying the Polar route over the top of the world, and doing it on schedule and at a high rate of speed. If the commercial planes could pioneer these routes and accept them as safe flying areas, speedy enemy bombers could do the same. Our military defense conception had to be revised when this most disturbing fact was finally acknowledged. The heart of the United States, in a third world war, could easily become a battleground. The long-distance, two-ocean defense system became obsolete. The airplane forced the American public to re-appraise and re-evaluate America's vulnerability and its traditional concepts concerning international relations.

In today's Aerospace Age, international affairs have become a dynamic force. Diplomacy and international relations are intelligently discussed by the average citizen. Although much of the credit can be given to the progress and enlargement of the communications system of the world, a part of this awareness of world events can be attributed to the rapid advances in commercial and private flying. It is no longer considered unusual when a high official of government or industry travels to another country or continent for a conference and is back at his desk in a day or so.

Where it formerly took days or even weeks for complete films of a great event in Europe to arrive and be distributed throughout the nation, today, by combining the airplane and the television set, the American public can see a coronation or an historical event in less than ten hours after the event takes place. Or, again through the medium of television, they may view the actual firing of a missile from Cape Canaveral, which, in itself, is a tribute to the importance of air power and already has influenced international affairs.

POLITICS

Another indication of aviation's importance may be noted in the use of airplanes by government officials, chiefly the President of the United States. The Office of the President has on call a small fleet which, in addition to jet aircraft, also contains helicopters.

It is notable that political campaigning methods have also changed during the past twenty years. It is no longer necessary for a candidate to spend much time away from his headquarters or to plan a cross-country trip where his speeches have to be given in geographic proximity. In future campaigns, a candidate may appear before an audience in Chicago on one day, in Dallas the next, in New York on the following day, and then in Los Angeles the day after that. Political leaders have become mobile and this factor has permitted and encouraged greater appreciation and understanding of American politics by a larger number of voters.

Summary

Today aviation exerts considerable influence upon the economic activities of mankind. The aerospace industry provides thousands of job opportunities. It has grown to be a dominant employer in manufacturing. Further, this industry consumes a sizeable portion of the total defense budget, which is sustained by all taxpayers in this country.

Commercial aviation is entering a new era, with ever-widening horizons. The commercial jet airliner promises to revolutionize the travel habits of businessmen and families alike. The distances of global travel have been reduced to a few hours of pleasant riding in air-conditioned, living-room comfort.

General aviation is coming into its own with the growing use of aircraft for business travel. Increasing acceptance of the airplane as an economic business asset will acquaint new thousands with private air travel. As consumer incomes increase, light aircraft ownership costs will fall within the reach of hundreds more. Freedom of movement, now associated with the automobile, may be shifted to the airplane.

Sociological change has followed the development of the airplane. The airplane has increased the living tempo, opened new markets, and affected the distribution of the world's population. Distant and previously inaccessible areas will be opened, new towns will be constructed, and sparsely populated regions lying adjacent to air routes will increase in population.

Formal education will be vitally affected by aviation with all phases of the present educational system directly influenced by aviation activity. Family life has also been changed, principally in its choice of vacation sites and in the dispersion of family members to different geographical areas. Some variation has been noted in eating habits since speedy transportation makes perishable products more easily available.

Politically, the airplane has changed military concepts. Today the United States Air Force has equal status with the Army and Navy. In international affairs, the airplane has forced the American public to re-evaluate its role in diplomatic relations. Now that the Polar route is being flown daily, the midwestern and west coast cities are as close to the capitals of Europe and Asia as are the cities on the east coast. Domestic political campaigns have been re-appraised in order to take advantage of airplane mobility. Political leaders can now cover more territory and speak to more citizens during a campaign than has ever before been possible.

Aviation in all of its varied facets represents a dynamic force in a growing world. The changes it has brought and will continue to bring represent a never-ending challenge to the youth of today.

Questions

1. How has aviation aided in the redistribution of the world's population?
2. What are the three factors used to indicate the economic value of air transportation?
3. The helicopter is useful for many tasks. To what use is it particularly well suited?
4. What did World War I indicate to military strategists with respect to military aviation?

5. Who was "Billy" Mitchell and what has been his contribution to the Aerospace Age?
6. List the types of jobs required to operate an airline.
7. When was the Air Force officially created as a separate service?
8. In what way has American family life been affected by the airplane?
9. What are the five classifications into which the aerospace industry is generally divided?
10. State why it is important for modern youth to understand the nature and various aspects of aerospace activities.
11. What does the definition of air power include?
12. About what per cent of the people in the United States have flown in an airplane?
13. Relate the various ways in which aerospace in the United States directly influences the economic activities of individuals.
14. What is the most important segment of general aviation? Discuss the reasons for its growing importance.
15. Compare the performance capability of a new commercial jet airliner with that of a conventionally-powered commercial airliner.
16. What is the economic significance of the growth in aerospace manufacturing since 1947?
17. Why has the ability to navigate the Polar route safely caused a change in United States military defense planning?

Chapter 2 History of Flight

Since the beginning of recorded history, there have been evidences in the drawings and folklore of all peoples that man has always wanted to fly—that he longed for wings. Even the earliest of prehistoric men, to whom the invention of the stone ax was a development of great importance, must have gazed upward and, like his descendants for thousands of years, envied the freedom of birds and their ability to sail gracefully far up into the sky.

The first expressions of man's desire to fly, and his first realizations of his utter inability and helplessness, are to be found in early legends and mythologies. Man, being unable to soar up into the heavens, endowed his gods with the ability to fly.

Everyone is familiar with the Greek messenger god, Hermes, and his winged sandals; the German Valkyrie who descended from the abode of the gods to battlefields on earth and carried back with them to Valhalla the slain heroes; the legend of Bellerophon; the wonderful winged horse Pegasus; and countless other stories.

The first concrete evidence of man's attempt to construct a flying machine occurred about 400 B.C. Archytas, a Greek philosopher and disciple of Pythagoras, became interested in flying and allegedly constructed a wooden pigeon. According to scanty records now available, the bird flew, but details of its construction and source of power were not recorded.

Undoubtedly there were other attempts to fly by men in later centuries, but the first man to work out plans intelligently for flying devices was the master artist Leonardo da Vinci. About the time of Christopher Columbus, da Vinci developed a toy helicopter by constructing small pinwheels out of paper. He also spent considerable time in designing flying machines patterned after bodies of birds. These machines had flapping wings which moved when the flyer pumped his arms and legs up and down. Although he built machines from his plans, needless to say da Vinci's physical strength could not develop sufficient power to raise himself from the ground. Had there existed at that time a practical engine, an airplane would probably have been flown successfully centuries before the Wright brothers made their flight.

Other drawings executed by da Vinci included the plan for the first propeller and the first parachute. As a result of his careful observations of birds, he became the first proponent of modern streamlining.

Balloons and Gliders

In many countries and for many years men continued their search for the secrets of flying. These early experimenters studied the physical structure of birds' wings and from this research attempted to construct man-carrying wings. These efforts to develop ornithopters were singularly unsuccessful.

Sir George Cayley (1773-1857), a distinguished British scientist, scoffed at the flapping-wing idea. It was his belief that a machine with a fixed wing or wings was the solution to flight and that the machine should have mechanical power to drive it through the air.

During the latter part of the 17th century and the early years of the 18th century it was in France that the greatest amount of research and experimentation was done. In 1678, Besnier built a pair of wooden wings covered with fabric. With these hand-made contrivances, he glided successfully, at first from low hills, and finally from the highest window in his house to the ground below. To him goes the honor of being the first successful glider pilot.

Handicapped as the early pioneers were by lack of power and suitable materials for their experiments, it is not surprising that man first left the earth in a balloon, not in an airplane. The discovery in 1766 of a very light gas called hydrogen, and the observation, by two French paper mill owners, the Montgolfier Brothers, that warmed air rises, was responsible for the early experiments in 1783.

Following the wave of enthusiasm and interest which developed after the successful balloon flight of the Montgolfiers, many men conducted other balloon flights. The major problem these men attempted to solve was that of finding a method to control the direction of a balloon flight.

The first flight by a dirigible balloon or airship is attributed to Henri Giffard. He constructed a lightweight steam engine of about 3 hp and fitted it to his airship, which had an envelope with pointed ends, thus establishing the cigar shape which was to be characteristic of airships throughout their period of development. On September 24, 1852, this airship made a flight of 17 miles, starting from the Hippodrome in Paris and landing near Trappes.

France continued to lead in the development of the airship for another hundred years, though inventors in Italy, Great Britain, and Germany were making some contributions to its development. One of the most colorful personalities among the experimenters was Santos-Dumont, a Brazilian living in France. Between 1897 and 1904 he built and flew 14 airships.

During this period the first known rigid airship was built by an Austrian, David Schwartz, in Berlin. It made a flight but did not live up to expectations. The work of Schwartz was probably most important because it influenced Count Ferdinand von Zeppelin, a retired German army officer, to begin work on dirigible airships.

Zeppelin was a fine engineer and his work with dirigibles was so outstanding that airships are often called zeppelins. The first airship built by Zeppelin was launched on July 2, 1900, at Lake Constance, Germany. It had a capacity of about 350,000 cubic feet of hydrogen, a cigar-shaped aluminum girder frame, and was propelled by two benzine engines each driving two four-bladed propellers. The outer cover was of linen. It was called the LZ-1 and was nearly 420 feet in length and 38 feet in diameter. This first rigid airship made three successful flights but its further development was abandoned thereafter because of lack of money.

Of all the early pioneers, the man whose work was most helpful to the Wright Brothers was Sir George Cayley. As a lad, Cayley was in the crowd that witnessed the balloon flights of de Rozier, who was the first man to fly in the Montgolfier balloon. Cayley first experimented with paper helicopters, flapping-wing gliders, and finally a rigid, fixed-wing glider. He at first flew the glider by running downhill with it suspended over his head. Later, he discovered that, with modifications, the wing had sufficient lifting power to sustain his weight. Continued experiments led him to adopt a double-wing glider or biplane. He also tried to design and construct a light engine which would permit his glider biplane to take off under its own power. However, due to the lack of materials which were both light and strong, he failed. Nevertheless, he had made a lasting contribution to the science of aeronautics.

Generally speaking, the era of haphazard experimentation was over by the middle of the 19th century. Through careful research, the outstanding pioneers who followed Cayley developed more effective wing shapes, methods of balance and control, and, extremely important, they made thousands of test flights. These men include the Frenchman Octave Chanute, the German Otto Lilienthal, Professor John J. Montgomery (the first American to achieve success), and Professor Samuel P. Langley.

Professor Langley, a scientist associated with the Smithsonian Institution, designed and built a few successful models but was destined never to achieve the distinction of being the first man to pilot an airplane. His designs were exceptionally good. Professor Langley's largest and last airplane crashed after taking off from a houseboat on the Potomac River shortly before the flight at Kitty Hawk. It is interesting to note that quite a few years later a machine was constructed following his original design and, with only a few minor modifications, was successfully flown by Glenn H. Curtiss.

Experiments of the Wright Brothers

The Wright brothers operated a small bicycle shop in Dayton, Ohio. Like most American boys, they had built and flown many kites. Their interest in airplanes, however, became seriously aroused after reading of the experiments and flights of Octave Chanute and Otto Lilienthal and the experiments of Professor Langley.

They collected as much data as was then available and began their experiments by copying the various types of wings that had been developed and by testing those wings under a wide variety of conditions. They found that both Langley and Lilienthal had been correct in many of their theories, but, by further experimentation, they were successful in discovering new facts concerning the airplane wing. They also developed a small wind tunnel in which they tested hundreds of variously-shaped wings and made careful note of the performance characteristics in each case.

Their scientific approach to the problem of flight was destined to bring them success. On the basis of their experimentations Wilbur and Orville Wright designed and built a glider, which, when tested at Kitty Hawk in 1902, was by far the most satisfactory glider yet built. They made over one thousand flights, some of which ranged between five hundred and a thousand feet—an unheard of distance at that time.

During this period the Wrights also designed, under necessity, a satisfactory rudder—the forerunner of our modern aileron, a control which banks the airplane to the left or right. To accomplish this the pilot actually bent or warped the trailing edge of each wing as necessary, thus enabling the glider to fly "straight and level." The basic method of moving the controls, developed by the Wrights in 1902, is practically the same as that in use today.

After bringing the glider to a high state of perfection, the Wrights next turned their attention to power. After searching widely among all types of gasoline and steam engines, they reluctantly came to the conclusion that no suitable engine existed. All of the types studied were either too heavy or lacked sufficient power. It was typical of these men that, faced with such a difficulty, they did not give up their dreams but sat down and painstakingly designed and built a light yet fairly powerful engine.

Still another handicap awaited them. No one could give them any valuable information on propellers. Although steamboats had been using water propellers for quite a long time, little work and practically no thought had been expended on propeller design. Thus they were further delayed by the necessity of designing, testing, and constructing many models of propellers, emerging in the summer of 1903 with two successful designs. Finally, all was in readiness.

Man's First Flight

On a cold, blustery morning, the 17th of December, 1903, man's dream for centuries was realized. Just after half past ten, Orville Wright took the pilot's position, a prone arrangement developed during their glider experiments. Wilbur stood at the wing tip to steady the machine as it moved along the rail. The engine was warmed up for two or three minutes, and then the aircraft moved along a launching rail and took off, to remain in the air for 12 seconds, when it darted to the ground. Its forward speed was 7 mph. There were only five people to witness this event, but fortunately the first flight was recorded by one photograph, which has been reproduced hundreds of thousands of times and seen by millions of people since that day. (Figure 7.)

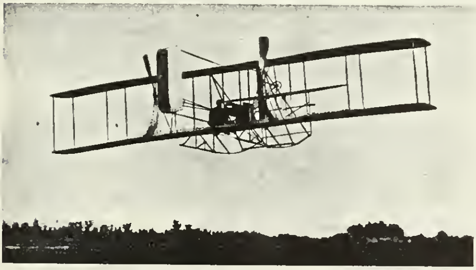


Figure 7—The Wright Biplane in Flight over the Sands of Kitty Hawk.

Later Developments

After the initial success of the Wright brothers, improvements in airplane and engine design came swiftly. Longer flights at greater speeds and higher altitudes succeeded each other with amazing rapidity. Louis Bleriot, a Frenchman, crossed the English Channel in 1909. C. K. Hamilton flew from New York to Philadelphia and back again in 1910. It was not until World War I, however, that large-scale development and construction of the airplane took place. For the first time, governments of the world spent considerable money and time to improve airplanes for reconnaissance, fighter, and bomber purposes.

At the end of the war, private flying expanded. Government surplus planes were sold to former military pilots. These aircraft, soon appearing wherever there were open grassy fields, introduced the miracle of flying to thousands of people. The search for improved design and construction of engines and airframes continued. Better materials and safer methods of construction were discovered. More powerful engines were built to assist man in his efforts to conquer space.

In 1919, the Atlantic Ocean was spanned by United States Navy airmen in a Curtiss flying boat, the NC-4. In 1922, General "Billy" Mitchell flew a Curtiss "Racer" at 222.9 mph to hold the world's speed record. Members of the United States Army Air Service flew around the World in 1924. In 1926, Commander Richard E. Byrd and Floyd Bennett flew over the North Pole. Charles Lindbergh and *The Spirit of St. Louis* made the first *non-stop* flight from New York to Paris in 1927. Byrd and Balchen flew over the South Pole in 1929. Speed over distances occupied the attention of Frank Hawks, Roscoe Turner, Kingsford-Smith and others. Women pilots, among them Ruth Nichols, Amelia Earhart, and Jacqueline Cochran, also helped to set some of the early records.

Round-the-world flying became a popular test. In 1931, Wiley Post, with Harold Gatty as navigator, made such a flight in a single-engine Lockheed—*The Winnie Mae*—in a little more than eight days. In 1933, Post did it alone in seven days. This record stood until 1938 when Howard Hughes and a crew of four in a twin-engine Lockheed flew the 14,791 miles in somewhat less than four days. In February, 1949, Captain James Gallagher and the crew of a United States

Air Force B-50—*The Lucky Lady II*—flew *non-stop* around the world in 94 hours and one minute. In April 1964, Mrs. Jerrie Mock, a Columbus, Ohio, housewife became the first woman to complete successfully a solo round-the-world flight.

Year by year, world speed records were steadily improved: Al Williams—266 mph in 1923; Adjutant Bonnet of France—278 mph in 1924; James Doolittle—294 mph in 1932; James R. Wendell—304 mph in 1933; Raymond Delmotte of France—314 mph in 1934; Howard Hughes—352 mph in 1935; and then the Germans forged ahead with Herman Wunster flying 379 mph in 1937 and Fritz Wendell—469 mph in 1939.

These surprising increases in speed set the stage for a new type of aircraft, the jet-powered airplane. On August 27, 1939, a German Air Force captain flew a Heinkel 178 with a turbojet engine. This German achievement was quickly followed by a successful British jet-powered aircraft in May 1941. But the honor of being the first man to break the sound barrier goes to an American flying an American-designed and manufactured airplane. On October 14, 1947, Capt. Charles (Chuck) Yaeger, in a Bell X-1, flew at a speed of Mach 1.45 (968 mph); on December 12, 1953, he flew at two and a half times the speed of sound. In exactly 50 years to the month, man had developed and refined aircraft construction and engine design to such a degree that speed had progressed from 7 mph to 1,650 mph.

Recently new world records in several categories were established. In 1961, A. Fedetov, a Russian, flew a P-166 jet 1,491.9 mph over a closed-circuit course.

Then in 1962, Maj. Clyde Evely and his USAF crew flew 12,532.28 miles in a B-52H, a non-stop "distance in a straight line", from Okinawa to Madrid. Maj. Robert M. White set an altitude record of 314,750 ft. in the X-15-1, and the Russian Gueorgui Mossolov flew an E-166 jet at 1,665.89 mph over a "straight course".

Air-Mail and Air-Passenger Transportation

Air transportation as a commercial enterprise had its beginning in the carrying of the air mail. Air-mail service began in the United States as an experiment, in September, 1911, when a temporary post office was set up on the outskirts of Mineola, New York. During the period of a week, mail was flown from the edge of this Long Island town to the post office in the town.

There were further small-scale experiments, and in 1912 the Post Office Department asked Congress for the modest sum of $50,000 with which to initiate a regular air-mail service. It was not until 1916, however, that Congress finally made some funds available. The Post Office Department advertised for bids for air-mail service, but no one submitted an offer since there were no airplanes of suitable construction for the purpose.

In 1918, Congress appropriated $100,000 for the establishment of an experimental air-mail route, and in May of that year the first official air mail route linked the cities of New York and Washington. By 1921 the first transcontinental air-mail route was formed, with the first flight, a dramatic milestone in air transportation history, being made in 33 hours and 21 minutes.

After air-mail service had been operated by the Post Office for several years, Congress, in 1925, passed the Air Mail Act (Kelly Act) which made provision for the carrying of air mail by private contractors. The Kelly Act provided the impetus which aroused private industry and capital to the opportunities in the field of air transportation. By 1927, private contractors had accepted responsibility for all air-mail routes, rapidly expanding this service to many new cities while planning for the coming era of passenger service.

The last air-mail route to be turned over to private contractors was the transcontinental route. William E. Boeing, an airplane builder, submitted the low bid and within five months had put into operation 25 new and specially constructed mail planes. This particular air-mail operation formed the nucleus of what was later to become United Air Lines.

Because of the pioneering done by air-mail pilots, the enactment of the Kelly Act and the Air Commerce Act of 1926, and the surge of interest by industry in the development of better planes, more powerful engines, and increasingly useful navigational aids, air-passenger and freight transportation have been able to assume an important role in American life.

Summary

Since the beginning of recorded history there have been evidences of man's desire to fly. When early man realized his inability and helplessness to soar through the air, he assigned the ability to fly only to his gods.

Archytas's wooden pigeon, about 400 B. C. was the first concrete evidence of man's attempt to construct a flying machine. Leonardo da Vinci, however, was the first to work out plans intelligently for flying devices, including ideas for a propeller and a parachute.

The first glider pilot was a Frenchman, Besnier. He glided successfully in 1678. Man first left the ground for extended periods in balloons. The Montgolfier brothers accomplished this feat in 1783. During the following 125 years balloons, airships, and zeppelins were constantly improved.

Sir George Cayley, an Englishman, Octave Chanute, a Frenchman, Otto Lilienthal, a German, and Professors John J. Montgomery and Samuel P. Langley, Americans, greatly influenced the experiments of the Wright brothers.

After experimentation with gliders and the development of a suitable engine, a satisfactory rudder, and a workable propeller, the Wright brothers achieved lasting fame by being the first men to fly a heavier-than-air craft at Kitty Hawk, N. C., on December 17, 1903.

In rapid succession, the Atlantic and Pacific Oceans were spanned. New speed and altitude records were constantly being set. Round-the-world flights became commonplace.

Engine and airframe design continued to improve. The first turbojet airplane was built and flown in 1939. Supersonic flight followed soon thereafter.

In the 1920's, the United States Post Office Department encouraged and subsidized the first air-mail routes. These routes, with the pilots and planes concerned, provided the nucleus for the development of the modern-day airlines.

Questions

1. What was the Kelly Act and why was it important?
2. When and where was the first jet airplane successfully flown?
3. What was the role of Count Zeppelin in the development of the airship?
4. Trace the development of air-mail service from 1911 to 1927.
5. Of what significance in aviation history are the dates 1909, 1919, 1927, and December 12, 1953?
6. What was the importance of da Vinci's research and planning?
7. In what type of device did man first leave the ground?
8. What were the limitations of the free balloon?
9. In what way did the Wright brothers use gliders?
10. Name the contributions of Sir George Cayley to gliding flight.
11. Who developed the rudder and how does it control the airplane?
12. What formed the basis for our present widespread commercial air transportation?

Chapter 3 Theory of Flight

Whenever, in casual conversation, a group of people start to discuss airplanes, someone is almost certain to exclaim, "Why, some of those airplanes weigh tons. I don't see how they stay in the air." Very few people understand the forces that control an airplane in flight.

For many years engineers have studied the motion of air over airplane parts in order to learn how a change in the shape of the part affects the force created on it by the moving air. Although a large amount of information is presently available on this subject, the desire to make airplanes go higher, faster, farther, and carry greater loads requires continuous research.

A balloon rises in the air because its bag, which is filled with a gas lighter than the air at low altitude, displaces the heavier low altitude air. The difference between the weight of the heavy air displaced and the light air inside the bag equals force, and force is the element which lifts the balloon. Air gets lighter as altitude increases; consequently, at an altitude where this weight difference between the air in the bag and the displaced air is equalized, the balloon stops rising and remains at that altitude. Balloons are referred to as lighter-than-air craft.

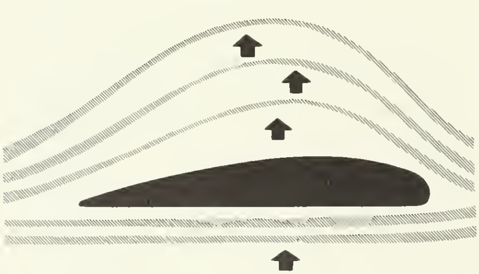


Figure 8—An exaggerated view of air movement around a wing moving through the air at a relatively high speed. The pressure on the upper wing surface is less than on the lower causing a force, called lift, to be directed upward.

The airplane does not get its lift in the same manner as the balloon; in an airplane, lift depends upon the relative motion between wing and air. Airplanes, therefore, are referred to as heavier-than-air craft.

To understand how very large loads are carried by airplanes, one should realize that each square foot of wing area can lift a certain weight at a certain speed. By increasing the wing area—lift—larger loads can be raised. The lift developed by a specific wing will depend upon its shape and size, the speed at which it moves through the air, and the angle at which it strikes the air.

Shape of the Wing

Imagine that a wing is cut along a line drawn between its front edge (leading edge) and its rear edge (trailing edge). This cross-section will expose a portion of the wing that shows the shape of the *airfoil.* This airfoil will be rounded at the leading edge and sharp at the trailing edge in those airplanes which are not designed to fly at supersonic speeds. The upper surface of the airfoil is curved and the lower surface is almost flat. The thickest part of the airfoil lies approximately one-third to one-half the distance between the leading edge and the trailing edge. (Figure 8.)

When looking down at the airplane, one sees the *span*. The span is the distance from one wing tip to the other. The *chord* is the distance between the leading and trailing edges. The span is usually between five and ten times as long as the chord. A wing with a large span in comparison to the chord has less resistance to motion through the air (drag) than does a wing with a small span in comparison to the chord.

Speed of the Wing

If we move the wing through the air at a relatively high speed with the rounded or leading edge forward, the following things happen: The blunt and thick leading edge pushes the air out of the way. Part of this displaced air flows rapidly (the speed is important) over the wing and part of it flows under the wing. The layers of air, after going over and under the wing, join again behind the trailing edge. The important thing to remember is that due to the curved upper surface the air that flowed over the wing had to go farther than the air that went under the wing. Consequently, air that flowed over the wing had to travel faster than the air that went under the more or less flat bottom surface.

The air which had to travel farther across the top of the wing is stretched out and becomes thinner, creating a reduced pressure on the upper surface. The air traveling along the bottom of the airfoil is slightly compressed, and consequently develops increased pressure. The difference in pressure between the air on the upper and lower surfaces of the wing, when exerted on the entire wing area, produces lift. (Figure 8.)

The faster the wing is moved through the air the greater the pressure difference will be, with a resulting increase in total lifting force. The heavier an airplane is in relation to its total wing area, the higher the speed must be to develop enough lift to get it off the ground and sustain flight.

Lift and Angle of Attack

There is another element that affects the amount of lift produced by a wing, i.e., the angle at which the wing strikes the air. If the wing is held flat and moved straight ahead, some lift is generated. More lift is obtained, however, if the leading edge of the wing is elevated slightly above the trailing edge, i.e., if the wing goes through the air at a higher angle of attack.

At a higher angle of attack the wing displaces more air; that is, it makes the air over the wing travel farther, and, up to a certain point, develops more lift. However, every wing has a stalling angle of attack at which lift drops off abruptly. This sudden loss of lift (stall) is caused by the swirling and burbling of the air over the top surface of the wing (Figure 9) and occurs when the angle of attack is so great that it exceeds the angle necessary for maximum lift. When an airplane stalls, the nose drops, the speed increases, and the angle of attack decreases. If, however, both the nose and one wing drop, the airplane will rotate like a leaf falling from a tree. This flight attitude is called a tail spin, and, although the nose is down and the airplane is diving, the new angle of attack exceeds the stalling angle. To compensate for this unusual diving attitude, the pilot must first lower the nose still farther, reduce the angle of attack below the stalling value, stop the rotation, and then bring the airplane back to a straight and level flight attitude.

Lift and Weight

The amount of the lift, then, is determined by (1) the shape of the wing, (2) the speed of the airplane, and (3) the angle of attack. The amount of lift required depends on the weight of the airplane and whether it is flying level, climbing, or diving. (Figure 10.) To climb, the wing's lift must be greater than the airplane's weight; during descent the wing's lift is less than the airplane's weight.

Thrust and Drag

To produce lift, the airplane wing must move through the air at a relatively high speed. This high speed is produced by a force or thrust which is exerted in the direction of the airplane's motion. Both a propeller and a jet engine produce thrust.

The blades of a propeller are small wings. When they rotate they create forces in the same manner as the wing creates lift except that the forces on the propeller blades act in the direction of the airplane's motion and are called thrust. A jet engine burns a mixture of fuel and air and exhausts this mixture toward the rear of the airplane. A force exerted inside

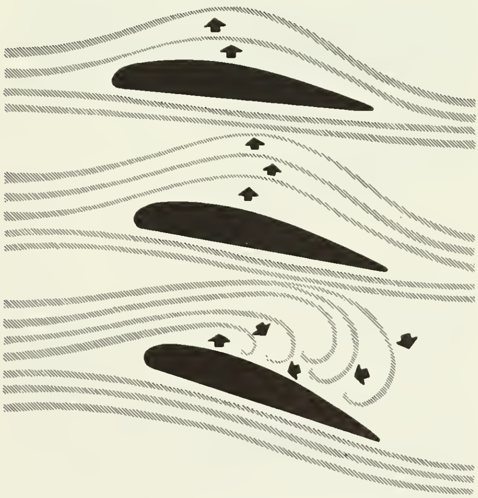


Figure 9—Lift increases as the angle of attack is increased, up to a certain point. When the angle of attack becomes too great, however, the air separates from the upper surface, destroying the smooth flow, and reducing the lift.

the jet engine and in an opposite direction to the movement of the gas is needed to exhaust this gas at a high speed. This force, also, is in the direction of the airplane's motion and is called thrust.

The amount of thrust required depends upon the airplane's drag, and upon whether it is climbing, diving, or flying straight and level. Drag is the resistance an airplane meets in moving through the air. The faster the airplane moves, the greater will be the drag. Moving air exerts a similar force against the body when one tries to stand in a high wind.

In level flight, if the airplane speed remains constant, thrust is equal to drag. (Figure 11.) To accelerate the airplane, thrust must be greater than drag and additional thrust is produced by burning more fuel in the engine. If thrust is increased, the airplane speeds forward until drag again equals thrust, and the airplane once more flies at a constant speed. As the speed increases, lift also increases; consequently, it is necessary to reduce the wing's angle of attack by lowering the airplane's nose so that lift will again equal the airplane's weight and the aircraft will remain in a straight-and-level flight attitude.

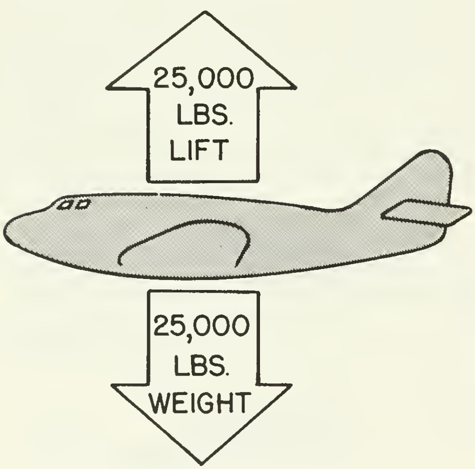


Figure 10—Lift must exactly equal the weight of an airplane in order to maintain steady flight.

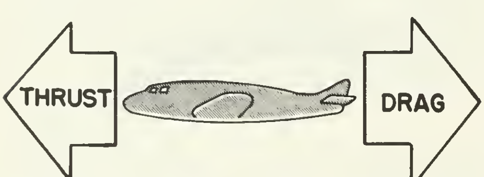


Figure 11—When the airplane is not accelerating, the thrust is equal to the drag.

Thrust must also be increased if the airplane is to climb at approximately the same speed it maintained while it was in level flight. To get the additional lift, the angle of attack must be increased, but this flight attitude also increases the drag. Additional thrust, therefore, is needed to counteract the additional drag and lift the airplane to its new altitude. During takeoff, maximum engine power is used to accelerate the airplane and cause it to climb rapidly. During descent, the weight of the airplane helps to overcome drag, thereby requiring less thrust to maintain a constant air speed.

Drag greatly affects the amount of thrust required for various flight attitudes. To obtain the desired airplane performance with minimum engine weight and fuel consumption it is necessary to minimize thrust. Consequently, airplane designers have studied the shape of various airplane parts to discover which shapes offer the least resistance to the movement of air across their surfaces. Those which have been found to have the least drag and which permit the air to flow smoothly over their surfaces are called streamlined shapes. They require the least thrust to move them through the air.

Inherent Stability

To fly properly, an airplane must be designed so that all the forces applied on it during flight will balance. In other words, the airplane must be stable enough to fly straight and level with a minimum of physical control by the pilot, i.e., the pilot must be able to change the plane's direction or cause it to climb or dive easily.

If the reader has built model airplanes, he will have discovered that before they will fly they must be balanced and the distribution of weight equalized. An airplane that is tail-heavy, nose-heavy, or one-wing-heavy is badly balanced. The airplane's center of gravity is that point about which the airplane balances. It should be near *but always* just ahead of the center of lift. This is the first consideration for inherent stability, or "built-in stability."

If a sheet of paper is skimmed through the air, it will fly an erratic and unpredictable flight path rather than a straight line. If the sheet of paper is folded into a dart shape, it will do better, but it will still turn and roll erratically. It has only a minimum amount of inherent stability. A carefully built model airplane, however, flies straight and level unless it is blown off course by air currents. The stabilizers built

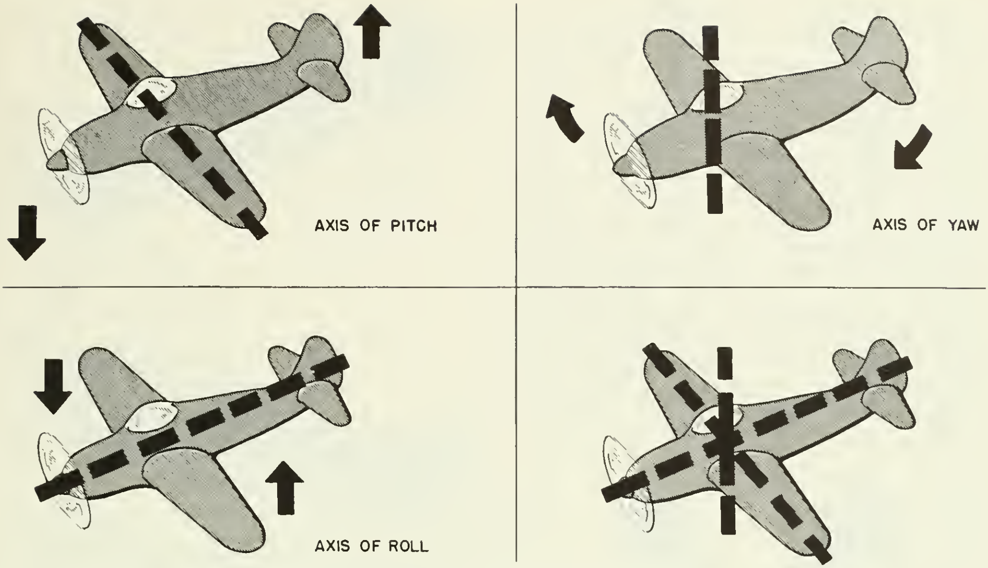


Figure 12—An airplane may be controlled about the three axes of pitch, yaw and roll.

into a model airplane are the same, in principle, as those used on an airplane.

The vertical stabilizer is a fixed tail airfoil which stands upright. It prevents the airplane from yawing, i.e., swinging left or right. The horizontal stabilizer, like a small wing, is the horizontal part of the tail. It prevents the airplane from nosing up or down.

There is still another way in which an airplane can move. It can roll, wing down or up. Consequently, wings are constructed and positioned on an airplane so that they tend to keep the airplane stable in roll.

The Axes of Rotation

An airplane is free to turn in three planes, whereas an automobile turns in only one plane. Think of an airplane as having three axes of rotation, all passing through the center of gravity. The longitudinal axis, or axis of roll, extends lengthwise through the airplane's fuselage; the lateral axis, or axis of pitch, goes lengthwise through the wings; and the vertical axis, or axis of yaw, is perpendicular to the other two, and perpendicular to the earth's surface when the airplane is in straight and level flight. (Figure 12.)

To illustrate these rotations cut a piece of cardboard into a rough airplane shape, and follow this explanation: Turn to the left or right around the vertical axis. That is called the axis of yaw and is the only axis about which you can turn an automobile.

Now put the nose down and the tail up, or the nose up and the tail down. That is called rotation about the axis of pitch, or lateral axis. By controlling that rotation you put an airplane in the proper position to climb or dive. Next roll the left wing down and the right wing up, or the other way around, and you have rotation about the axis of roll, or the longitudinal axis.

To control the flight path of the airplane around its three axes, movable control surfaces are used: the rudder, elevator, and ailerons.

Rudder

Movement about the axis of yaw is controlled by the rudder, and the rudder is controlled by foot pressure on the cockpit's rudder pedals. (Figure 13.) When pressure is applied to the right rudder pedal, the nose of the airplane swings to the right. When pressure is applied to the left rudder pedal, the nose of the airplane swings to the left. The nose swings because the action of the rudder pedal turns the hinged rudder away from the longitudinal axis, and as the air strikes the rudder it literally pushes the tail of the airplane to the opposite side.

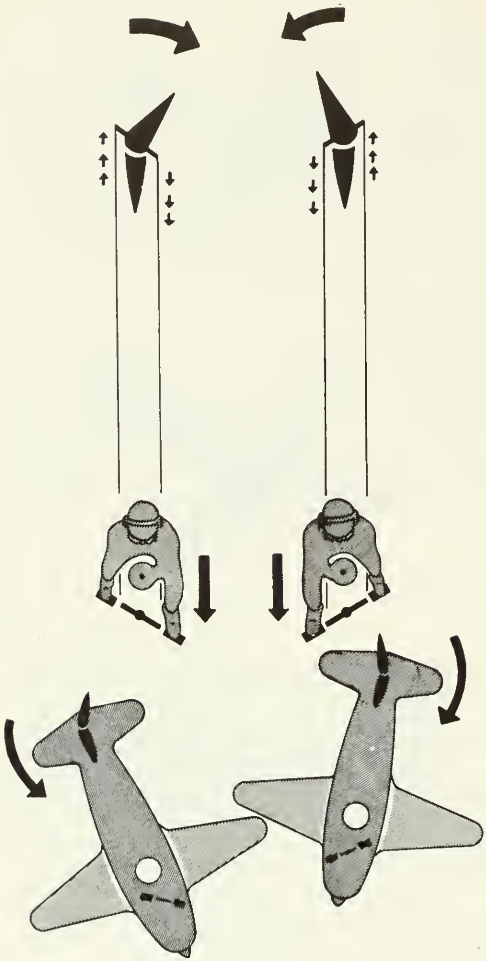


Figure 13—Pushing the left-rudder pedal moves the rudder to the left causing the airplane to rotate to the left about its vertical axis. Pushing the right-rudder pedal makes the airplane rotate to the right.

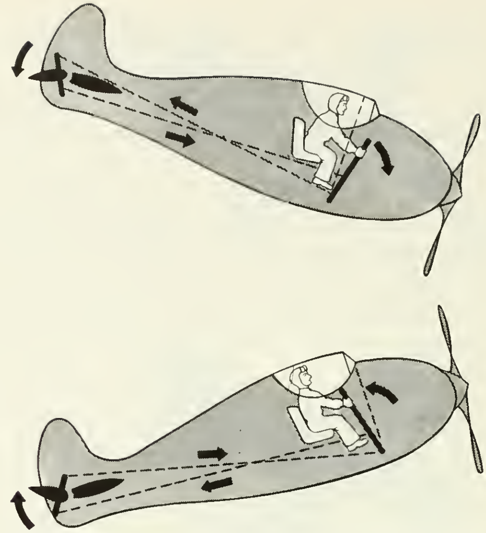


Figure 14—Forward movement of the stick lowers the elevators causing the airplane to nose down with rotation about its lateral axis. Backward movement of the stick raises the elevators causing the airplane to nose up.

Elevators

Movement around the axis of pitch is controlled by the elevators, as shown in figure 14. The elevators respond to forward and backward pressure on the control stick or wheel. In normal flight when forward stick is applied, the nose of the airplane is lowered. This action is caused by the lowering of the elevators which, as the wind strikes the elevator surface, forces the tail up and the nose down. The reverse action occurs when the stick is moved backward.

Ailerons

Movement around the axis of roll is controlled by the ailerons. The ailerons respond to sideways pressure applied to the control stick as shown in figure 15. Pressure applied to the stick toward the left depresses the left wing. Pressure on the stick toward the right depresses the right wing. The ailerons are linked together by control cables so that when one aileron is down, the opposite aileron is always up. As in the case of the elevators and rudder, the wind strikes the obstructing surfaces, raising the wing whose aileron is down, lowering the wing whose aileron is up, thus turning the airplane around its longitudinal axis.

Coordination of Controls

Control pressures are not used separately. The simplest maneuver needs coordination of all three pressures. A simple turn to the left requires coordinated pressures on the rudder, elevator and ailerons.

Trim Tabs

Even though an airplane has inherent stability, it does not always tend to fly straight and level. Remember that the weight distribution in an airplane affects its stability and that various speeds affect the air-

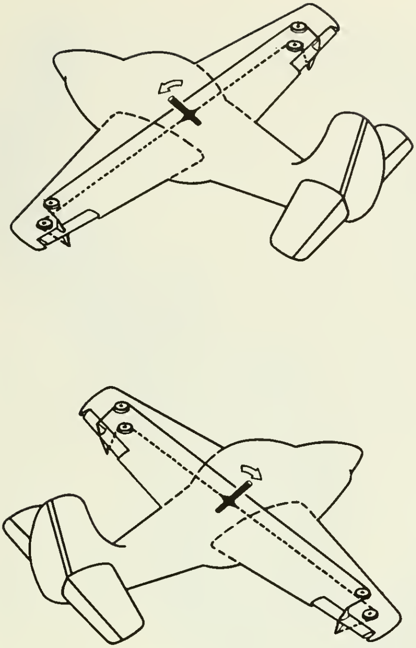


Figure 15—Movement of the stick to the pilot's left raises the left aileron and lowers the right aileron, causing the airplane to bank to the left. Similarly, right stick banks the airplane to the right.

plane's flight characteristics. If the fuel from one wing tank is completely used before fuel is used from another tank, the airplane tends to roll toward the full tank. All these variations require a pilot to exert additional pressure on the controls for correction.

While climbing or gliding, it is necessary to exert pressure constantly to keep the airplane in the desired attitude. This constant control pressure is tiring in a small airplane, exhausting in a medium-size airplane, and impossible for any length of time in a heavy airplane.

For this reason airplanes are constructed with trim tabs. Trim tabs are small, hinged, control surfaces attached to the main control surfaces, i.e., rudder, elevators, and ailerons. (Figure 16.) Trim tabs are controlled by rotating a crank or a wheel in the cockpit or by pushing a button which electrically moves the tabs. By using trim tabs the pilot can balance the forces on the controls so that, with hands off the controls, the airplane will fly either straight and level or in a climbing or gliding attitude. Trim tabs actually operate like the control surfaces to which they are attached. That is, if the rudder tab (Figure 17) is set toward the left, it pushes the rudder to the right, thus making the airplane yaw to the right.

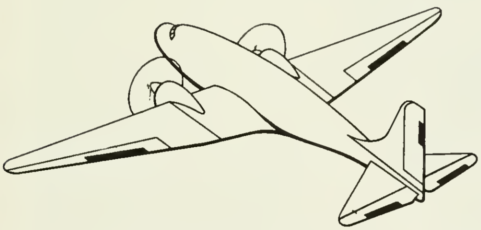


Figure 16—This drawing shows location of trim tabs which are adjusted by the pilot to produce straight and level flight, constant climb, glide, etc.

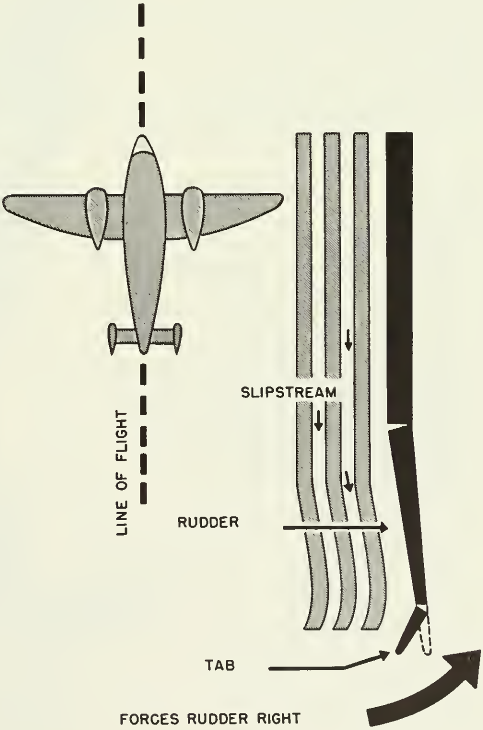


Figure 17—Diagram Showing How the Airstream Acts on the Rudder Trim Tab to Push the Rudder to the Right

Summary

Lift is the force which raises the airplane off the ground and sustains it in the air. The lifting surface, or wing, is shaped so that when it passes rapidly through the air it produces the greatest amount of lift in proportion to the smallest possible amount of drag.

The amount of lift can be varied by changing the angle at which the wing strikes the air. This angle is known as the angle of attack. If the angle of attack is too great, as in an extremely steep climb, the air will cease to flow smoothly over the top of the wing, lift will be destroyed, and the airplane will stall.

Lift acts in the opposite direction to the weight, i.e., when lift exceeds weight the airplane climbs and when lift is less than weight the airplane descends.

In order to propel the airplane through the air rapidly enough to maintain lift, the airplane must have thrust. Thrust acts in a direction opposite to drag. Drag is the resistance the airplane encounters while moving through the air. In normal level flight at constant airspeed, lift balances weight and thrust balances drag.

These four forces—lift, weight, thrust, and drag—must be controllable by the actions of the pilot so that the airplane can climb, glide, accelerate, decelerate, etc. However, in order that these forces may be easily controlled, the airplane must be very carefully balanced. In other words, it must be stable.

Special airfoils are built into the airplane to achieve this stability. The horizontal stabilizer tends to keep the airplane from pitching, the vertical stabilizer assists in keeping the airplane from swinging to the left or right, while the wings are designed and placed on the airplane so that they tend to keep it from rolling.

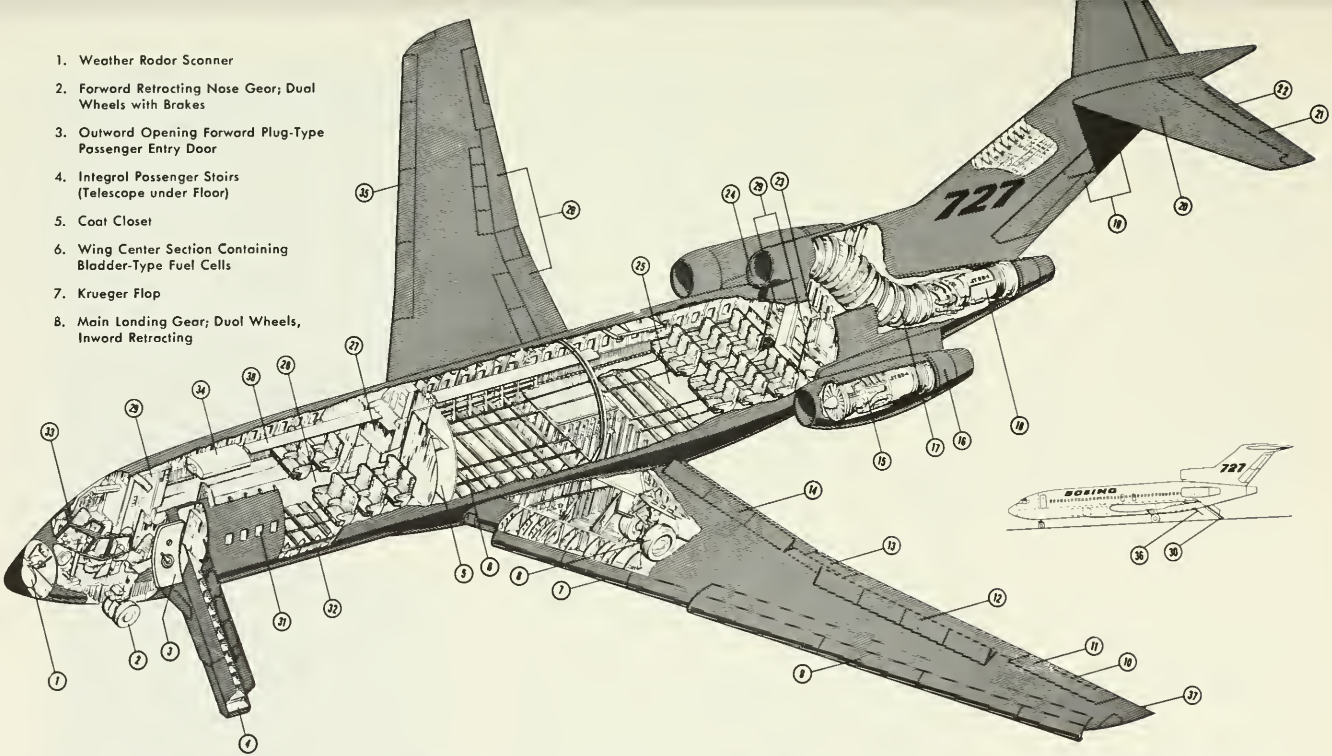
So that the pilot may be able to force the airplane to rotate around one or more of its axes, control surfaces are supplied. The rudder swings the nose of the ship left or right around the airplane axis of yaw (vertical axis), the elevator forces the tail of the airplane up or down (lateral axis), while the ailerons bank the wings left or right around the axis of roll (longitudinal axis). Although in conventional airplanes these controls are separate and distinct, they must be coordinated in most maneuvers in order to produce the proper flight action.

Additional controls required in all large airliners, and desirable in small planes, are the trim tabs. These small control surfaces, located on the rudder, the ailerons, and the elevators, assist the pilot by deflecting the control surfaces just the right amount to keep the airplane at the desired attitude.

Questions

1. What is lift?
2. Describe how wing lift is affected by its:
   a. Airfoil shape.
   b. Speed through the air.
   c. Angle of attack.
3. What is the general shape of an airfoil?
4. What happens to the air when a wing is moved through it at a relatively high speed?
5. How much lift is required?
6. What is thrust? Drag?
7. How much thrust is needed?
8. What are the relationships between thrust-drag and weight-lift in straight and level flight?
9. For what reasons is stability important?
10. What is inherent stability? What are the considerations for it?
11. What are the stabilizing surfaces and their functions?
12. What are the axes of rotation?
13. What controls the airplane around each axis?
14. What is a trim tab? Where are they placed? For what reason?

1. Weather Radar Scanner
2. Forward Retracting Nose Gear; Dual Wheels with Brakes
3. Outward Opening Forward Plug-Type Passenger Entry Door
4. Integral Passenger Stairs (Telescope under Floor)
5. Coat Closet
6. Wing Center Section Containing Bladder-Type Fuel Cells
7. Krueger Flap
8. Main Landing Gear; Dual Wheels, Inward Retracting



9. Leading Edge Slots
10. Aileron Control Tab
11. Low Speed Outboard Aileron
12. Flight Speed Brakes and Lateral Control Spoilers
13. High Speed Inboard Aileron
14. Ground Speed Brakes
15. Turbofan Engine (14,000 Lbs. Static Thrust)
16. Thrust Reverser Unit with Covering Door
17. Intake Duct for Center Engine
18. Center Engine
19. Dual, Separately Powered Rudder Segments
20. Movable Horizontal Stabilizer
21. Elevator
22. Elevator Control Tab
23. Rear Plug-Type Passenger Entry Door (Inward Opening)
24. Center Engine Air Inlet
25. Tourist Section (Six Abreast Seating)
26. Triple Slotted, High Lift Trailing Edge Flaps
27. Double Unit Mid-Cabin Galley
28. First Class Section (Four Abreast Seating)
29. Lavatory (One Forward; Two Aft)
30. Aft Integral Passenger Stairs
31. Windows: Three-Pane Acrylic Plastic on 20" Spacing
32. Fail-Safe Fuselage Structure; Semi-Monocoque, Aluminum Alloy Skin, Stringers Z-Type Frames
33. Control Cabin
34. Life Raft Stowage
35. Wing Leading Edge and Engine Inlets Anti-Iced by Engine Bleed Air
36. Retractable Tail Skid
37. Fuel Dump Chute
38. Overhead Air Distribution System (Side Wall System Not Shown)

Figure 18—Side and Top Diagram of an Airplane

Chapter 4 Aircraft

The airplane of today is far removed from the flimsy, kite-like, underpowered craft of 1903, and there is much evidence that this advancement will continue in the years to come. Following World War I the airplane became an intricate and complex product of skilled, precision workmanship, possessing qualities of high performance and dependability. The great role played by the airplane in World War II was a direct result of the continued refinement of the design techniques and the manufacturing skills that gave the airplane ever-increasing performance and utility.

Since the last great conflict, the airplane has been widely accepted by both civilian and military users. Due to this increased use, the aircraft and allied industries now employ more persons than any other industry in the United States. Aircraft production has created many new jobs, and there is an ever-increasing need for new processes, new materials, and new skills.

Aircraft are divided into two general classes: heavier-than-air craft and lighter-than-air craft. The major emphasis today is on the airplane with its many variations in design, type, size, construction, and power. It is the purpose of this chapter to describe the basic types of airplanes and their principal components.

General Structure of an Airplane

Structurally, the airplane is usually divided into five main sections, i.e., (1) wings, (2) fuselage (or hull, in the case of a flying boat), (3) tail assembly, (4) landing gear, and (5) powerplant (which includes the propeller, if there is one.) (Figure 18.)

A visit to any large airport will show that airplanes are either monoplanes, with one wing (figure 19), or biplanes, having two wings (figure 20). Early attempts to build airplanes with still more wings proved to be unsatisfactory. The monoplane is now considered more efficient than the biplane and consequently is in widespread use for commercial, military, and private flying. Biplanes today are used principally for crop spraying and instructional purposes.

Figure 19—Monoplane

Figure 20—Conventional Biplane Showing Upper and Lower Wings and Wing Struts

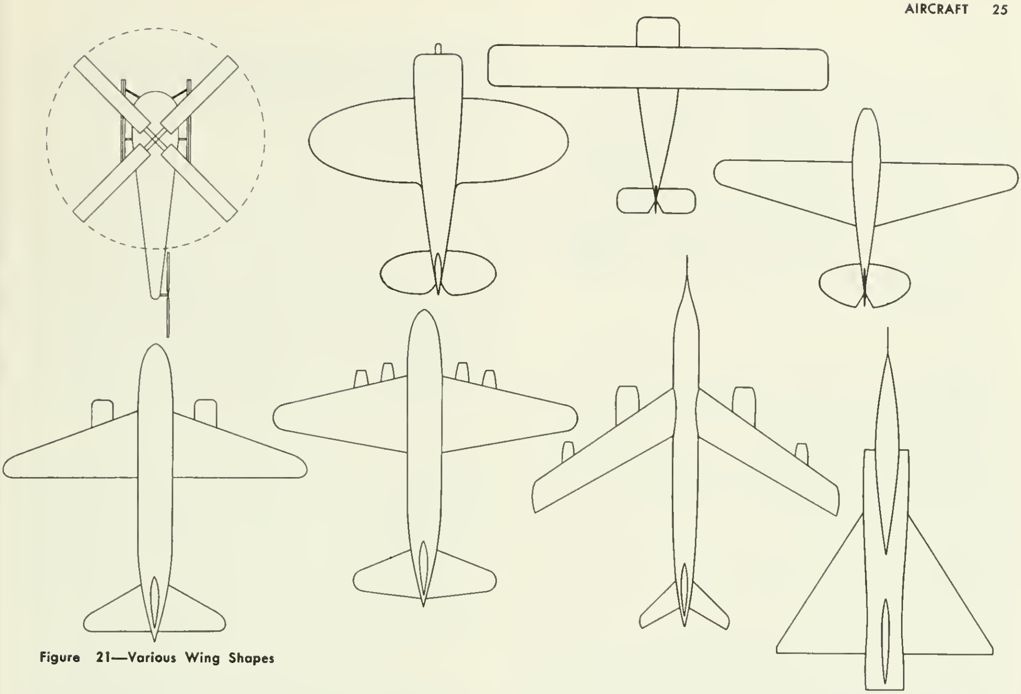


Figure 21—Various Wing Shapes

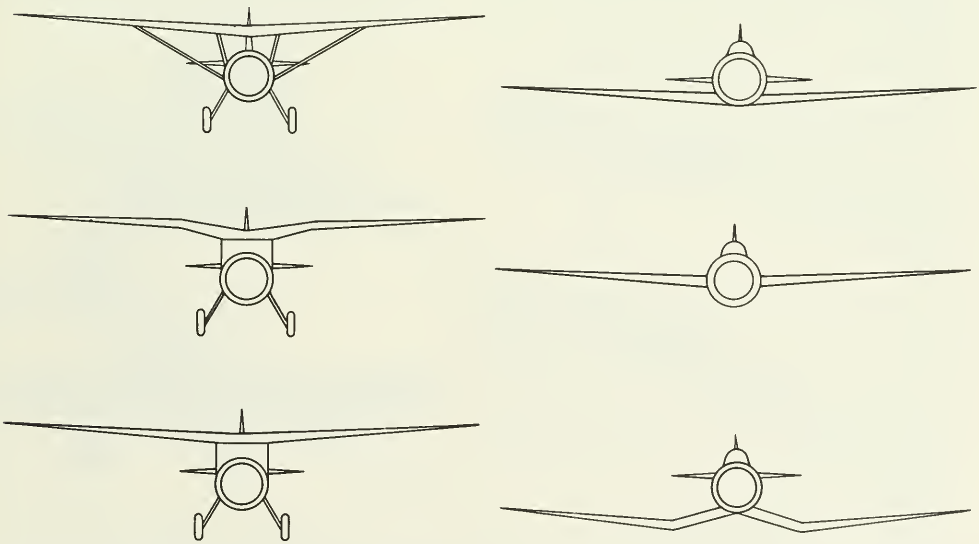


Figure 22—Possible Wing Locations

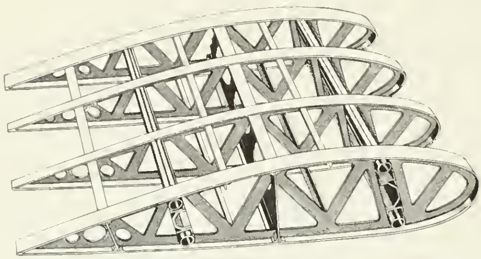


Figure 23—Diagram showing internal wing construction including the curved ribs, cross bracing, and the front and rear spars.

Monoplanes may be classified according to the location of the wings on the fuselage and the shape of the wings. The wings, which may also be used to carry the fuel tanks and engines, may be mounted high, low, or in the middle of the fuselage and may be of several different shapes. (Figures 21 and 22.)

Wings

In general, wing construction is very similar in all types of airplanes. Briefly, the main structure of a wing consists of two long spars of aluminum alloy running outward from the fuselage end of the wing toward the wing tip. (Figure 23.) Curved ribs are secured to the spars and covered with thin aluminum alloy "skin" to give the wing its familiar curved shape. In the case of some light airplanes the spars are made of wood, and the skin is tightly stretched cotton or linen fabric which is painted with "dope" to give it a tough, weather resistant surface of the proper shape.

Wings are secured to the airplane fuselage by using one of two systems. The first is the *full cantilever* type in which the wing structure is made very strong and is fastened to the airplane fuselage without any external struts or wires.

The second system is the *externally braced* wing in which heavy struts or streamlined wires extend from the wing to the fuselage. In this case the wing may be of lighter construction than the full cantilever type, but the struts or wires increase the amount of drag and thereby reduce the speed of the airplane. The modern achievement of high-speed aircraft is partially due to the elimination of such external bracing as struts and wires. The externally braced wing construction is now used only on the slower and less expensive light planes.

As a part of the trailing edge, or rearmost part of the wing, and outboard toward the tips, are the *ailerons*, controlled by sideways pressure on the stick or by rotation of the control wheel. The purpose of the aileron is to produce a rolling or banking motion. In the area of the trailing edge of the wing, between the ailerons and the fuselage of some airplanes, are the *flaps*. Flaps are hinged devices which vary the camber or curvature of the wing. (Figure 24.) Correct use of the flaps in flight is to steepen the gliding angle without changing the gliding speed. Flaps shorten the landing roll primarily by allowing a lower landing speed, not by adding resistance, although the latter is also a factor. In actual use, the flaps are often raised during the landing roll so that lift is decreased and more weight is placed on the wheels. This is done to give the tires better traction for their braking action. Flaps are usually used for resistance only under conditions of poor tire adhesion, i.e., ice or snow on the runway. They may be used during takeoff to increase the lift of the wing, thereby shortening the distance of the takeoff run.

Flaps are controlled directly by the pilot, using either a simple lever arrangement or, in the case of larger airplanes, levers actuated by a hydraulic pump or by an electric motor. Frequently the flap control system selected by the airplane manufacturer will also be used to raise and lower the landing gear. In the wings of some airplanes may be found *slots,* which are high-lift devices located in the leading edge of

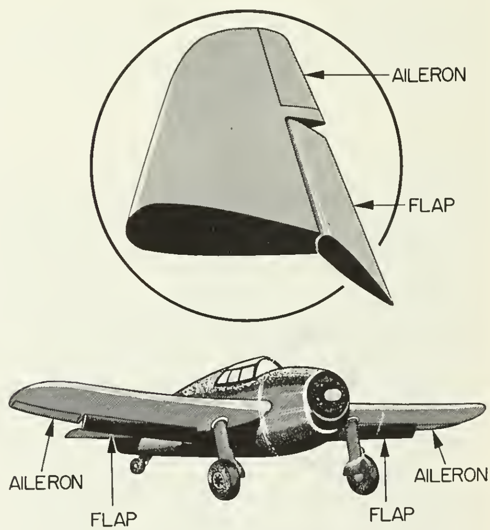


Figure 24—A drawing showing the location of flaps which in a lowered position (as shown) will steepen the gliding angle and may result in a shorter landing run.

the wing in front of the ailerons. Their function is to improve the airflow over the wing at high angles of attack, thereby lowering the stalling speed. (Figure 25.)

Fuselage

The airplane *fuselage* is the main body of the airplane and carries the crew, controls, passengers, and cargo. It must be constructed so that it has great strength for its weight, provides enough room, and has a proper streamlined or aerodynamic shape. The fuselage, called the hull in a flying boat (figure 26), may also contain the engine and fuel tank. An *amphibian* is an airplane whose hull is equipped with retractable wheels to enable it to operate from either land or water. (Figure 27.)

Fuselages are classified according to the way in which the structure has been built. The two main types of construction are the *truss* and the *semimonocoque*. (Figures 28 and 29.) The first is made of steel tubing; the second with an internally braced metal skin.

Regardless of the attitude or position of an airplane, i.e., parked, taking off, landing, flying straight and level, turning, or performing aerobatic maneuvers, there are always stresses on the fuselage structure. The bracing of the welded steel-truss type acts like the structure of a bridge, since loads will be distributed by the parts to the entire fuselage. The semimonocoque gets its strength from the metal skin or shell which is reinforced by the internal bulkheads and stringers.

Tail Assembly

The *empennage*, or tail assembly of an airplane (figure 18), is composed of several parts, each of which has a definite control function. The *horizontal stabilizer* prevents the nose of the airplane from pitching up and down. The *elevator*, a hinged portion of the horizontal stabilizer, controls the angle of attack. The *vertical fin* helps to maintain the direction of flight. The *rudder* swings the nose right or left and, in conjunction with the ailerons, is used to make coordinated turns. These surfaces are of many sizes and

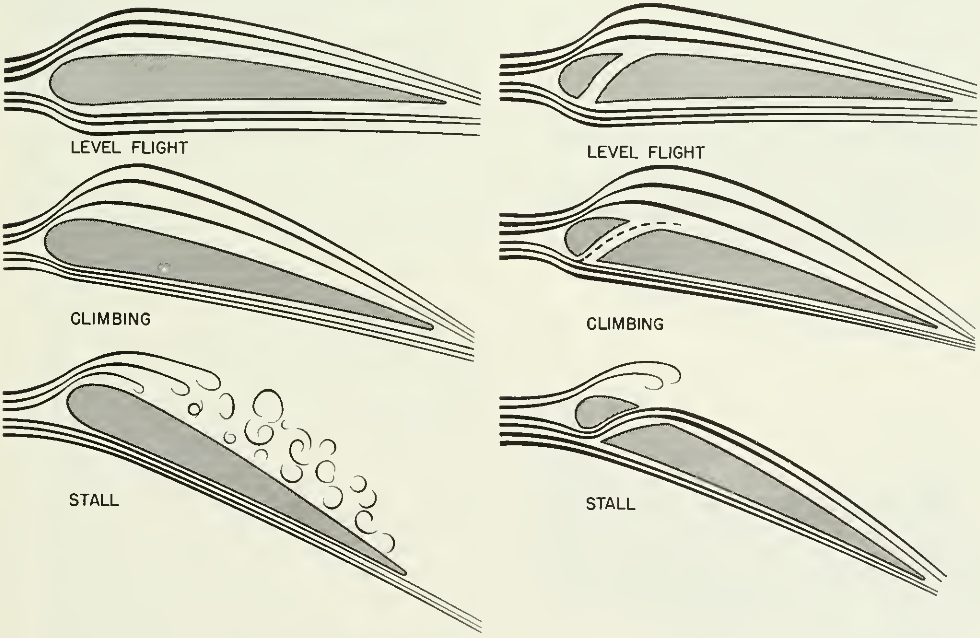


Figure 25—Wing Slots Diagram. On the left side, the normal flow of air over the wing is observed. Note the burble or breakdown of smooth flowing air in the stall condition without slots and then compare the air flow over the slotted wing at the same angle of attack in the diagram on the right.

Figure 26—Flying Boat

Figure 27—Amphibian airplane with a hull for water landings and wheels (retractable) for runway landings.

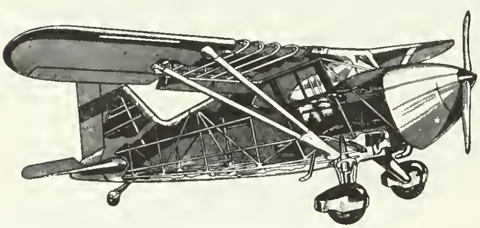


Figure 28—Welded Steel Tubular Fuselage

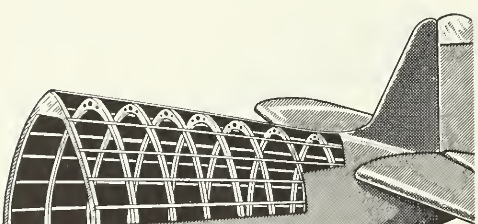


Figure 29—Semi-Manacaque Fuselage

Figure 30—Fixed Landing Gear

Figure 31—Tricycle Landing Gear

shapes, and there are many variations in positioning the vertical and horizontal elements.

Frequently, in discussing control surfaces, the term *balanced control* is employed. This merely means that the control, whether aileron, elevator, or rudder, is so arranged and operated that when the pilot moves any control some aerodynamic force is set in motion to assist him. Normally the pilot's strength would be the only force exerted in moving the control surfaces. However, when balanced controls are used, pressure of the air strikes the balanced section which is forward of the hinge, thus exerting a force on both sides of the hinge and making it easier for the pilot to move the control in the desired direction.

In very large airplanes, and those capable of supersonic speed, it is necessary to give the pilot additional assistance in moving the controls. This is accomplished by the use of *servo units,* which are electrically or hydraulically operated mechanisms which move the control surfaces in response to the pressures imposed on the cockpit controls by the pilot.

Figure 32—Landing Gear Being Retracted

Landing Gear

An airplane's landing gear may be the *conventional* type, with two main wheels and a tail wheel, (figure 30), or it may be the *tricycle type,* with two main wheels and a nose wheel, (figure 31). The wheels may be fixed or retractable, i.e., folding into the fuselage or wings, (figure 32).

To take up the impact of the landing, the wheels of most airplanes are attached to *oleo struts,* which are shock-absorbing devices that use oil to cushion the blow. (Figure 33.) This type of shock absorber is located in the landing gear struts to which the wheels are attached, and is composed of an outer cylinder fitted over a piston. The piston is on the end of a short strut attached to the wheel axle. Between the piston and a wall or bulkhead in the outer cylinder is a space filled with oil. The impact of the landing pushes the piston upward, forcing the oil through a small opening in the bulkhead into the chamber above it, thereby cushioning the shock.

On some light airplanes the shock of landing is reduced by the use of *shock cords.* These consist of many rubber bands tightly bound into a bundle with a cloth covering. They tend to cushion the landing by stretching and thereby distributing the impact over a greater period of time. The same principle is employed by other light planes equipped with landing gear struts made of spring steel. Just as the rubber shock cords stretch to give the effect of a soft landing, so the steel struts accomplish the same end by bending outward as the wheels make contact with the runway.

To aid in controlling airplanes on the ground, the main wheels are equipped with *brakes* which may be

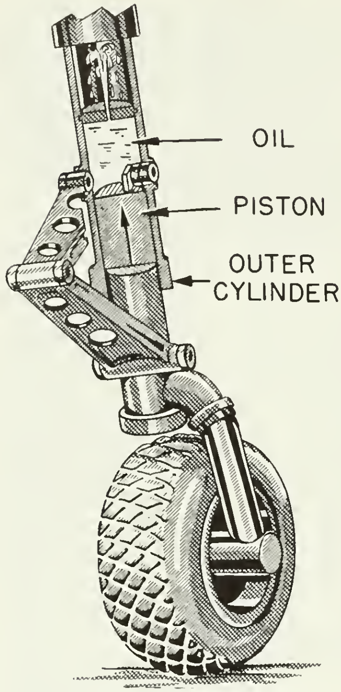


Figure 33—Principle of Oleo Strut Operation

operated separately or together. Brakes are used not only to slow up a fast rolling airplane but also as an aid to steering and parking. For example, pressure on the left brake and slightly advanced throttle will cause the airplane to turn to the left around the left wheel. As little use as possible is made of brakes, because the weight and speed of the airplane may result in overheating and subsequent damage to the brake mechanism.

Special types of landing gear include *skiis* for snow and ice and *floats* for water. For carrier landings, airplanes are equipped with an *arrester hook* that catches in a system of cables on the flight deck, bringing the airplane to a stop in a short distance.

Powerplants

Lack of suitable power retarded the development of the airplane for many years. After an adequate engine was devised it more than kept pace with the changes in the airframe structure.

A commonly-used powerplant is the internal combustion gasoline engine. This type of powerplant may consist of as few as four cylinders or as many as twenty-eight. The cylinders of the smaller engines are arranged in a *horizontally-opposed* fashion, while those having more than six cylinders are arranged *radially* around the crankshaft. (Figure 43) The number of individual engines required by an airplane is determined by the horsepower needed to provide the necessary thrust. While a single engine may adequately supply the horsepower requirements for a small light plane, as many as four may be needed on a large transport.

Engines may be mounted in several ways. The *tractor* type has the propeller attached to the front of the engine and pulls the airplane through the air. The *pusher*, as its name implies, pushes the airplane by having its propeller attached to the rear of the engine. Single, tractor-type engines are usually mounted in the nose of the fuselage. Airplanes with two or more engines may have their powerplants mounted in the wing, atop the wing, or under the wing.

Propellers

Converting the energy of the engine's revolving crankshaft into a pulling or pushing force is accomplished by the *propeller*—a rotating airfoil providing the forward thrust for airplanes and airships. Propellers can have two, three, or four blades and can vary greatly in their configuration. Some have long slender blades, while others are broad, with short square-cut, paddle-like blades. Occasionally two *counter-rotating* propellers are driven by a single engine.

The propeller derives its pulling or pushing effect from the angle at which the blade is set on the hub. This angle is called *pitch*. The pitch or blade angle may be changed automatically, by mechanical means or by hand, in order to give the propeller its greatest efficiency. *Low pitch*, or a flat blade angle, provides higher revolutions per minute while *high pitch*, or a greater blade angle, gives lower revolutions. (Figure 34.)

Propellers are classed as *fixed pitch*, a blade angle that cannot be adjusted; *adjustable pitch*, a blade angle that can be changed only on the ground; *controllable pitch*, a blade angle that can be changed by the pilot from the cockpit; and *constant speed*, a blade angle that automatically adjusts itself according to the amount of power used. Some constant speed propellers may be *feathered*, i.e., their blades may be turned so that the leading edges are aligned with the line of flight. (Figure 35.) Feathering a propeller stops a disabled and vibrating engine, decreases the drag of the propeller, and increases the performance of the airplane while operating with the remaining engine or engines. (Figures 36 and 37.) Propellers may also have *reversible pitch* for use as a landing brake. In this type, the blade angle is shifted to provide thrust in the opposite direction.

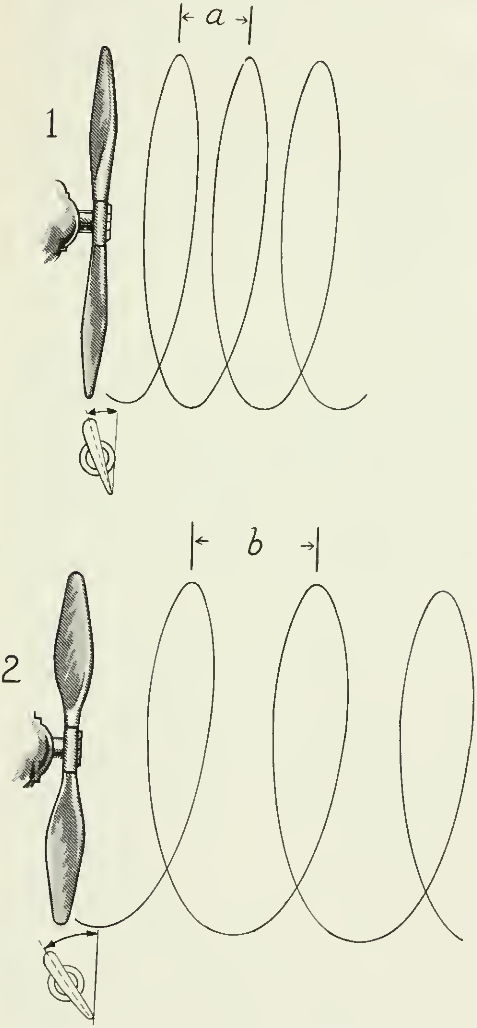


Figure 34—1. Fine or low pitch, high RPM for take-off (blades have low angle of attack). 2. Coarse or high pitch, low RPM for cruising (blades have high angle of attack). A & B are illustrative distances that each moves forward in one revolution.

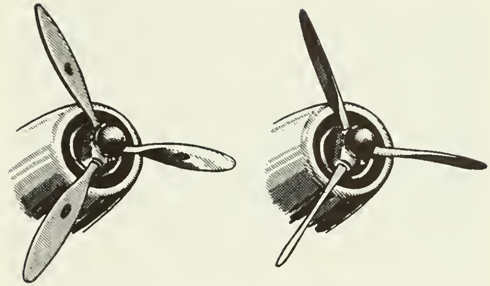


Figure 35—Full Feathering Propeller. In the left diagram the blades are set for normal operation while on the right the blades are feathered.

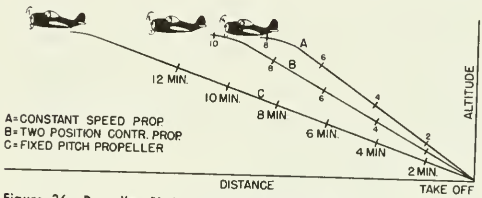


Figure 36—Propeller Pitch Performance Comparisons

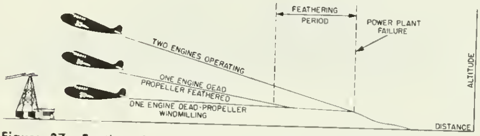


Figure 37—Feathered and Unfeathered Propeller Performance

Jet Propulsion

The jet engine usually eliminates the propeller and provides much greater speed than is possible with the propeller-driven, internal-combustion engine. The jet engine derives its thrust by compressing the air that is drawn into the front of the engine and combining it with fuel which is then burned in the combustion chambers. The hot and greatly expanded gases thus formed develop thrust as they are exhausted out of the tail pipe. A portion of the power formed by the burning exhaust is used to turn a turbine wheel which drives the compressor and other components. The one exception to the elimination of the propeller is the turbo-prop engine, which not only gives forward thrust with its blast of hot air but also gains additional thrust from a propeller. (See Chapter V.)

The jet engine is now widely utilized by the military services, and speeds far in excess of the speed of sound are commonplace with jet-propelled military aircraft. Like the internal-combustion engine, the jet powerplant is frequently mounted in the wing, but it is also occasionally suspended below the wing, where it is held in place by a mounting structure called a *pylon*. In the modern jet fighter the engine is usually located in the fuselage behind the pilot.

Airplane Accessories

Many devices are in use today to insure the comfort and safety of the passenger and the crew. Many of these devices are electronic in nature, such as the auto-pilot, which will dutifully perform the work of the pilot by flying the airplane and keeping it steadily on course. Various other devices are sensitive to the presence of fire or smoke in remote areas such as the cargo compartment and will immediately sound an alarm when such danger occurs.

Among the mechanical accessories used on military and commercial airplanes are *de-icer boots*. (Figure 38.) These consist of flexible rubber sheets containing inflatable elastic tubing and are mounted in the leading edge of the wing and tail surfaces. When inflated and deflated at regular intervals, they distort and stretch the leading edge of the boot in such a manner that ice formations crack and blow away. Many metal aircraft now use an internal heater, located inside the wing just behind the leading edge, which, when activated, heats the metal skin and melts any ice which may have formed. To combat ice formations on the propellers a "slinger" ring may be installed. This distributes de-icing fluid along the blades while in flight, loosening any ice that may have formed and preventing further formation.

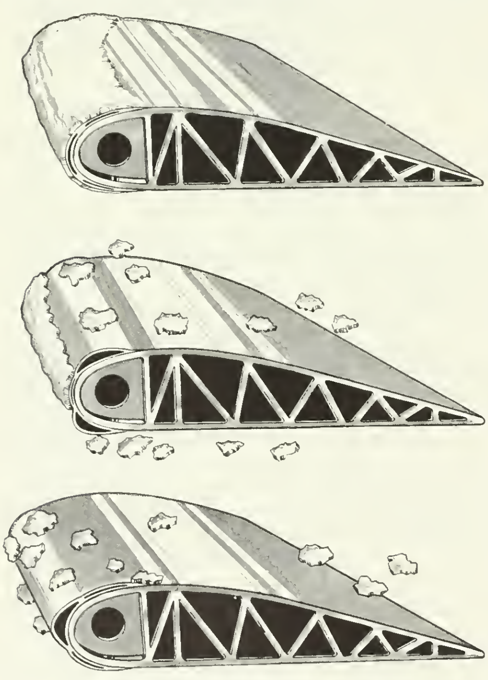


Figure 38—De-Icer Boot Operation. In the top drawing, rime ice has formed. In the center, the upper and lower boot sections have expanded, cracking off the ice. In the bottom view, the center boot portion expands, the top and bottom sections collapse, thus completely removing the ice.

Commercial airliners are equipped with *cabin pressurization* equipment. This equipment can maintain a simulated altitude of two or three thousand feet even though the aircraft itself may be flying at twenty thousand feet, thereby providing an atmosphere with enough oxygen to prevent drowsiness in the crew and permit comfortable breathing by the passengers.

Other Aircraft Types

Other types of aircraft include the rotary, lighter-than-air craft, ornithopter, and the convertiplane. There are two general types of rotary aircraft—the helicopter and the gyroplane.

The rotor blades of the *helicopter* are merely revolving wings, getting their lift from the motion of air over a curved surface in the same manner as the wing of an airplane. The revolving blades create an upward force (lift), and if they are tipped, the helicopter will move in the direction in which the blades have been tipped. (Figure 40.)

Due to the rotation of the blades in one direction, the helicopter fuselage tends to revolve in the opposite direction. To counteract this tendency, the helicopter is usually equipped with a small propeller on the tail which directs a blast of air sufficient to overcome the effects of this torque or turning motion. By increasing or decreasing the pitch of the blades of this tail rotor, the pilot can control the direction of forward motion. Other types of helicopters overcome the undesirable effects of torque by incorporating two sets of counter-rotating blades. This also provides for a greater lifting force and is now commonly used on the larger models.

The helicopter is unique because it can hover over one spot, and for this reason can take off or land in a space not much larger than the diameter of the rotor blades. A free-wheeling device attached to the rotor drive shaft allows the rotor blades to act like those of an autogiro by lowering the craft gently to the earth in the event of engine failure.

The *gyroplane* has unpowered, overhead rotating blades for ordinary flight. These blades may be geared to the engine for jump takeoffs. Forward flight in an autogiro is accomplished by the use of a conventional aircraft engine and propeller.

There are three general kinds of airships—the nonrigid, the semirigid, and the rigid. The *nonrigid* airship has a streamlined, gas-tight rubberized envelope or skin which is not supported by a framework nor reinforced by any stiffening materials. It maintains its shape by the internal pressure of the gas within the envelope. *Blimps* are the typical example of this type of airship.

The *semirigid* airship has a structural metal keel and a metal cone to strengthen its bow. This reduces the bending strains on the envelope and tends to keep the airship in its inflated shape lengthwise. The envelope still has to be kept in its flying shape by the pressure of the gas within it.

If inside framework is used to support the gas envelope and the airship is not dependent upon the inside pressure of the gas to maintain its shape, the airship is said to be a *rigid* type. Since 1938 there have been no known rigid-type airships constructed.

An airship flies because of its lift and thrust. The lift comes from the lighter-than-air gas which raises the airship into the air. The hull of the airship provides a large enclosed space in which the lifting gas can be contained. Often the space will be divided into separate compartments for the gas. These compartments are called balloonets.

Thrust, the force which moves the airship through the air, is obtained usually from the engines and propellers which are often located in gondolas or cars suspended from the hull. These are sometimes called "power eggs."

All airships, either inside or outside the hull, carry a car or keel structure, usually of metal, to provide space for personnel and cargo, in addition to storage room for fuel and equipment.

Control of an airship is by certain fixed and movable surfaces, usually at the stern of the airship, which help guide the airship in the same general way as do the rudder and elevator of an airplane. Usually the controls are directed from the control car by connecting cables.

An *ornithopter* is an aircraft designed to fly or propel itself through air by means of flapping wings. This idea is the oldest in the history of flying. Man naturally first turned to the flight of birds for ideas to aid him in his own desire to travel through the air. While some small-scale models have flown, no successful man-carrying ornithopters have been developed.

All ornithopters, no matter how varied in design, may be classified in two ways. The first type uses various forms of wings for support in the air and fastens the wings to the body of a man. The second type uses a cabin or cockpit to house the pilot. To it the flapping wings are attached and from it the wings are operated.

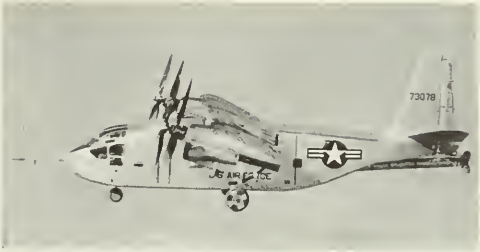


Figure 39—X-18 IN FLIGHT TESTS—Shown is the 16½ ton X-18 during flight tests over Edwords Air Force Base, Calif. Wings have reached an angle of attack of 50 degrees during flight. Now in a ground program to study the effects of downwash during simulated hovering, the X-18 is expected to be back in flight tests at a later date for full hovering and vertical operation.

Early experimenters used the first method. Most came to the conclusion that the strength of birds was much greater in relation to their weight than man's strength in relation to his weight and that it would be impossible for man to fly by his own strength alone. However, experimenters are still working on this problem.

A *convertiplane* is an aircraft so built that it can perform, at the will of the pilot, as any one of two or more types of aircraft. Some types may be adjusted to fly either as a helicopter, autogiro, or fixed-wing aircraft. Aircraft that are essentially convertiplanes are often called STOL aircraft, meaning that they require only a short take off and landing run. Still others are referred to as VTOL as they can actually take off and land vertically. (Figure 39.)

There are two basic types of convertiplanes. The first type looks more like the typical airplane and uses the same source of power for forward motion that it does for rising vertically or hovering. Thus it may rotate its propeller or propellers, or even the whole wing structure, from the horizontal to the vertical, to change from forward motion to hovering flight or a straight-down landing.

Figure 40—Helicopter

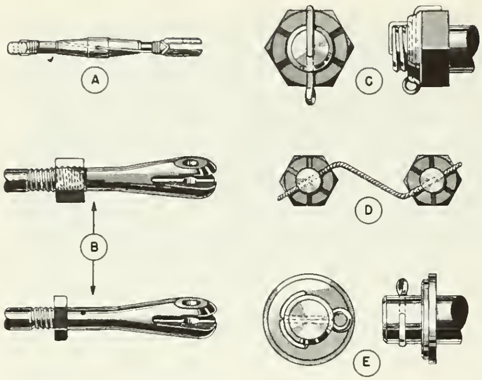


Figure 41—Aircraft Safetying Methods

The second type of convertiplane resembles the helicopter more than it does the fixed-wing aircraft. In this type, the rotor axis remains vertical. In forward flight the rotor blades may be fixed in place, allowed to revolve without power, locked in a trailing position, or folded into the fuselage. These types require a propeller or other means for forward propulsion.

Convertiplanes usually are powered by the same type gasoline or jet engines used by other civil and military aircraft. If the convertiplane is using small jet engines, it may vary the position of the engines, or use diversion valves, so that the thrust will be in the direction desired.

Aircraft Construction

Modern military and commercial airplanes are constructed chiefly of aluminum and aluminum alloys. Other metals such as magnesium, titanium, copper, and the many alloys of steel, have characteristics which lend themselves well to the construction of various aircraft components. Metal parts are joined by riveting, welding, soldering, brazing, and special adhesives. Parts designed for future disassembly are fastened together with nuts, bolts, and screws, or other similar devices. Such hardware as nuts, bolts, and turnbuckles must be secured so they cannot become loose during flight. (Figure 41.) This precaution is called *safetying,* and is accomplished with cotter pins, safety wire, airplane safety pins, and elastic stop nuts.

Some light airplanes have components made of wood such as spruce, fir, or pine. These woods are particularly useful because of their strength-weight ratio. Other components require the stiffness that is to be found in birch, mahogany, or ash. Wooden parts are fastened together with nails and resin or casein glues. Cotton or linen fabric, aluminum or aluminum alloys, and fiber glass are normally used to cover the frame of the airplane.

Many other materials are required in the production of the modern airplane. Of these, the family of plastics is playing an ever-increasing role. Synthetics are now found in carpet and upholstering materials, windows, cable pulleys, electrical insulation, paints and finishes, and in many other airplane accessories. In addition, such materials as glass, asbestos, leather, rubber, cotton, and many others have characteristics of some particular value in the construction of the airplane.

Aircraft Inspections

A program of regular inspections is required of every airplane. This government-enforced policy tends to insure the continued airworthiness of the airplane and is a major factor in the enviable safety record established by modern aviation. At intervals not to exceed one year the condition of the entire airframe and powerplant and all their components is carefully examined. In addition to this, all aircraft used as air carriers must be submitted for similar inspections, determined by the amount of flight time accrued. At regular intervals between these periodic inspections are others, less detailed in nature and completeness. All inspections necessitate the skill and knowledge of the airframe and powerplant mechanic, who is required, by law, to certificate the work he has completed.

Finally, every airplane should have a preflight inspection in order to maintain further the efficiency and safety of the structure, engine, equipment, and accessories. Inspection procedure should include the powerplant, landing gear, wings, tail assembly, and fuselage. Such an inspection is normally the responsibility of the pilot, or, in the case of a large transport aircraft, the flight engineer.

The following is a general preflight check list. In addition to this list, each type of airplane requires its own particular list.

A. Propeller
   1. Inspect blades for pits, cracks, and nicks; inspect hub(s) and attaching parts for defects, tightness, and safetying.

B. Engine
   1. Inspect engine cowling, exhaust stacks, and collector rings for cracks and security.
   2. Check spark plug terminal assemblies for cleanliness and tightness; check accessible ignition wiring and harness for security of mounting.

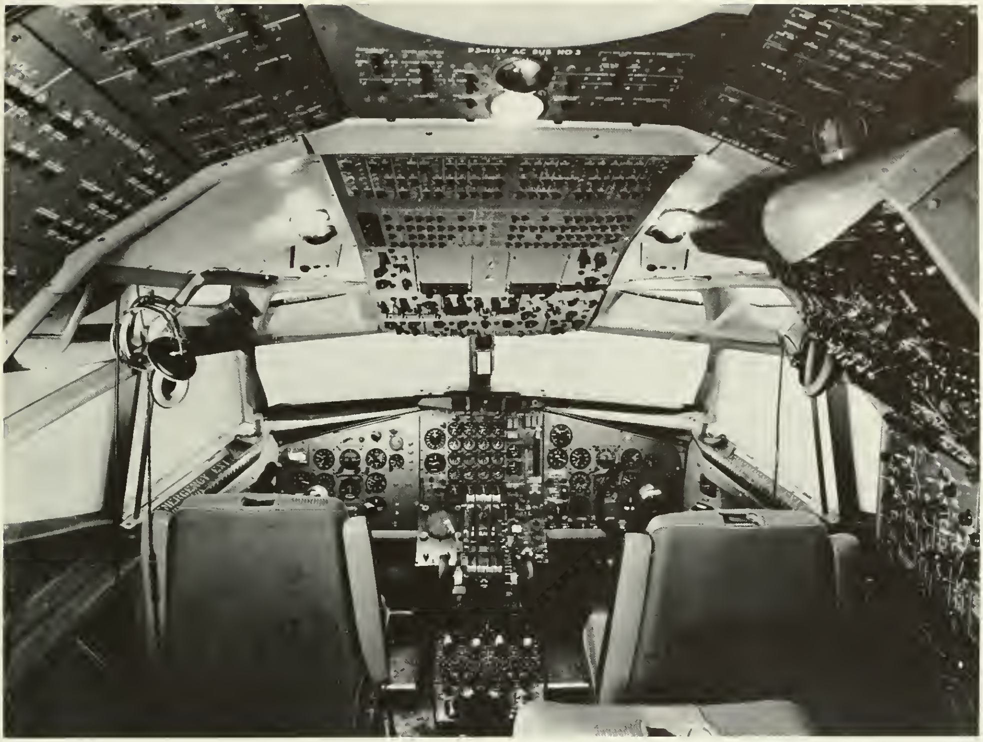


Figure 42—The cockpit section of the Link 707 simulator is an exact replica of the flight deck of the actual aircraft. This photo, taken from behind the pilot and co-pilot seats, shows the complete arrangement of instruments and controls found in the simulator.

3. Check all bolts and nuts on engine mount.
4. CHECK FUEL AND OIL SUPPLY, making certain that the vent openings are clear and the tank caps are on tight.

C. Landing Gear
1. Inspect tires for defects and proper inflation.
2. Inspect wheels for cracks and distortion; inspect the brake-actuating mechanism for security and cleanliness.
3. Inspect the landing gear attachment bolts; inspect the struts for proper inflation.

D. Wings
1. Inspect the metal or fabric covering for such damage as holes, dents and wrinkles; check attachment fittings for security.
2. Check struts and flying wires for security of terminal connections; check aileron hinges, pins, horns, and tabs.
3. Inspect all accessible control cables, tubes, and pulleys for security.

E. Empennage
1. Inspect the covering for damage, the edges for dents and distortion, and the fittings for security.
2. Check struts and brace wires for security of terminal connections; inspect control surfaces, hinges, pins, horns, and tabs.
3. Inspect control cables, tubes, and pulleys for security and lubrication; check the tail wheel assembly for general condition and security.

F. Fuselage
1. Inspect the covering for damage and distortion and check the windows, windshield, and doors for security and cleanliness.
2. Check all removable cowling, fairing, and inspection plates for security.
3. Check the control column, rudder pedals, and trim mechanism for security of attachment and freedom of movement.
4. Check the proper functioning of the lighting

system and the location of the spare fuses or circuit breakers.

5. Inspect for security of safety belts and the proper functioning of adjustable seats.

G. Warming Up

1. See that chocks are under the wheels.
2. Be certain that the master switch is OFF before turning the propeller over by hand; be sure that the front is "clear" before using a starter.
3. Check position of the gasoline shut-off valve, carburetor heat control, and carburetor mixture control.
4. Test engine(s) on each magneto and on all tanks.
5. Check radio equipment for proper functioning.
6. Note oil temperature, pressure and rpm.

Supersonic Transport

The newest development in civil aircraft design is the supersonic transport, generally spoken of as the SST. This could cut flight times at least in half. The British and French governments are working jointly on an SST, which is expected to be in the Mach 2 range (1,200-1,400 mph) and available by 1971. It is also known that the Russians are working on such an aircraft. Both developments are for relatively short-range aircraft.

The United States is planning a longer-range and faster SST. Its range is to be about 4,000 miles and the speed will be up to Mach 3 (1,800-2,000 mph). This is a joint industry-government project and is planned for service about 1972. One of the engineering developments expected in the SST are wings which can be adjusted to the speed desired, thus providing lower landing speeds and more efficient lift.

Summary

Aircraft are divided into two classes: (1) heavier-than-air and (2) lighter-than-air. Present-day emphasis is on the heavier-than-air craft, particularly the airplane. The helicopter, autogiro, ornithopter, and convertiplane are other types of heavier-than-air craft.

The major sub-assemblies of the airplane's structure are (1) wings, (2) fuselage, (3) tail assembly, (4) landing gear, and (5) powerplant. Airplanes having one wing are called monoplanes; those with two wings are called biplanes. Aerodynamically, monoplanes are more efficient.

The framework or structure of the wings, fuselage, and tail surfaces is relatively light because of the kinds of metal used, and very strong because of the manner in which individual internal members of the structure are formed and fabricated. The structure is covered with either doped fabric or sheets of very light metal.

The fuselage houses the crew, controls, cargo, and passengers. Occasionally the powerplant and the fuel tanks are mounted in the fuselage. The engines in a multi-engine plane are mounted on the wings, the powerplant supporting members being attached to the main spar or spars. Engines and propellers can be of the tractor (pull) type or of the pusher type.

The term undercarriage refers to the structure or mechanism upon which the airplane rests when it is not airborne. In the case of land planes, it consists of wheels and struts mounted to the structure to absorb the shock of landing. The wheels are equipped with brakes to stop the landing roll and to facilitate ground handling. The undercarriage may be of the fixed type or may be completely retractable.

The tail assembly consists of vertical and horizontal airfoils, both fixed and movable. These surfaces vary in size, shape, and arrangement, according to the design of the particular make of airplane. The movable surfaces are controllable from the cockpit, and in conjunction with the ailerons serve to determine the flight attitude of the airplane.

Propellers may have two, three, or four blades. The effectiveness of the propeller (which is actually an airfoil) is computed from the number of revolutions per minute (rpm) and the angle at which the blades are set. This angle is called pitch and may be fixed, adjustable, controllable, or constant speed. Simple wood or metal propellers with no moving parts have a fixed pitch. Low pitch means that the blades are attacking the air at a relatively flat angle. Low pitch is used during takeoff (if the propeller pitch is controllable) because greater power is obtained that way. High pitch means that the blades are attacking the air at a relatively large angle. If the pitch is controllable, high pitch is used at cruising speed.

Airplanes are constructed of materials having light weight and great strength. These include the alloys of aluminum, steel, and magnesium. In some light planes such woods as spruce, fir, and pine are used for structural members, and the covering is made of cotton or linen fabric which is coated with dope to make it taut and weather resistant. The metal parts are joined by such techniques as welding, brazing, and riveting, while glue is used for fastening together the parts made of wood. All aircraft hardware such as bolts and nuts is secured by various methods of safetying.

To insure safety in flight, every airplane must undergo regular inspections. Of these, the preflight inspection is the most common and is usually performed by the pilot. Much more complete inspections are performed periodically by the airplane mechanic.

Questions

1. Identify the five major components of an airplane and explain the purpose of each.
2. Briefly describe the construction of a wing, and explain the two methods of attaching and bracing the wings of the fuselage.
3. Identify the ailerons and the flaps and explain the purpose of each.
4. In what area of the wing are slots located, and what is their purpose?
5. Name and describe the two main types of fuselage construction.
6. List the major components of the empennage.
7. Of what value to the pilot are balanced controls and servo units?
8. Explain how the effect of a soft landing is achieved by the various types of landing gears.
9. Differentiate between the tractor and pusher types of aircraft.
10. What types of engines are used to power airplanes, and in what positions are they located on the airframe?
11. What are the different types of propellers and what advantages are to be derived from changing propeller pitch?
12. Explain the purpose and operation of de-icer boots.
13. List some of the accessories that make for safer and more comfortable flight.
14. How is forward motion accomplished with a helicopter and with an autogiro?
15. What are the three general types of airships?
16. What are the two basic types of convertiplanes?
17. List some of the materials that are used in airplane construction and describe how these materials are fastened together.
18. What is the purpose of safetying aircraft hardware?

Chapter 5 The Aircraft Engine

Man's failure in his early attempts at flight were due primarily to two obstacles: insufficient knowledge of the basic principles of aerodynamics and the lack of a suitable source of power. The second obstacle was the last to be overcome. Several pioneers attempted flight using only their own power, but it soon became apparent that man was not sufficiently powerful to lift and propel himself in flight—with or without the most efficient aerodynamic devices. The requirements were obvious—an engine must be built which was capable of producing considerably more power per unit of weight. The solution called for use of lighter, stronger materials, new engine design to eliminate unnecessary parts and weight, and possibly a new fuel.

The first partial solution was quite crude though the operating principles of this engine, built by the Wright brothers in 1903, are still used in our present reciprocating or piston-type engines. The Wright engine's shortcoming was its relatively high weight per horsepower. With a weight of about 180 pounds and an output of approximately 30 horsepower, it developed only 1 6 horsepower per pound. Continued research in the use of lighter materials, more powerful fuels, the principle of supercharging, and more efficient arrangement of cylinders has since increased the ratio of horsepower to weight in reciprocating engines to approximately one horsepower per pound. When the aviation industry demanded a more powerful engine, the jet or "reaction" engine was developed. The jet engine is capable of producing several horsepower per pound of weight at high speeds.

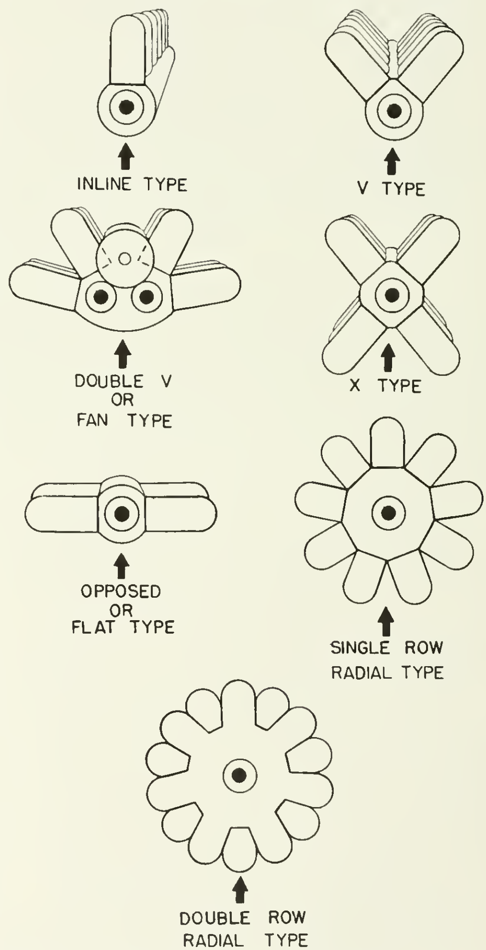


Figure 43—Aircraft Engine Cylinder Arrangements

Aircraft Engine Requirements

Although the fundamental aircraft engine requirement is still the same as when the Wright brothers built their engine—as much power as possible from a given weight—the airplane engine may vary according to the purpose for which the plane is intended. Some types of engines are more suited to light private airplanes, others better suited for civilian transports, and still others more adapted to military aircraft.

Regardless of size, type, or principle of operation, all aircraft engines possess certain mutual characteristics. These characteristics are:

(1) development of a reasonably large amount of power for a given weight,
(2) reliability and performance at various speeds,
(3) fuel and oil consumption compatible with power produced,
(4) lack of excessive vibration,
(5) relatively easy maintenance.

Aircraft Engine Types

Installation of the engine in the airplane raised several new problems including cooling and streamlining. To overcome these problems, while fulfilling the previously mentioned requirements, manufacturers have designed engines with many different cylinder arrangements. (Figure 43.) One of the first air-cooled radial engines was a French rotary type, i.e., the cylinders and crankcase revolved around a stationary crankshaft. The French rotary type engine had good cooling characteristics, but because of excessive vibration, it became obsolete. The most commonly used engines have their cylinders arranged parallel to each other in tandem (*in-line*), in two tandem rows at approximately right angles (*V*), in two rows on opposite sides of the crankshaft (*flat or horizontal opposed*), or like spokes of a wheel around a central shaft (*radial*).

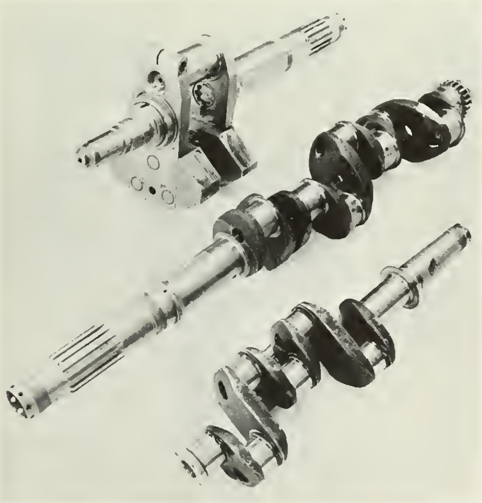
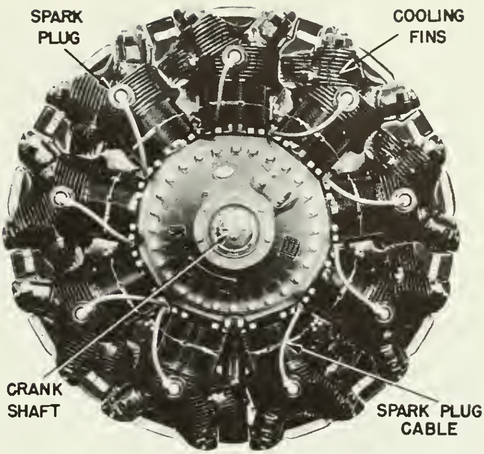


Figure 44—Types of Crankshafts



Courtesy Wright Aeronautical Corp.

Figure 45—Front View of 9-Cylinder Radial Engine

Because cooling difficulties more than offset streamlining advantages of the in-line and V-type engines, most modern reciprocating engines are horizontally opposed or radial. Opposed engines are used in almost all light airplanes, including small twin-engine planes where the engines are "buried" in the wings. The number and the size of the cylinders used in opposed engines are so limited by cooling problems and crankshaft design that opposed engines rarely exceed 250-300 horsepower. Larger airplanes, requiring more power, use radial engines—some with two or four rows or "banks" of cylinders. Such engines can develop in excess of 3,500 horsepower per engine. When even more power is needed, engines are used in pairs, in groups of four, or as many as six or eight per plane. However, more power per engine requires a different type—the jet or rocket.

Aircraft Engine Parts

Some knowledge of the parts of an engine is prerequisite to understanding its principles of operation. (Figures 44, 45 and 46.) The main function of the crankshaft is to change reciprocating motion into rotary motion. The force of the expanding gases on the top of the piston is transmitted to the crankshaft through the connecting rod or a link rod. The type of crankshaft varies with the engine. A single row radial engine uses a crankshaft with one *throw* or *crank*, about which a *master rod* is fitted. Link rods connect this master rod with all of the cylinders except one—

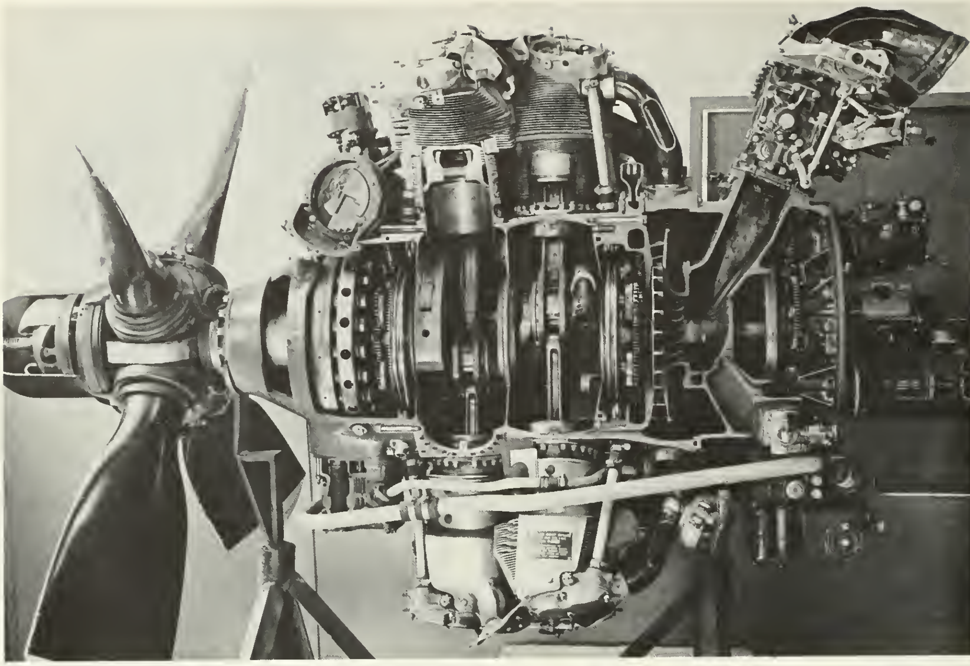


Figure 46—Cutaway View of Twin-Row Radial Engine

the master rod cylinder. An in-line or opposed engine normally uses a crankshaft with as many throws as it has cylinders and with a connecting rod between each cylinder's piston and its respective crank throw. The crankshaft may be connected directly to the propeller, or through reduction gears which slow the rotation of the propeller relative to the crankshaft. The cylinder head is forged or cast aluminum and is threaded and then shrunk onto a steel cylinder barrel which has a hardened inner wall. The intake valve has a solid stem, while the exhaust valve may be hollow and filled with metallic sodium to improve the heat transfer to the cylinder. Cooling fins on both head and barrel aid in keeping cylinders below dangerous temperatures. Piston rings help prevent loss of gas pressure above the piston during compression and power development.

The Four-Stroke Cycle Principle

Reciprocating engines operate by repeating the same cycle of events in each cylinder, i.e., (1) a charge of fuel and air is forced into the cylinder, (2) the charge is compressed, (3) the charge is ignited, (4) power is obtained from the expanding gases, and (5) the burned gases are expelled. The first event may differ somewhat in diesel engines or in those equipped with direct fuel injection, but,

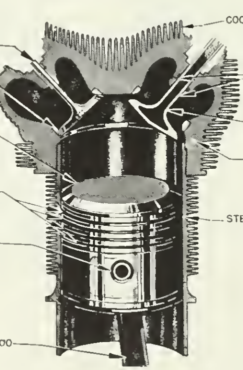


Figure 47—Airplane Engine Cylinder Nomenclature

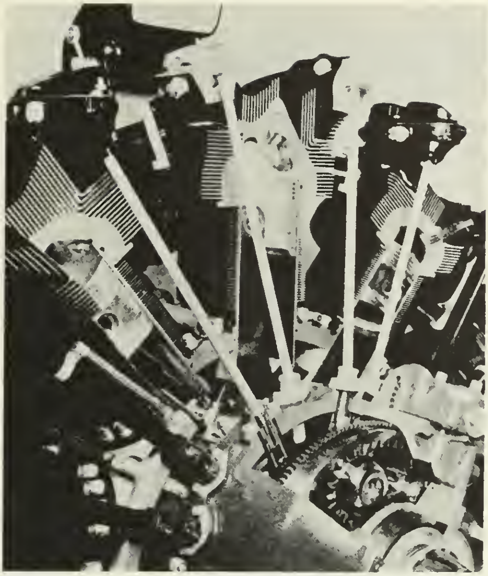


Figure 48—Valve Operating Mechanism of a Radial Engine

fundamentally, the same events are present. These are sometimes called: (1) intake, (2) compression, (3) ignition, (4) power, and (5) exhaust. Most engines require two complete revolutions of the crankshaft or four strokes (a movement of the piston from top dead center to bottom dead center in the cylinder, or vice versa, is called a stroke) to complete all five events in the cycle. Such engines are called four-stroke cycle engines, or sometimes *four-cycle* engines.

Two valves, operated by a cam shaft or a cam ring and a connecting linkage, are required in each cylinder to complete this cycle of events. (Figure 47.) The gears actuating the valve-operating mechanism and the magneto are correctly meshed with those on the crankshaft to give correct timing to these events. (Figures 48 and 49.)

In more detail, the five events in a complete cycle are:

1. *Intake.* With the exhaust valve closed and the intake valve open, the piston moves downward in the cylinder, reducing the pressure therein and causing air (and fuel, if a carburetor is used) to flow through the induction system into the cylinder.

2. *Compression.* The intake valve closes shortly after the piston passes bottom dead center, and the

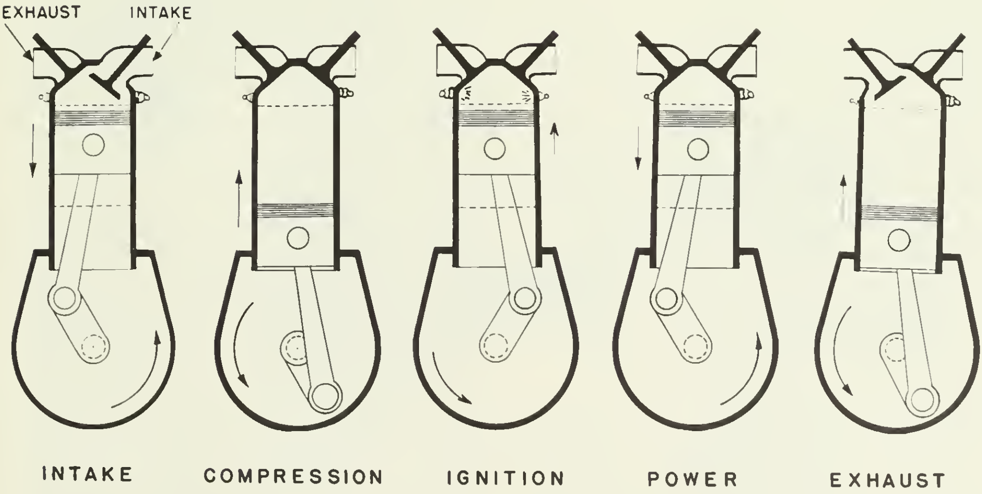


Figure 49—Stages of the Four-Stroke Cycle Engine

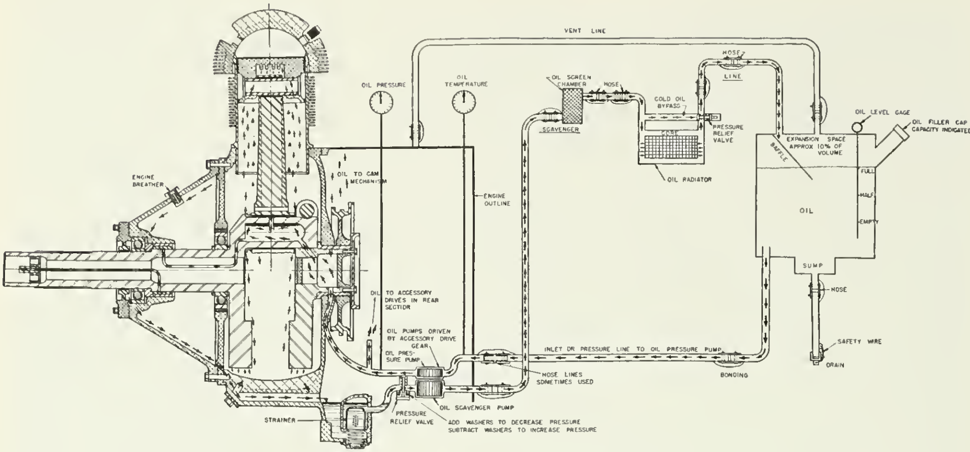


Figure 50—Diagram Showing the Radial Engine Lubrication System

fuel and air charge is compressed as the piston moves toward top dead center.

3. *Ignition.* A high-voltage current flowing from the magneto through the distributor at the correct instant, usually 20°-30° before top dead center, jumps a gap in the spark plug and ignites the fuel charge.

4. *Power.* The burning gases create very high pressures inside the cylinder and after the piston has passed top dead center (carried there by momentum or the force on other pistons) it is forced down, causing the crankshaft to rotate.

5. *Exhaust.* When the piston approaches the bottom of the cylinder, the exhaust valve opens and stays open almost three-fourths of a revolution, thus permitting the burned gases to be forced out by the upward travelling piston.

The complete cycle is repeated approximately 1,000 times by each cylinder during every minute of operation. An eighteen cylinder engine gets its power from approximately 300 power strokes per second.

Engine Systems

Although the engine functions as a complete unit, its operation is more easily studied by a breakdown into smaller functions, or systems. This breakdown would include the lubrication, fuel and induction, ignition, and mechanical systems. The *mechanical system* is composed of cylinders, pistons, valves, etc., and has already been discussed in the four-stroke cycle principle. The *lubrication system,* besides performing the obvious and necessary function of lubricating the moving parts of the engine, has several other responsibilities, e.g., helps to cool the engine, provides for a better seal between piston rings and cylinder walls, prevents corrosion, and actuates hydraulic units such as valve lifters and propeller controls. (Figure 50.) Aircraft engines use a pressure lubrication system in which oil is pumped through drilled passages to the many engine parts which require lubrication. Other parts, such as cylinder walls, piston pins, and some roller or ball bearings, receive oil by splash and spray. The oil supply may be carried either in the engine's crankcase (wet-sump) or in an external tank (dry-sump). Most opposed-type engines are the wet-sump variety, but radial engines are always dry-sump. The dry-sump engine is so called because the oil which settles into the sump (collection place) is pumped back to the external tank as quickly as possible by a *scavenging pump.* If the external tank is very large, as in a large airliner, a small *hopper tank* within the main supply tank receives the oil pumped from the engine by the scavenger pump for recirculation within the engine. When the supply of oil in the hopper tank drops below the level of that in the main tank, additional oil is added from the main supply. Several benefits derive from the use of a hopper tank, the most important being a more rapid warm-up of the engine.

FUEL AND INDUCTION SYSTEM

Internal combustion engines must be supplied with the correct mixture of fuel and air, which is taken into the cylinders, compressed, ignited, and burned to supply power. This process may be accomplished by use of a fuel injection system which includes an air-metering device, or a carburetor, in which air and fuel are properly mixed before entering the intake manifold and cylinders. (Figure 51.)

The carburetor must be able to provide the proper mixture (about one part of fuel to fifteen parts of air, by weight) at all speeds. The correct mixture requires: (1) an idling system when the throttle is almost closed; (2) a main metering system for all other throttle positions; (3) an accelerating system to prevent temporary lean mixtures upon rapid acceleration; (4) an economizer system to supply extra fuel at higher engine speeds; and (5) a mixture control to allow for different air densities.

The throttle controls air flow through a restriction or *venturi,* in which a fuel *discharge nozzle* is placed. Increased air velocity causes a pressure drop, and fuel then flows from the discharge nozzle into the air stream. A wider throttle opening permits faster air flow and more fuel to be discharged.

Fuel must be vaporized and mixed with the oxygen in the air before it can burn. As fuel vaporization occurs, the mixture's temperature drops, sometimes as much as 60° F. Water vapor in the air may be condensed and frozen, even when outside air temperatures are as high as 80° F. Ice may collect on the *butterfly valve* (throttle) of the carburetor or in the intake manifold and, if allowed to build up, will cause engine stoppage. Carburetor ice is usually prevented by a carburetor air heater, which sends air, heated by the exhaust stacks, through the carburetor. Excessive use of the carburetor air heater may cause loss of power, or detonation; consequently carburetor heat should be used only when required.

At higher altitudes, the difference in pressure between the inside of the cylinder on the intake stroke and the outside atmosphere may be so small that air and fuel flow into the engine are greatly reduced without some help. Full fuel and air flow are restored by a supercharger; in fact, the density of the intake charge may be increased to more than twice that obtained by an unsupercharged engine at sea level. The *supercharger* is a centrifugal pump which forces more air-fuel mixture into the cylinders. It may be *internal,* driven by a gear train connected to the crankshaft, or *external,* driven by the exhaust. The external type is called a *turbosupercharger.* (Figure 52.) Most of the larger radial engines have internal or integral superchargers, which have the additional responsi-

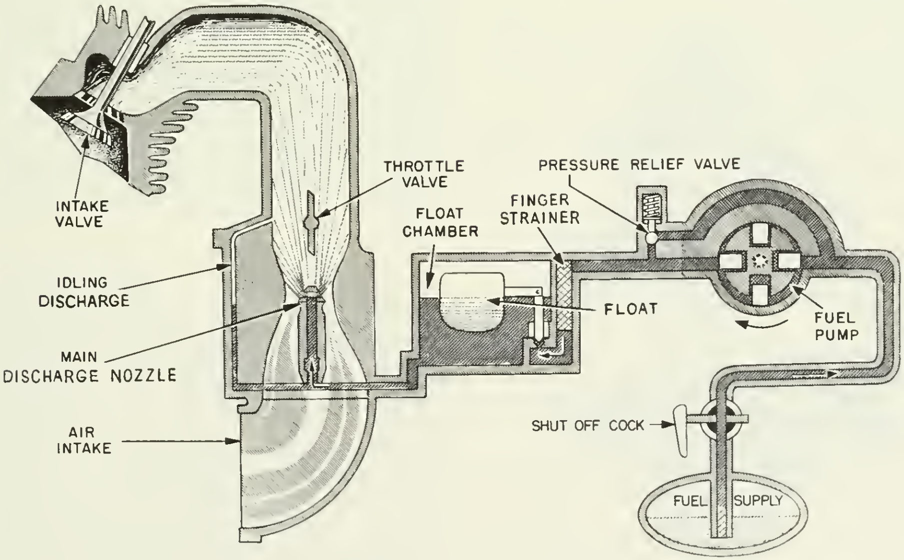


Figure 51—A typical aircraft fuel system showing how the gasoline is pumped from the fuel tank into the carburetor float chamber, drawn out of the main jet by suction, and, in an atomized or vaporized form, flows inside the intake manifold to the intake valve of the cylinder.

bility of providing an even distribution of fuel to all of the cylinders.

IGNITION SYSTEM

The compressed fuel-air mixture is ignited in the cylinder, at the correct time, by a spark from a *spark plug.* (Figure 53.) The spark is caused by a high-voltage current developed by a *magneto.* (Figure 54.) As the permanent magnet rotates, a fluctuating magnetic field is developed in the *pole shoes,* around which both the *primary* and *secondary coils* are wound. The change in magnetic field creates a low-voltage current in the primary circuit, which includes, besides a coil with a relatively few turns of fairly heavy wire, a *condenser,* a *switch,* and a set of *breaker points.* The primary circuit is interrupted by the breaker points aided by the condenser at the most opportune time to cause a very rapid collapse in the magnetic field through the pole shoes. As a result, a high-voltage current is induced in the secondary circuit, which includes, besides a coil with many turns of fine wire, the *distributor, ignition leads,* and *spark plugs.* The distributor causes current to flow to the spark plugs in the correct sequence, or firing order. An aircraft engine usually has two complete ignition systems, with two magnetos and distributors and two complete sets of spark plugs, not only for better ignition, but also as a safety factor.

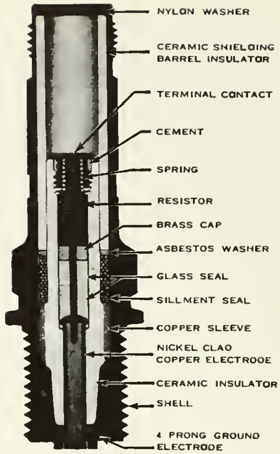


Figure 53—A Simplified Cutaway Drawing of a Spark Plug

ACCESSORIES

Accessories include those items which aid an engine's operation, but do not necessarily cause it to function. All large engines, and many smaller ones, are equipped with electric starters which are usually powered by a storage battery. A second accessory, the *generator,* is required to recharge the battery that also provides power for lights, flap and landing gear actuating motors, radio equipment, etc. Other accessories found on many engines include vacuum pumps for operating certain instruments, and propeller governors which control propeller blade pitch to maintain a constant engine speed through wide variations in throttle setting.

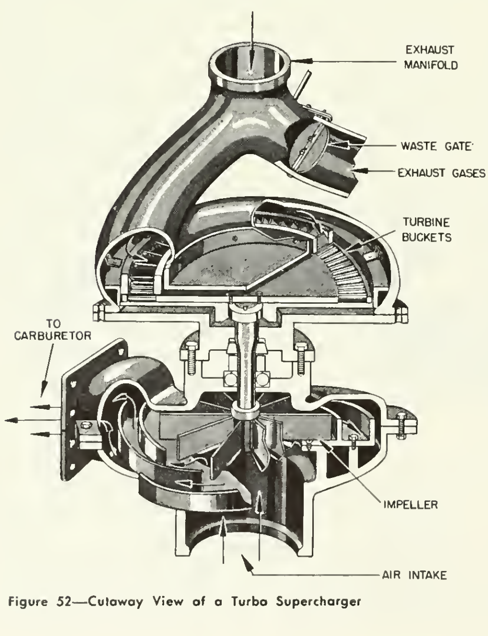


Figure 52—Cutaway View of a Turbo Supercharger

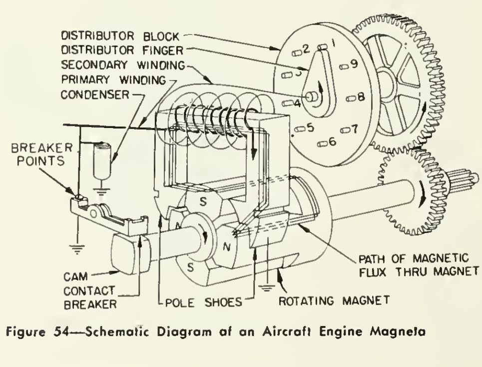


Figure 54—Schematic Diagram of an Aircraft Engine Magneto

Power Factors

Fundamentally, an internal combustion engine changes heat energy into mechanical energy and its power depends upon the rate at which it can do work. Three factors are involved in power development, (1) engine size or piston displacement, (2) speed of rotation, and (3) the amount of pressure on the piston.

The horsepower formula is: $H.P. = \frac{PLAN}{33{,}000}$. "P" is the effective pressure on the piston measured in pounds per square inch. "L" is the distance, measured in feet, which the piston moves from top dead center to bottom dead center (stroke). "A" is the cross-sectional area of the cylinder in square inches. "N" is the number of power strokes which the engine has in one minute. The constant divisor of 33,000 is used because one horsepower is defined as that power required to perform 33,000 foot pounds of work in one minute.

For example, a nine-cylinder engine with a 6-inch cylinder diameter (bore), a 6-inch stroke, turning at 2200 rpm with a mean effective pressure of 160 pounds per square inch will develop horsepower at the rate of

$$\frac{160 \times \frac{1}{2} \times 3^2 \times 3.1416 \times 9900}{33{,}000}$$

or about 680 horsepower. Everything in the substitution should be obvious with the possible exception of the value of "N", which was 9900. This value is obtained from the fact that in two complete revolutions of the crankshaft of any four-stroke cycle engine, each of the cylinders should deliver one power stroke. Therefore, a nine-cylinder engine rotating 2200 times per minute should have $9 \times \frac{2200}{2}$ or 9900 power strokes in one minute.

Modern Powerplants

Jet and rocket propulsion devices are often called reaction engines because their thrust is produced as a result of a reaction to an action. Perhaps the best explanation of the effect is a comparison with a more familiar occurrence, propulsion by a propeller driven aircraft.

Figure 55 shows a typical engine nacelle and propeller. Anyone who has been behind such an engine when it is operating knows that a large amount of air is being pushed to the rear with a high velocity. According to Newton's third law, for every action there is an equal and opposite reaction. In this instance, a force is being produced on the propeller and engine combination in the opposite direction from that in which air is being thrown by the propeller. This combination might be called a "reaction engine."

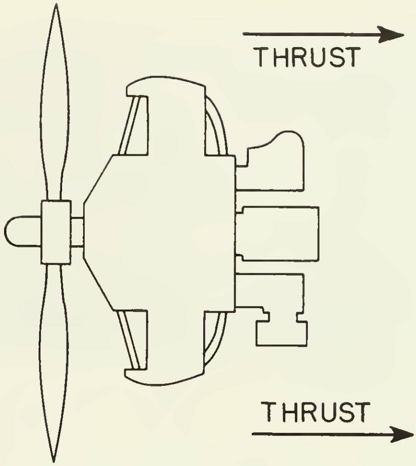


Figure 55—Typical Reciprocating Engine-Propeller Combination

Figure 56 shows the same items as above, except they have been enclosed in a tube, and the airflow is directed to the rear through this tube.

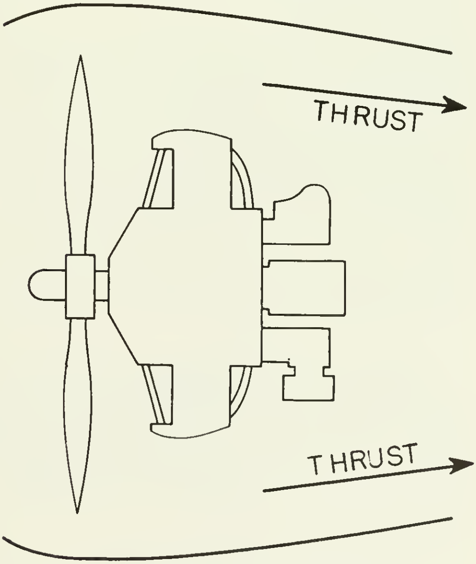


Figure 56—Reciprocating Engine-Propeller Combination Enclosed in a Tube

In figure 57 the engine-propeller combination has been replaced by a turbine wheel at the rear, a compressor at the front, and combustion chambers in which fuel and air are burned between the two. This combination causes air flow through the tube in the same manner as the engine-propeller combination in Figure 56. The mass of air being moved in this arrangement may be less but the final velocity of the moving gas is much greater and the resultant thrust can be much greater. This thrust is the reaction, which was caused by the action of air moving toward the rear, and is transmitted from the component parts of the engine through its frame to the aircraft.

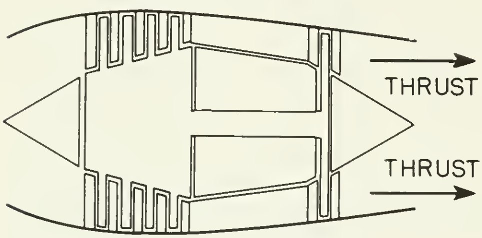


Figure 57—Compressor-Turbine Combination Enclosed in a Tube (Typical Turbojet Engine)

The same result—a high-velocity flow of gases—is accomplished in the engine shown in figure 58 by burning fuel inside a container which is open at only one end. Such a device is called a rocket.

Thrust is NOT the reaction of the expelled gases upon the air outside the engine. Thrust would be the same if the gases were being expelled into a vacuum. Thrust depends upon: (1) the mass of gas being moved, and (2) the velocity with which it is expelled from the exhaust or tail pipe. Technically, the second factor is the change in the velocity of the entering and leaving gases, but it is sufficient for our purpose to consider only final velocity. The mass of gas being moved is increased by forcing as much air as possible into the inlet section of the engine. The velocity is increased by heating and expanding the air and by burning the fuel which has been mixed with it, then expelling it through a restricted exhaust passage.

Three types of jet engines may be considered, although only one merits much discussion at present. The most simple of the jet engines is the *ram jet*, or *athodyd* (a contraction of aero thermodynamic duct). (Figure 59.) It is often called a "flying stovepipe" because it consists of a tube into which fuel is injected, burned, and then the hot gases expelled from the tail pipe. The "catch" is that the air which enters this jet must be compressed by the ramming action of the device itself. Consequently, it will not operate until it has reached a very high velocity—at least 500-600 miles per hour. It can be used to power helicopter rotors, as an auxiliary powerplant in an aircraft which has another engine to bring the aircraft up to the required speed, or in some other limited applications.

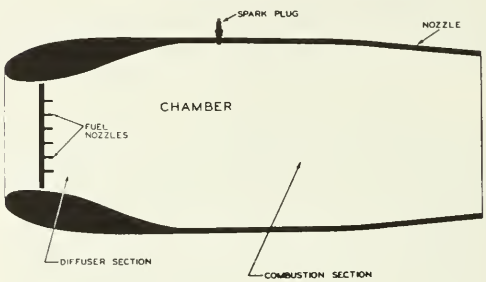


Figure 59—Schematic Diagram of a Ram Jet Engine

The *pulse jet* (Figure 60) is almost as simple as the ram jet, except for the addition of automatic shutters in the inlet section. These shutters open as the engine moves through the air thus permitting air to enter the inlet opening. The shutters close when fuel, which has been injected into the same section, burns and causes the air to heat and expand. The heated gases

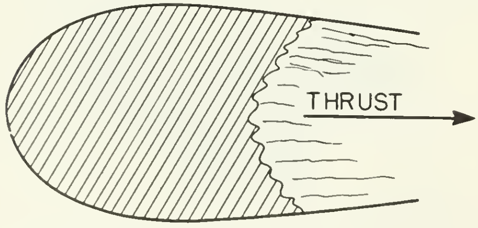


Figure 58—Simple Rocket Engine

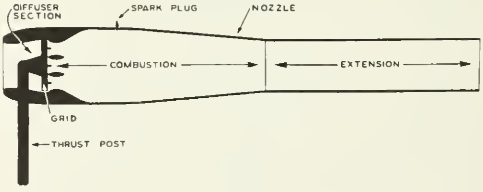


Figure 60—Schematic Diagram of a Pulse Jet Engine

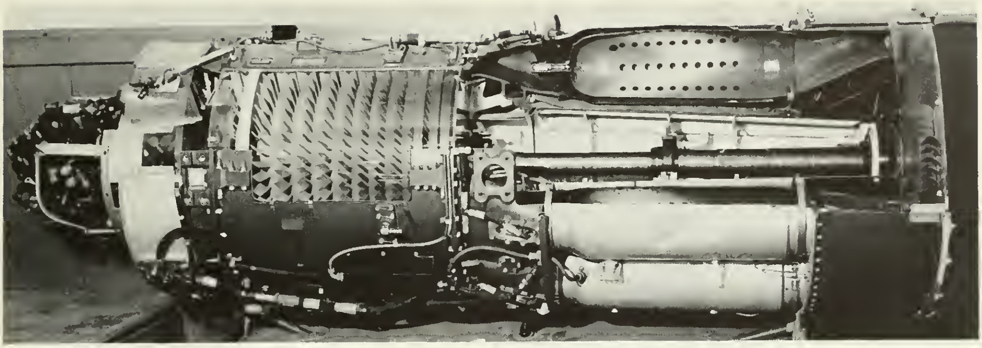


Figure 61—Cutaway View of a Turbojet Engine

are then forced out the rear at high velocity. The drop in pressure, as the gases leave the exhaust section, again forces open the shutters, and the same cycle is repeated as often as 50-60 times per second. Although the pulse jet is simple to build, it loses efficiency at high speeds and is exceptionally noisy. There have been some military applications of this engine, notably the German "buzz bomb" of World War II, but its disadvantages are such as practically to eliminate it from commercial use.

The third, and by far most important commercially, is the *turbojet*. This classification is sometimes further subdivided into (1) the *pure jet* engine, without a propeller (Figure 61), and (2) the *turboprop engine*, which incorporates a propeller driven by the main shaft through a reduction gear train.

Turbojets are also classified according to the type of compressor used. Earlier models invariably used a compressor similar to the centrifugal pump of the turbo supercharger and were called centrifugal flow engines. Because considerable energy was expended to change the direction of airflow as it was being compressed, the centrifugal pump was later replaced by a device similar to a turbine wheel in the turbo supercharger. This engine was called axial flow and permitted air to flow in more of a straight line during its compression.

Regardless of type or manufacturer, turbojet engines consist, primarily, of four sections. These sections are: (1) compression, (2) combustion, (3) turbine, and (4) exhaust. The turbine lies directly behind the combustion section, and is driven by the gases leaving the combustion chamber. The shaft, which the turbine turns, also supports the compressor which compresses the incoming air before it enters the combustion chambers. Fuel is injected into the combustion section by a spray nozzle and burned. Ignition is continuous, and spark plugs or ignitors are required

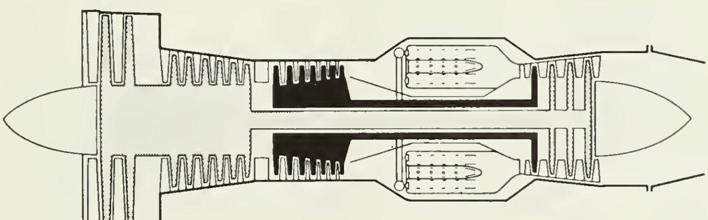


Figure 62—Gas Generator Section of a Turbofan Engine

only for starting the engine. After the heated gas passes the turbine section, it flows through the exhaust cone to the atmosphere, increasing in velocity and decreasing in pressure until it leaves the cone.

In addition to the basic units of the turbojet engine, numerous appliances and accessories are required. These include fuel pumps, pressure regulators, oil pressure and scavenger pumps, a starter, a generator, and an ignition system. Some accessories have a more demanding job to perform than their reciprocating engine counterparts; e.g., fuel pumps (there are usually two per engine) must be able to develop pressure twenty to fifty times that of the normal fuel pump of a reciprocating engine. The pressure regulators must be able to control fuel flow in widely varying conditions of atmospheric temperature and pressure. The starter must be able to accelerate the compressor, turbine and shaft from zero to 2000 or 3000 rpm in a very few seconds. The electric starter requires about 1,200 amperes of current during this period; however, larger jet engines often use a small gas turbine engine as a starter. There may also be other minor accessories, such as vacuum pumps, electric motors to move controllable vanes in the inlet or exhaust sections, etc.

COMPRESSORS

The first turbojets used centrifugal-flow compressors. (Figure 63.) The centrifugal-flow compressor is easy to build and maintain, but rather inefficient because the airflow direction is changed so often during its passage through the engine; e.g., this compressor is usually double sided, and consequently the air entering the rear inlet must traverse a complete circle before it enters the combustion chamber. The maximum compression ratio obtainable with centrifugal-flow compressors is only about 3 to 1.

More recently developed turbojets, and almost all of the turboprop engines, use an axial-flow compressor. (Figure 64.) This compressor has several rows of compressor blades set into a rotating drum and separated by rows of somewhat similar blades in a fixed outer case called stators. The rotating blades (actually airfoils) force the air toward the rear with the stators serving as guide vanes to direct the air to the next row of blades. An engine with twelve rows of rotating blades has thirteen rows of stators and is called a twelve-stage compressor. The entire compressor is driven by one turbine wheel. This type of compressor can compress incoming air by as much as a 5 to 1 ratio. When higher compression ratios are desired, a split compressor, consisting of two different compressor sections, each with a row of rotors on its shaft, and separate turbines on the opposite ends of the shafts, may be used. Sometimes two or more stages of turbines are used to drive the compressor in the high compression section. Split compressors can achieve compression ratios as high as 12 to 1.

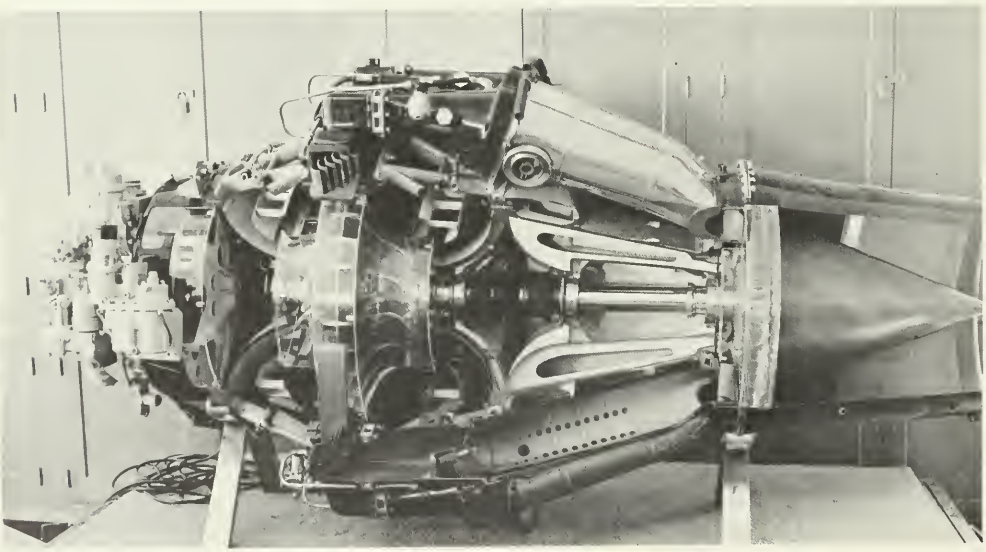


Figure 63—Cutaway View of a Centrifugal Flow Compressor Engine

COMBUSTION CHAMBERS

Only a small part of the compressed air mixes with fuel and burns as it travels through the engine, although all of it is heated. A *cannular combustion chamber* has an inner and an outer liner, and as air leaves the compression section some flows between these liners while the rest enters the inner chamber where it mixes with fuel supplied by the fuel nozzle in the front of this chamber. The spray is controlled in such a way that the burning is concentrated near the center of the inner liner in order to prevent the burning of the metal. Thus, a layer of air separates the burning mixture from the inner liner. Since combustion chambers are connected by cross-ignition tubes, only two igniters are needed and then only for starting. As many as twelve to fourteen combustion chambers may be used in the average turbojet engine.

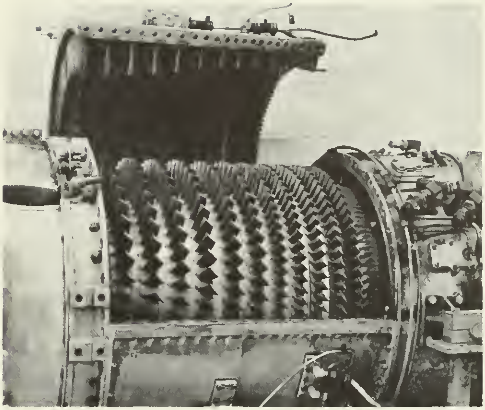


Figure 64—Axial Flow Compressor of Turbojet Power Unit

TURBINES

Turbine assemblies are quite similar in design and construction. The most critical stresses occur in this section because turbine blades or *buckets* must withstand high temperatures (sometimes as high as 1500° F.) and centrifugal forces. *Clearances* are very critical, and, because of expansion at high temperatures, will vary with the change in temperature. Cooling the turbine wheel and lubricating the bearings are major problems. The first is usually solved by ducting air from the compressor section to the turbine, and the second by using a special type of lubricant.

The biggest difference between turbojet and turboprop engines (aside from the additional propeller and gear box in the turboprop) is in the turbine section. One turbine wheel, with its outer rim of buckets, is normally sufficient to drive several rows of compressor blades. However, if the main shaft must also turn a propeller, more rows of turbines are needed. Whether one or more turbines are used, a row of stationary blades is placed in front of each turbine to direct the gas flow toward the buckets at the correct angle. This particular row of stator blades is called a *nozzle diaphragm*.

EXHAUST CONES

The efficiency of a turbojet is increased by properly controlling the hot exhaust gases. The exhaust cone or nozzle may be convergent, divergent, or both, although the increased velocity of the convergent type is desired. Some engines use a variable cone which can be changed to get maximum efficiency. A *thrust augmenter*, called an *afterburner*, is often used in military turbojets. In effect, the afterburner becomes a ram jet engine which receives the compressed gas at its inlet and into which fuel is then discharged. Such a combination is often called a turboramjet. Since the gas is already aflame as it enters the afterburner, it continues to burn and the exhaust velocity is thereby greatly increased with only a slight increase in over-all engine weight. Fuel consumption is somewhat increased in proportion to thrust gained, but the increase in thrust per pound of weight, including both engine and fuel, is more than sufficient to warrant use of the afterburner when maximum performance is required.

THRUST VERSUS POWER

It is possible to calculate the power which a reciprocating engine will develop when its piston displacement, rpm, and mean effective pressures are known, and to test this calculation with a Prony brake. For a jet engine, however, only thrust can be ascertained until the forward speed factor is added. Since work is defined as force times distance ($W=F \times D$) and power is work per unit of time,

$$\text{then power} = \frac{\text{force} \times \text{distance.}}{\text{time}}$$

A jet engine developing 5,000 pounds of thrust tends to push itself, and the aircraft in which it is mounted, forward with that thrust. However, if the airplane is not moving, the force of 5,000 pounds multiplied by a distance of zero gives a product of zero foot-pounds of work and zero power. The same thrust, while pushing the airplane forward at a speed of 240 miles per hour (or 352 feet per second) is performing work at the rate of 5,000 × 352 × 60 foot-pounds per minute. Dividing this by 33,000, the number of foot-pounds per minute required for one horsepower, gives 3200 horsepower. The same thrust at a higher speed means more power. Thus at a speed of 375 mph., the amount of horsepower developed by a jet engine is numerically equivalent to its thrust. For example a 5000 pound thrust engine develops 5000 H.P. at 375 mph. since

$$\frac{5000 \times 375 \times 5280}{60 \times 33{,}000} = 5000.$$

TURBOJET, TURBOPROP, AND TURBOFAN ENGINES

The low efficiency of a turbojet engine at low altitudes and low speeds is a major deterrent to its use for other than long range aircraft. As a compromise between the turbojet and the reciprocating engine–propeller combination, the turboprop engine was developed. In the turboprop engine, a major part of the energy in the gases emerging from the combustion chambers is tranformed into mechanical energy in the rotating shaft. A propeller is connected to the shaft by reduction gears, so most of the thrust developed by the turbine engine is utilized through the propeller. A considerable increase in efficiency at low altitudes and low speeds is thus obtained through the use of the turboprop. However, a possible shortcoming still exists with the use of the propeller—that of poor efficiency when its rotational speed is too great. Most of the more powerful reciprocating engines use propeller reduction gears to prevent the prop tip speeds from becoming supersonic, at which point the developing shock waves cause loss of propeller efficiency.

The turbofan engine is a modification of the standard turbojet engine. It can produce more thrust by expelling a greater volume and weight of cooler gas. Through its large intake the turbofan pulls in four times as much air as the standard turbine engine. This gives a greater volume of gases expelled at lower velocity and temperature, thus producing increased thrust at a lower noise level. The turbofan engine has one or more rows of compressor blades extended several inches beyond their normal length to direct air back through an area which surrounds the regular engine giving what is called a *forward-fan* engine. The fan acts quite similar to an ordinary propeller. An alternative procedure is to extend one or more of the rows of turbine blades, resulting in an *aft-fan* engine. With a fan, there is a sufficient increase in thrust and efficiency to propel an airplane faster than the speed of sound without using an afterburner.

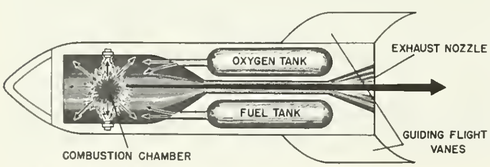


Figure 65—Rocket Power Unit

A more recent development, one which engineers are expecting to utilize in the engines of supersonic airliners designed to travel at speeds of Mach 3 or above, is the *fan burner*. Similar in operation to the afterburner of the normal turbojet engine, the fan burner engine obtains additional thrust by burning additional fuel in the fan duct. Thrust can be doubled with a fan burner, and in addition, these engines have lower operating temperatures, a wider range of available power, and a much lower weight per horsepower. In fact, the fan burner engine has proved to be very efficient and economical at low altitudes and speed without burning in the fan stream, and at high altitudes and speeds with burning in the fan stream. The high-thrust turboramjet has apparently been far surpassed in thrust as well as economy by the fan burner engine.

ROCKET PROPULSION

Recent military successes in the field of rocket propulsion have raised hopes and predictions of extremely rapid intercontinental travel, and even interplanetary travel. While it is true that rockets can be and have been developed which can deliver tremendous thrust, there are still many unsolved problems delaying wide acceptance of this method of propulsion for anything other than military projectiles. This does not rule out the use of rockets as auxiliary power for takeoff or emergency purposes for some manned aircraft, and for satellites of the earth, sun, moon, or some other planetary body. (See Chapter 12.)

A major problem at present is fuel consumption. Whether the fuel be liquid or solid, rockets must still carry their own oxygen supply, thereby increasing fuel load weight and decreasing pay load weight. Rocket power is successful when the vehicle it powers can attain very high speeds and high altitudes. Both of these conditions have physiological implications which are serious.

Another difficult problem involves control of a rocket-powered aircraft while in flight. If the flight is made at sufficient altitude to warrant use of rocket propulsion, aerodynamic controls will be almost useless. If the rocket leaves the low heavier layer of atmosphere and progresses to a high speed in the thin upper layer, the re-entry into the lower altitudes with its resultant friction and heat also causes trouble.

The military implications of rocket propulsion are awesome and frightening, particularly when coupled with electronics systems which permit remote or automatic control of various "stages" of the composite rocket, and with intricate and remarkably accurate guidance systems. A schematic drawing of the essential parts of a rocket appears in figure 65.

ATOMIC PROPULSION

The success of the atomic-powered submarine has led to a clamor for an airplane powered by an atomic engine; in fact, the flight of such a plane by another government has been reported. Although the report may be premature, the possibility of such an engine cannot be denied. Basically, the engine would develop thrust using the same principle as the jet, with the atomic reactor providing the heat normally obtained in the combustion chambers of the conventional jet. Major problems, including lack of protection from radiation of the atomic materials, have delayed development of this engine. Quite possibly, its principal application may be that of an auxiliary engine—to be used only when the airplane has reached high speed and altitude by use of another type engine. Interplanetary travel may become a reality if and when the atomic engine is perfected.

Summary

Early powerplants were unsuitable for aircraft because they were heavy, cumbersome, and unable to deliver sufficient horsepower. First aircraft engines were crude and inefficient, but had the same operating principle of present-day reciprocating engines.

To be satisfactory for aircraft use, an engine must be powerful, compact, and light in weight. Fuel and oil consumption must be within reason, and maintenance must be relatively easy.

Almost all current reciprocating aircraft engines are air-cooled and either of the radial or horizontally-opposed type.

Practically all aircraft engines operate on the four-stroke cycle principle. There are five events in each cycle: intake, compression, ignition, power and exhaust.

The main functions of the lubrication system are to (1) lubricate, or reduce friction, (2) cool the engine, and (3) give a better seal between piston rings and the cylinder wall.

The carburetor acts as a control and mixing chamber for liquid gasoline and air. Gasoline is atomized and vaporized in the induction pipes and cylinders. The fuel charge is ignited at the proper instant by a spark plug which receives high voltage current from the magneto via the distributor and ignition leads.

Reaction engines, such as the ram jet, pulse jet, turbojet, turboprop, and rocket devices, produce thrust by expelling gases through a jet or nozzle. Jet engines use oxygen from the earth's atmosphere but rockets carry their own oxygen, enabling them to produce thrust outside the atmosphere.

Questions

1. Why are the most high-powered reciprocating engines of the multi-row radial type?
2. Name the five events in a complete cycle in a four-stroke cycle engine.
3. How many power strokes should be delivered per minute by a nine-cylinder engine operating at 2200 R. P. M.?
4. What is to be substituted for each of the letters, P, L, A, and N in the horsepower formula? What does the 33,000 in the denominator represent?
5. What is the function of a carburetor in a reciprocating engine? How is carburetor icing eliminated or prevented?
6. What are the two main functions of the lubrication system?
7. What causes high-voltage current to be induced in the secondary circuit of a magneto?
8. Under what operating conditions is a supercharger required? Why?
9. Name four different kinds of jet engines.
10. What is an afterburner, and what is its purpose?
11. What advantages does a turboprop engine have over a turbojet engine?
12. What is the purpose of the turbine in a turbojet? In a prop jet?
13. Why is a split compressor used in high performance jet engines?
14. Why is the turbofan engine superior to other types of jet engines?
15. Where is the "fan" located in the turbofan engine?

Chapter 6 Airplane Instruments

Due to the inability of the human senses to cope completely with variable climatic conditions and complicated mechanical devices, it is essential that certain physical characteristics of the airplane be measured and indicated. These measured indications must be extremely accurate and readily accessible to the pilot. Safe, economical, and reliable operation of modern aircraft and their powerplants is absolutely dependent upon the proper use of instruments.

Instruments are divided into three classes: (1) flight instruments; (2) navigation instruments; and (3) engine instruments. The number of instruments found in various aircraft depends upon the size of the aircraft, and upon the purpose for which the aircraft is used. Multi-engine aircraft, for example, require a separate set of instruments for each engine and often require a duplicate set of instruments for the second pilot or the flight engineer.

In addition, the wide variety of aircraft operational temperatures, pressures, and speeds make it necessary to paint operational markings in various colors on the cover glasses or faces of the instruments. Short radial lines and arcs of circles indicate the safe operating limits prescribed by the manufacturer for a particular engine or aircraft.

The Federal Aviation Agency (FAA) also has requirements that must be met for certain conditions of flight operation, e.g., visual flight rules (VFR), instrument flight rules (IFR), and day and night operation. These FAA requirements also govern the number and kind of instruments to be found in a specific airplane.

Some of the more important instruments found in airplane cockpits are the airspeed indicator, altimeter, rate of climb indicator, compass, tachometer, oil pressure gage, oil temperature gage, turn and bank indicator, directional gyro, and gyro horizon. Before describing their operation and functions, it is necessary to discuss two other fundamental aircraft accessories which are part of the instrument system, i.e., the pitot-static tube and the venturi tube.

Pitot-Static Tube

The airplane's pitot-static tube (Figure 66) furnishes accurate measurements of (1) impact (pitot) and (2) static pressures. The pitot-static tube is composed of two separate tubes of seamless brass tubing mounted together in a housing or head. Specifically, the pitot-static tube is used to supply impact pressure to the sensitive element in the airspeed indicator and to maintain static pressure inside the housing of the airspeed indicator, altimeter, and rate of climb instrument. The pitot-static tube is positioned on the airplane so that its axis is parallel to the longitudinal axis of the airplane. It is attached to the airplane in a location that is away from the propeller's slipstream and in undisturbed air.

The pitot tube is open on the front so that it is subjected to the full impact of the air pressure which is created by the forward motion of the airplane. The static tube, however, is closed on the front end with holes drilled into its sides, top, and bottom in order to subject it to the pressure of the static or still air.

The pitot and static pressures obtained from these tubes are transmitted to the cockpit instruments by air-tight tubing. The instrument connection points for this tubing are always marked with "P" for pitot pressure and "S" for static pressure, to make easy, sure

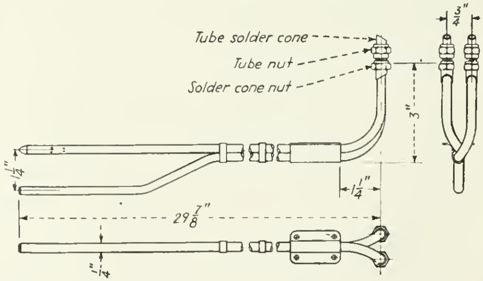


Figure 66—Standard Pitot-Static Tube. 1. Solder Cone Nut; 2. Tube Nut; 3. Tube Solder Cone.

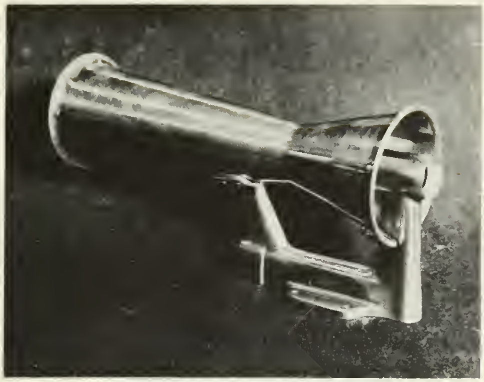


Figure 67—Venturi Tube

mechanical connections. Water, snow, ice, or other foreign matter which enters the pitot tube results in either restriction or complete stoppage of the air flow. Stoppage, of course, causes either inaccurate readings or complete operational failure of the airspeed indicator instrument.

Venturi Tube

The airplane's venturi tube (Figure 67) develops suction or lower than normal atmospheric sea-level pressure. This suction operates vacuum-driven instruments on those aircraft which do not have engine-driven vacuum pumps.

Although the hollow venturi tube flares out on both ends, it has a restriction in the "throat" of the tube. When air passes through the throat of the tube, the velocity of the air increases, thereby causing a decrease in the air pressure. A tube connected to this restricted portion of the venturi then develops a pressure which is lower than the normal atmospheric sea-level pressure. A four-inch venturi, for example, causes a three-pound-per-square-inch drop in pressure, i.e., to 11.7 psi. Vacuum or suction is measured by an instrument which is calibrated in inches of mercury. Each inch of mercury weighs .49 lbs. per inch.

Venturi tubes, like pitot tubes, are mounted outside the airplane and freeze or restrict when subjected to ice and snow; therefore, an engine-driven vacuum pump is usually considered more dependable.

The Airspeed Indicator

The airspeed indicator is a flight instrument which aids in (1) determining the best climbing and gliding angles, (2) selecting the most satisfactory power settings for efficient flying speeds, and (3) maintaining the speed of the airplane within its safe operating limits.

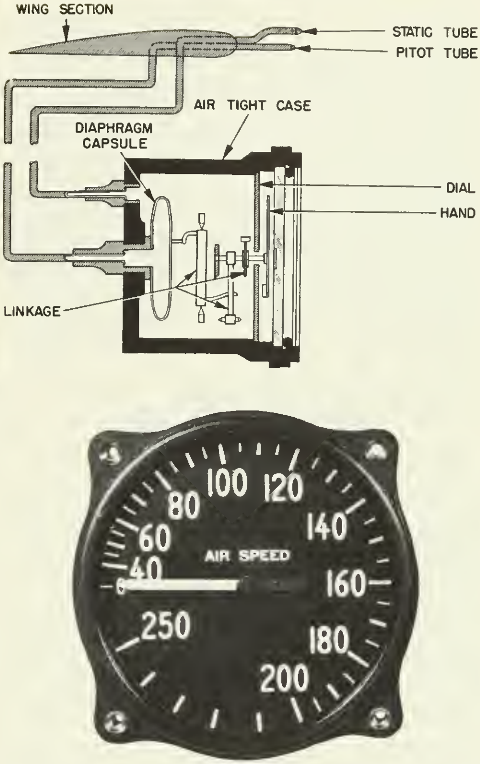


Figure 68—The Pitot-Static Tube Showing the Connections to the Airspeed Indicator

The airspeed indicator is composed of an air-tight case and a sensitive diaphragm capsule. The air-tight case is connected to the static tube, which keeps it at existing atmospheric pressure at all times. The diaphragm capsule is connected to the pitot tube. As the airplane moves through the air, the pitot pressure causes the diaphragm to expand with an increase in speed and to contract with a decrease in speed. The difference between pitot pressures in the diaphragm and static pressures in the air-tight case operates a series of gears and levers which visually show the indicated airspeed (IAS), either in statute miles per hour or nautical miles (knots) per hour, on the face of the dial. (Figure 68.)

The dial shows the indicated airspeed at which the airplane is moving through the air. This indicated airspeed is always different from true ground speed, except in still air at normal sea-level atmospheric pressure. The pilot, however, is always able to calculate his ground speed from his indicated airspeed if he knows both the altitude at which he is flying, the temperature at that altitude, and the direction and speed of the wind. As the airplane gains altitude, the air becomes less dense and creates a lower atmospheric pressure. This lower atmospheric pressure affects the accuracy of the airspeed instrument, thereby necessitating the use of a correction factor to recalculate the true airspeed (TAS)—2 per cent for each 1000 feet of altitude, i.e., for each 1000 feet of altitude, the airplane actually travels 2 per cent faster than the airspeed indicator reads. For example, at 5000 feet of altitude the airspeed indicator reads 150 mph. Applying the correction factor:

$$\text{TAS} = 150\text{ mph} + (2\% \times 5000\text{ ft.} \times 150\text{ mph})$$
$$\text{TAS} = 150\text{ mph} + (.02 \times 5 \times 150)$$
$$\text{TAS} = 150\text{ mph} + 15\text{ mph}$$
$$\text{TAS} = 165\text{ mph}$$

It must also be borne in mind that if an airplane is flying at 100 mph, True Indicated Air Speed (TIAS) into a 20-mph headwind, the actual speed with respect to the ground (GS) would be only 80 mph. (See definition of Calibrated Air Speed in Appendix.)

The reliability of the airspeed indicator is dependent upon (1) the pressures delivered to the airspeed indicator's mechanism by the pitot-static tube, and (2) the accurate response of this mechanism to the pitot-static tube pressures.

The Altimeter

The altimeter, a flight instrument, has two specific functions:

1. To measure the elevation of the aircraft above any given point on the ground regardless of that point's elevation above sea level. This altitude measurement method is called the "Field Elevation Pressure" system and represents the field elevation barometric pressure at a point which is 10 feet above the average elevation of the airport's runways.

2. To measure the altitude of the airplane above sea level. This altitude measurement method is called the "Altimeter Setting" system and represents atmospheric pressure, in inches of mercury, at normal sea-level pressures. Thus, the altimeter—an aneroid barometer—(Figure 69) is a sensitive instrument, calibrated in feet of altitude instead of inches of mercury, which measures atmospheric pressure.

The aneroid is either a sealed diaphragm capsule or a metal cell enclosed in an airtight case which is connected to the static tube. Atmospheric pressures from the static tube act on the capsule by either compressing or expanding the diaphragm. The movements of the diaphragm are then transferred, through a system of levers and gears, to indicating hands on the face of the altimeter. As the airplane's altitude increases, atmospheric pressure decreases and allows the sealed diaphragm to expand. The amount of expansion controls the hands on the face of the altimeter. As the airplane descends, however, the increase in atmospheric pressure causes the diaphragm to contract and indicates a decrease in altitude. Atmospheric pressures

Figure 69—Altimeter

constantly change and whenever a change in pressures occurs the altimeter hands move—even when the airplane is in a stationary position on the ground.

Because of the changing barometric pressure, the altimeter fails to indicate the correct height unless other means are provided to keep it accurate, such as a knob on the front of the instrument. If a pilot, flying locally, wants to know his height above that particular airport, he sets the dial hands, before takeoff, to read "zero." After takeoff, the altimeter indicates his altitude only above that airport. The above description is an example of how the Field Elevation Pressure system is used to indicate altitude.

If a pilot is flying cross-country, he uses the Altimeter Setting system because he must know his specific height above sea level. All map elevations are given in terms of height above sea level. Prior to takeoff the pilot will set his altimeter, by means of the knob, at the surveyed elevation of his departure airport rather than on zero. On this setting the reading on the barometric scale will be the local pressure corrected to sea level barometric pressure. After takeoff, the altimeter indicates the airplane's altitude above sea level rather than the altitude above the surveyed airport's elevation.

Rate of Climb Indicator

The rate of climb indicator, a flight instrument, is also called a vertical speed indicator and is used to show either a gain or a loss of altitude regardless of the atitude of the aircraft. Specifically, it is used (1) to show rate of ascent or descent, (2) to accomplish banked turns without gain or loss of altitude, and (3) to establish constant and definite rates of descent when making instrument landings.

The rate of climb instrument (Figure 70) also consists of a metal diaphragm enclosed in an airtight case. The diaphragm is connected to the static tube and the air-tight case is sealed except for a small, calibrated leak which leads to the internally-connected static line. The capsule—diaphragm—is subject to the ascending and descending pressure changes. To measure this rate of change in atmospheric pressure, the dial hands indicate a rate of change in feet per minute. The static

Figure 70—Vertical Speed Indicator

pressure inside the capsule or diaphragm changes faster than the air pressure inside the case because the small-size hole in the case permits a calibrated leak. Normally, when the airplane is neither ascending nor descending, the pressure both inside and outside the capsule is equal, and the instrument hand reads "zero."

The face of the instrument is marked both in a zero-to-2000-feet clockwise direction and a zero-to-2000-feet counterclockwise direction. Each increment or marking represents 100 feet per minute. The unit pointer—hand—rotates from the zero mark in either a clockwise or counterclockwise direction. Normally, the instrument has a sector stop which limits the motion of the pointer, for either ascent or descent, to 1900 feet per minute. All rates of climb have an inherent lag of six to nine seconds because of a built-in restriction which prevents instrument oversensitiveness which might be caused by bumpy air.

The Magnetic Compass

The magnetic compass (Figure 71) is a navigational instrument used to indicate the heading on which the airplane is flying. The magnetic compass consists of a metal bowl filled with a liquid and a numbered, magnetic card element which has attached to it a system of magnetized needles. This card and the magnetized needles are suspended on a pivot and are always free to turn. The magnetized needles normally point toward magnetic north. The magnetized card is calibrated into a 360-degree circle. A reference line, called the *lubber line,* and the graduations of the card are always visible through a glass window on the front of the bowl.

Figure 71—Magnetic Compass

The liquid inside the instrument—a mixture of kerosene and mineral oil which will not freeze—dampens the oscillations of the card. There is also an expansion chamber built into the compass to provide for expansion and contraction of the damping fluid—which would result from altitude and temperature changes. The magnetic compass also has permanent magnets located above the card, which compensate for compass deviations that are caused by radio, electrical equipment, and metal parts of the airplane. The compensating assembly, or magnets, may be rotated by adjusting screws which are marked N-S and E-W on the face of the magnetic compass.

The compass is mounted in the airplane so that the lubber line and the card pivot are aligned parallel to the longitudinal axis of the airplane. The magnetic compass is the only instrument in the airplane which indicates earth's magnetic north.

The magnetic compass, however, is subject to errors which must be taken into consideration "when establishing a true heading." Variation is caused by the difference in the geographical location between the True North and the Magnetic North. Since the magnetic compass always points to Magnetic North, magnetic variation is always indicated on aeronautical charts.

Errors in the magnetic compass can also be caused by acceleration, turning, and by bumpy or rough air since the card swings while it tries to keep itself aligned with Magnetic North.

Tachometers

The tachometer is an engine instrument and is used to measure the engine crankshaft speed in revolutions per minute (rpm).

On airplanes equipped with fixed pitch or adjustable pitch propellers this instrument is of primary importance because engine speed is directly related to the power output of the engine. The tachometer responds instantly to any change in engine speed.

Some specific uses of the tachometer, when used on airplanes with fixed pitch propellers, are (1) to test the engine and magnetos prior to takeoff, (2) to aid the pilot in selecting the best power settings, (3) to indicate a loss in power, and (4) to indicate safe operating limits of the engine.

There are two types of tachometers used on modern airplanes: (1) magnetic tachometers, and (2) electric tachometers.

MAGNETIC TACHOMETER

The magnetic tachometer (Figure 72) derives its name from its internal mechanism. It is similar to and works on the same principle as an automobile speedometer except that it is calibrated in revolutions per minute (rpm) instead of miles per hour (mph). The magnetic tachometer is driven by a flexible shaft encased in a metal housing. On some of the smaller engines the flexible tachometer shaft is driven from an extended shaft on one of the oil pump gears located on the back of the engine. On other engines a special tachometer drive is used which consists of a gear train meshing with an accessory gear on the back of the engine.

The mechanism of the tachometer consists of a rotating magnet, a round drum, and a hairspring. The rotating magnet is driven by the tachometer shaft through suitable couplings. The round drum or cup fits loosely over the rotating magnet and is fastened to a staff or shaft which is geared to the pointer shaft. The hairspring is attached to the shaft on the drum. When the rotating magnet is turned, the force or pull of the magnetic field pulls the drum against the force of the hairspring. When the force of the magnet equals the strength of the spring, the drum turns and rotates the pointer shaft by means of the gearing. The faster the rotating magnet turns, the more lines of magnetic force are applied to the drum, causing the pointer to move and thereby show an increase in rpm. The face of the instrument is calibrated in increments of 100 rpm.

Figure 72—Magnetic Tachometer

Figure 73—Electrical Tachometer

ELECTRIC TACHOMETER

The electric tachometer (Figure 73) consists of two units: the indicator, which is mounted on the instrument panel, and the generator, which is attached to the tachometer drive of the engine. The two units are connected by means of an insulated electrical cable. Because this instrument needs no flexible tachometer shaft to drive its mechanism, it is readily adaptable to multi-engine installations and to those aircraft where the distance from the engine to the instrument panel is excessive. The electric tachometer is actually a voltmeter, but calibrated in revolutions per minute instead of in volts. The mechanism, contained in the indicator unit, is a permanent magnet with a moving coil connected to a pointer. The moving coil moves within the air gap of the permanent magnet. The pointer and coil movement are dampened by a hairspring and are mounted in jewelled bearings which permit steady and accurate readings. The electrical output of the tachometer generator is routed through a coil in the indicator unit. As engine speed increases the tachometer generator increases its energy output. This increased voltage feeds into the moving coil of the indicator unit and causes the coil to move against the restraining hairspring, thereby indicating an increase in rpm. A decrease in engine speed results in a decreased voltage output of the tachometer generator and the hairspring is then able to overcome the attraction between the coil and the permanent magnet, thereby causing the pointer to move toward the lower end of the scale.

Oil Pressure Gage

The oil pressure gage (Figure 74) is an engine instrument required on all airplanes. It shows the pressure at which the lubricant is being forced into the bearings and to the other points of the lubricating system. Among the uses of the oil pressure gage are (1) a warning of an impending engine failure if the oil pump fails or oil lines break, and (2) visual indi-

Figure 74—Oil Pressure Gage

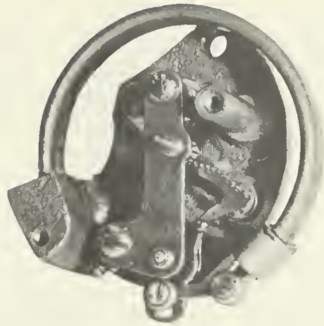


Figure 75—Bourdon Tube

cation that oil is circulating under proper pressure before takeoff.

The oil pressure gage is calibrated in pounds per square inch (psi). The instrument contains a Bourdon tube mechanism (Figure 75) which is used in almost all fluid pressure gages. A Bourdon tube is a hollow curved tube made of spring-tempered brass or bronze and has an elliptical cross-section. It is sealed at its outer end. The outer end of the tube is free to move, while the other end is rigidly fastened to the instrument case. The outer or free end of the tube is attached to a lever and gear segment which actuates the pointer. The stationary end of the tube has an opening connected to a fitting on the back of the instrument case. The fitting has a restriction to prevent surging and oscillation of the pointer. An oil line from a high pressure passage in the engine connects to the restricted fitting on the back of the instrument case. When the engine is started, some pressure should be indicated on the oil pressure gage almost immediately. If no pressure is indicated after thirty seconds of operation, the engine should be shut off and the cause for operational failure investigated so as to prevent damage to the engine.

Oil Temperature Gage

The oil temperature gage (Figure 76) is an engine instrument used on all aircraft. The Federal Aviation Agency requires a suitable means for taking the oil temperature as it enters the engine. This FAA requirement is important since oil plays a big part in the cooling of aircraft engines.

The oil temperature gage is used (1) to enable the pilot to operate the engine within safe operating temperatures, and (2) to warn the pilot of engine overheating. The oil temperature gage used on most aircraft is a vapor pressure type thermometer and is calibrated in degrees of Fahrenheit or Centrigrade.

Figure 76—Oil Temperature Gage

A vapor pressure thermometer consists of three units: the indicator unit, which is mounted in the instrument panel; the bulb, which is located at the point of temperature measurement; and the capillary tube, which connects the indicator to the bulb.

The indicator unit contains a Bourdon tube mechanism similar to the oil pressure gage except that the Bourdon tube also has a *progressive restrainer* to permit the use of a uniformly graduated scale. The progressive restrainer is necessary because vapor pressure does not increase uniformly with temperature. The bulb is a hollow brass cylinder about three inches long and one-half inch in diameter. It contains a volatile liquid, methyl chloride, which actuates the instrument or indicator unit.

The capillary tube is a very small annealed copper tube protected with either a shield of braided wire or a helical wound tube. The capillary tube connects the bulb and the indicator unit and is used to transmit the vapor pressure from the bulb to the opening in the Bourdon tube.

The operation of the vapor pressure thermometer is entirely automatic. As the temperature of the bulb increases, the liquid methyl chloride, being very volatile, changes to a gas. This change causes an increase in pressure which is transmitted through the capillary tube to the Bourdon tube. The Bourdon tube tends to straighten out and its movement is transmitted through the linkage to the pointer on the face of the gage.

The three units of a vapor pressure thermometer are integrated and cannot be taken apart without losing the gas and thereby rendering the instrument useless. For this reason care must be taken to prevent cutting, denting, or stretching the capillary tube.

Turn and Bank Indicator

The turn and bank indicator (Figure 77) is a flight instrument which is actually a combination of two instruments. It combines an inclinometer—a pendulous device—and a rate of turn indicator—a gyroscopic de-

Figure 77—Turn and Bank Indicator

vice. It is becoming a widely-used flight instrument, especially under conditions of poor visibility.

The turn and bank indicator enables the pilot (1) to maintain straight and laterally level flight, (2) to make precision turns at pretermined rates, and (3) to coordinate rudder and ailerons when making banked turns. It may be either a vacuum-operated instrument or an electrically-driven instrument. Both types operate in the same manner and on the same general principles.

The turn indicator portion indicates motion about the vertical axis of the airplane and measures the rate of this motion. It is composed of a suction or vacuum-driven gyro rotor located in the rear of the instrument case, a restraining spring, a dashpot for damping, and an indicator needle or hand to indicate the rate of turn. The dial is marked with the letters "L" and "R" and also has a neutral position with an index mark on each side. The index marks indicate a timed one-minute turn of 360° when the needle coincides with the index. The turn indicator operates on the gyroscopic principle of *precession*. Due to the rigidity of

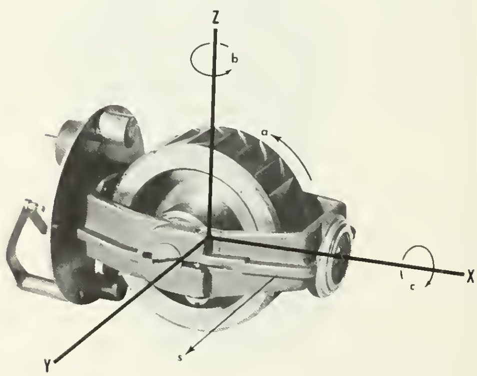


Figure 78—The Gyro Assembly

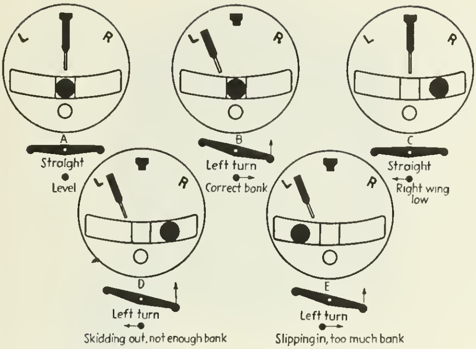


Figure 79—Visual Indications of Various Turn and Bank Conditions

a spinning gyro, it tends to precess at right angles to an applied torque. The gyro rotor is mounted so that it turns about the lateral axis of the airplane. When mounted in this manner, the gyro responds only to motion about the vertical axis of the airplane.

If the airplane turns to the left, (Figure 78) the gyro assembly rotates as indicated by the arrow "b." The immediate reaction of the gyro to this turning force is a rotation "c" about the "X" axis until "Z" has aligned itself with the original position of "Y." This is the natural reaction of a gyro *mounted in this manner* and is called precession.

The precession of the gyro, or its reaction to the applied torque, acts against the force of a restraining spring and is limited by stops to a movement of about 45 degrees from each side of the vertical. The spring serves to balance the gyroscopic reaction or precession during a turn and to return the assembly to its neutral or vertical position as soon as the airplane assumes a straight flight pattern. The action of the gyro assembly is damped by the dashpot and when properly adjusted the displacement of the gyro and the needle is directly proportional to the rate of turn of the airplane. When centered, the needle shows that the airplane is flying straight, disregarding drift, pitch, and bank. When the needle is off center it indicates that the airplane is turning in the direction shown by the needle. Figure 79 shows indicator readings for several different conditions.

The bank indicator portion of the instrument consists of a black glass ball inside a curved glass tube. The glass tube contains a nonfreezing liquid which serves as a damping fluid. The bank indicator or inclinometer is located in the front of the instrument case and is visible through the instrument's glass cover.

The action of the bank indicator can be compared to a pendulum which is acted upon by centrifugal force. It shows motion about the longitudinal axis of the airplane. When the airplane is making a perfectly banked turn, the ball, due to centrifugal force, remains in the center of the glass. The correct bank is always indicated for any turn, but no indication is ever given of the amount of bank. In straight flight or in a turn, the centered ball indicates proper lateral attitude of the airplane. If the ball moves in the direction of the turn, it indicates that the airplane is slipping, i.e., the angle of bank is too steep. If the ball moves in a direction opposite to the turn, it indicates that the airplane is skidding toward the outside of the turn, i.e., the airplane is not banked enough.

The indications of these two instruments combined in one dial always show the rate of turn and the lateral attitude of the airplane during straight flight or during turns.

The Directional Gyro

The directional gyro is a navigational instrument sometimes called a gyro compass or a turn indicator. This instrument establishes a fixed reference point to assist the pilot in maintaining flight direction. Unlike a magnetic compass the directional gyro has no directive force to return it to a fixed heading. It must be checked occasionally and, if necessary, reset by a caging knob.

The directional gyro (1) supplements the compass in keeping "on course," (2) shows the amount of turn, (3) maintains alignment when making instrument landings, and (4) aids in locating radio beacon stations. (Figure 80.) It is a horizontal, axis-free compass provided with an azimuth card and a setting device. The instrument, itself, is vacuum operated by suction from the engine-driven vacuum pump or the venturi tube.

The spinning gyro rotor is mounted horizontally and is supported in a gimbal ring which is free to turn about an axis on bearings in the vertical ring. The ver-


Figure 80—Directional Gyro

tical ring is mounted in bearings and is free to turn about the vertical axis. The circular azimuth card visible through the instrument cover glass is graduated in degrees and is attached to the vertical ring. A caging knob in the front of the instrument is used to set the card on a desired heading and to cage the gyro. When the knob is pushed in, it engages a pinion gear to a gear attached to the gimbal ring. By turning the knob, when it is thus engaged, the gimbal ring, vertical ring, and azimuth card can be rotated to any desired heading. The rotor, spinning at approximately 12,000 rpm, obeys a gyroscopic principle of rigidity. Thus the rotor, gimbal ring, and the circular azimuth card remain fixed, the airplane moving around them.

When establishing a course, the pilot refers to the magnetic compass, then cages the gyro and selects a heading by use of the caging knob. After setting the card, the knob is pulled out, and the instrument is then in operation and will function properly until it is either upset or recaged.

Any bank in excess of 55 degrees will upset the gyro and cause the card to spin. The airplane must then be leveled, the gyro caged, and reset. The directional gyro will gradually drift off a heading over a period of time and should be reset at 15-minute intervals. Gyro drift should not exceed 5 degrees in 15 minutes on any single heading. Care should be taken in both setting the instrument and uncaging the gyro. The knob must always be pulled straight out with no turning motion. If the knob is turned, even slightly, the card will begin to turn slowly and the instrument's natural tendency to drift off course will be speeded up.

The Gyro Horizon

The gyro horizon (Figure 81) is a flight instrument often called an *artificial horizon* or an *attitude gyro.* By visually showing a miniature airplane and a gyro-actuated horizon, the pilot can look at the instrument and determine his flight attitude without reference to the ground.

The gyro horizon (1) enables the pilot to orient himself under conditions of poor visibility by providing a reference in the form of an artificial horizon; (2) shows the attitude of the airplane's flight with reference to the real horizon and to the ground; and (3) aids in maintaining the proper glide angle when making an instrument landing.

The gyro horizon is a vacuum-driven instrument which utilizes vacuum or suction from the vacuum pump or venturi tube as its source of power. The instrument has a gyro rotor, which spins at approximately 12,000 rpm, mounted in a case. The rotor is mounted so that its axle is vertical, thus allowing it

Figure 81—Gyro Horizon

to spin in a horizontal plane. The case contains the rotor, on pivots, which is attached to a gimbal ring The horizon bar is attached to an arm pivoted at the rear of the gimbal ring and is controlled by the gyro through a guide pin. This entire assembly is mounted on pivots located at the front and the back of the case. The dial is an integral part of the gimbal mount and follows the precession movement of the rotor. A miniature airplane image is located on the front of the instrument and is adjustable. The gyro horizon always indicates the attitude of the airplane in which the instrument is mounted.

A caging knob is located on the front of the instrument to level the internal mechanism properly when it is upset. The limits of operation of the gyro horizon are 60 degrees of pitch and 90 degrees of bank. Anytime that these limits are exceeded, the mechanism will be upset and its readings will be erroneous.

The gyro horizon operates on the same fundamental gyroscopic principle as the directional gyro, i.e., rigidity. When the rotor is spinning, it will maintain itself in its plane of rotation unless upset. On the face of the instrument the position of the gyro rotor is indicated by the horizon bar, which is actuated by a pin protruding from the gyro case through a slot in the gimbal ring. Any tendency of the gyro to depart from its true position is corrected by a pendulous device which constantly maintains the axle of the gyro in its vertical position.

The horizon bar remains stationary. Only the instrument case and the miniature airplane move when the airplane is banked, nosed up, or nosed down. To keep the airplane laterally level, the miniature airplane is kept parallel to the horizon bar. To keep the airplane longitudinally level the miniature airplane must keep the same position with reference to the horizon bar as the nose of the airplane keeps with reference to the earth's horizon. Sometimes this may be a slightly nose-up or nose-down attitude, depending on power and load. The easiest way to determine the correct position of the miniature airplane with respect to the horizon bar is to observe the rate of climb indicator. If this instrument indicates level flight with neither a rate of ascent nor a rate of descent, then the miniature airplane can be manually set to coincide with the horizon bar. A graduated scale from 0 to 90 degrees both left and right are located on the outer circumference of the instrument face to indicate the degree of bank. An index mark is provided on the curved portion of the dial as a reference point.

Summary

As the design of the modern airplane has become more complicated over the years, it has resulted in an increased number of complex mechanical devices, designed to measure the performance of the airplane. These instruments are divided into three classes: (1) flight, (2) engine, and (3) navigation. The aircraft and engine manufacturers, in cooperation with the Federal Aviation Agency, have established safe operating limits for the airplane's airframe and engine. These safety limits are indicated either by markings on the instruments or by placards in the cockpit.

The pitot-static tube and the venturi tube are necessary to the proper operation of many of the airplane's instruments. Some airplanes, however, use a vacuum pump instead of a venturi tube to supply suction for the gyro instruments.

Flight instruments include the airspeed indicator, altimeter, rate of climb indicator, turn and bank indicator, and the gyro horizon. The airspeed indicator is the airplane's speedometer, measuring the airplane's speed through the air rather than over the ground. The altimeter indicates the airplane's altitude either above the airport or above sea level. The rate of climb indicator shows that the airplane is either ascending or descending. The turn and bank indicator demonstrates the airplane's angle of bank and rate of turn. The gyro horizon is a visual aid which represents the attitude of the airplane with respect to the earth's horizon.

Engine instruments include the tachometer, oil pressure gage, and oil temperature gage. The tachometer shows the engine speed and in some cases indicates the power output of the engine. The oil pressure gage indicates the amount of pressure of the oil when it is circulating in the engine. The oil temperature gage provides a means of determining oil and engine temperatures.

The two navigation instruments are the magnetic compass and the directional gyro. The magnetic compass always points to the earth's Magnetic North and provides the pilot with a means by which he can determine the direction of the airplane's flight path. The directional gyro serves as a fixed reference point and aids the pilot in maintaining directional control of the airplane.

Questions

1. How may the safe, economical and reliable operation of an airplane best be determined?
2. How are instruments classified?
3. Who determines the safe operating limits of an airplane?
4. What determines instrument requirements?
5. What is a venturi tube used for?
6. How does a venturi tube cause a decrease in pressure?
7. What is the disadvantage of a venturi tube as compared to an engine driven vacuum pump?
8. If an airplane was traveling 150 mph with a tailwind of 20 mph, what would its groundspeed be?
9. What instrument is used to determine the best climbing and gliding angles?
10. What is the primary difference between a Gyro compass and a magnetic compass?
11. Which flight instrument would indicate the rate of change in altitude?
12. Why would a pilot use the altimeter setting system when flying cross country?
13. Is compass deviation the same as magnetic variation?
14. Which instrument would be used to indicate power setting on an airplane with a fixed pitch propeller?
15. Why is oil temperature so important on an aircraft engine?
16. Which flight instrument is best suited to indicate a proper banked turn?
17. What would be indicated to the pilot if the black ball of the turn and bank moved in a direction opposite the turn?
18. Which flight instrument would show the attitude of the airplane's flight with reference to the earth's horizon?
19. Which navigation instrument aids the pilot in determining direction other than the magnetic compass?
20. What advantage does the electrical tachometer have over the magnetic tachometer?

Chapter 7 Flight Technique

The flight techniques employed by the Wright brothers during their experimental flights at Kitty Hawk in 1903 are comparatively the same as those used by modern-day pilots. This chapter will discuss the primary techniques which all pilots employ whether they are flying small, propeller-driven aircraft or huge jet-propelled airliners.

Airplane Attitude and Controls

When discussing flight maneuvers, the word "attitude" is frequently used. Attitude describes the position of the airplane in space with respect to the ground, i.e., it defines the "squareness with the earth" of the wings and fuselage. For example, a nose-high or climbing attitude would mean that the longitudinal axis of the airplane is inclined upward with respect to the plane of the earth's surface.

Attitude must not be confused with either the *angle of attack* or the *flight path*. The flight path is the direction, up and down as well as sideways, taken by the airplane and is a result of attitude and power. The angle of attack is the angle at which the wing strikes the air.

The four fundamental flight attitudes are (1) straight and level flying, (2) climbing, (3) gliding, and (4) turning. All four attitudes are controlled from the cockpit by the elevator, the ailerons, and the rudder controls (Figure 82) while altitude is controlled only by the throttle or power setting.

CONTROLS

The *throttle* controls the engine power, which, through the propeller, develops the thrust that propels the airplane through the air. Airflow around the wing produces the lift which enables the airplane to climb, descend, fly straight and level, or make turns.

The *elevator control* (Figure 82) (stick or control column) moves the hinged elevator up or down. In normal flight, movement of the control forward depresses the elevator, raises the tail, and makes the nose point downward. Movement of the control to the rear raises the elevator, depresses the tail, and makes the nose point upward.

The hinged *rudder* (Figure 82), controlled by the rudder pedals, *yaws* or swings the airplane about its vertical axis, i.e., points the nose toward the right or left. For example, right rudder pressure moves the trailing edge of the rudder to the right and causes the airplane's tail to swing to the left and the nose to the right. Left rudder pressure moves the trailing edge of the rudder to the left and causes the airplane's tail to swing to the right and the nose to the left.

The *ailerons* (Figure 82), connected to the stick or wheel, give the airplane a rolling motion. Movement of the stick (or wheel) to the right depresses the left aileron and raises the right aileron, thereby increasing the lift of the left wing and decreasing the lift of the right wing. This action causes the airplane to roll to the right. Pressure on the stick (or rotation of the wheel) to the left has the opposite effect.

STRAIGHT AND LEVEL FLIGHT

During *straight and level* flight the throttle is set to produce constant power when the rudder, elevators and ailerons are streamlined, i.e., lined up with their respective fixed surfaces—rudder with fin, elevators with horizontal stabilizer, and ailerons with wing. In straight and level flight the lateral and longitudinal axes of the airplane are parallel to the earth's surface, and the yawing or vertical axis is perpendicular to the earth's surface.

If this straight and level flight attitude is disturbed by rough air or by movement of the controls, it is corrected by the coordinated use of stick (or wheel) and rudder. As will be explained in detail later, the rudder and ailerons are always used together. For

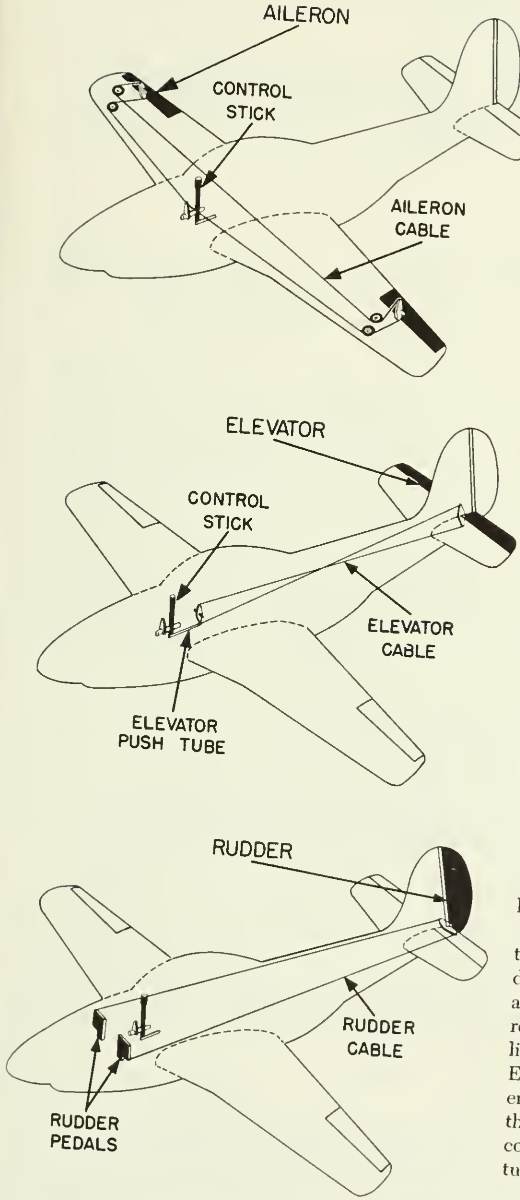


Figure 82—Schematic Diagram of the Controls, Control Cables and Control Surfaces of an Airplane

example, when a gust of wind banks an airplane, the rudder as well as the ailerons must be used to return the airplane to level flight.

During straight and level flight, two factors affect attitude—*airspeed* and *load*. (Figure 83.) During flight at slow airspeed or when the airplane is heavily loaded, the angle of attack must be increased to produce the needed lift required to maintain level flight at a given power setting. This is accomplished by changing the airplane's attitude to a slightly nose-high position and at the same time adjusting the elevator *trim tab* so that it will maintain the new attitude.

THE CLIMB

To *climb* an airplane the pilot will add power and change the airplane's attitude to a slightly nose-high position (Figure 84), since the addition of power and an increased angle of attack will increase the lift and thereby raise the airplane. This procedure may best be compared to driving an automobile up a hill. To go uphill at the same speed at which he drives on a level road, an automobile driver must "step on the gas"; that is, he must increase engine power since it takes more effort to raise the weight of the car while propelling it at the same speed. If the driver did not increase the power, the automobile might still get to the top of the hill, but its speed would gradually lessen to a rate slower than that which it had maintained on the level road.

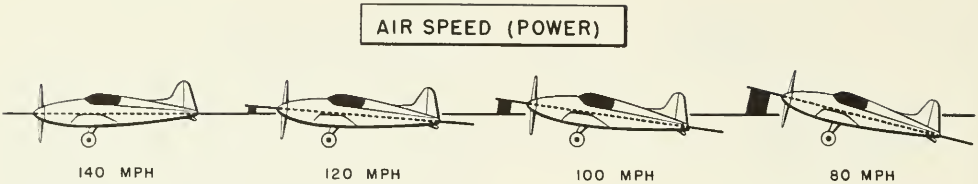
The same reasoning applies to airplanes, which will climb at constant power settings but at a sacrifice of speed or will climb with added power at no sacrifice in speed. Thus, a definite relationship between engine power, airplane attitude, and airspeed is realized.

THE GLIDE

A *glide* is a descent at a normal angle of attack with little or no thrust from the engine.

When the engine of an airplane in level flight is throttled, the thrust needed to balance the airplane's drag is absent. Since drag is now the primary force, a reduction in speed occurs. The decrease in speed results in a decrease in lift. Since weight now exceeds lift, the flight path of the aircraft curves downward. Earth's gravity is substituted for the power of the engine and supplies the thrust at this time. In effect, the airplane is going "downhill." The pilot, however, controls the airspeed by adjusting the airplane's attitude with the control column.

In any given attitude when the thrust, supplied by gravity, equals the drag, the airspeed remains constant. Thus, once again the forces are balanced—thrust equals drag and lift equals weight—and the



aircraft descends at a constant rate and at a constant airspeed.

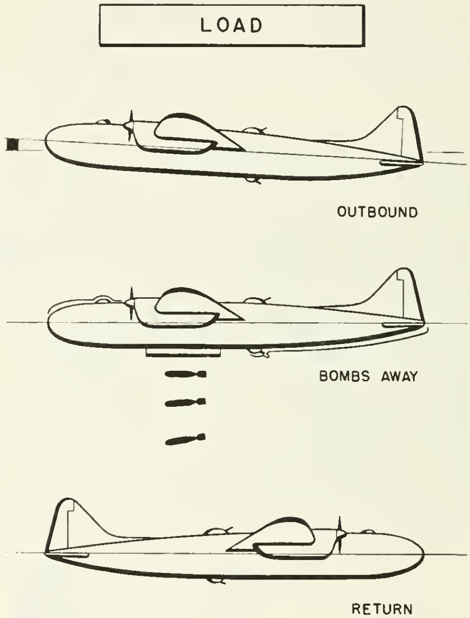
This rate of descent cannot be controlled by changing the airplane's attitude. If the nose were raised, for example, the speed would decrease and lift be reduced in the same proportion that lift was increased when the angle of attack was increased. Consequently, there is no change in either the lift or the rate of descent. In contrast, if the nose were lowered, the angle of attack would decrease and the speed increase, again without noticeable effect on lift or rate of descent. The only way in which a pilot can control the rate of descent is by changing the power setting, i.e., the rate of descent can only be reduced by increasing the angle of attack and by keeping the same airspeed through an addition of power. Once again a definite relationship between engine power, airplane attitude, and airspeed is apparent.

THE TURN

An airplane, like any moving object, requires a sideways force to make it turn. In a normal turn this force is developed by *banking* the wings so that lift, which always acts perpendicular to the *span line* of the wings, is exerted sideways as well as upward.

The lift in a turn is divided into two parts: one acting vertically and opposite to the force of gravity; the other acting horizontally and in the direction of the turn. (Figure 85.) When the airplane is banked the horizontal lift pulls the airplane sideways and as the banked airplane is pulled to the side, the air pressure on the vertical side of the tail surfaces pushes the tail around the turn in much the same way that a weathervane is turned when wind blows on it from the side. As long as the airplane is banked, this weathervaning takes place and results in a continuous turning movement.

In a properly executed turn, therefore, the turning force is not supplied by the rudder since an aircraft cannot be steered around a corner in the same manner as an automobile; it must be banked. If an airplane is not banked, there is no force to pull it from a straight flight path, unless the aircraft is *skidded*.



FACTOR	ATTITUDE
AIR SPEED —LOW HIGH	NOSE-HIGH LEVEL OR NOSE-LOW
LOAD-HEAVILY LOADED EMPTY	NOSE-HIGH LEVEL OR NOSE-LOW

Figure 83—The Factors Affecting Attitude

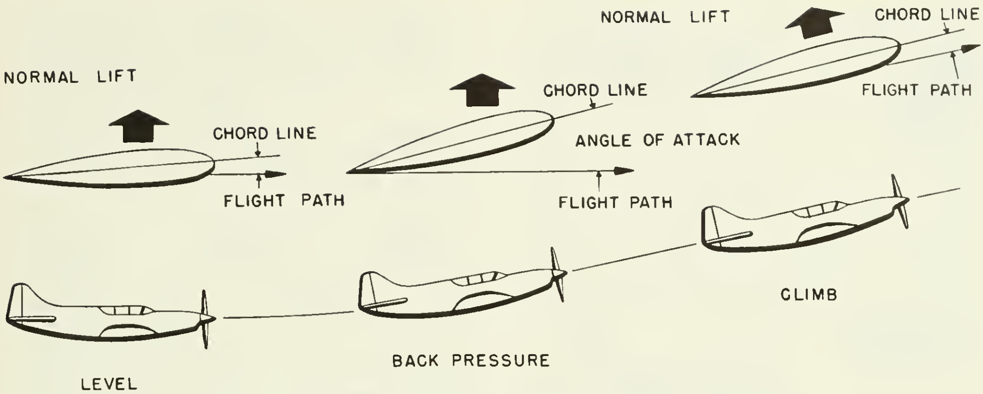


Figure 84—The Aerodynamic Functions of an Airplane Wing in a Climb with Power Constant

USE OF RUDDER IN A TURN

During entry into and recovery from turns, and at any other time that the ailerons are used, the rudder is used to counteract aileron drag, often known as the *adverse yaw* effect. Adverse yaw is the tendency of an airplane to swing (yaw) momentarily toward the side of the down-turned aileron, or away from the desired direction of turn. Adverse yaw is caused by an increased drag of the lowered aileron on the wing which is being raised.

When right stick, for example, is applied, one would expect the airplane to bank and to turn to the right. However, as soon as aileron is applied the drag produced by the lowered left aileron holds back the left wing, causing the nose to swing momentarily to the left. When the airplane begins to bank to the right, the inclined lift force then pulls the airplane into a right turn.

Adverse yaw is nullified by applying rudder and aileron control at the same time. In the above example, right rudder used in coordination with the right aileron swings the nose of the airplane immediately to the right, balancing the adverse yaw effect to the left. After the bank is established, both the rudder and aileron controls are returned to a center or neutral position.

OVERBANKING TENDENCY

When the airplane is in a turn, the wing on the outside of the circle travels faster than the wing on the inside of the circle, e.g., a person sitting on the outside edge of a merry-go-round moves faster than a person sitting nearer to its center. The greater speed of the outer wing causes it to have more lift than the inner wing and therefore the airplane has a tendency to overbank. This overbanking tendency is counteracted by applying opposite aileron.

LOSS OF VERTICAL LIFT

As illustrated in figure 86, banking the airplane causes a loss of vertical lift, i.e., the airplane will lose altitude in a turn unless the vertical part of the lift is increased to equal the weight of the airplane. An increase in vertical lift is produced by increasing the angle of attack with the elevators. As the angle of attack is increased, the drag also increases and slows the airplane. Therefore, in order to maintain a constant airspeed, more power must also be added.

RATE OR TURN

At a given airspeed, the rate at which an airplane turns depends upon the force which is pulling it out of a straight path, i.e., upon the size of the horizontal part or component of the lift. This depends directly on the angle of bank. The greater the angle of bank, the faster the rate of turn will be. Also, the greater the angle of bank, the more power that must be added to maintain vertical lift and avoid losing altitude.

SLIPPING AND SKIDDING

An airplane points directly along its flight path except when it is being slipped or skidded. Using only the rudder to yaw the airplane, the nose can be skidded either to the right or to the left of the direction in which the airplane is moving. If the wings are held level, the airplane will slide through the air sideways and slowly change its flight path. (Figure 87.) This is called a *skidding turn*.

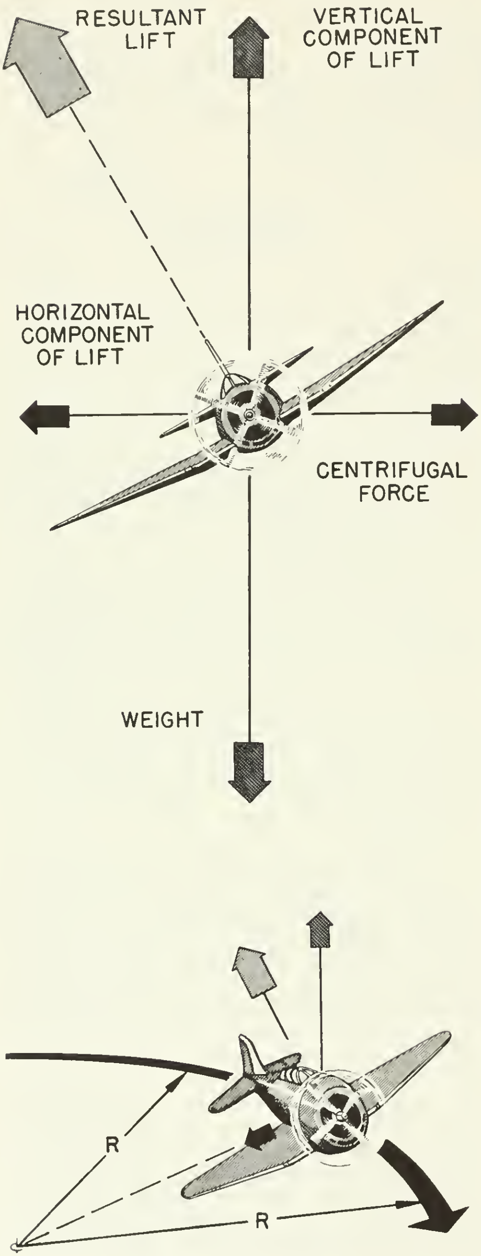


Figure 85—The Forces Acting on an Airplane in a Normal Turn

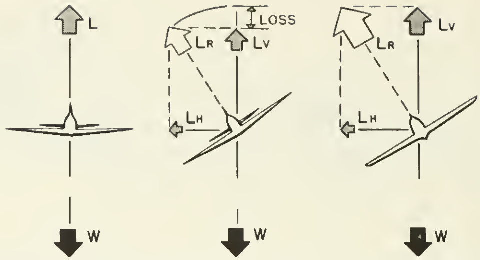


Figure 86—Loss of vertical lift in a turn due to component of lift moving toward the horizontal. L—Lift L_v—Vertical Lift W—Weight L_h—Horizontal Lift L_r—Resultant Lift

The airplane is not pointed in the direction of its flight path. In a skidding turn to the right, for example, the nose points to the right of the flight path, but, upon release of the rudder pedal pressure, the airplane weathervanes and points once again in the direction of the flight path.

Similarly, the airplane may be skidded while executing an ordinary banked turn by applying too much rudder or by failing to return the rudder pedals to a neutral position after the turn has been started. The skid tends to carry the airplane outward—away from the direction of turn—and the pilot's weight is also forced toward the outside of the turn.

If the wings are not held level with the ailerons, and rudder alone is applied, the airplane yaws, i.e., one wing moves forward faster than does the other wing. However, this increased wing speed also increases wing lift; consequently, the airplane banks. When the airplane banks, it is pulled from its straight flight path as explained above. If rudder pedal pressure is released after a given angle of bank is established, a normal turn will result. Back pressure on the elevator column is required, however, to compensate for the decreased vertical lift, but the turn will have been made with only the rudder, causing the airplane to skid at the beginning of the turn.

An airplane may be slipped either without changing its heading or while in a turn. In a straight slip the airplane is banked with ailerons but prevented from

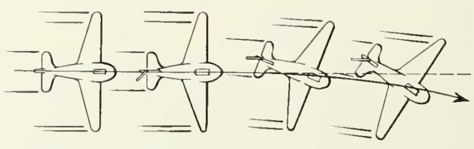


Figure 87—A Skidding Turn Caused by Rudder Being Applied with Wings Held Level

turning by the use of the opposite rudder. The direction the airplane is pointed does not change, but the bank causes the aircraft to be pulled sideways. The resulting decreased lift from the inclined airfoil causes the airplane to lose altitude.

Slipping also takes place during a banked turn if the airplane is not allowed to turn as fast as it should in respect to the angle at which it is banked. This kind of slipping is caused by holding some pressure on the outside rudder pedal. In a slip during a turn, the weight of the pilot is forced toward the inside of the turn.

Use of either aileron or rudder alone during normal flight results in slipping or skidding and should be avoided. When entering turns, the two controls should be used together so that the nose starts moving in the desired direction at the same moment that the airplane begins to bank.

Many flight conditions, principles, and maneuvers are difficult for the student to visualize by merely reading a text. Visual aids and demonstration devices, therefore, are recommended for classroom use. Wind tunnels, instrument mockups, Link trainers, and model airplanes, are among many instructional devices presently available.

The Takeoff

After a visual preflight inspection of the aircraft, the pilot starts the engine and taxis to the downwind end of the runway which he will use for takeoff. During the takeoff, the airplane is always headed into the wind so that the additional speed of the air over the wing will permit a shorter takeoff run. Stopping at least 100 feet from this runway, the pilot checks his engine and all other systems and instruments on the airplane. When he is satisfied that everything is working properly, he taxis onto the runway. As soon as he is lined up on the runway, he slowly and smoothly opens the throttle. By means of rudder control, he keeps the aircraft on a straight course as the plane gathers momentum.

If the airplane has a conventional landing gear (with tail wheel), the control column is pushed forward to raise the tail, changing the airplane's attitude from a three-point to a slightly nose-high attitude. If the airplane has a tricycle gear, a little back pressure is applied to the control column to raise the nose gear off the runway, again putting the airplane into a slightly nose-high attitude. When the speed becomes great enough to generate sufficient lift, the airplane leaves the runway. At this point the nose is lowered slightly so that the airspeed may increase quickly to the normal climbing airspeed. When this airspeed is reached, the pilot reduces the throttle setting from maximum takeoff power to climb power and puts the airplane into the normal climbing attitude.

The pilot will continue to climb straight ahead until he reaches an altitude of 400 to 1,000 feet, depending upon the type of airplane he is flying. At the specified altitude he will leave the traffic pattern. If the airport is served by a control tower, the tower may give him definite instructions for leaving the pattern. In the absence of tower instructions, he will leave the pattern according to the standard procedure established for airports which are not served by a control tower, i.e., a 90 degree turn to the left and then a 45 degree turn to the right. (Figure 88.)

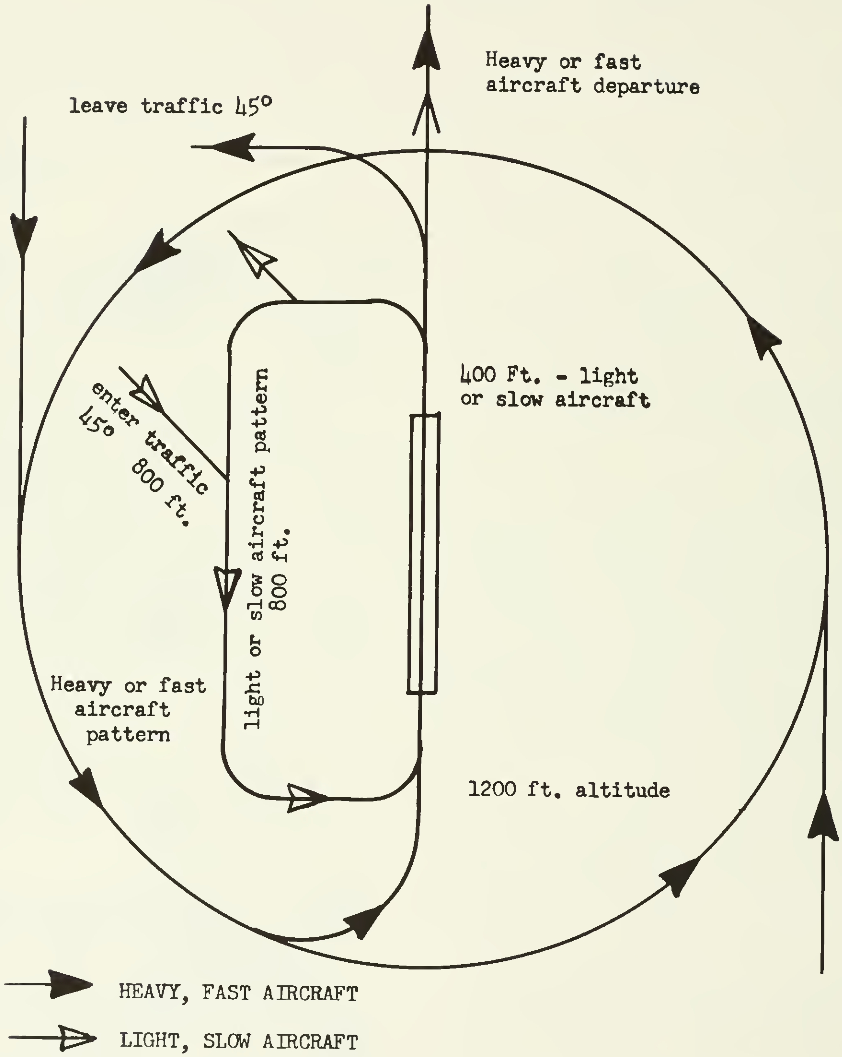
Landing Approach

To land at any airport the pilot again uses a standard procedure unless otherwise directed by the airport's control tower. The standard pattern consists of a downwind leg, a base leg, and a final approach. (Figure 88.)

On the downwind leg, the airplane flies with the wind and parallel to the active runway. It is on the downwind leg that the pilot completes the prelanding check and reduces power. The point at which he begins his descent and the manner in which he continues it to the end of the runway depends upon the type of airplane he is flying. In small, slow airplanes, the pilot continues level flight on the downwind leg until the airplane is directly opposite the touchdown spot. At this point, the throttle is closed completely and a power-off glide, which will include two 90 degree turns to the left, begins. After making the first 90 degree turn, the pilot is on the base leg. This leg of the landing pattern is crosswind and perpendicular to the runway. On the base leg the pilot opens the throttle momentarily in order to keep the engine from cooling too rapidly during the glide. The second 90 degree turn to the left places the airplane on the final approach leg, at which point it continues to glide to the point of landing. This is called the power-off approach and landing.

In larger and/or faster airplanes, the throttle is not usually closed completely on the downwind leg since a power-on approach is more appropriate. In a power-on approach, the pilot controls his rate of descent by varying the power setting. His aim is to have a constant and moderate rate of descent as he continues around the pattern to the point of landing. Just before reaching the point of contact with the runway, the pilot closes the throttle completely. Also, with larger and/or faster airplanes, the pilot may make a shallow left turn of 180 degrees from downwind leg to final

TRAFFIC PATTERNS



THE ABOVE PATTERNS WILL BE USED FOR ALL WIND DIRECTIONS

Figure 88—Traffic Patterns

approach rather than two steeper 90 degree turns. Regardless of the size or speed of the aircraft, there are two methods which can be used to touch down with conventional landing gear.

One method of landing an airplane with a conventional gear is to make a *wheel* landing, i.e., touch down on the two main wheels only, keeping the tail wheel off the runway. When the airplane descends to the bottom of the final approach, the pilot applies back pressure on the control column and levels off a few inches above the runway. Since the airplane has no power at this point, its forward speed rapidly decreases. As the speed decreases, the wings produce diminishing lift and the airplane settles slowly to the runway. To prevent the airplane from settling too rapidly, resulting in a hard landing, the pilot constantly increases the back pressure on the control column, thereby permitting the airplane to touch down gently. As the airplane slows after contacting the runway, the tail wheel is allowed to touch down also. When the airplane has slowed to taxi speed, the landing is considered completed.

The second method often used to land with conventional gear is to make a *three-point* or *full-stall* landing, i.e., to touch down with all three wheels at the same time. This landing starts just as the wheel landing does, but differs in technique from the wheel landing only in the amount of back pressure the pilot applies to the control column. He does not allow the airplane to settle to the runway until the control column is all the way back and the wings are completely stalled. This type of landing is well adapted to very light airplanes since the stalled attitude keeps gusts of wind from lifting the airplane from the runway after it has finally touched down.

There is a slight variation in the landing technique of an airplane equipped with a conventional gear and one equipped with a tricycle gear. That used for landing an airplane equipped with a tricycle landing gear is exactly the same as that used for a wheel landing in those airplanes equipped with a conventional landing gear, except that, as the tricycle-geared airplane slows after touchdown, the nose wheel, rather than the tail wheel, is allowed to contact the runway.

Summary

Attitude, the relationship of the axes of an airplane to the earth's surface, is controlled with the stick (or wheel) and the rudder pedals.

Forward and backward movement of the stick (or wheel) moves the elevators, causing the nose to move down or up. This changes the angle of attack, which is defined as the angle between the chord of the wing and the relative wind.

Movement of the stick or rotation of the wheel to right or left controls the ailerons and produces banking. Pressure or movement of the rudder pedals actuates the rudder, causing the nose to yaw or move to the right with right rudder pressure and to the left with left rudder pressure.

During straight and level flight, the control surfaces are approximately streamlined with the surfaces to which they are attached and the four forces acting on the airplane in flight are balanced, that is, thrust equals drag and lift equals weight.

Thrust is supplied by the engine and the propeller; drag is represented by anything which tends to retard the airplane during flight; lift is created by the wings; and weight is the expression of the force of gravity which tends to pull the airplane earthward.

To climb, the angle of attack is increased and power is added. For any given attitude and power setting, a certain airspeed will result. In a glide, no power is used and the airplane must be nosed down to maintain a safe flying speed, with the thrust, which at other times is supplied by the engine, being provided by gravity. During a powered descent, the amount of power used and the attitude established and maintained by the elevators determines the rate of descent.

Turns are produced by banking—the rate of turn being determined by the amount of bank. In order to turn without slipping or skidding, the rudder is coordinated with the ailerons when rolling into and out of the bank. While the airplane is in the bank, both controls should be in a neutral position. Some back pressure should be maintained on the stick or wheel to avoid losing altitude.

Takeoffs are always made into the wind. By use of the rudders, the airplane is held in a straight path while on the ground. During the takeoff run, the airplane is put into a slightly nose-high attitude until sufficient speed is reached thereby creating lift and causing the airplane to leave the runway and become airborne.

Landing technique is basically the same for any airplane. Approaches to landings may be made by gliding (power off) or by using power (power on). When the airplane is leveled off within a few inches of the runway, it loses speed and consequently lift. To prevent too rapid a loss of lift, the airplane's angle of attack is gradually increased by back pressure on the stick or wheel. With this gradual loss of lift, the airplane settles to the runway.

Questions

1. Explain the meaning of the word "attitude" as it is used when discussing flight maneuvers.
2. What is angle of attack?
3. What are the four fundamental flight attitudes?
4. If you moved the control stick forward while flying an airplane, what effect would this have on the attitude of the airplane?
5. Describe briefly how an airplane, in flight, is turned.
6. What is the rudder used for in turning an airplane in flight?
7. What is slipping? Skidding?
8. What is the correct attitude for an airplane as it leaves the runway on take-off?
9. In speaking of an airport traffic pattern, what is the downwind leg? The base leg? The final approach?
10. When an airplane is approaching a runway for landing, which is the primary control for governing the rate of descent?

Chapter 8 Air Navigation

Navigation, in some one of its many forms, is employed by every individual when he moves from "here" to "there." In early history, man moved about on foot and navigated by using prominent landmarks, such as trees, hills, valleys, bodies of water, contours of land, sun, stars, etc. These familiar features guided him away from home and back again safely.

After the wheel was invented, man was able to travel farther, and consequently he needed a written record of these well-known signposts. This record was the basis for the development of the modern maps and charts.

Travel was not limited, however, to land only. Water was often an easier form of transportation and permitted greater mobility for travelers and for traders. The magnetic compass and more complex charts gave man much needed assistance in traversing new areas. Celestial navigation was evolved to ascertain direction more accurately, thus enabling man to travel more freely across the world's surface.

With the invention of the airplane, the importance of navigation increased. Pilots had to be fully cognizant of the principles of navigation if they were to fly safely from one point to another.

Modern man still utilizes the earlier methods of navigation. A man on foot is still guided by familiar landmarks, but as mobility increases, the need for more extensive navigation aids grows. Automobile drivers require markers and road signs. Ship captains are equipped with improved maps, compasses, and radios. Airplane pilots are supplied with their own maps and charts, and with electronic aids. The ancient types of navigational aids are still in use but with modern improvements.

This chapter will discuss air navigation, define it, and describe four of its forms which are applicable to flight.

What Is Navigation?

Navigation is the science or art of conducting or steering a vessel, i.e., a boat, car, or airplane, across or through a medium, such as land, water, or air. It refers to man's ability to journey on or over the surface of the earth.

Air navigation, then, is a science which determines geographic position and maintains a desired direction in the air with respect to specific positions and directions on the ground. Aerial navigation is not unlike sea navigation in many of its problems and methods. It differs from sea navigation because the speed of the aircraft is many times that of a ship, and the effects of air currents on an aircraft are more critical than the effects of sea currents on a ship.

Forms of Air Navigation

Pilots, in the early days of flight, flew their aircraft for only short distances and at low altitudes. Flight was easily directed by referring to known landmarks, such as rivers, roads, and railroads. As science improved airplanes, longer flights at higher speeds and higher altitudes were possible—if the pilot could be freed from his continuous visual search for familiar guideposts. Because the airplane was now capable of flying under a variety of conditions (over water, over poorly-mapped terrain, in adverse weather conditions, and at high altitudes), improved navigational facilities were developed.

The four common types of air navigation are: (1) pilotage, (2) dead reckoning, (3) radio, and (4) celestial.

Pilotage. This form of air navigation is performed by locating landmarks on the ground and then matching them to a chart of the territory over which the airplane is flying.

Dead Reckoning. This form of air navigation is performed by determining the direction to point the aircraft, prior to the flight. After the correct heading is calculated, considering compass errors and wind drift, the compass is the primary navigational aid used to keep the airplane traveling in the correct direction. Dead reckoning involves distance and speed problems which determine the length of time required for the aircraft to arrive over a destination.

Radio Navigation. This form of air navigation is performed only if the aircraft is equipped with radio equipment. This equipment is used to determine position in flying a desired course over any part of the United States and over most of the world. Hundreds of ground transmitting stations have now been erected for extensive use in air navigation.

Celestial Navigation. This form of air navigation is performed by observing angular reference to the sun, stars, and moon.

A pilot rarely uses only one form of navigation. Usually a combination of these four methods is practised to provide an accurate method for following a course. Before going into more detail, it may be well to cover some of the principles of map making.

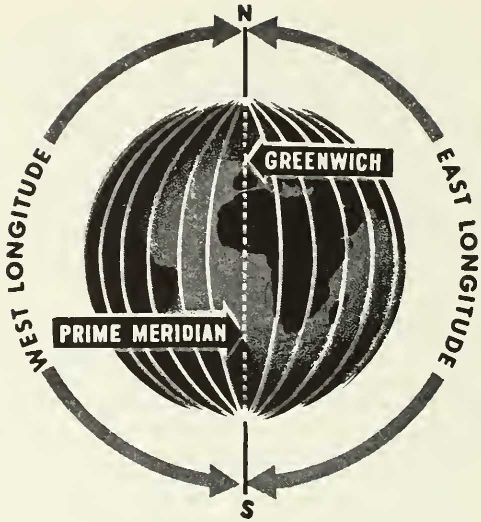


Figure 90—Lines of Longitude

Position, Direction, and Distance

Position, direction, and distance are the fundamentals of navigation. Although the earth is not a perfect sphere, for the purposes of navigation it is considered to be spherical. The earth can be likened to a spinning ball which has an imaginary axis passing through its center from the North Pole to the South Pole. (Figure 89.)

Position. The Equator is an imaginary line around the earth midway between the North and South Poles. Imaginary lines, on a globe or map of the earth, drawn parallel to the Equator are called *parallels* of latitude. Lines perpendicular to the plane of the Equator are *meridians* or lines of longitude. The meridian which passes through Greenwich, England, is called the *prime meridian*.

These parallels and meridians form coordinates which make it easy to locate any position on the earth's surface north or south of the Equator and east or west of the prime meridian in degrees, minutes, or seconds of latitude and longitude. (Figures 90 and 91.)

Direction. When the airplane is moving about in a familiar area where north, east, south, and west are known, direction is very simple. But to fly an airplane over a long, unfamiliar route presents the problem of keeping the airplane headed in the right direction; consequently, a system for expressing direction is needed. (Figure 92.)

In navigation, direction is expressed in degrees,

Figure 89—An Imaginary Axis through the Center of the Earth

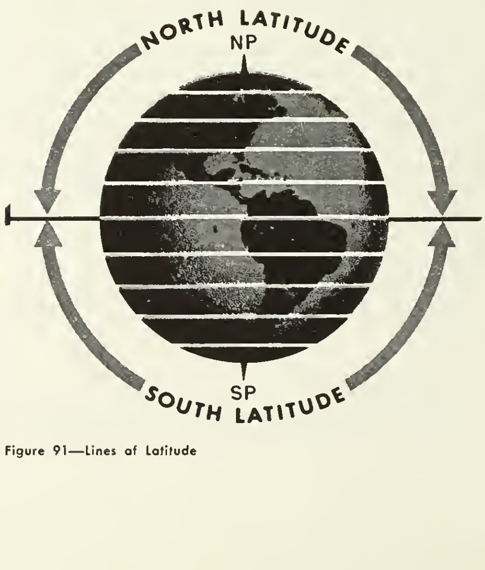


Figure 91—Lines of Latitude

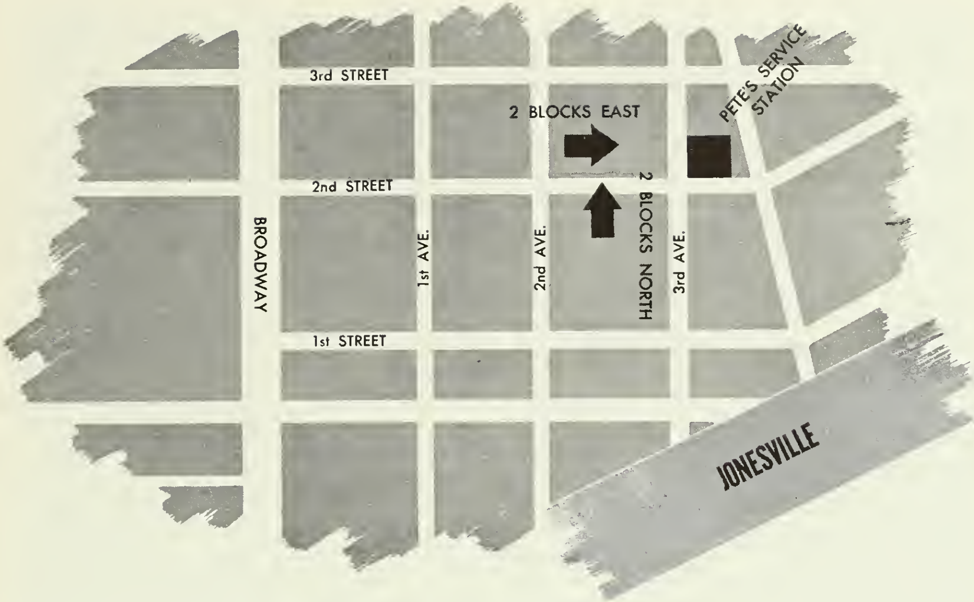


Figure 92—Latitude and longitude coordinates are similar to street and avenue intersections.

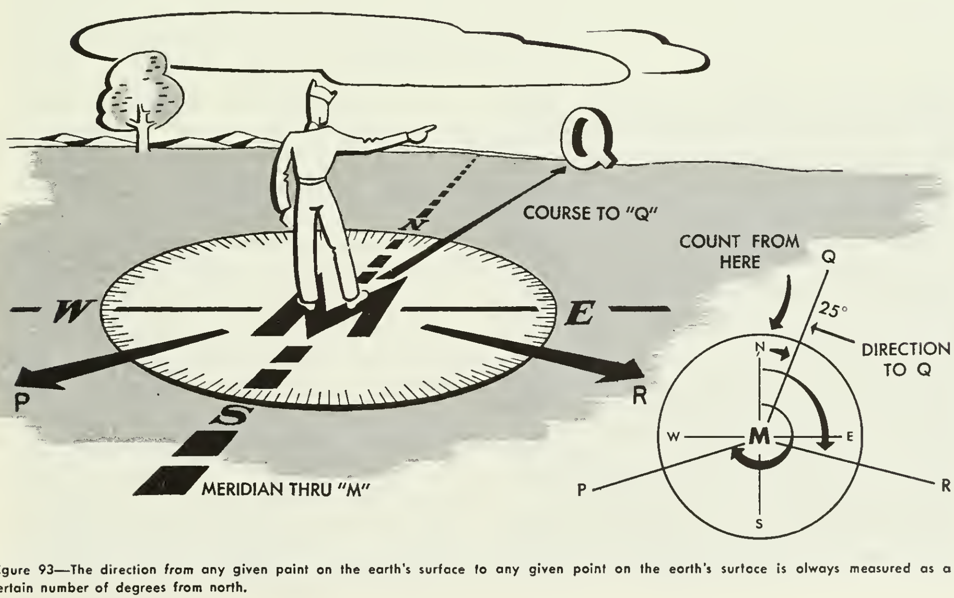


Figure 93—The direction from any given point on the earth's surface to any given point on the earth's surface is always measured as a certain number of degrees from north.

clockwise from north. North is 360 degrees; east, 90 degrees; south, 180 degrees; and west, 270 degrees. The direction *from* any given point on the earth's surface *to* any given point on the earth's surface is always measured as a certain number of degrees from north. (Figure 93.) As an aid to navigation, the Compass Rose has been devised to act as a graphic portrayal in determining direction. (Figure 94.)

The path which an airplane intends to follow over the earth is called a course. When the direction of the course is measured from true north, it is called *true course.* True course may be determined on navigational charts by measuring the angle between the course line and the closest meridian, since all meridians are also *true north lines.*

In plotting a true course, a line drawn on a sphere must be arced to follow the curvature of the earth. This line will be the shortest distance between two points, since it would be a section of the great circle which would divide the earth into two equal parts. On a flat surface, such as a map, this line will appear to be straight for short distances, but direction must be re-measured at approximately every 3 degrees or 4 degrees of longitude to avoid flying a straight line rather than the shorter, circular line which conforms to the shape of the earth.

Distance. Distance can be expressed in many different units. In air navigation, either a statute mile (5,280 feet) or a nautical mile (6,080 feet) is used. The nautical mile is now used more frequently, since one nautical mile is equal to one minute of arc at the equator and on all the lines of longitude. Either one

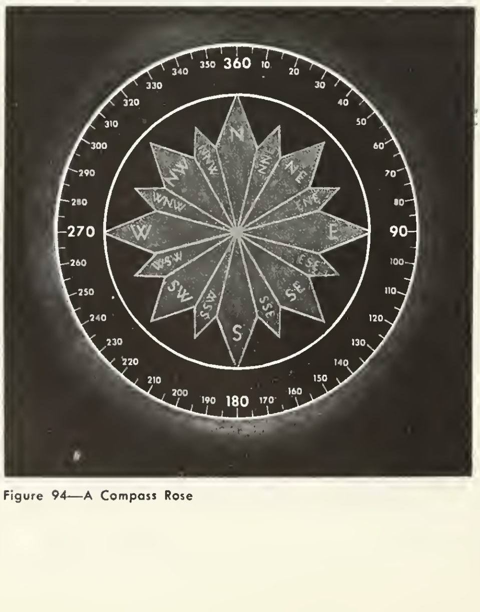


Figure 94—A Compass Rose

or the other unit should be used when solving air navigational problems in order to avoid confusion and mistakes.

Maps and Charts

A *map* is a diagram representing all or any portion of the earth's surface, and a map especially designed for navigation is called a *chart.* A chart used for air navigation will indicate outstanding features of both land and water as well as all radio stations. The pilot will use the chart to keep track of the airplane's position, and to measure the direction of the course and the distance between the point of departure and the destination.

It would be difficult to draw a chart large enough to represent the entire United States and at the same time present landmarks which are required for air navigation. The United States, therefore, is divided into 87 sections, each of which is represented on a chart. (Figures 95 and 96.)

A globe, which is a true representation of the earth's surface and which is large enough to show detail necessary for navigation, would be far too bulky to be carried in the aircraft. Consequently, a projection of the earth's spherical surface is printed on a flat surface for more convenient use.

Since the earth is a globe, it is impossible to draw a flat map of the world that is accurate as to shape, size, and scale. The earth's surface cannot be represented on a flat surface without distortion. Distortion is better understood if one takes an orange, cuts it in half, then peels it carefully so that the skin comes off in one piece. Now try to flatten out the piece of skin without either cracking or stretching it, i.e., distorting it. It can't be done. Maps and charts of small areas have the least amount of distortion, but distortion cannot be entirely avoided. In map making, many systems have been devised to control and minimize distortion, depending upon the use of the map.

The exact position of any point on the earth can be found by the use of astronomy. Nearby points or features may then be found either by surveying or by aerial photography. The map is then made by drawing the geographic features on a framework of meridians and parallels known as a *graticule.* The process involved in the construction of the graticule is called *projection.* Once the graticule is drawn, features may be plotted in their correct position with reference to the meridians and parallels. If a light bulb were inserted inside a transparent globe which showed the earth's features, including the meridians and lines of parallel, and these features were projected upon a flat surface, a picture would appear which would be very similar to the features of the globe but the pic-

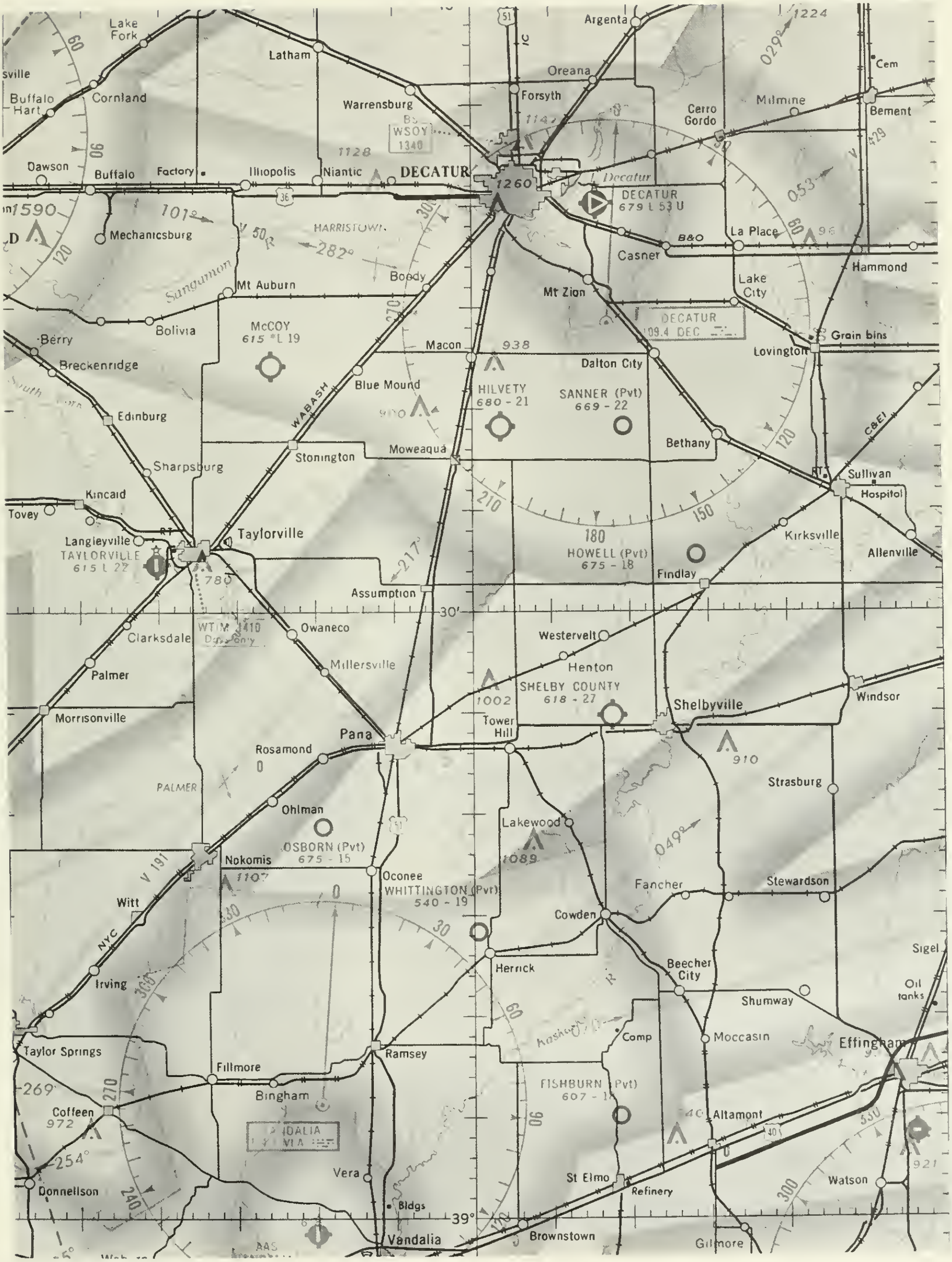


Figure 95—Sectional Chart

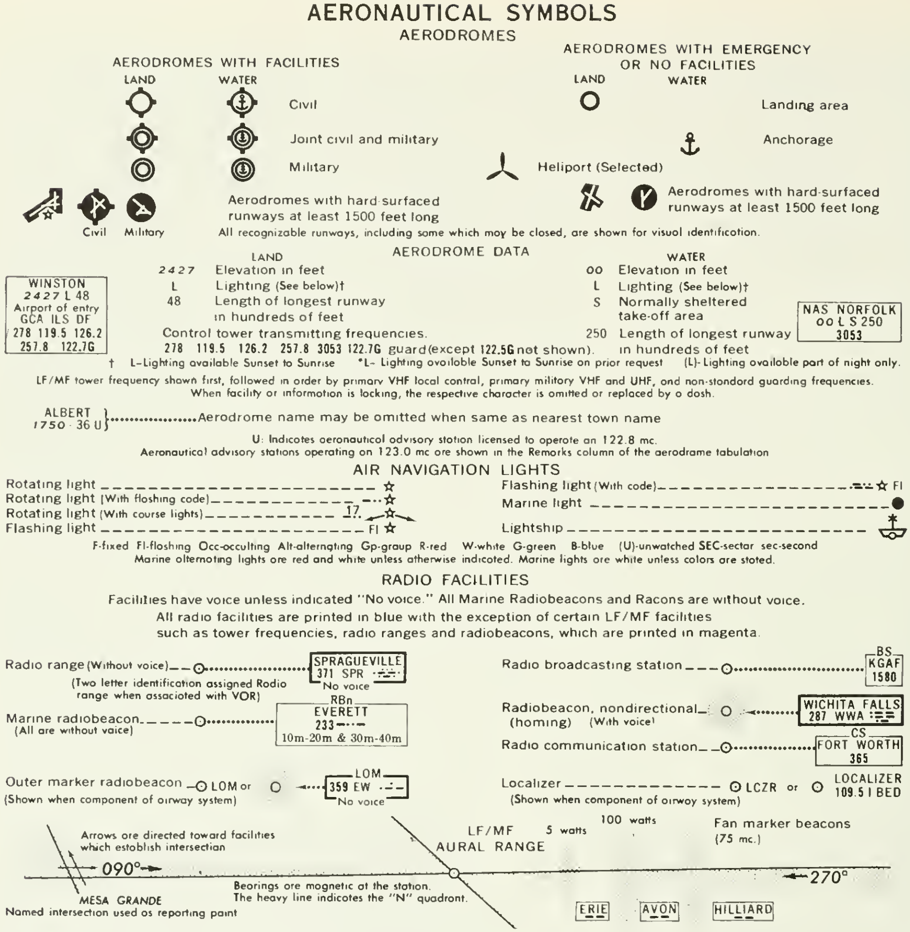


Figure 96—Standard Symbols Used on a Sectional Chart

ture would be distorted; the smaller the section taken out of the picture, however, the less the amount of distortion.

Most aerial navigation charts are made from a Lambert Conformal Conic Projection. This may be thought of as a projection upon the surface of a cone which intersects the earth along two parallels of latitude. The axis of the cone coincides with the axis of the earth. (Figure 97.) A straight line drawn on the chart coincides with a great circle and is the shortest distance between two points.

Charts or maps are made to specified scales. For instance, one inch on a map may represent eight miles on the ground. This presents no problem as long as the scale is clearly shown for each map.

The Coast and Geodetic Survey of the Department of Commerce now publishes the aeronautical charts of the United States. The two most commonly used charts are the Sectional and Regional Charts. The Sectional Chart covers a smaller area, gives more detail, and is used for shorter flights. The Regional Chart covers a larger area with less detail, and usually is used for longer flights.

Plotting a Course

To plan a flight, a pilot must first obtain a chart (or charts) of the section of the country over which he intends to fly. To obtain a true course heading on this Lambert Chart, he draws a straight line from the departure point to the destination. He then places

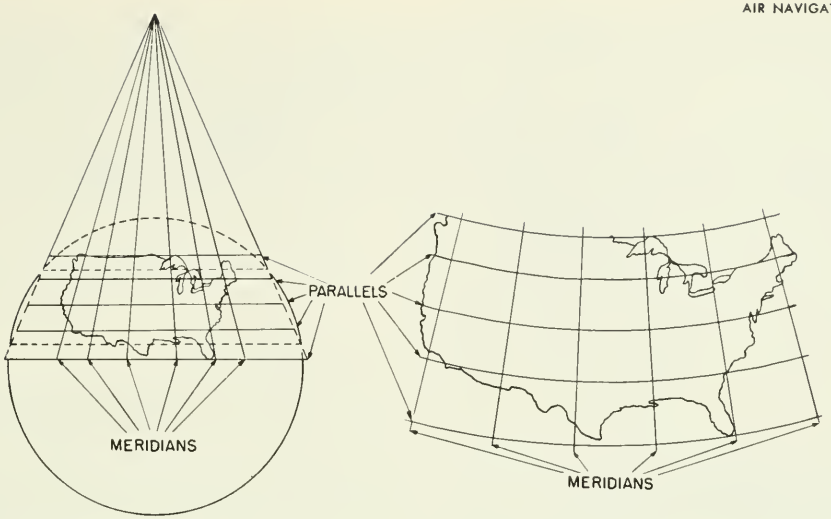


Figure 97—Method of Obtaining a Lambert Projection

a *protractor* so that its midpoint covers the intersection of the true course line and any one of the meridians about half way between the destination and the departure point. Zero degrees on the protractor is aligned with this meridian, and the true course heading is read at the point where the true course line intersects the outside scale on the protractor. The angle between the true course line and the meridian which it intersects represents the angle of direction from true north, i.e., the North Pole. (Figure 98.)

The pilot knows, however, that the magnetic compass, by which he steers, does not point to the North Pole but to the magnetic pole which is located in northwestern Greenland. To compensate for this error, the pilot must calculate the amount of magnetic variation. In the United States, the amount of magnetic variation fluctuates from 25 degrees East in the State of Washington to 22 degrees West in the State of Maine, with 0 degrees running through the Great Lakes south to Florida. These lines of magnetic vari-

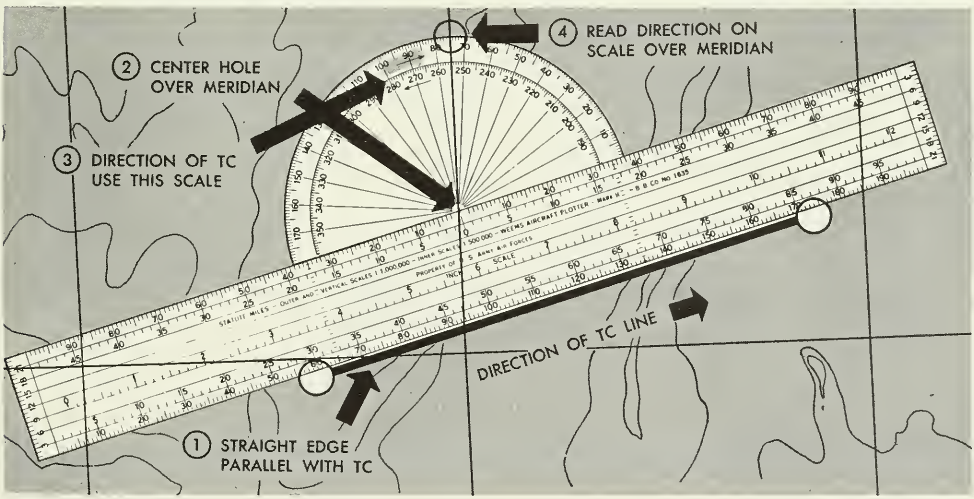


Figure 98—Measuring a True Course Line with Protractor

Figure 99—This diagram shows the agonic and isogonic lines of variation.

ation error are indicated on aeronautical charts and are known as Isogonic lines (Figure 99.)

To correct for a magnetic variation of 10 degrees *East*, for example, the pilot will *subtract* 10 degrees from his true course degree heading. The degree setting, after correction for variation, is called the *magnetic course* heading. The pilot will *add* 10 degrees to his true course heading if the magnetic variation is 10 degrees *West.*

The airplane itself also creates magnetic fields which disturb the compass. These magnetic interferences are called *deviation errors* and they, too, must be corrected. To discover the amount of deviation error for a particular airplane, the aircraft is placed upon a Compass Rose with no error. This Compass Rose is usually painted on a concrete taxi strip away from the buildings of the airport. The compass of the airplane is then compared with the Compass Rose and the difference between the two is the deviation error. This deviation error is recorded on the aircraft's compass deviation card and placed near the compass. From this, the pilot knows how much error he must allow before he obtains a correct compass reading.

Briefly, the pilot uses the following formula to determine compass course:

$$\text{True Course} \pm \text{Variation} = \text{Magnetic Course}$$
$$\text{Magnetic Course} \pm \text{Deviation} = \text{Compass Course}$$

$$(TC) \pm (V) = (MC) \pm (D) = (CC)$$

Wind Drift Correction

An airplane in the air has no more attachment to the ground than a ship has to the bottom of the ocean when sailing free. The air mass, in which the aircraft flies, moves over the surface of the earth at varied velocities. The air masses attempt to push the aircraft in the direction they are moving. The pilot wishing to fly over certain ground references must not let the air mass carry him in the wrong direction. Therefore he must compensate for wind drift in order to fly his intended track or course. (Figure 100.)

A pilot receives information about the amount of wind and the direction of the wind from a weather station. With this knowledge, he can correct his true course to a true heading by using either a computer or a wind triangle. (Figure 101.)

When the pilot has organized and solved the many navigational problems relative to his flight, he will usually put this data on a form called a "flight log" or a "flight planning sheet," which he will carry with him during the trip. (Figure 102.)

After checking the weather information and plot-

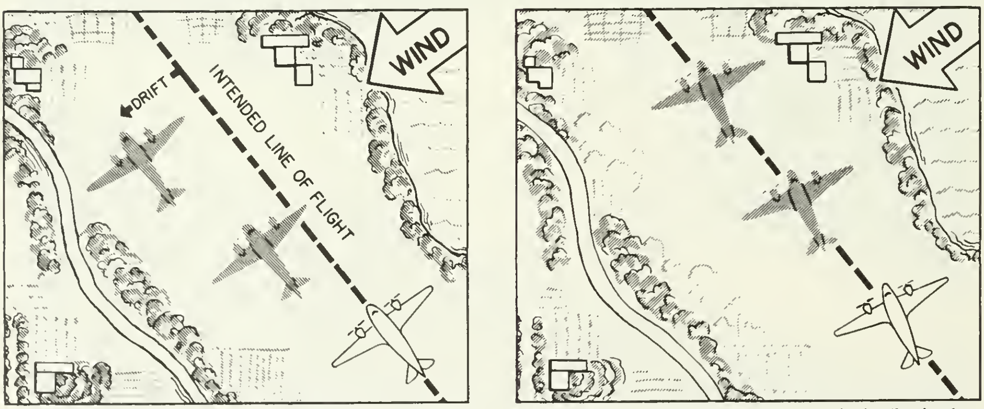


Figure 100—(Left)—Heading an airplane directly along its course without regard for wind direction or velocity will generally result in the airplane drifting off course.

(Right)—Heading the airplane a definite amount in the direction from which the wind is blowing will cancel out the drifting effect on the airplane.

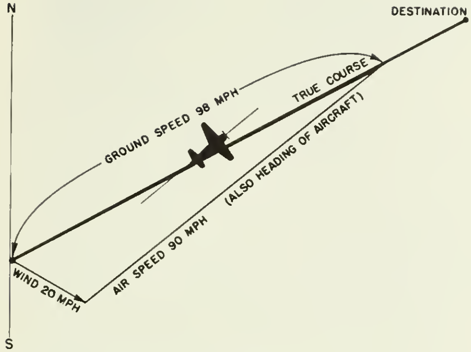


Figure 101—A Typical Wind Triangle

ting his intended course, the pilot will inspect his aircraft (See Chapter 4) and will then be ready for takeoff. He may decide to use only one certain form of navigation, but more likely he will use some combination of the four forms.

Pilotage Navigation

The six steps in planning a pilotage flight are: (1) a true course line is drawn between departure point and destination; (2) the angular direction of the true course line is measured at the mid-meridian; (3) the *course line* is marked in segments of 10 or more miles, depending upon the size segment appropriate to the speed and range of the airplane; (4) landmarks along or near the route are designated as *check points* to be used to check heading and to determine ground speed; (5) prominent terrain features are selected along either side of the course and at the destination and are called *brackets;* and (6) compass course is determined.

In flight, the five steps to be followed in navigating by pilotage are: (1) fly direct to the first check point and take up the compass heading; (2) check wind drift; (3) correct heading; (4) determine elapsed time between check points and note ground speed; and (5) maintain a continuous scrutiny of the course flown, by use of check points and brackets.

Pilotage is used for short flights in slow aircraft. Normally the pilot will use this form of navigation at an early stage of his training.

Dead Reckoning Navigation

If a pilot flies over an area that is sparsely settled, wooded, desert, or lacking in conspicuous landmarks, he will be unable to use pilotage. If his airplane has no radio equipment, he must depend upon dead reckoning to reach his destination.

The pilot, by using either a computer or a wind triangle, determines the amount of drift and calculates the compass heading he must fly to reach his destination. He also estimates the time en route. After he is airborne, and over the departure airport, he turns to his predetermined heading, checks the time, and flies until his estimated time en route has expired. At this point, if his calculations are correct, he should find himself over his destination.

A combination of pilotage and dead reckoning can be employed very successfully and is used more frequently than is any one system alone. These two forms

CONTACT FLIGHT LOG

TIME OF DEPARTURE	DISTANCE		ELAPSED TIME		CLOCK TIME		GS		CH		REMARKS
CHECK-POINTS	POINT TO POINT	CUMULATIVE	ESTIMATED	ACTUAL	ESTIMATED	ACTUAL	ESTIMATED	ACTUAL	ESTIMATED	ACTUAL	BRACKETS, WEATHER RADIO DATA, ETC.
1.											
2.											
3.											
4.											
5.											
6.											

Figure 102—Contact Flight Log

of navigation do not depend upon radio assistance for any portion of the trip.

Radio Navigation

The first aeronautical radio aid to navigation was a two-way communication system which linked the airplane to the airport. The pilot was thereby kept informed of weather conditions en route and could also receive other information of value to him. Later, directional radio equipment was developed, which enabled pilots, while in flight, to determine the direction to specific radio stations.

The entire United States is covered with a vast system of airways, similar to highways, which are controlled by the federal government. Along these airways, spaced at appropriate distances, are radio stations which continually transmit signals. These airways (radio roads), which the pilot follows, are called *beams, radials,* or *tracks.* (Figures 103 and 104.)

If Very High Frequency radio (omni station) is the primary navigational aid on the airway, it is called *Victor Airway.* When Low Frequency radio is the primary electronic aid, the airways are *colored airways,* i.e., red, green, blue, or amber airways.

Radio navigational charts are now available, which locate the radio transmitters. By using radio navigation, a pilot can fly directly to an airport without ever seeing the ground. This is common procedure during days when clouds obscure the vision of the pilot. Pilots who fly in adverse weather should have an instrument rating. Without special instrument training, only the foolhardy attempt to fly when the ground cannot be seen.

Radio Transmission. Radiating electro-magnetic fields which travel long distances are called radio waves. Radio waves vary in frequency from about 10,000 cycles to many million cycles per second.

To avoid the use of many digits, when referring to frequencies, two units of frequency are used. One thousand cycles equals one kilocycle (Kc), and one million cycles equals one megacycle (Mg).

A radio system consists of a transmitter, which broadcasts the radio waves through a transmitting antenna, a receiving antenna, and a receiver which converts the radio waves to voice signals. (Fig-

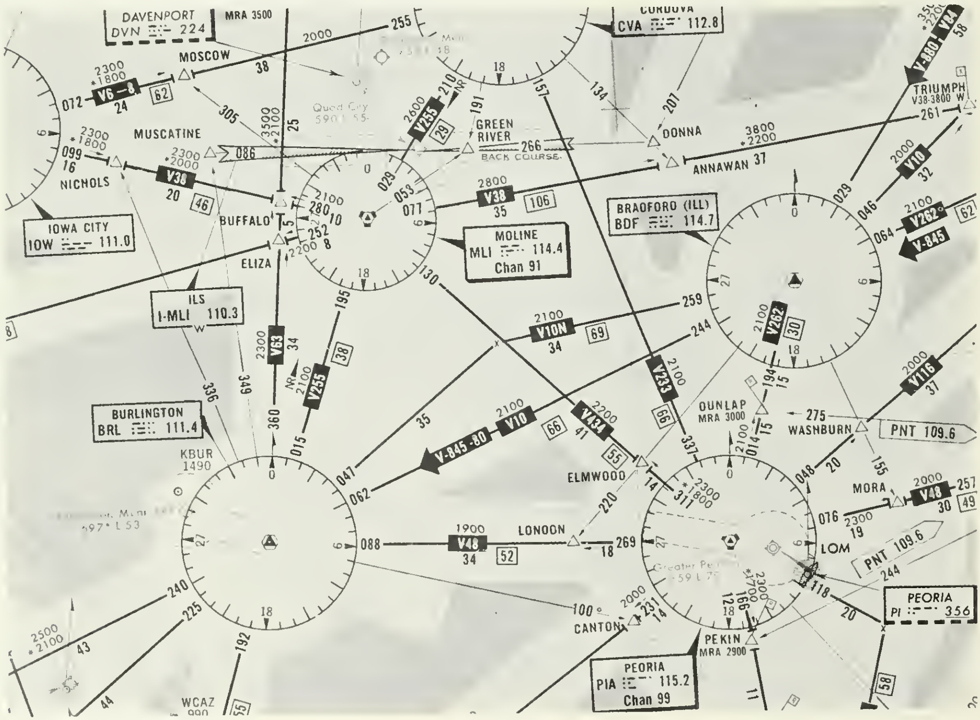


Figure 103—Radio Facility Chart

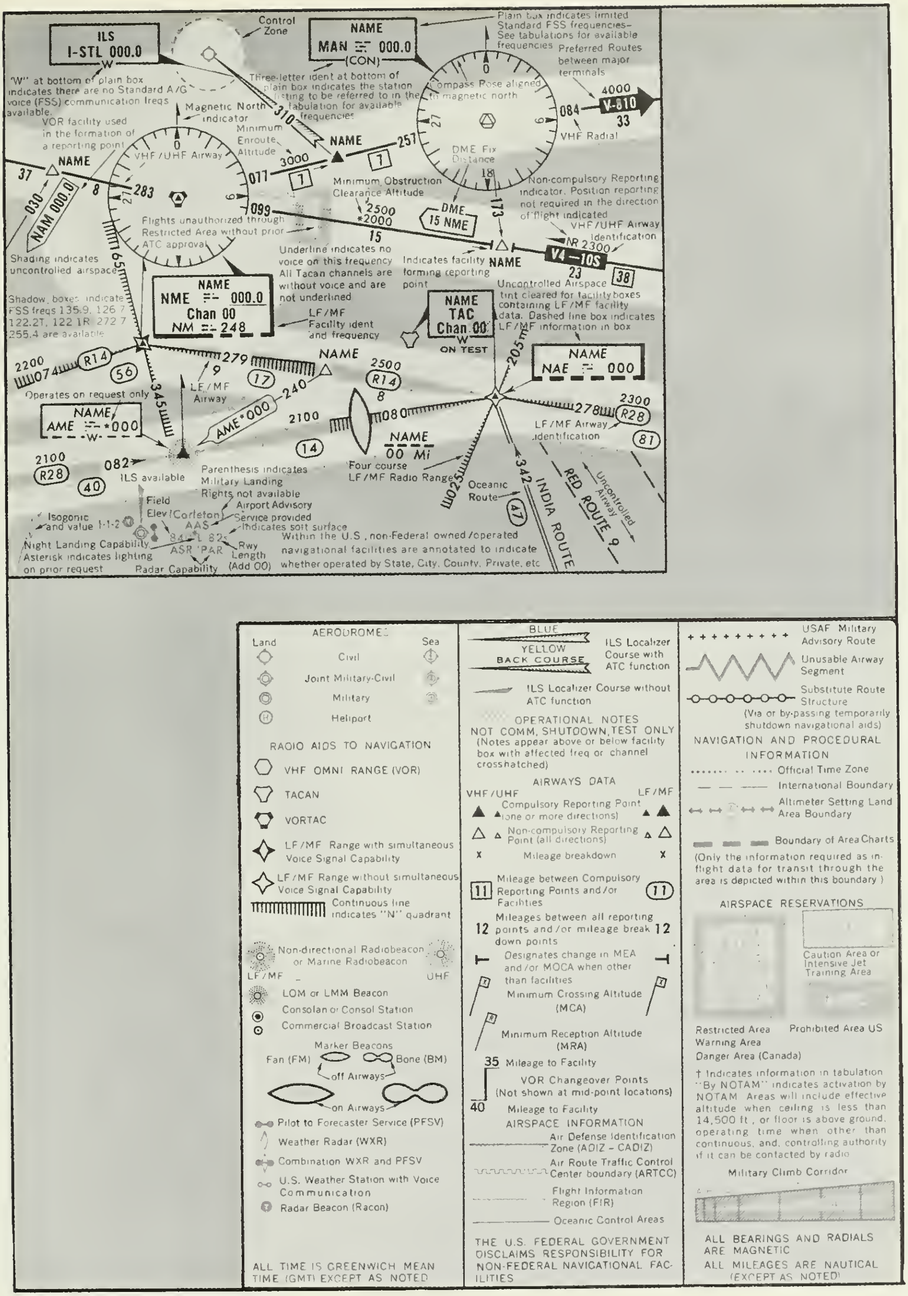


Figure 104—Radio Facility Chart Legend

RADIO SYSTEM

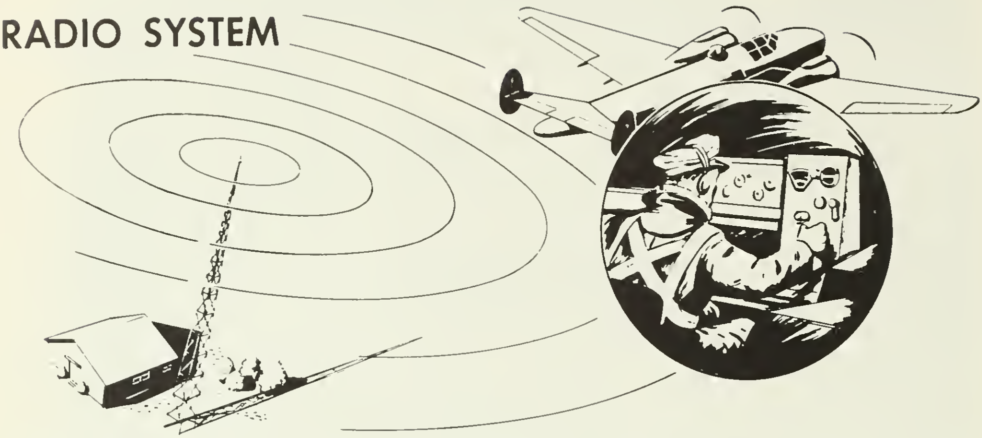


Figure 105—The above illustrates a 2-way radio system, with a transmitter and a receiver located in both the ground station and in the airplane.

ure 105.) Radio signals may be transmitted in a non-directional manner (Figure 105) or in certain specified directions, thus forming beams or radials by which pilots can navigate. (Figure 106.)

The two most commonly used frequency bands are the Low Frequency (L/F) band, ranging from 200 Kcs to 400 Kcs, and the Very High Frequency (VHF) band, ranging from 30 Mgs to 300 Mgs. The VHF band is more popular, since this group of frequencies is not affected by electrical disturbances such as thunderstorms, which create static. L/F radio navigational equipment is still very common but is being replaced rapidly with VHF equipment.

The L/F transmitting station consists of four towers and four antennas. One signal only is transmitted from each tower. Two of the towers transmit the letter "N" (—-) and the two opposing towers transmit the letter "A" (-—). (Figure 106.)

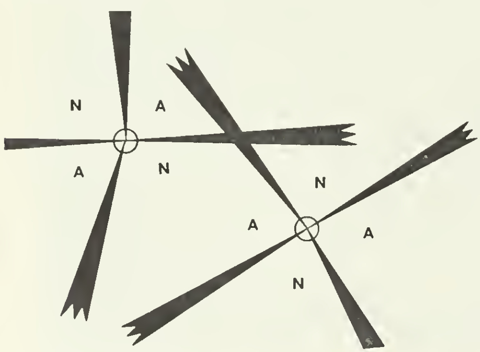


Figure 106—Directional Radio Transmissions

Where the two signals meet or overlap, a solid hum, called a beam, is produced. This beam is directed along an airway and extends out to meet a beam from another station. A pilot can fly a certain heading along the beam and listen to the signals. The signals will tell him whether he is on the beam, or to the left or to the right of the beam. (Figure 107.)

Since aircraft normally fly from airport to airport, radio transmitting stations are usually constructed near the airport. Each station sends its signals over a specified frequency and also transmits an identification signal in Morse Code; e.g., Springfield, Illinois, transmits the letters "S" (- - -) "P" (- — — -) "I" (- -) to identify itself.

Automatic Direction Finder. Another radio aid to navigation is the Automatic Direction Finder. This equipment can be tuned to certain Low Frequency stations and to standard broadcasting stations.

A receiving antenna that automatically swings toward the transmitting station is employed. Attached to the antenna is a small electric motor that will rotate when the antenna rotates. This motor is in phase, electrically, with a similar motor attached to a needle located in the cockpit of the plane. Consequently, when the antenna rotates, this needle will rotate until it points directly toward the transmitting station. The rotating needle, which moves over a Compass Rose painted on the surface of the dial, can move 360 degrees—always pointing in the direction of the transmitting station. (Figure 108.)

Visual Omni Range (VOR). The most widely used

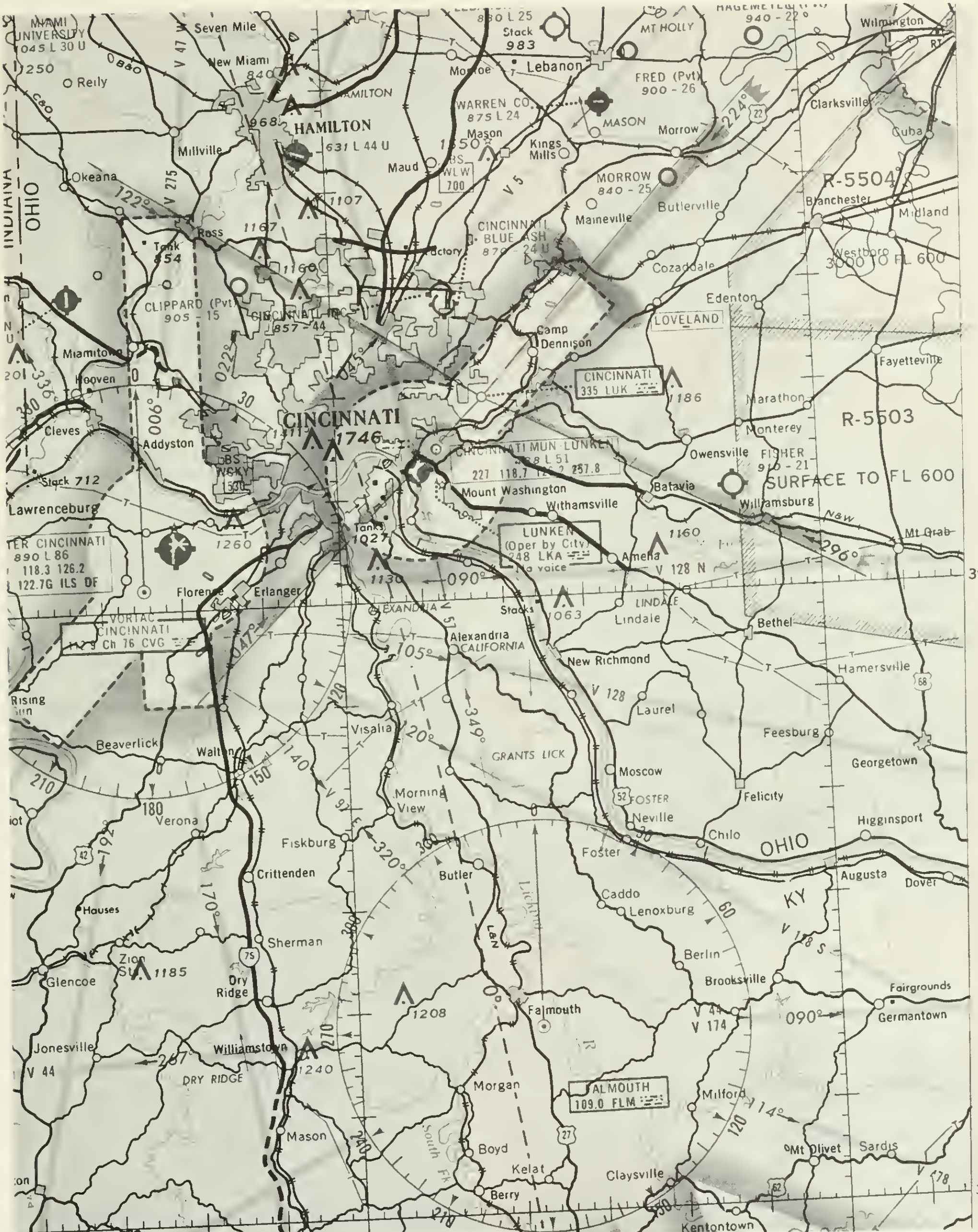


Figure 107—Part of a Sectional Chart Showing Four Directional Beams Transmitted by a Low Frequency Station

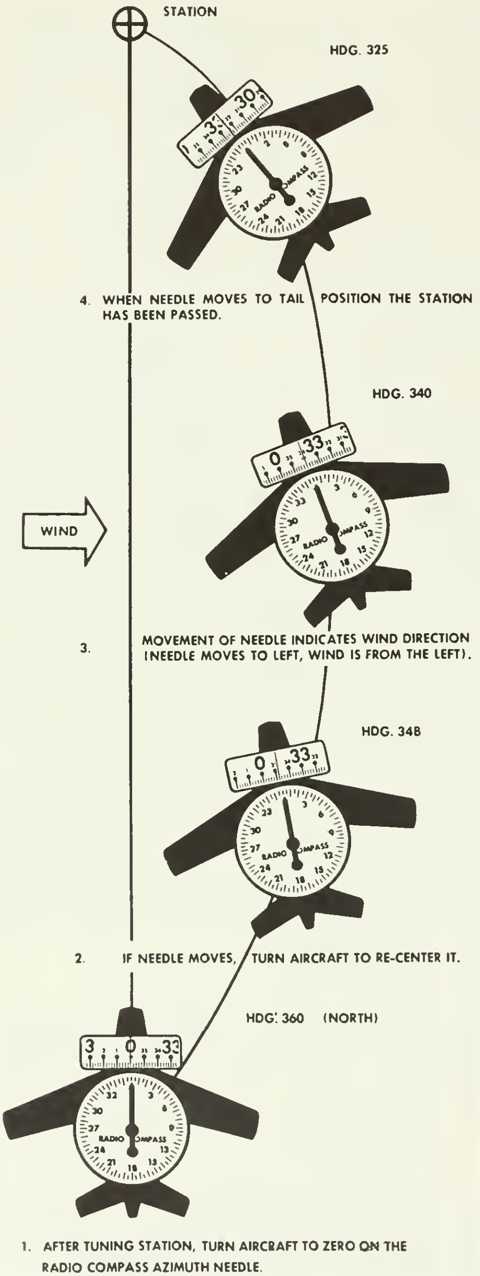


Figure 108—The Rotating Needle of the Automatic Direction Finder (ADF)

form of the radio navigational aids by commercial and private pilots is the Very High Frequency Visual Omni Range. Air traffic increased in the past decade to such an extent that navigational aids were inadequate to handle the flow of traffic. To solve this problem, VOR (Visual Omni Range) was developed.

VOR is a navigational aid that eliminates many of the deficiencies found in previous equipment, such as static due to atmospheric disturbances, interference from mountains, and a limited number of beams or courses to the station.

Instead of four courses, only, to the station, VOR provides 360 courses to or from an omni-range station. All VOR stations are located on *Victor Airways.*

The Omni Range is designed to operate within a frequency band of 112-118 megacycles. It produces a pattern of courses from the station similar to the spokes of a wheel, with the station representing the hub. These spokes are known as *radials* and are numbered or identified by their magnetic direction from the station. Beginning at North, which is the 360-degree radial, they are numbered clockwise around the station.

To use VOR, the aircraft must be equipped with an Omni (VHF) radio. This Omni radio has two unusual features, i.e., the communication feature which permits the pilot to talk directly with the persons, if any, who are tending the station, and the navigation feature which enables the pilot to determine on which radial he is flying, thereby giving him the compass course the aircraft must fly in order to reach the station. (Figure 109.)

To use the Omni range, the pilot first tunes in the desired station on the *frequency selector* (1) and identifies the station by its transmission of a three letter code; e.g., Minneapolis Omni would be identified as "M" (— —) "S" (- - -) "P" (- — — -).

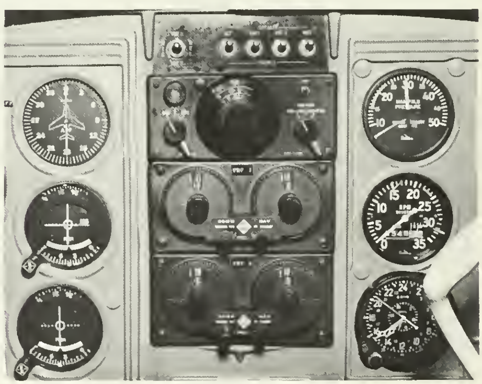


Figure 109—Aircraft VHF Transmitter and Receiver

The pilot then rotates the *course selector* (2) manually until the *needle* (3), which will move from side to side, is squarely in the center. He then reads, from the course selector, the course he must fly to reach the range station. The course selector will indicate the course either *to* the station or the course *from* the station, depending upon the position of the *to-from* indicator needle.

After this orientation has been completed, and the pilot has turned the aircraft to the compass course indicated by the course selector, he must keep the needle centered by searching for the heading that will keep him on the radial. (When the aircraft is to the left of the radial, the needle will point to the right, or toward the radial. When the aircraft is on the radial, the needle will *center*. When the aircraft is to the right of the radial, the needle will point to the left.)

There are numerous other aids for radio navigation, but those that have been covered are the most popular types used by private pilots today.

Celestial Navigation

In celestial navigation, position on the earth's surface is determined by reference to the heavenly bodies. During daytime flights, the sun is used as a reference, and at night the moon, planets, and stars are used as references.

The accuracy of celestial navigation depends upon the skill of the navigator, the accuracy of his intruments, and the prevailing weather conditions.

The items of equipment required for celestial navigation are: (1) a sextant, for observing celestial bodies; (2) a watch with a second hand; (3) an air almanac, for locating the position of the celestial bodies; and (4) numerical tables, for computing the line of position.

A celestial navigator no longer needs to be an expert mathematician. Modern methods have simplified this type of navigation to the point where anyone who can add or subtract can figure his geographic position in a very few minutes. The mathematics formerly required has been eliminated through the use of numerical tables.

Summary

Navigation refers to man's ability to journey on or over the surface of the earth, and air navigation is a science which determines geographic position and maintains a desired direction in the air with respect to specific positions and directions on the ground.

Position, direction, and distance are fundamentals of air navigation. Position is expressed in degrees and minutes of longitude and latitude. Direction is expressed by the angular difference, in degrees, between a specific heading and "north," or 360 degrees. Distance is expressed in terms of nautical or statute miles.

Maps and charts designed for aerial navigation will indicate outstanding terrain features as well as radio and other electronic aids. Most aerial navigational charts are made from Lambert Conformal Conic Projections.

In plotting a course from the departure point to the destination, a pilot must determine: (1) direction, (2) distance, (3) speed, (4) magnetic variation, and (5) wind drift corrections.

There are four common types of air navigation: (1) pilotage—locating landmarks on the ground and matching them to a chart of the same area; (2) dead reckoning—determining the direction, speed, and distance prior to takeoff; (3) radio—determining position by use of electronic equipment; and (4) celestial—observing the angular reference to the sun, moon, and stars. Each of the above listed navigational methods requires specific techniques. Varying weather conditions and pilot ability determine the method to be employed for a particular flight.

Questions

1. Why is navigation important to any means of transportation?
2. What is air navigation?
3. What form of air navigation is performed by observing angular reference to the sun, stars, and moon?
4. How does pilotage differ from dead reckoning?
5. How is direction measured on a map?
6. What is a great circle?
7. Explain how compass heading is derived, and what is the difference between compass heading and compass course?
8. How does the movement of an air mass over the ground effect an aircraft in flight within the air mass? How is this effect corrected?
9. What is radio navigation?
10. What are the two most common radio frequency bands?
11. What advantage does a pilot have using a VHF radio?
12. Explain briefly the fundamentals of VOR.
13. List the equipment necessary for celestial navigation.
14. How many degrees of direction are there on the earth's surface?
15. Is true north the same as magnetic north? Explain.

Chapter 9 Meteorology

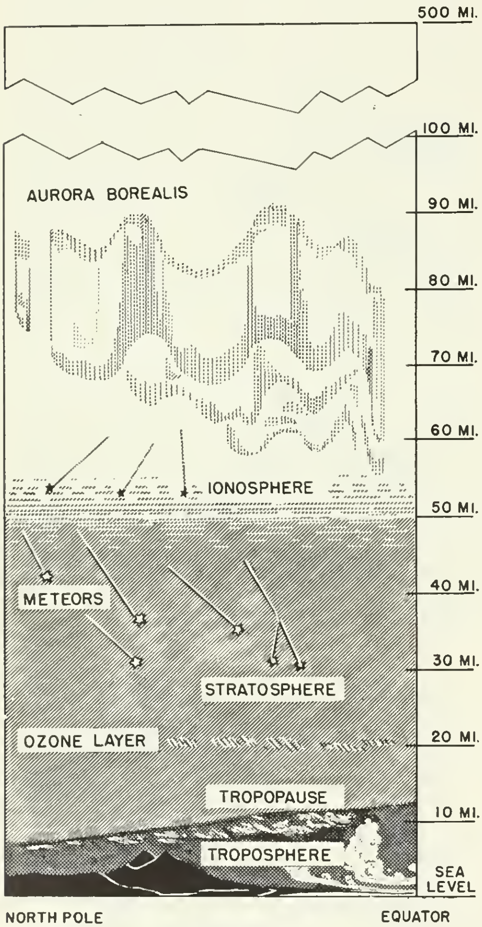


Figure 110—The Atmospheric Regions or Levels of the "Ocean" of Air Surrounding the Earth

Because weather affects man directly, it has become his most common topic of casual conversation. Droughts, rainy seasons, and unusual weather conditions, such as excessive heat waves and cold spells, directly control the type of food man buys, the clothes he wears, his plans for a weekend of tennis or ice skating, his summer vacation period, and the transportation systems he uses.

The advent of the airplane and the approach of the Aerospace age has caused the science of meteorology and weather forecasting to become even more important to larger numbers of people. Of all the many courses of study that are included in aviation training, meteorology—the study of the earth's atmosphere—is one of the most important.

The Atmosphere

Surrounding the earth, held tightly to it by gravity, and rotating with it, is a huge ocean of air called the atmosphere. Although it extends upward many miles, our common weather occurs only in the lowest layer called the troposphere. The troposphere is a relatively thin layer, its height varying from season to season, but on the average is about 30,000 feet at the poles and 60,000 feet at the equator. The next layer above the troposphere is the stratosphere. For the most part, weather does not occur in this layer although some rather heavy turbulence is occasionally encountered by high-flying airplanes. Temperature remains relatively constant, or may increase slightly, with increasing altitude. Above the stratosphere is the ionosphere which is important from an aviation standpoint because it reflects some of the radio waves from communications and navigation facilities.

Elements of Meteorology

To understand weather, it is necessary to know certain basic facts and theories about the more important meteorological elements which, when combined, make up the weather.

TEMPERATURE

Temperature, the measure of heat, is an important element of meteorology. Heat is transferred from the sun to earth by a radiation process called *insolation*. The sun's heat is not absorbed by the earth's atmosphere but is transferred directly to the earth's surface. A small amount of heat is absorbed and stored in the surface. The remainder is then reflected into the atmosphere by radiation, convection, and conduction processes.

The air at the surface is heated by conduction—the transferring of heat by contact—and by radiation—the transferring of heat by wave motion. When this surface air is heated, it expands, becomes lighter than the surrounding air, and consequently rises into the atmosphere. This method of carrying heat upward into the atmosphere is called *convection*. The heights to which these convective currents rise depend upon the intensity of the heating and the stability of the air masses. Convective currents cause turbulence, cumulus clouds, and sometimes thunderstorms. The fact that the air is heated by the earth and not the sun directly explains why the temperature is highest at the surface of the earth and progressively colder as the atmosphere is penetrated.

When the sun's rays strike the earth's surface in a direct rather than an angular manner, more heat is produced on that portion of the surface and subsequently reflected into the atmosphere. This phenomenon accounts for the variety of climates on the earth and the changing seasons of the year. In addition, the amount of heat which is absorbed by the earth is dependent upon the character of the earth's surface. When the sun shines on water, the heat is distributed throughout the entire depth by the action of tides, waves, and currents. Therefore, a relatively greater amount of heat is absorbed by large bodies of water. On the other hand, because land is a poor heat conductor, land areas absorb a relatively small amount of heat in a shallow layer. Consequently, during the daytime, land areas reflect more heat into the air, causing considerable increase in temperature levels of the atmosphere, while large bodies of water reflect less heat into the air, and increase temperature levels very little. At night, the ground soon loses its small amount of stored heat and the air above it cools quickly. The water, however, having stored more heat during the day, consequently supplies it to the air throughout the period of darkness. This is why there is little change in temperature between day and night over oceans, while the change over land is considerably greater.

Although land areas do not absorb large amounts of heat, different types of land surfaces do absorb it in

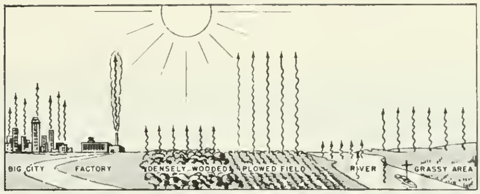


Figure 111—Strength of Convective Currents Varies According to the Ground Characteristics

varying degrees. (Figure 111.) Barren areas of sand or plowed fields, for example, do not absorb as much heat as those areas which are covered with vegetation. Over these barren areas, then, the temperature difference between day and night is greater than it is over the vegetated areas.

PRESSURE

Another meteorological element which must be understood is pressure—the weight of the atmosphere on earth. The highest pressure is at the earth's surface and it decreases as the altitude increases. Moreover, at any given altitude, the pressure constantly changes. At sea level, the average pressure is 14.7 pounds per square inch. This amount of pressure will support a column of mercury 29.92 inches high in a barometer and is equal to 1013.2 millibars. In aviation technology, pressure is always reported in terms of inches of mercury or millibars of pressure.

Differences in pressure over the earth's surface are caused by differences in the intensity of the heating of its surface by the sun. These differences in pressure will influence the movement of air. Generally speaking, air will move from areas of relatively high pressure toward areas of relatively low pressure.

MOISTURE

Water exists in the atmosphere in three different physical states: solid, liquid, and gas. As a solid it takes the form of snow, hail, ice-crystal clouds, or ice-crystal fog. As a liquid it is found as minute water droplets in clouds and fog, as drizzle, and as rain. As a gas it is known as water vapor.

Under a constant pressure, warm air supports more water vapor than does cold air. The amount of water vapor in the air is measured in terms of *relative humidity*, i.e., the ratio between the amount of water vapor actually present in a specified volume of air at a given temperature and the amount of water vapor which this same volume of air is theoretically able to support. As air temperatures decrease, air's ability to support water vapor also decreases, and the relative humidity increases. If this cooling process continues,

Figure 112—A Composite Drawing of the Principal Types of Clouds Showing the Approximate Levels at Which They Are Found

a temperature is reached where the relative humidity reaches 100 per cent. Further cooling of the air then causes excess water vapor to be condensed into a liquid. When this event occurs, temperature has reached the *dew point,* and the liquid water, in the form of small droplets, will remain suspended in the atmosphere in the form of clouds. If condensation continues, the droplets grow too large to be suspended and fall to the earth. This is called *precipitation.* If the temperature within the cloud is above freezing (32° F.), the precipitation will be in the form of rain, but if the temperature is below freezing, the precipitation will be in the form of snow. Condensation which occurs only at the earth's surface is called fog.

CLOUDS

As indicated in the discussion of moisture, clouds are formed when the air is cooled to the dew point temperature level. Clouds are divided into two basic categories—stratus and cumulus.

When whole layers of air are cooled, the clouds which are formed appear as smooth stratified layers, i.e., stratus clouds. These air layers are cooled in two ways: (1) by cooler air moving into and mixing with the stationary layer of air; and (2) by the air layer rising to a higher altitude. When a layer of air rises in the atmosphere it also expands since there is a decrease in pressure. This new expansion of air will, in turn, cause additional cooling.

When individual currents of air rather than whole layers of air rise into the atmosphere and cool to the dew point temperature level, the clouds which are formed have a lumpy or billowy appearance, i.e., cumulus clouds.

While there are only two basic cloud categories, there are many variations within each classification. For purposes of identification and weather analysis, all of the various cloud types are separated into four families: (1) high clouds; (2) middle clouds; (3) low clouds; and (4) clouds with vertical development. (Figure 112.)

High Clouds

Clouds which form above 20,000 feet are classed as high clouds and are divided into three basic cloud formations:

Cirrus clouds are the highest and thinnest of all the cloud types. Their average height is about 32,000 feet, and they are composed of ice crystals which have a silky or fibrous appearance. Cirrus clouds are not thick enough to shade the sun and they do not present any problem to flying. However, certain types of cirrus clouds will indicate approaching bad-flying weather.

Cirro-stratus clouds reach an average height of 28,000 feet. At this altitude they appear as thin, whitish sheets, either in patches or as a complete covering in the sky. These clouds do not shade the sun or moon but at times cause a halo to form around them. Ciro-stratus clouds are very thin and are also formed by ice crystals. Although they present no problem to flying activities, if they follow cirrus clouds they may indicate the approach of a low-pressure area with its usual bad-weather conditions.

Cirro-cumulus clouds appear as small white globular masses or flakes at an average altitude of 22,000 feet. They produce some slight shading of the sun but are thin enough so that they are not a problem to flight.

Middle Clouds

Clouds with bases ranging from 6,500 feet to 20,000 feet are classed as middle clouds and are divided into two basic cloud formations:

Alto-stratus clouds appear as smooth, gray clouds which have light and dark patches that are caused by differences in thickness. When they follow cirro-stratus clouds into an area, they indicate approaching bad weather.

Alto-cumulus clouds appear in the form of large white or grayish globular masses. They are fairly thin and produce partial shading of the sun.

Low Clouds

Clouds with bases below 6,500 feet are classed as low clouds and are divided into three basic cloud formations:

Strato-cumulus clouds form at an average height of 6,000 feet and have an average thickness of about 1,400 feet. When viewed from below, the clouds have a wavy appearance. They occur most frequently in winter and often persist for two or three days.

Nimbo-stratus clouds are the clouds from which steady rain falls. These clouds are dark gray in color, which is an indication of considerable thickness. These clouds do present some flight problems.

Stratus clouds appear in uniform layers. The thickness of these clouds varies immensely so that at times they appear as a haze in the sky and at other times they are very dark gray. Stratus clouds often appear with other types of clouds such as cumulo-nimbus and nimbo-stratus. They do produce precipitation in the form of drizzle.

Clouds of Vertical Development

Clouds formed by vertically rising air are classified as clouds of vertical development. The bases of these clouds generally range from about 1500 to 5000 feet above ground.

Cumulus clouds vary in size from a small spot in the sky to a large dark cloud many thousands of feet in diameter and thickness. Their tops are dome-shaped with rounded protuberances. These "fair-weather" cumulus clouds are formed as a result of the intense heating of the earth's surface. As the earth heats the air directly above it, the warmed air rises; as it rises, it is cooled until it reaches the dew point temperature. When the column of air reaches the dew point temperature, the cloud is formed.

Cumulo-nimbus clouds are cumulus clouds which have continued to grow in size until enough condensation has taken place to produce raindrops. When the raindrops become too heavy to be supported by the convective currents—updrafts—the raindrops fall from the cloud. From below, cumulo-nimbus clouds look like large, dark cumulus clouds. The tops of cumulo-nimbus clouds may rise to altitudes of 50,000 to 60,000 feet.

CIRCULATION

Since unequal heating of the earth's surface causes uneven heating of the atmosphere, the atmosphere is in constant motion. Where the earth is intensely heated, the warm air rises, forming an area of relatively low pressure. Surrounding air, which is colder, will move into this low-pressure area, become warmed, and rise, thereby making room at the surface for more air. This cycle of circulation is constantly operating across the entire surface of the earth. (Figure 113.) Within this primary circulation there is secondary circulation. Large masses of air move toward low-pressure areas and cause changes in weather across the surface over which they move. Within the air masses there are also circulation movements, but on a smaller scale. For example, a rising convective current from a plowed field will create a low-pressure area within the air mass itself.

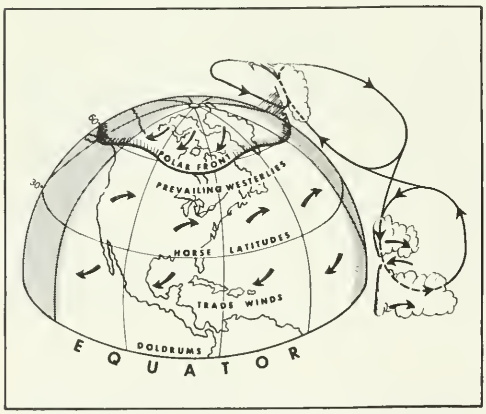


Figure 113—The theoretical winds on an Earth of uniform and even surface would follow the pattern shown here (cross section on right).

Circulation accounts for wind—moving air. Primary circulations determine the general globular wind directions. Moving air masses influence wind direction and velocity over smaller areas, and circulation movements within the air masses influence wind direction and velocity in an even smaller region. Generally speaking, good weather is associated with high-pressure areas and bad or stormy weather with low-pressure areas. Low pressure—bad weather is caused by air moving inward toward low-pressure areas meeting air which is at a different temperature. Mixing takes place, usually cooling the warmer low-pressure air or forcing the warmer air aloft where it is cooled. When the temperature of the warmer air reaches the dew point, clouds and, often, precipitation result. In high pressure—good weather, air will neither be mixed nor cooled since circulation movements are outward and away from the high-pressure area.

AIR MASSES AND FRONTS

Air masses are large bodies of air which are horizontally uniform in temperature level and moisture content. They are identified according to their source region and their temperature. An air mass which forms over water is called a *maritime air mass* and contains large amounts of water vapor. An air mass which forms over land is called a *continental air mass* and contains relatively small amounts of water vapor. Air masses which form in the arctic and polar regions are called *arctic or polar air masses* and those which form in the tropical regions are called *tropical air masses.* A cold air mass is "cold" if it is colder than the surface over which it is moving. A warm air mass is "warm" if it is warmer than the surface over which it is moving. For example, a mass of air which forms over Northern Canada and then moves quickly down over the Middle West would be classified as a Continental Polar Cold air mass (cPk) because it was formed over land, in a polar region, and its temperature is colder than the temperature of the surface over which it is passing.

A *front* is the boundary zone between two contrasting air masses. When air masses are stationary the front is called a *stationary front.* When the air masses are moving, with a colder air mass replacing a warmer air mass, the front is called a *cold front.* When a warmer air mass replaces a cooler air mass, the front is called a *warm front.* Fronts are very important to flying activities because weather changes almost always are associated with them.

The preceding paragraphs have pointed out and briefly described some of the important meteorological elements of weather. The principles which were discussed should help the student to understand better the physical phenomenon called weather.

Elements of Weather Important in Aviation

The weather elements to be discussed in this section are those which are of most importance to pilots. Every good pilot studies these elements when he plans a flight.

CEILING

Ceiling refers to the upper boundary of the air space between the earth's surface and the lowest cloud layer. More specifically, it is height measured to the base of the lowest layer of clouds which covers more than one-half of the visible sky.

The ceiling is important to everyone who flies, but its importance varies, depending upon the qualifications of the pilot and the type of equipment in his airplane. A certified pilot with an instrument rating is primarily interested in the ceiling at his destination, since he is qualified to fly through clouds and poor weather conditions if his airplane is properly equipped. First, he must know if the ceiling is so low that he will have to make an instrument approach to the airport. Second, if he must plan to make an instrument approach, the height of the ceiling will partially determine the type of instrument approach it will be necessary to make. Third, if the ceiling is extremely low, so that there is no margin of safety, the pilot will probably land at an alternate airport rather than at his intended destination.

A pilot who is not qualified to fly solely by reference to instruments or a pilot who is flying an airplane not equipped with the necessary instruments must rely on his visual ability to see the ground. This means, of course, that the pilot must stay out of clouds. This pilot is interested in knowing the ceilings en route as well as the ceiling at his destination because he needs to know if he has enough room between the earth and the clouds in which to fly his airplane safely.

VISIBILITY

Visibility is spoken of in terms of miles of distance a pilot is able to see horizontally outside of clouds. Visibility is important because the more restricted it is, the closer airplanes will be before they can see each other. Also, the more restricted the visibility, the harder it is to navigate by pilotage and the harder it is to keep track of the attitude of the airplane.

Just as with ceiling, a person capable of flying and navigating by instruments is not too concerned with visibility except at his destination. At his destination, visibility will determine whether or not the pilot must make an instrument approach. If an instrument approach is necessary, the visibility will have some bearing on the type of approach which he uses. If visibility is too restricted, i.e., a safety margin does not exist, the pilot will either decide not to go or will land at an alternate airport.

Four common restrictions to visibility are (1) fog, (2) precipitation, (3) haze, and (4) smoke.

Fog varies in intensity but it can, and often does, cut visibility to zero or to 1/16 of a mile, which is too restricted even for safe instrument landings. Fog occurs most often during the nighttime hours when the sky is clear and when the earth is radiating its heat into space; then, as the cool ground cools the air above it to the dew point temperature level, fog may form. This type of fog usually dissipates soon after the sun rises in the morning.

Precipitation does not generally reduce visibility to the degree that fog does; however, there are certain exceptions. Snow, for example, can erase in-flight forward visibility entirely, even though it is not heavy.

Figure 114—Pilot's forward visibility in snow can approach zero even though snow is not heavy.

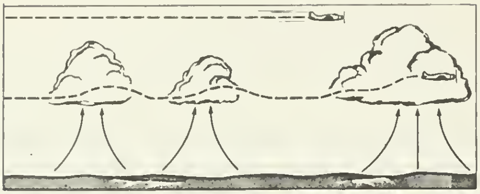


Figure 115—Avoiding Convective Turbulence by Flying above Cumulus Clouds

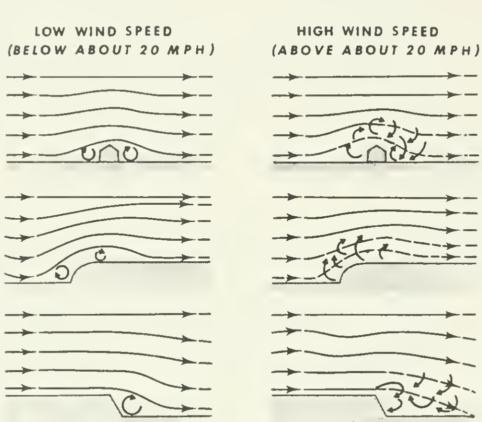


Figure 116—Surface obstructions cause eddies and other irregular wind movements.

Figure 117—Turbulent Air at the Boundary between Calm, Cold Air Below and Moving, Warm Air Above

Figure 118—Clear-Air Turbulence in the Wake of an Aircraft

(Figure 114.) When the ground is covered with snow and when the snowfall is heavy, it produces visibility conditions equal to zero. Rain from thunderstorms can occasionally be so heavy that the pilot is unable to see the horizon.

Although haze is caused by impurities in the air, it does not usually reduce visibility limits to less than 3 to 5 miles. However, it causes the light from the sun to be diffused so that visibility may be less than one mile looking toward the sun while it is considerably more looking away from the sun.

Smoke causes the same effect as haze and is a problem only in low altitudes over industrial areas. Smoke is most detrimental to visibility, however, when it is mixed with fog or haze.

TURBULENCE

Turbulence refers to irregular movements of the air—gustiness. Generally turbulence is not a serious hazard to flight, but it does produce uncomfortable conditions. In some cases it can be hazardous, but only if it is unexpected.

The most common cause of turbulence is unequal heating of the earth's surface on a clear day. (Figure 111.) The resulting convective currents rising from the earth's surface to the atmosphere cause the flight path to be rough, up to a certain altitude. This altitude is usually marked, if there is sufficient moisture in the air, by cumulus clouds. Above the cumulus clouds, the air is smooth. (Figure 115.)

Other types of turbulence are caused by wind blowing over irregular terrain, (Figure 116) by wind shear—wind from different directions or of different speeds moving side by side—(Figure 117) and by the slipstream of airplanes. (Figure 118.) The latter is a problem only on takeoffs and landings when one airplane follows too closely behind another.

The thunderstorm produces the most violent of all turbulences because it is composed of a series of strong updrafts and downdrafts existing side by side. (Figure 119.) It is not uncommon for updrafts with speeds of 30 feet per second and downdrafts with speeds of 15 feet per second to exist side by side. Thunderstorms are hazardous, however, only if the pilot is not prepared for them and if he does not have his airplane moving at a safe flying speed. Only experienced instrument pilots flying stable airplanes completely equipped for instrument flight attempt to fly through thunderstorms. Generally the pilot will do all he can to avoid them. If thunderstorms are scattered, the pilot can go around or between them. If he must go through a line of storms, he will try to pick the least violent areas through which to fly. The pilot can do this by visually observing the storms

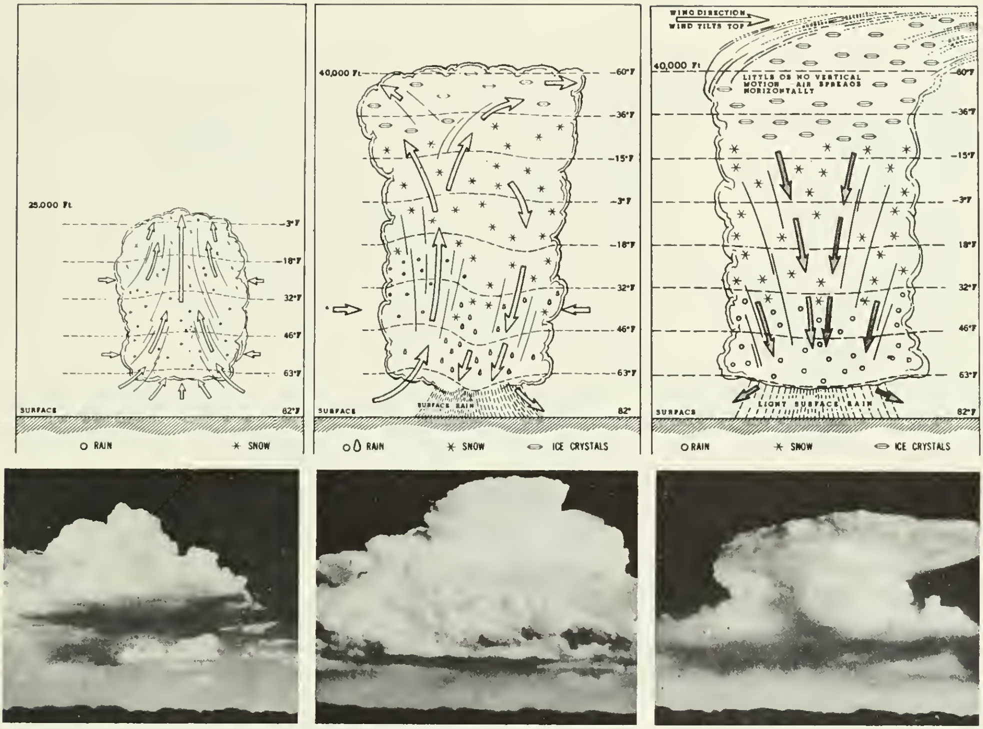


Figure 119—The above shows the three stages in the life cycle of a thunderstorm. (a) cumulus stage; (b) mature stage; and (c) dissipating stage. Arrows indicate direction of drafts.

or, if he is operating in the clouds, observing them by radar.

ICING

It is quite common for water to exist in the atmosphere in a liquid state at freezing or below freezing temperatures. If this water is disturbed, however, it will immediately freeze. This disturbance, when created by an airplane, will cause the liquid to solidify and freeze onto the airplane itself. Occasionally rain will fall through layers of air that are at freezing temperature levels. The surface skin of an airplane flying through these same air layers will also be at freezing temperature levels. As the airplane strikes the raindrops, they immediately freeze to the airplane. (Figure 120.) Icing is a flight hazard because as ice collects on the airplane it (1) increases drag, which tends to slow the forward speed of the airplane; (2) changes the shape of the propellers, thereby reducing their effectiveness; (3) changes the shape of the wing, thereby reducing the amount of lift the wing can produce; and (4) increases the total weight of the airplane.

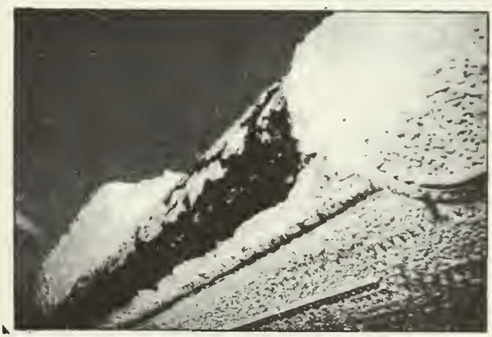
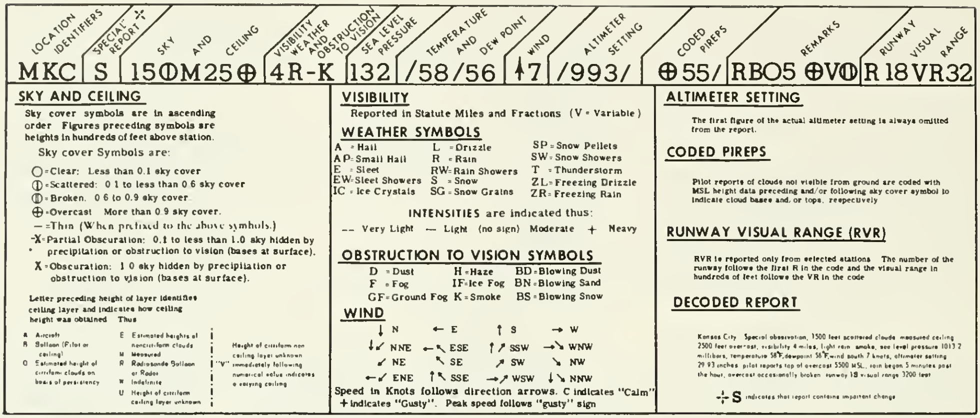


Figure 120—Rime Ice, with Some Glaze Ice, on Outer Right Wing Panel



NOTE: Since January 1, 1964, wind direction has been reported to the nearest 10 degrees by means of a two-digit number. The third digit of the direction, which is always a zero, is omitted. Winds from the northwest would be reported as 31; from the east as 09; etc. Velocity is still indicated in knots but a G is added to denote gusty conditions.

Figure 121—Key to Aviation Weather Report

In airplanes which are not equipped with anti-icing or de-icing equipment, icing weather conditions must be avoided. With fully equipped airplanes, however, icing conditions will not suspend flight operations if de-icing equipment is properly used.

Weather Information Available to Pilots

Weather information is available to the pilot in two forms—reports and forecasts. Reports are compiled from visual observation of the existing weather conditions. From these reports and with a complete knowledge of the physics of the atmosphere, meteorologists can accurately forecast weather conditions for the next several hours.

HOURLY SEQUENCE REPORTS

Approximately every hour on the hour, 24 hours a day, at weather bureau stations and Federal Aviation Agency (FAA) communication stations throughout the country, trained personnel observe certain weather conditions and report them, via teletype, to all the other stations in the network and also to any airport or agency that subscribes to the teletype service. (Figure 121.) Since these reports are made so frequently and since they report existing weather conditions from more than 500 stations, hourly sequence reports are very valuable to pilots in flight planning.

PILOT REPORTS

Pilots encountering unusual weather conditions during flying report this weather to the nearest FAA communication or weather bureau station for distribution to other pilots by teletype or radio. Pilot reports are important from two standpoints: (1) a pilot actually flying through the weather can supplement the information gathered by the observer on the ground who cannot always determine the exact weather conditions existing at flight altitude; and (2) pilot reports serve as gapfiller reports on unobserved weather between stations.

MAPS

At six-hour intervals, observers at each of the weather bureau's stations report the existing weather at their station to a central station. At the central station, these reports are used to make a map which shows the weather throughout the entire country. This weather map is then sent to each weather bureau station via a facsimile machine. (Figure 122.) Actually, several maps are made and distributed, which show existing conditions both at the surface and at several specified altitudes above the surface.

WINDS ALOFT REPORTS

Weather bureau stations also periodically check the winds aloft. (Figure 123.) This wind information is

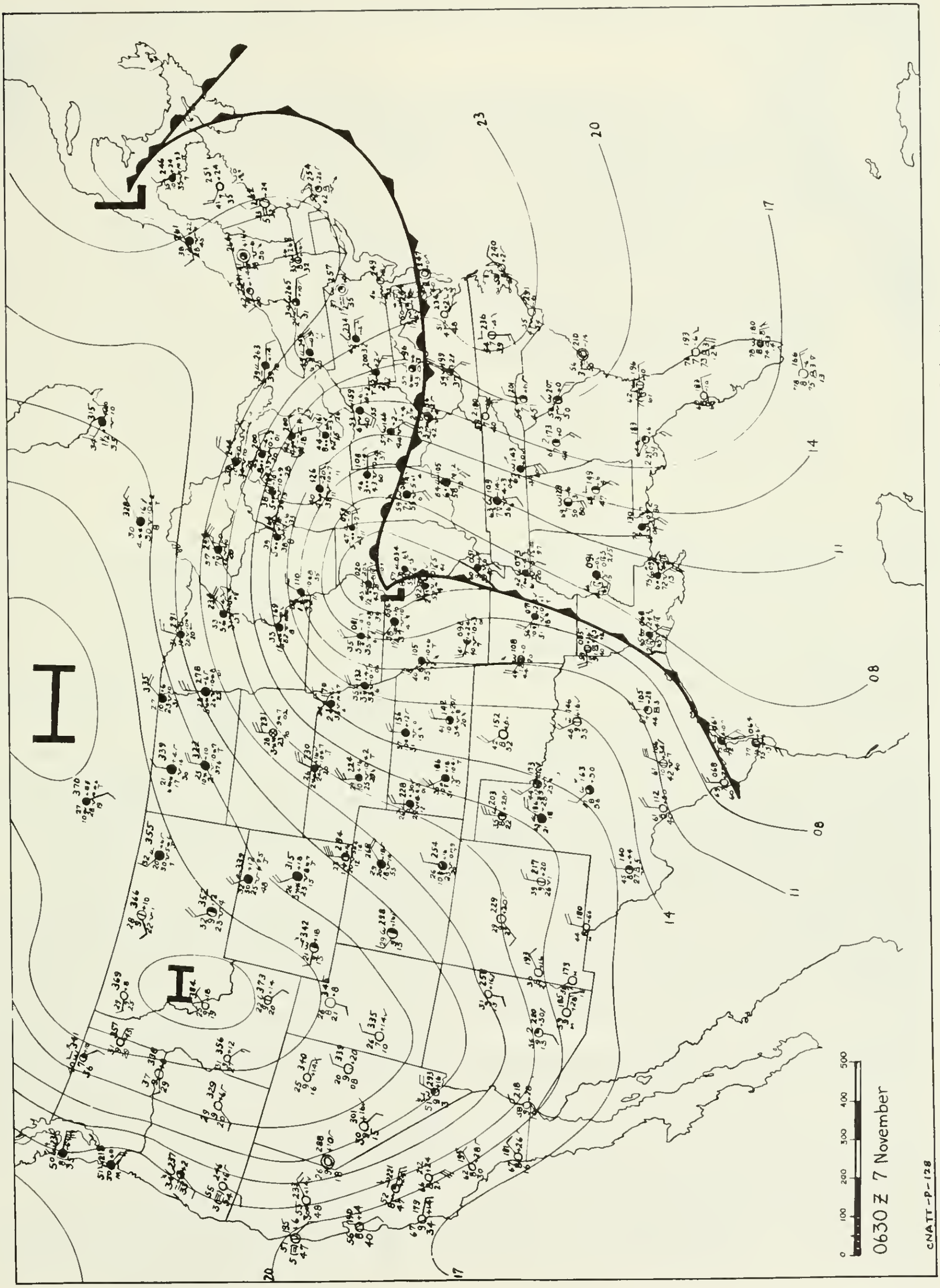


Figure 122—Sample Black and White Surface Weather Map. Also Called Facsimile Surface Map

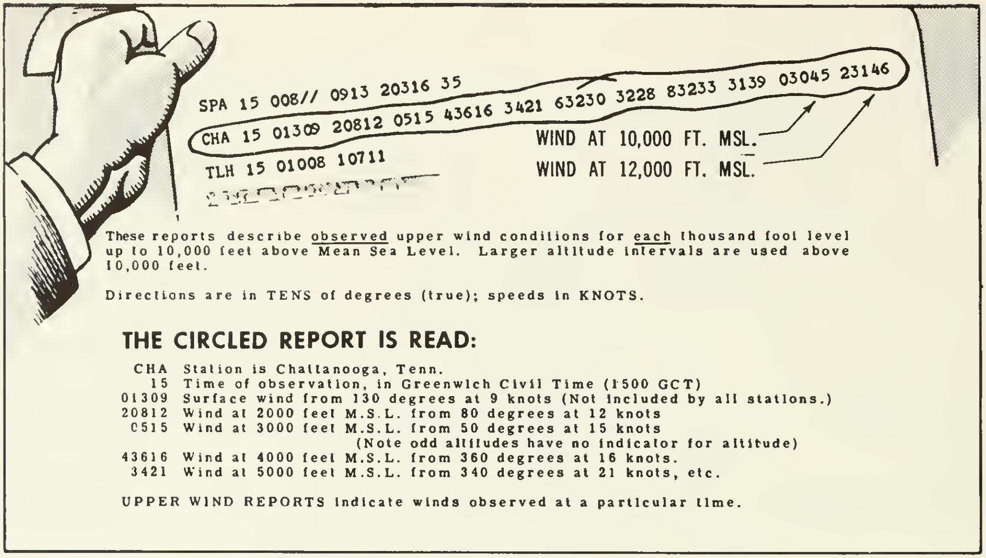


Figure 123—Key to Report of Winds Aloft

sent, via teletype, to all other weather bureau stations and is useful to the pilot as it enables him to select the best altitude at which to fly.

AREA FORECASTS

Every six hours major weather bureau stations forecast the weather for their particular area for the next 12-hour period. (Figure 124.) This forecast includes expected clouds, weather, icing, and turbulence. These forecasts are distributed by teletype to all airports and to all other agencies who subscribe to the service.

TERMINAL FORECASTS

Every six hours, at each of the weather bureau stations, trained forecasters forecast the weather for twelve hours in advance. (Figure 125.) These forecasts are also distributed by teletype just as are the area forecasts.

The above are the more important reports and forecasts which are made available to pilots. There are many methods and instruments used by the personnel who gather and disseminate the weather data, but to describe them is beyond the scope of this chapter. There are still many unanswered questions in meteorology. Instruments, such as radar, have helped to solve many of the puzzles. It is expected that the breakthrough into space will result in the solving of many others.

Summary

Meteorology, the scientific study of the atmosphere, is extremely important inasmuch as weather directly affects all people, particularly those who fly.

The atmosphere consists of many parts. Of greatest current importance is the troposphere—that part of the atmosphere which is next to the earth's surface. It is within the troposphere that man exists, pilots do most of their flying, and changes in weather conditions take place.

Temperature is one of the most important elements of meteorology. Differences in the temperature of the air result from differences in the heating of the earth's surface by the sun. This causes varying climatic conditions in the world and changing weather conditions within climatic regions. Changes in air temperature cause clouds and precipitation, since cool air will not support as much water vapor as warm air. When cooling of warm moist air takes place, condensation occurs at a certain temperature level called dew point. Condensed water vapor results in clouds or fog. Further cooling and condensation of water vapor may result in precipitation.

There are four categories of clouds: high, middle, low, and clouds of vertical development. The two basic types of clouds are stratus and cumulus with variations within each of these types.

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FCST 07C-19C
MINN  N DAK  S DAK

CLDS AND WX. HEIGHTS MSL UNLESS NOTED. CNDS IN 50 MILE
WIDE SQAL LINE ZONE THRU SERN MINN MOSTLY 60⊕ BUT
VSBYS BRFLY 2-4 MIS AND CIGS NEAR 20 HND ABV GND
WITHIN HVYR TSTM AREAS. THIS SQAL LINE WILL MOVE SEWD
ABT 25 MPH AND DSIPT BY ABT 10C. STRATUS OVC 5-10 HND
ABV GND IN NERN MINN WILL CLR BY MID MRNG BUT LCL
AREAS LOW CLDS 6-12 HND BRKN ABV GND WILL PERSIST
UNTIL ABT NOON ALNG THE SLOW MOVG COLD FNT FROM INTER-
NATIONAL FALLS TO HURON AT 05C AND STNRY FROM THERE
WWD TO BYND RAPID CITY. 10-12 THSD BRKN GNRL IN CNTRL
AND WRN PTNS DAKOTAS WITH A FEW HI LVL TSTMS DVLPG IN
LATE AFTN

ICG. LGT TO OCNLY MDT ICGIC ABV 120 XCP LCLY HVY IN
TSTM AREAS. FRZG LVL 120-140

TURBC. MDT TO HVY IN TSTMS

OTLK 19C SUN TO 07C MON. TSTMS CNTRL AND WRN DAKOTAS
WILL END BY ERY AFTN BUT ANTHR SQAL LINE WILL DVLP
FROM NERN MINN TO SERN CORNER S DAK BY 19C THAT WILL
MOVE EWD ABT 25 MPH WITH LCLY SVR CNDS AND THEN DSIPT
SHORTLY AFT MIDN. ELSW UNRSTD VSBYS AND NO CLDS BLO
10 THSD MSL.
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PLAIN LANGUAGE INTERPRETATION

Area forecast for period 7 a.m. to 7 p.m. Central Standard Time for Minnesota, North Dakota, South Dakota.

Clouds and Weather. Heights mean sea level unless noted. Conditions in a 50 mile squall line zone through southeastern Minnesota mostly 6000 foot overcast but visibilities briefly 2 to 4 miles and ceilings near 2000 feet above ground within heavier thunderstorm area. This squall line will move southeastward about 25 miles per hour and dissipate by about 10 a.m. Central Standard Time. Stratus overcast 500 to 1000 feet above ground in northeastern Minnesota will clear by middle of the morning but local areas of low broken clouds 600 to 1200 feet above ground will persist until about noon along the slow moving cold front lying from International Falls to Huron at 5 a.m. and is stationary from there westward to beyond Rapid City. Broken clouds at 10,000 feet to 12,000 feet will be general in central and western portions of the Dakotas with a few high-level thunderstorms developing in the late afternoon.

Icing. Light to occasionally moderate icing in clouds above 12,000 feet except locally heavy in thunderstorm areas. Freezing level height 12,000 feet to 14,000 feet.

Turbulence. Moderate to heavy in thunderstorms.

Outlook. 7 p.m. Sunday to 7 a.m. Monday. Thunderstorms in central and western Dakotas will end by early afternoon but another squall line will develop from northeastern Minnesota to the southeastern corner of South Dakota by 7 p.m. that will move eastward about 25 miles per hour with locally severe conditions and then dissipate shortly after midnight. Elsewhere unrestricted visibilities and no clouds below 10,000 feet above mean sea level.

Figure 124—Area Aviation Forecast and Interpretation

KEY TO AVIATION WEATHER FORECASTS.......

TERMINAL FORECASTS contain information for specific airports on ceiling, cloud heights, cloud amounts, visibility, weather condition and surface wind. They are written in a form similar to the AVIATION WEATHER REPORT.

CEILING Identified by the letter "C"
CLOUD HEIGHTS: In hundreds of feet above the station
CLOUD LAYERS Stated in ascending order of height
VISIBILITY: In statute miles, but omitted if over 8 miles
SURFACE WIND: In knots but omitted when less than 10

Examples of TERMINAL FORECASTS:

C15◐ | Ceiling 1500' broken clouds
C15⊕6K | Ceiling 1500' overcast visibility 6 miles, smoke
20⦶C70⊕↘30+ | Scattered clouds at 2000' ceiling 7000' overcast, surface wind northwest 30 knots gusty
O11/2GF | Clear, visibility one and one half miles, ground fog
C5X1/4S | Sky obscured vertical visibility 500', visibility one fourth mile moderate snow

AREA FORECASTS are 12-hour forecasts of cloud and weather conditions, cloud tops, fronts, icing and turbulence for an area the size of several states. A 12-hour OUTLOOK is added. Heights of cloud tops, icing, and turbulence are above SEA LEVEL.

SIGMET advises airmen in flight of severe or extreme weather conditions potentially hazardous to all aircraft.

ADVISORIES FOR LIGHT AIRCRAFT advises airmen in flight of weather conditions of less severity than SIGMET but which may be hazardous to light aircraft. Both types of advisories are broadcast by FAA on NAVAID voice channels.

WINDS ALOFT FORECASTS provide a 12-hour forecast of wind conditions at selected flight levels. Temperatures aloft are included for selected stations.

Examples of WINDS ALOFT FORECASTS:

Without Temperature
5-2030 | 5,000 MSL wind from 200° at 30 knots

With Temperature
10-2540/3 | 10,000 MSL wind from 250° at 40 knots Temperature +3°C

PILOTS report in-flight weather to nearest FSS.

U. S. DEPARTMENT OF COMMERCE ☆ WEATHER BUREAU ☆ WASHINGTON 25, D. C.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1961 O - 595413
REVISED JUNE 1961

Figure 125—Terminal Forecasts and Interpretation

The atmosphere is constantly in motion. This motion is called circulation. Primary circulation occurs on a world-wide scale; secondary circulation occurs on a more localized scale within the boundaries of the primary circulation. Circulation is caused by unequal air pressure, which, in turn, is caused by unequal heating of the earth's surface.

Huge masses of air, in which temperature and moisture characteristics are uniform, are constantly moving across the surface of the earth. Boundaries between these air masses are called fronts. The leading edge of a cold air mass which is replacing warm air is called a cold front. The leading edge of a warm air mass which is replacing cooler air is called a warm front. Generally, cold fronts produce turbulent weather conditions, such as thunderstorms in summer, over a relatively narrow area along the front. Warm fronts, on the other hand, produce less turbulent weather, but over a much wider area along the front.

The most important weather conditions from a pilot's viewpoint are ceiling, visibility, turbulence, and icing.

Ceiling is the upper boundary of the airspace between earth and the base of the lowest level of clouds covering more than one-half of the sky. Ceiling measurements tell the pilot how much space he has in which to fly and still maintain visual contact with the earth's surface.

Visibility is the maximum horizontal distance which a pilot can see when flying outside of clouds.

Turbulence is the result of irregular currents of air. A ride in an airplane under these conditions can be rough and uncomfortable in varying degrees. Turbulence may be caused by convective currents, wind blowing over irregular terrain, wind shear, or an aircraft slipstream.

Ice will form on an airplane if it is flying through visible moisture and if the temperature of this moisture or the temperature of airplane's surface skin is at or below freezing. Icing on an airplane increases drag and weight and decreases thrust and lift.

The United States weather bureau maintains more than 500 stations throughout the country. These stations observe and forecast the weather and make their reports and forecasts available to pilots.

Questions

1. In which part of the atmosphere does common weather occur?
2. What is temperature?
3. Describe briefly how the atmosphere is heated.
4. What is convection?
5. Over what kind of surface will there be the least change in temperature between night and day?
6. What is relative humidity?
7. Which is capable of containing more vapor, warm air or cold air?
8. Describe briefly how clouds form.
9. Name the clouds that produce rain.
10. What kind of weather is generally associated with low pressure areas?
11. Give two characteristics of a continental polar air mass.
12. What is a cold front?
13. What is a warm front?
14. What is a ceiling?
15. What are four common restrictions to visibility?
16. How much of the sky is covered when a layer of clouds is described as scattered? As broken?
17. How does an accumulation of ice on an airplane effect its flight characteristics?
18. List the sources of weather information available to pilots.
19. How long a period is covered by area forecasts?
20. How often are terminal forecasts made?

Chapter 10 Air Traffic Control and Communications

Figure 126—Airport Control Tower

A few years ago, when relatively few airplanes were flying, airplane traffic at the larger air terminals, such as New York, Chicago, and San Francisco, was no problem. Now a highly developed system of air traffic control is required to control airplanes flying along the civil airways as well as those arriving or departing from the air terminals. The purpose of this chapter is to discuss briefly air traffic control methods and radio and radar procedures.

Air Terminal Problems

Every transportation control system—land, water, and air—regulates in some measure the traffic which is en route, as well as the traffic at points of arrival and departure. A large railroad terminal, the center for converging routes, schedules incoming and outgoing trains by switches and signals. Buses and automobiles depend upon safety rules and traffic signals to reach their destination. Ocean liners observe maritime law as they sail the sea lanes from port to port.

The airplane presents a different problem. Although its passage is also controlled by rules and signals, the airplane operates at various heights, on invisible aerial highways, and often unseen. In addition, it is unable to stop en route. A train can halt on its rails, an automobile or bus can stop on the road; a steamer can anchor offshore or in midstream; but an airliner, even when it has been slowed to approach an airport for landing, is still traveling between 100 and 230 miles per hour. Jet airliners especially complicate the problem, because they operate at the higher speeds and because at low altitudes, they consume fuel at an extremely high rate. Another unique problem of air traffic control is caused by the airplane's need to rely on humans using radios and other electronic instruments to fly safely through clouds, rain, fog, and darkness on invisible pathways from one airport to another, rather than on steel rails or concrete highways. Aircraft are aided by controllers in Air Route Traffic Control (ARTC) centers and in airport control towers. (Figure 126.)

Aircraft Communication

Since the radiotelephone and the omnirange VOR have achieved such widespread use and importance, the pilot, to fly safely, must have expert knowledge of his radios and of their operation. The pilot must receive, acknowledge, transmit, navigate, and comply with instructions which he receives through radiotelephone transmissions. His life and the lives of others may depend on the accuracy with which he carries out these instructions.

In radiotelephone communication, the accuracy with which messages are received depends largely upon the clearness of the speaker's voice. Loud talking into the microphone is unnecessary and makes reception difficult. A normal tone of voice is used, with the microphone being held close to the mouth but slightly at an angle. (Figure 127.) In radio conversation it must be remembered that engine and static noises are in competition with the spoken word, even though modern high frequency radio equipment does eliminate much of the static caused by atmospheric conditions. It is important to be concise and businesslike and to know what is to be said before beginning the conversation.

To limit the possibility of error in the transmission of names or difficult words, a standardized phonetic alphabet has been devised to identify individual letters:

"A" – Alfa	"N" – November
"B" – Bravo	"O" – Oscar
"C" – Charlie	"P" – Papa
"D" – Delta	"Q" – Quebec
"E" – Echo	"R" – Romeo
"F" – Foxtrot	"S" – Sierra
"G" – Golf	"T" – Tango
"H" – Hotel	"U" – Uniform
"I" – India	"V" – Victor
"J" – Juliette	"W" – Whiskey
"K" – Kilo	"X" – Xray
"L" – Lima	"Y" – Yankee
"M" – Mike	"Z" – Zulu

In the case of numerals, an exaggerated pronunciation is emphasized. Numerals "9" and "5," which can be easily confused, become "ni-ner" and "fi-yiv." All numbers are transmitted as numerals or digits except in the case of an even hundred or thousand; then the word "hundred" or "thousand" is used. When transmitting numbers, extreme care is required since numbers are used to give time, altitude, altimeter setting, headings, and weather information.

To avoid confusion, flight time is based on the 24-hour Greenwich Meridian clock. The 24-hour clock eliminates the necessity of saying a.m. and p.m. When transmitting time, the first two numerals always designate the hour and the last two the minutes. Midnight is "0000," spoken as "ze-ro ze-ro ze-ro ze-ro"; noon is "1200," spoken as one two ze-ro ze-ro"; 7:45 a.m. is "0745," spoken as "ze-ro sev-en four five"; and 5:28 p.m. is "1728," spoken as "one sev-en two eight." The last two numerals, indicating minutes, are ordinarily used in traffic control procedure when no misunderstanding can result. For instance, both the pilot and the control tower operator or communications station operator know that it is about 10:15. Giving instructions to the pilot, the operator says, "Time is one five." If it were 10:46, the time would be given as "four six."

Call signs identify the transmitting or receiving stations. When calling airport control towers, the expression "Tower" is used, and when calling a flight service station, the word "Radio" is used. A control tower is designated by the name of the airport or city at which it is located, e.g., "Midway Tower" or "Peoria Tower." Flight service stations are called by adding the word "Radio" to the name of the station, e.g., "Chicago Area Radio" or "Peoria Radio."

Airplane call signs consist of words, letters, numbers, or a combination of these factors. Private airplanes use the name of the manufacturer and the registration (N) number, e.g., "Cessna November three four sev-en niner five." Commercial transport call signs may be the name of the airline and the flight number, e.g., "American four" (American Airlines, Trip 4).

A set of procedure words and phrases now in use for communication between the airplane and the ground station or another airplane, and their meanings, are given below:

Word or Phrase	*Meaning*
Roger	Message received and meaning understood.
Wilco	Will comply with instructions.
Acknowledge	Let me know you have received and understood my message.
Say again	Repeat.
I say again	I will repeat.
Over	Transmission ended; I expect a reply.
Out	Communication ended; no reply expected.

Every radiotelephone message has three parts: (1) the call; (2) the text; and (3) the ending.

The call includes: (1) the call sign of the receiving station; (2) a connecting word or phrase; and (3) the call sign of the transmitting station.

Airplane:	"Springfield Radio, this is Beechcraft three four ze-ro six bravo. Over."
Station:	"Beechcraft three four ze-ro six bravo, this is Springfield Radio. Over."

The message is then transmitted and the communication ended. If there is no possibility of confusion, a shortened call form may be used *after* communication has been established.

Airplane:	"Springfield radio, this is Beechcraft three four ze-ro six bravo. Request current altimeter setting. Over."
Station:	"Beechcraft three four ze-ro six bravo, altimeter setting too ni-ner ni-ner. Over."
Airplane:	Ze-ro six bravo. Out."

Figure 127—Proper Way to Hold a Microphone for Radio-Telephone Transmission

Such radio communications procedure, when carefully followed by both pilots and ground communication stations, provides an extremely effective link between the airplane and the ground. This procedure also permits large traffic centers to handle hundreds of airplanes each day with a minimum amount of trouble and a maximum amount of safety. New systems of electronic signalling are expected to speed up and simplify communication procedures; some may eliminate voice communication entirely.

Airport Traffic Control Tower

At smaller airports, where the traffic is not heavy, the pilot can approach the airport directly, inspect the traffic circle for other airplanes which may be circling, observe field conditions, wind direction and velocity, and then fit into the pattern and make his final approach and landing. Most small airports have a "Unicom" system, which is nothing more than a small radio station that transmits and receives on one frequency only. This frequency is 122.8 Mcs. In case there is a tower, 123.0 Mcs is used. Unicom is used only as a private aviation communication system and is only an advisory station. At these smaller airports, it is the pilot's responsibility to choose the active runway, maintain separation from other airplanes, and make a safe landing.

At busy airports, however, the above procedure would create dangerous and delaying conditions. For this reason, the airport traffic control tower is given the responsibility for: (1) directing all incoming and outgoing traffic; (2) permitting airplanes to enter the traffic pattern at the proper time; (3) controlling the approach and landing sequence on specified runways; (4) giving taxiing and takeoff instructions; and (5) reporting field and weather conditions. (Figure 128.)

The Control Tower, in today's aviation activities, is far more important than it was ten years ago. Many towers in high-density traffic areas, such as Chicago, control so much traffic that it is necessary to divide tower responsibilities into special areas, i.e., (1) Ground Control, which controls all aircraft from the ramp or parking area to just short of takeoff position, and from the active runway, after landing, to the ramp or parking area; (2) Tower Control, which controls all takeoffs and landings; (3) Approach Control and Departure Control, which controls aircraft just prior to the landing procedure and immediately after takeoff. The work of Approach and Departure Control is particularly important during instrument flight conditions.

The areas that are particularly important to the pilot flying under Visual Flight Rules (VFR) conditions are those of Ground Control and Tower Control. When an aircraft is departing from a busy airport, taxi instructions, wind direction and velocity, runway in use, field condition, altimeter setting, clearance to taxi, and local traffic information are transmitted from Ground Control. At the point just prior to taxiing onto the active runway, and after making the pre-takeoff check, the control of traffic switches from Ground Control to Tower Control. The Tower then clears the aircraft for taxiing onto the active runway and for takeoff.

When approaching the airport, upon first contacting the Tower, the pilot reports his location relative to the airport. The Tower then gives the pilot the wind direction and velocity, the active runway, altimeter setting, field conditions, and the next "call in" or check point. When the pilot reports from the new check point, he receives his clearance to land, landing sequence, and information on other traffic. After landing,

Figure 128—Interior of an Airport Control Tower Showing the Tower Operator Giving Weather Information to an Aircraft in Flight.

the pilot is instructed by the Tower to turn off the active runway and to switch to Ground Control. It is extremely important that all directions be carefully obeyed as they are given by the particular control agency, and that all communications be brief and to the point.

A Typical Radio-Phone Conversation

Airplane: "Midway Ground Control, this is Beechcraft three four ze-ro six Bravo south ramp, ready to taxi, VFR departure St. Louis. Over."

Ground Control: "Beechcraft three four ze-ro six Bravo, cleared to runway two two left, wind southwest at one five, altimeter two niner niner niner, time one three ze-ro five Greenwich, taxi west on ramp and north on runway three six, hold short of runway two two left."

Airplane: "Roger, ze-ro six Bravo."

The pilot proceeds to the northeast/southwest runway and, after checking engine and instruments, requests his takeoff clearance from the Tower Control.

Airplane: "Midway Tower, this is Beechcraft three four ze-ro six Bravo, ready for takeoff. Over."

Tower: "Beechcraft three four ze-ro six Bravo, cleared for takeoff."

Airplane: "Roger, ze-ro six Bravo."

An aircraft should call the control tower when coming in for a landing under VFR conditions approximately 15 miles from the airport. The following should be included:

1. Geographical Position
2. Time (optional)
3. Flight altitude of the aircraft
4. Request for information or clearance if pertinent.

EXAMPLE:

Airplane: "Midway Tower, this is Beechcraft three four ze-ro six Bravo."

Tower: "Beechcraft three four ze-ro six Bravo, this is Midway Tower. Go ahead."

Figure 129—Airport Control Tower Operator Manning a Light Signal Gun

Airplane: "Midway Tower, this is Beechcraft ze-ro six Bravo, fifteen miles south, two five at three thousand landing at Midway. Over."

Tower: "Ze-ro six Bravo, runway two two Left, wind southwest at one five, altimeter two niner niner two, report two miles south. Over."

Airplane: "Wilco, ze-ro six Bravo."

When the pilot has reached a position two miles south of the field he renews contact with the Tower.

Airplane: "Midway Tower, this is ze-ro six Bravo, two miles south."

Tower: "Ze-ro six Bravo, you are number two to land. Call Tower on base."

Airplane: "Roger, ze-ro six Bravo."

The pilot enters the traffic pattern (Figure 88) and calls again as he turns onto his base leg; that is the leg before the final turn into the runway.

Airplane: "Midway Tower, ze-ro six Bravo turning base."

Tower: Ze-ro six Bravo, cleared to land."

Airplane: "Roger, ze-ro six Bravo."

After landing, Tower Control will clear the pilot from the active runway and request that he change to Ground Control, which will direct him to the parking or ramp area.

Several points in the above typical conversation between the Tower and the airplane should be explained at this point. Note that the Tower, in giving landing information to the incoming airplane, says, "Wind southwest at 15 knots, use runway 22." All runways are numbered according to their magnetic direction, e.g., when landing toward the east the compass will read 90 degrees and the approach will be over the west end of the runway which is marked with a large figure "9." In the above-mentioned example, since the wind is from the southwest, the aircraft will approach for a landing over the northeastern end of the northeast/southwest runway. The magnetic heading will be 220 degrees—the figure "22" on the end of the runway. This same runway will be marked "4" at its southwestern end—040 degrees will be the magnetic heading.

When flying from one area to another, there is normally a change in barometric pressure. To make certain that the altimeter in the airplane indicates the proper altitude, the barometric pressure corrected to sea level at his destination is radioed to the pilot. By changing the barometric pressure reading in his altimeter to conform with the newly received barometric pressure, the pilot is able to read his correct altitude.

To receive clearance to land at large airports, airplanes carry two-way radios, i.e., a transmitter and a receiver, but at smaller airports, light signals may be used instead of radiotelephone communication. Following this method an outbound airplane moves far

Figure 130—An Air Route Traffic Control Center.

enough out from the ramp or parking area to permit the Tower to see it. Using a light-projecting device (Figure 129) operated like a gun, the tower operator flashes a red light, meaning "hold your position," or a flashing green light, meaning "begin taxiing." Before turning onto the runway for takeoff, the airplane stops, faces the tower, and waits for another signal. In this position, a flashing red light means "clear the runway and hold your position," a green light signifies "permission to take off" or "continue taxiing," and a flashing white light means "return to the hangar line."

Inbound aircraft receive their first signal during the approach leg; a red light means "do not land, continue circling the field," and a green light means "cleared to land." Acknowledgment of all light signals received while in flight is made by rolling the airplane slightly from side to side or by blinking the navigation lights.

Air Traffic Service

Airplanes en route under VFR conditions may fly at a minimum altitude of 500 feet, except over congested areas where at least 1,000 feet above the highest obstacle must be maintained. Under VFR conditions the same aircraft may follow a civil airway directly to its destination. A civil or federal airway, maintained by the FAA, is a 10-mile wide aerial highway free of dangerous obstacles. Radio navigation aids enable the pilot to guide his plane along these airways.

Since all airways are designated Air Route Traffic Control Areas, all traffic flying on Instrument Flight Rules (IFR) in these areas is controlled by the Air Route Traffic Control center (ARTC). (Figure 130.) The ARTC issues traffic clearances directly to planes in flight through direct communications, Omni radio stations, airport control towers, or approach and departure controls. (Figure 128.)

When bad weather eliminates contact flight, pilots with instrument ratings fly along the civil airways at assigned altitudes and at known airspeeds, and arrive at their destinations at predetermined times.

Between any two major cities there can be a dozen airplanes traveling in the same direction. To make certain that there are no collisions, these airplanes flying at different speeds are required to fly at different altitudes, which are assigned by the Air Route Traffic Control center. As an additional safety factor, airplanes are separated by a time interval at the takeoff point. Radar is also used in high traffic areas not only to separate traffic but to speed and vector its movement.

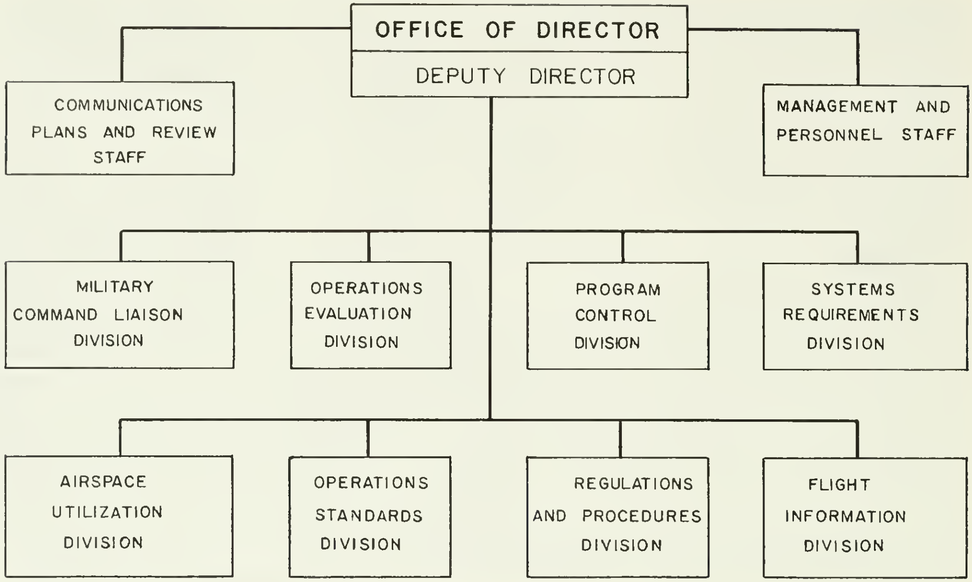


Figure 131—Table of Organization of Air Traffic Service.

These services come under the control of Air Traffic Service. (See Figure 131) The primary responsibilities of the Air Traffic Service are to:

A. Assist the administrator in developing the plans, standards, and systems for control of air traffic.
B. Keep aircraft safely separated while operating in controlled space when on the ground, during take-off and ascent, enroute, or during approach and landing.
C. Provide pre-flight and in-flight assistance service to all pilots.

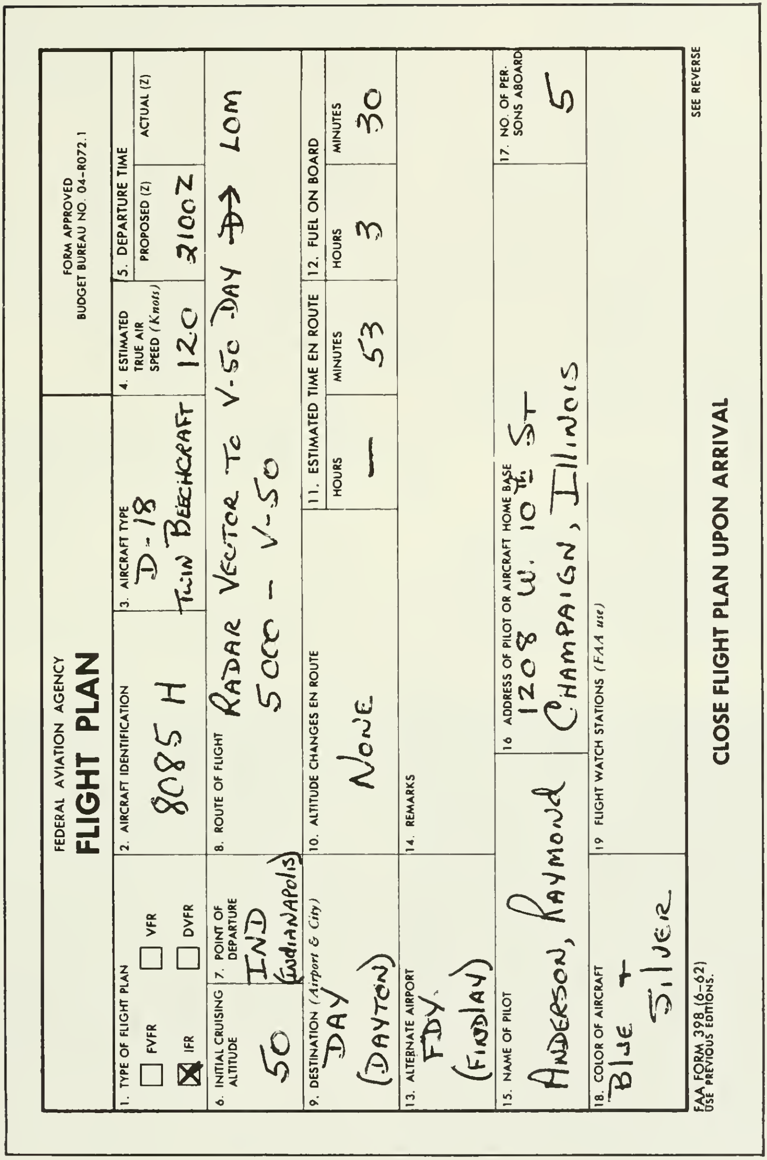
The specific functions of the three divisions of Air Traffic Service are:

1. AIR ROUTE TRAFFIC CONTROL
   Supervises the operation of aircraft flying under Instrument Flight Rules (IFR) in controlled airspace. (Long range radar which extends outward to 200 miles and upward to 60,000 feet, is used by ARTC centers to control enroute traffic.)
2. TOWERS
   Supervise the operation of aircraft on and in the vicinity of airports. Approach and Departure control use short range radar to control incoming and departing aircraft.
3. FLIGHT SERVICE STATIONS
   These stations have no control functions but are very important because they provide:
   A. Pre-flight weather briefings.
   B. In-flight following service.
   C. Local and area weather reports, changes in radio frequencies, operating conditions at certain airports, temporary airport restrictions and similar notices of interest to airmen.

Flight Plans

Flight plans must contain pilot and airplane identification, time and point of departure, proposed cruising altitude and airspeed, proposed route, destination, estimated time of arrival, and the alternate airport to be used in an emergency. Flight plans are required for all airplanes operating on IFR. For safety reasons it is recommended that pilots flying VFR file flight plans on all cross-country flights.

Instrument flight plan approval may be obtained from the appropriate Air Route Traffic Control center by filing it with the nearest center, tower, or communications station. The tower, station, or service will in turn request ARTC clearance. Although flight plans are normally filed while on the ground, filing a flight



FEDERAL AVIATION AGENCY

FLIGHT PLAN

FORM APPROVED
BUDGET BUREAU NO. 04-R072.1

1. TYPE OF FLIGHT PLAN: ☐ FVFR ☐ VFR ☒ IFR ☐ DVFR
2. AIRCRAFT IDENTIFICATION: 8085 H
3. AIRCRAFT TYPE: D-18 Twin Beechcraft
4. ESTIMATED TRUE AIR SPEED (*Knots*): 120
5. DEPARTURE TIME: PROPOSED (Z): 2100Z; ACTUAL (Z):
6. INITIAL CRUISING ALTITUDE: 50
7. POINT OF DEPARTURE: IND (Indianapolis)
8. ROUTE OF FLIGHT: Radar Vector To V-50 DAY → LOM 5000 - V-50
9. DESTINATION (*Airport & City*): DAY (Dayton)
10. ALTITUDE CHANGES EN ROUTE: None
11. ESTIMATED TIME EN ROUTE: HOURS —; MINUTES 53
12. FUEL ON BOARD: HOURS 3; MINUTES 30
13. ALTERNATE AIRPORT: FDY. (Findlay)
14. REMARKS:
15. NAME OF PILOT: Anderson, Raymond
16. ADDRESS OF PILOT OR AIRCRAFT HOME BASE: 1208 W. 10th St Champaign, Illinois
17. NO. OF PERSONS ABOARD: 5
18. COLOR OF AIRCRAFT: Blue + Silver
19. FLIGHT WATCH STATIONS (*FAA use*):

CLOSE FLIGHT PLAN UPON ARRIVAL

FAA FORM 398 (6-62)
USE PREVIOUS EDITIONS.

SEE REVERSE

Figure 132—A Typical Flight Plan

plan or requesting a change in a flight plan while in flight is accomplished by contacting the nearest communications station or center for approval. Clearance will be relayed from ARTC to the pilot through the communications station or from the Air Route Traffic Control center.

When a clearance is issued by an ARTC center it must be adhered to in all respects and at all times, except in an emergency. En route, the pilot must report flight progress to ARTC whenever he passes over a compulsory reporting point, such as an omni station. This progress report includes the following information: instrument flight plan, present fix or reporting point, altitude, time over the fix, next reporting point, and estimated time of arrival over next reporting point. This information is used by ARTC to keep the various instrument flights proceeding along the airways separated by both altitude and time. Air Route Traffic Control centers are linked by a teletype and direct interphone network with other airport towers, FAA communications stations, and military radio facilities. (Figure 131.)

Typical Instrument Flight Procedure

You, a qualified instrument pilot flying a D-18 twin-engine Beechcraft, are planning an instrument flight from Indianapolis, Indiana to Dayton, Ohio. Your first stop is at the weather bureau where you receive information about present and forecasted weather conditions along your route of flight, at your destination, and at your alternate airport. You also get briefed on the icing levels and type of icing you may encounter, the estimated wind direction and velocity at your intended altitude, and special hazards or conditions, such as heavy thunderstorms or tornados, which you might encounter. Before you leave the weather bureau, you call the tower, radio, or Air Route Traffic Control center and file your proposed instrument flight plan. (Figure 132.) All IFR proposals should be filed at least thirty minutes prior to departure time.

After filing your flight plan, you proceed to your airplane and perform an intensive preflight inspection, store and secure the baggage, load your passengers, make certain they fasten their safety belts and request that no one smokes until airborne. Secure the door, proceed to the pilot's compartment, and fasten your own belt before you start the engines. After starting your engines, but before taxiing away from the ramp, call Indianapolis Ground Control.

Pilot: "Indianapolis Ground Control, this is Twin Beechcraft eight ze-ro five eight Hotel, Instrument Flight (IFR), Dayton. Over."

Ground Control: "Beechcraft eight ze-ro five eight Hotel, Runway three one, wind northwest at ten, altimeter two niner eight ze-ro, time two one four five Greenwich, taxi west then south on ramp, hold short of runway three one."

Pilot: "Roger, five eight Hotel."

The aircraft is now cleared to just short of the

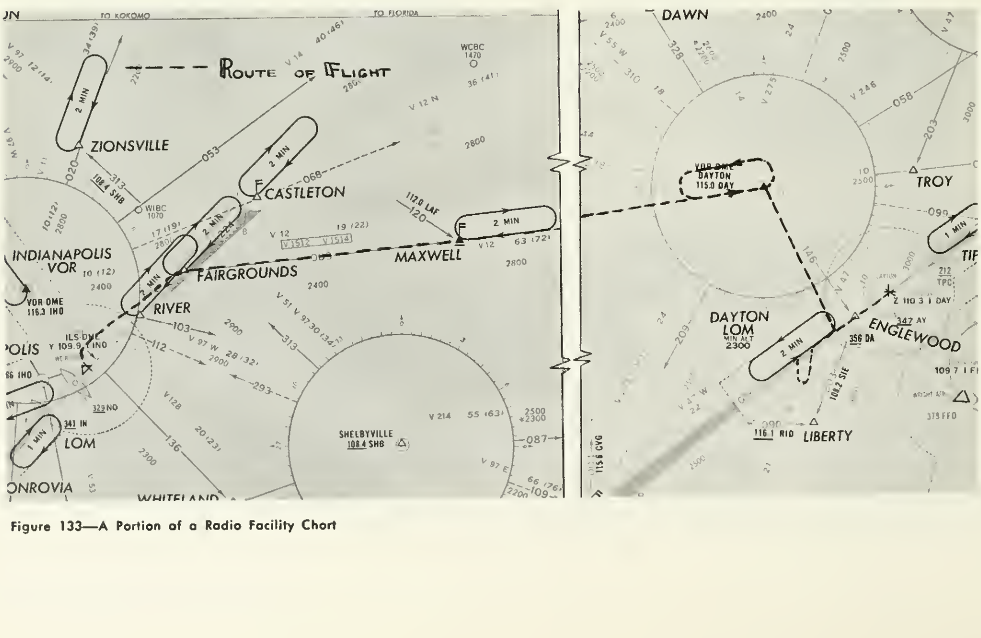


Figure 133—A Portion of a Radio Facility Chart

take-off position on runway 31. In the next transmission, Ground Control (if available) or control tower will issue the instrument flight clearance which they received from Air Route Traffic Control. This is the exact route to be followed after leaving the airport and reaching the "Clearance Limit," i.e., the farthest point along the route to which you are cleared.

Ground Control: "Beechcraft eight ze-ro five Hotel, this is Indianapolis Ground Control, have your ATC clearance, ready to copy?

Pilot: "Indianapolis Ground, five eight Hotel, ready to copy."

Ground Control: "ATC clears Beechcraft eight ze-ro five eight Hotel to the Dayton Omni, via direct Fairground Intersection, Victor fifty, Dayton Omni, maintain five thousand, contact Indianapolis Departure Control one one eight point five after release from tower, right turn out of traffic, over."

The pilot reads back the entire clearance to be certain he understands. A shorthand method is used when copying the clearance:

EXAMPLE: C 8058 H Day.
D Fairground △, V-50 M 50, etc
DepC 118.5 RT

After copying and reading back the clearance, change the radio setting to the appropriate tower control frequency and call the tower:

Pilot: "Indianapolis Tower, this is Beechcraft eight ze-ro five eight Hotel, ready for takeoff, over."

Ind. Tower: "Beechcraft eight ze-ro five eight Hotel, this is Indianapolis Tower, cleared for takeoff, right turn out, contact Departure Control one one eight point five immediately after takeoff."

Pilot: "Indianapolis Tower, this is five eight Hotel, Roger, out."

After takeoff, make a right turn, start the climb to 5,000 feet, and change to Departure Control. Departure Control now issues new headings, or directions, to reach the Fairground intersection. Since most approach and departure controls have radar, they will give headings and vectors by radar.

When you contact Indianapolis Departure Control, it should sound like this:

Pilot: "Indianapolis Departure Control, this is Beechcraft eight ze-ro five eight Hotel. Over."

Ind. Dep. Control: "Beechcraft eight ze-ro five eight Hotel, this is Indianapolis Departure Control. Over."

Pilot: "Indianapolis Departure Control, five eight Hotel, off Indianapolis five ze-ro, estimating Fairground Intersection five five, climbing to five thousand. Over."

Ind. Dep. Control: "Beechcraft five eight Hotel, Indianapolis Departure Control, radar contact, maintain heading ze-ro four five, report over Fairground Intersection this frequency. Over."

Pilot: "Five eight Hotel. Roger."

Upon reaching the Fairground intersection, the pilot will initiate the call by saying:

Pilot: "Indianapolis Departure Control, Beechcraft five eight Hotel, Fairground Intersection five five, five thousand, estimating Dayton Omni three five, Destination. Over."

Ind. Dep. Control: "Five eight Hotel, Roger on your position, contact Indianapolis Center one two four point niner immediately. Over."

Pilot: "Indianapolis Departure Control, five eight Hotel switching to one two four point niner now. Five eight Hotel out."

From now on, ARTC controls the flight and issues new clearances until the flight is turned over to approach control at the destination. In this example the pilot is instructed to contact the center immediately and the conversation will then sound like this.

Pilot: "Indianapolis Center, this is Beechcraft eight ze-ro five eight Hotel, Fairground Intersection. Over."

Ind. Center: "Beechcraft eight ze-ro five eight Hotel, this is Indianapolis Center. Clearance. Over."

Pilot: "Indianapolis Center, five eight Hotel ready to copy."

Ind. Center: "Beechcraft eight ze-ro five eight Hotel, contact Dayton Approach Control on one two five point seven, ten minutes west of Dayton Omni."

The pilot would then report his new clearance and say "Roger. Out," but would be required to maintain a listening watch on this frequency 124.9 mc until he switches over to contact Dayton approach Control on 125.7 mc. This call should be made 10 minutes prior to his estimated time of arrival (ETA) which was 2235 Greenwich, so at 2225 Greenwich, he would say:

Pilot: "Dayton Approach Control, this is Beechcraft eight ze-ro five eight Hotel. Over."

Dayton

Approach Control: "Beechcraft eight ze-ro five eight Hotel, this is Dayton Approach Control. Over."

Pilot: "Dayton Approach Control, five eight Hotel estimating Dayton Omni three five, five thousand, Dayton Omni clearance limit. Over."

Dayton Approach Control: "Beechcraft eight ze-ro five eight Hotel. Clearance. ATC clears Beechcraft eight ze-ro five eight Hotel to descend to and maintain three thousand and hold west on Victor fifty, right hand turns, one-minute pattern, report leaving five thousand and expect approach clearance at two three one five Greenwich. Over."

The following is a shorthand form which is used by the pilot to copy the clearance.

C 8058H↘M→30, H W
V50 RT 1 Min RL 50, EAC 15.

The pilot reads the clearance back and proceeds to the omni station, descends to 3,000 feet and enters a race track pattern. At 2315 Greenwich Dayton Approach Control issues a new clearance.

Dayton Approach Control: "Beechcraft eight ze-ro five eight Hotel, this is Dayton Approach Control. Clearance. ATC clears Beechcraft eight ze-ro five eight Hotel for an ILS (Instrument Landing System) approach to the Dayton Airport, report leaving three thousand and the Dayton Omni, contact Dayton Tower one one niner point five over Outer Marker inbound. Over."

The pilot reads the clearance back and proceeds to follow instructions. In many terminal areas where approach control uses radar, the pilot would be vectored to the final ILS approach by radar.

When the pilot arrives over the ILS outer marker, he contacts the tower and continues his approach. The tower will give him the latest altimeter setting, winds, and landing information. As soon as he breaks out VFR and has the runway in sight, he can tell the tower and they will then clear him to land and cancel his Instrument Flight Plan.

When the pilot has visually identified the airport, he immediately cancels his flight plan. He should do this because approach control will not clear any other aircraft for an approach until he has cancelled or safely landed.

If the weather is so bad that the pilot does not see the runway until he is at minimum altitude, the flight plan is automatically cancelled without a request when the airplane touches down on the runway. In order to do this, the tower maintains direct communications with ARTC to notify them of the safe arrival.

Summary

Air traffic is controlled by the federally-operated Air Route Traffic Control system and by the local field Control Tower. Air traffic arriving at or departing from a field is guided and directed by the Control Tower. After leaving the Control Tower's jurisdiction, all flights are controlled by the Air Route Traffic Control (ARTC) system which separates flights by time and by altitude, to eliminate the possibility of collision.

Communication between ground stations and airplanes is conducted by radiotelephone. In order that such communication will be understandable, the pilot must refrain from using unnecessary words, must clearly indicate whether he is calling the "Tower," "Radio," or "Center," and must always identify his aircraft.

To expedite air traffic in the vicinity of the airport, the Control Tower operator is charged with assigning a landing sequence number to incoming planes. He also informs the pilot about the altimeter setting, the wind direction and velocity, the ground obstructions, and the other air traffic. Similarly, before takeoff, the Control Tower operator grants permission for airplanes to taxi to the proper runway and, finally, clears them for takeoff.

Airliners and private airplanes equipped with a two-way radio must file a flight plan when flying cross-country under IFR conditions. This flight plan, when submitted to Air Route Traffic Control, indicates the takeoff time, destination, preferential route to be followed, altitude, airspeed, aircraft number, alternate airport, and pilot's name. It is frequently filed with the local Control Tower which relays it to ARTC. Air Route Traffic Control then lists the flight and surveys the route for conflicting air traffic. If there is no danger of collision with other flights, the flight plan is approved and the pilot is given permission to take off. It is extremely important that the pilot radio his position over radio check points and that, upon landing at his destination, he notify the Control Tower operator to close his flight plan.

Questions

1. List the words which are used in the standard phonetic alphabet.
2. When the 24-hour clock is used what time would it be at 1:00 a.m.? 3:15 p.m.? 12:00 noon? 9:30 p.m.?
3. What are the three primary responsibilities of Air Traffic Service?
4. For what type of radio station is the word "tower" the call signal? The word "radio"?
5. What are the parts of a radiotelephone message?
6. What are the functions of ARTC?
7. In the absence of radio, how does a tower control traffic?
8. Why should a pilot cancel his IFR flight plan as soon as he has the field in sight?
9. What information do inbound and outbound pilots get from the tower when they are on a VFR flight plan?
10. What facts must be included in a flight plan?
11. What is the procedure for filing and receiving approval of a flight plan?

Chapter **II** The Federal Aviation Agency

In the early days of aviation when there were only a few thousand pilots and a few hundred airplanes, there were practically no regulations governing safety in flying. Airplanes, good and bad, were designed, assembled, and flown by anyone who wished to do so.

After 1920, the number of airplanes and pilots materially increased and, unfortunately, so did the number of accidents. Newspapers were constantly filled with stories of careless, untrained, or irresponsible pilots who had "cracked up," some with and some without passengers. During this period, the majority of the accidents occurred because pilots flew either in unairworthy airplanes or in dangerous weather conditions. Another prominent cause for so many of the early crackups was the irresponsible pilot who attempted aerobatics in overloaded airplanes, flew under bridges, dived at football crowds and "showed off" in general.

Government Regulations

In order to prevent needless and tragic accidents, Congress, in 1926, enacted legislation which was designed to promote safety throughout the industry. Pilots were forbidden by law to carry passengers, give instruction, or otherwise earn their living by using an airplane until they had demonstrated flying proficiency and until they had passed written examinations which demonstrated their knowledge of Flight Regulations, Navigation, Meteorology, etc. In addition, Congress established standards for airplane and engine manufacturing companies which prevented them from using unsatisfactory materials, unsound airplane designs, and faulty construction methods.

It was logical that major control of flying activities should be assumed by the federal government; consequently, the Civil Aeronautics Administration was established in 1938. City, county, and even state boundaries are traversed so quickly that local law enforcement usually was impossible. For this reason it became essential that a minimum set of rules be established for use on a national as well as on a state or local level. However, because of the vast number of people required to enforce these federal regulations, state governments, in their own interests, cooperated with the federal government by policing aviation activities within their own borders. In 1944, the Model Aviation Act was prepared following a conference between federal and state aviation officials. This Act established a basis whereby state laws could be brought into conformity with federal regulations and with statutes of other states.

Today, most states have special commissions or departments both to foster and to regulate aviation. Special aviation police, state police, and county and municipal department forces are used to enforce aviation safety practices. The majority of pilots are aware of their responsibilities and do not need policing. These pilots do nothing to jeopardize their own lives or the lives and property of others. Such men are part of the large majority who know that "There are old pilots and there are bold pilots, but there are no old bold pilots."

Internationally, aviation activities operate within a framework developed by the International Civil Aviation Organization (ICAO), a department of the United Nations, with headquarters in Montreal, Canada. This organization deals on an international scale with the activities that are similar in nature to those sponsored by the Federal Aviation Agency on a national scale. ICAO provides, operates, and maintains communication and navigational facilities, standardizes names, terminology, and systems of measurement, and promotes personal travel by helping to eliminate red tape in connection with passports, visas, and the like.

Functions of the Federal Aviation Agency

Federal promotion and regulation of civil aviation is controlled by two governmental bodies—the Federal Aviation Agency (FAA) and the Civil Aeronautics Board (CAB).

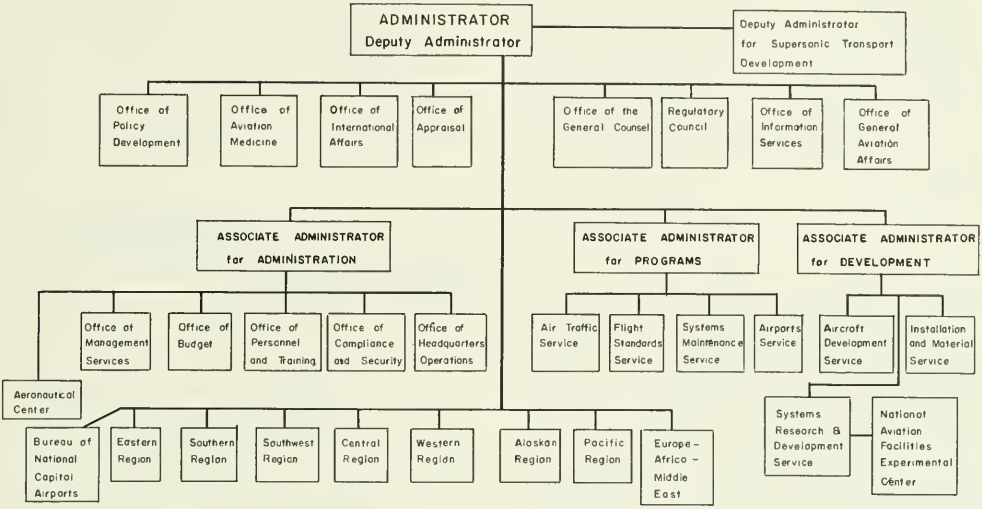


Figure 134—Federal Aviation Agency Table of Organization

The CAB is a quasi-judicial body composed of five members appointed by the President. The Board is principally concerned with the economic regulation of organizations engaged in public air transportation and accidents involving their aircraft.

The FAA is assigned to the executive branch of the federal government by the Federal Aviation Act of 1958. On January 1, 1959, the Federal Aviation Agency assumed all duties and responsibilities formerly handled by the Civil Aeronautics Administration, which had operated under the Department of Commerce.

The function of the FAA is to regulate and promote civil aviation and to provide for the safe and efficient use of the airspace by civil and military aircraft. The scope of this function is vast. Four general areas of activity are: (1) Control of both civil and military air traffic by making the air traffic rules, and in addition, by issuing specific instructions to specific aircraft under certain conditions of flight; (2) Providing all ground facilities for traffic control as well as for navigation and communications between controlling facilities and aircraft; (3) Determining the qualifications and specifications to be met by all persons engaged in flight activities and all aircraft, then testing to insure that these standards are constantly met; and (4) Research and development for new methods and equipment.

The FAA is headed by an Administrator. Two Deputy Administrators and three Associate Administrators are responsible to the Administrator for planning, directing, and coordinating all operations.

The Deputy Administrators

A Deputy Administrator has been appointed to coordinate FAA work on the supersonic transport program and to present research findings and recommendations to a presidential committee.

The other Deputy Administrator, who serves as acting Administrator in the absence of the Administrator, is the general manager for FAA operations and is responsible for coordination of activities of the Regional offices. He is also responsible for affairs of the FAA in Europe, Africa, and the Middle East, and the activities of the Bureau of National Capital Airports.

There are seven Regional offices headed by Assistant Administrators who are responsible to the Deputy Administrator for the direction and execution of all programs in the field.

Associate Administrators

Three Associate Administrators direct and coordinate administration, programs, and development. The Associate Administrator for Administration advises and assists the Administrator in all matters concerning administrative management, security, budget, and personnel. The Associate Administrator for Programs is responsible for air traffic service, systems maintenance service, and airport service. The Associate Administrator for Development is responsible for aircraft development, installation of facilities, material service, research and development, which includes the National Aviation Facilities Experimental Center at Atlantic City, N. J.

Federal Aviation Regulations

The first few simple rules governing air traffic were third-dimension adaptations of maritime Rules of the Road. In the interest of aviation safety, however, new air traffic rules had to be developed as traffic increased to the point that both night and day operations, in all kinds of weather, became common-place. Rapid expansion in other branches of aviation also necessitated additional regulations. Presently, there are Federal Aviation Regulations which cover almost all phases of aviation. In addition, Advisory Circulars are issued as necessary to cover short-lived rules or procedures, as well as for clarification of standing rules and procedures. Because of the large number of regulations and the high frequency with which they are changed to meet current needs, it is neither practicable nor within the scope of this chapter to quote specific rules. The following index of the Federal Aviation Regulations will serve to illustrate the wide variety of activities presently covered by regulations:

Subchapter A DEFINITIONS

Part 1—Definitions and Abbreviations.

Subchapter B PROCEDURAL RULES

Part 11—General Rule-making Procedures.
Part 13—Enforcement Procedures.

Subchapter C AIRCRAFT

Part 21—Aircraft Certification Procedures.
Part 23—Airworthiness Standards: Normal, Utility, and Acrobatic Airplanes.
Part 25—Airworthiness Standards: Transport Category Airplanes.
Part 27—Airworthiness Standards: Normal Rotorcraft.
Part 29—Airworthiness Standards: Transport Rotorcraft.
Part 33—Airworthiness Standards: Aircraft Engines.
Part 35—Airworthiness Standards: Propellers.
Part 37—Technical Standard Orders for Materials, Parts, and Appliances.
Part 39—Airworthiness Directives.
Part 41—Airworthiness Operating and Equipment Standards.
Part 43—Maintenance and Alteration.
Part 45—Identification and Registration Marking.

Subchapter D AIRMEN

Part 61—Certification: Pilots and Instructors.
Part 63—Flight Crewmembers Other Than Pilots.
Part 65—Certification: Airmen Other Than Flight Crewmembers.
Part 67—Medical Standards and Certification.

Subchapter E AIRSPACE

Part 71—Designation of Federal Airways, Controlled Airspace, and Reporting Points.
Part 73—Special Use Airspace.
Part 75—Establishment of Jet Routes.
Part 77—Notice of Construction or Alteration Affecting Navigable Airspace.

Subchapter F AIR TRAFFIC AND GENERAL OPERATING RULES

Part 91—General Operating and Flight Rules.
Part 93—Special Air Traffic Rules and Airport Traffic Patterns.
Part 95—IFR Altitudes.
Part 97—Standard Instrument Approach Procedures.
Part 99—Security Control of Air Traffic.
Part 101—Moored Balloons, Kites, and Unmanned Rockets.
Part 103—Transportation of Dangerous Articles and Magnetized Materials.
Part 105—Parachute Jumping.

Subchapter H SCHOOLS AND OTHER CERTIFICATED AGENCIES

Part 141—Pilot Schools.
Part 143—Ground Instructors.
Part 145—Repair Stations.
Part 147—Mechanic Schools.
Part 149—Parachute Lofts.

Subchapter I AIRPORTS

Part 151—Federal Aid to Airports.
Part 153—Acquisition of U. S. Land for Public Airports.
Part 155—Release of Airport Property from Surplus Property Disposal Restrictions.
Part 157—Notice of Construction, Alteration, or Deactivation of Airports.

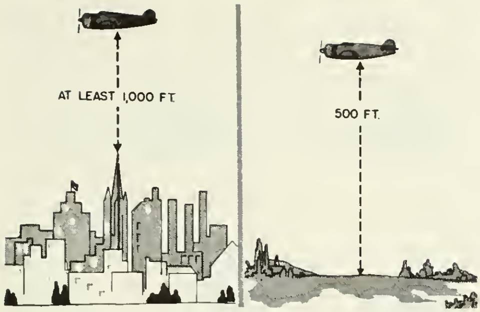


Figure 135—Minimum Safe Altitudes for Aircraft

Part 159—National Capital Airports.
Part 161—Cold Bay, Alaska Airport.
Part 163—Canton Island Airport.
Part 165—Wake Island Code.

Subchapter K ADMINISTRATIVE REGULATIONS

Part 181—Seal.
Part 183—Representatives of the Administrator.
Part 185—Testimony of Employees and Production of Records in Legal Proceedings.
Part 187—Fees for Copying and Certifying Federal Aviation Agency Records.
Part 189—Use of Federal Aviation Agency Communications Systems.

Specific regulations, by part number, can be obtained from the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C.

Pilot Regulations

To act as an airplane pilot, an airman must possess a pilot certificate issued by the FAA. To obtain a certificate, the applicant must meet certain requirements of age, citizenship, physical condition, knowledge and experience, and must pass both a written and a practical examination on flight techniques. These examinations are given by an FAA Safety Inspector or by a Flight Examiner. A Flight Examiner is an experienced flight instructor appointed by the FAA to administer flight examinations.

Requirements vary according to the type of certificate the applicant is seeking. Ratings on the certificate indicate additional privileges and/or restrictions. A pilot may hold a Student, Private, Commercial, or Flight Instructor Certificate. Ratings endorsed on the pilot certificate will indicate the pilot's ability to fly under instrument flight rule conditions, in single or multi-engine aircraft, helicopters, gliders, and land or seaplanes. Airline captains are required to have an Air Transport Rating (ATR). Special ratings are also required to fly aircraft which exceed 12,500 pounds gross weight if passengers are to be carried.

Air Traffic Rules

Air traffic rules provide for safety to persons and property by regulating the flow of traffic in flight and on the ground. In accomplishing this, they establish definite patterns and procedures for practically all conditions and maneuvers.

In Part 91 of the Federal Aviation Regulations, the air traffic rules are grouped into three sections. The first section is called *General Flight Rules* (GFR) and consists of those rules which apply to all flights, regardless of the conditions under which they are conducted. The following illustrate some of the many general rules: (1) Aircraft must not be flown below certain specified altitudes (figure 135); (2) Pilots must follow definite rules to avoid the possibility of collision (figures 136 and 137); and (3) When flying within a specified area of an airport served by an F.A.A. control tower, pilots must not fly their aircraft in excess of certain speeds, must follow specified basic

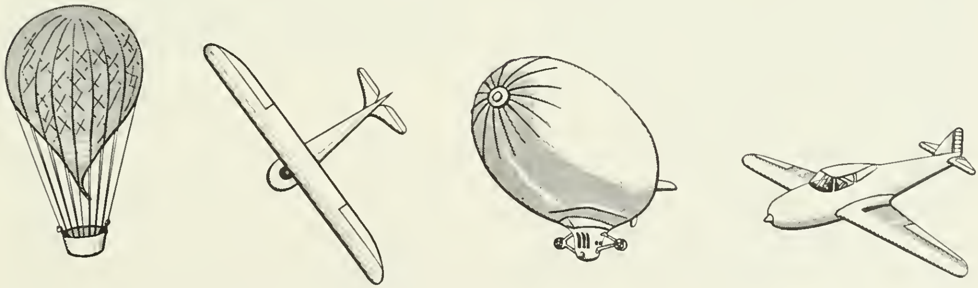


Figure 136—Right of Way for Free Balloons, Gliders, Airships and Airplanes in That Order

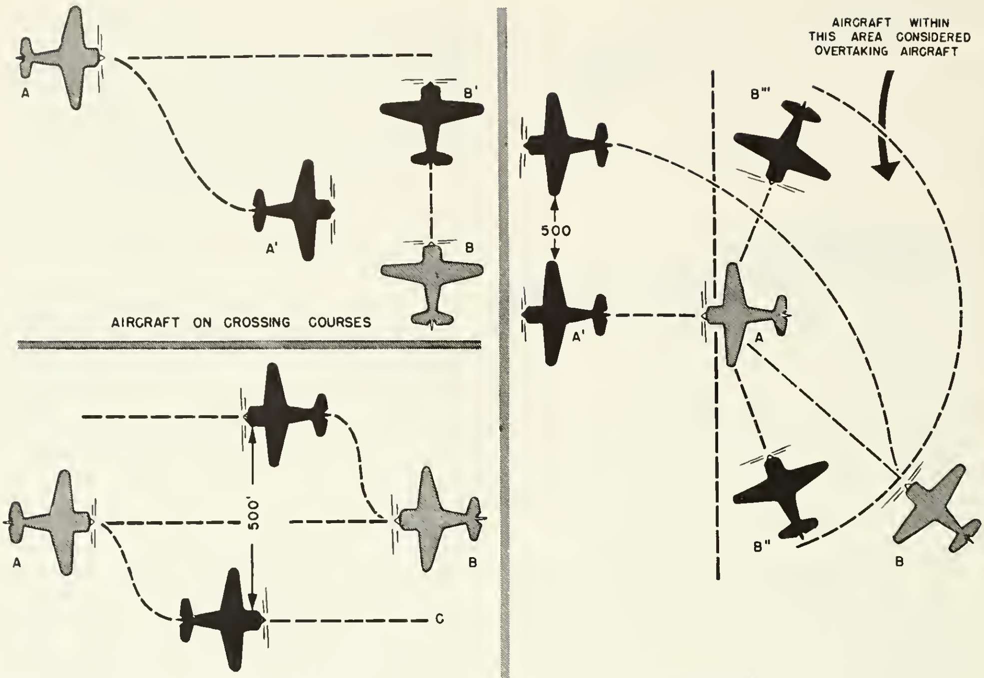


Figure 137—Rights of Way for Aircraft in Flight

patterns, and must communicate with the tower by two-way radio in order to receive specific instructions and clearances.

The second section of Part 91 is called *Visual Flight Rules* (VFR). Pilots fly under VFR when their entire flight can be conducted in weather conditions equal to or better than the minimums specified in this section. Practically all of the visual flight rules are concerned with weather minimums which state the minimum distance from clouds that aircraft must remain, and the minimum horizontal distance that a pilot must be able to see. These distances vary with the various classes of airspace (Figure 138). Additionally, there is a rule that governs the selection of altitudes for cross-country flights.

When weather conditions are below the minimums specified for VFR flight, a pilot may not fly unless he has both an instrument rating and an airplane which is properly equipped for instrument flight. When these two requirements are met, a pilot may fly if he adheres to the rules specified in the third section of Part 91, *Instrument Flight Rules* (IFR). Every detail of an IFR flight is very carefully controlled by one or more of the *FAA Air Route Traffic Control* (ARTC) centers. To take off, to continue a flight already in progress, or to land under IFR conditions, a pilot must receive clearance from an Air Route Traffic Control center. Either in person or by radio, the pilot in command must submit and receive approval for an IFR flight plan, and he must then follow the approved flight plan without deviation. An IFR flight plan involves flying at specified altitudes, on a specific route, and includes time and position reports over designated check points. The ARTC center correlates this information from all pilots who are flying within

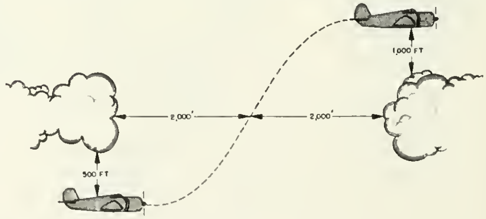


Figure 138—Minimum Cloud Clearance inside Control Area

the center's jurisdiction, and continually issues clearances to keep airplanes separated by assigning different routes or by time and/or altitude intervals. Besides being thoroughly familiar with the vast amount of navigational information required to fly under instrument procedures, the pilot must also be expert in all phases of communication procedures. (See Chapter 10.)

Summary

During the early days of aviation, flying activities were limited to a comparatively few thousand pilots and few hundred airplanes. Since there were no regulations governing flight activities at that time, there were a considerable number of accidents. With the expansion of private flying activity, the opening of air-mail routes, and the scheduling of commercial passenger flights, the need for air traffic and safety regulations became apparent.

The Air Commerce Act of 1926 established regulations governing licensing of pilots and airplanes, airways inspection, air traffic rules and other elements of aviation. The Bureau of Air Commerce, operating under the U. S. Department of Commerce, was subsequently replaced by the Civil Aeronautics Administration in 1938, and was, in turn, replaced by the Federal Aviation Agency in 1959. The FAA is charged with the responsibility of giving flight and ground school examinations, operating the civil airways, rendering assistance to aircraft manufacturers, supplying educational institutions with material and guidance, and making and enforcing the Federal Aviation Regulations.

The Civil Aeronautics Board, which was created at the same time as the Civil Aeronautics Administration, still functions as an independent agency. The CAB issues certificates of public necessity, regulates the economics of air commerce, and is responsible for investigation of aircraft accidents.

Some regulations establish the requirements for student, private, and commercial certificates and ratings. Other regulations set high standards for the aircraft equipment manufacturers, regarding safe design, satisfactory materials, and approved construction methods.

Regulations, known as Air Traffic Rules, carefully set forth procedures and patterns to insure an orderly and safe flow of traffic in the air and on the ground. The air traffic rules are arranged in three sections: (1) General Flight Rules (GFR) which apply to all flights, (2) Visual Flight Rules (VFR) for flights which can be accomplished in weather conditions equal to or better than certain specified minimums, and (3) Instrument Flight Rules (IFR) for those flights which, because of weather, cannot be accomplished under VFR.

Questions

1. Why are government regulations necessary in aviation?
2. What organization governs aviation on an international scale?
3. To what extent do the various states govern aviation activities?
4. What is the primary function of the Federal Aviation Agency?
5. What is the primary function of the Civil Aeronautics Board?
6. List four general areas of aviation activity in which the FAA is continually engaged.
7. Where would you send an order for certain Federal Aviation Regulations?
8. What types of requirements must be met so that a person may qualify for a pilot certificate?
9. In which part of the regulations are the Air Traffic Rules found?
10. Name the two conditions of flight for which specific traffic rules are written?

Chapter 12 Space Travel

Space is man's new frontier. By wide use of the airplane, explorers have filled in the few remaining blank spaces on the world's map. For new challenges, new boundaries, and new explorations, man must look either below or above the earth's surface, and he has chosen "space" for his next great search.

Today, with interplanetary travel almost within grasp, man stands upon the threshold of an experience which has no precedent in his past actions. So it behooves the airman of today—the spaceman of tomorrow—to know the medium in which he will be operating.

The Solar System

The earth's solar system, with the sun as its center, is a relatively minute section of the vast galactic star system called the Milky Way—which in turn is only one galactic star system among the many, many systems composing the universe. Until man has first solved the perplexingly complex problems concerning the earth's solar system, he cannot intelligently determine the means by which intergalactic travel and communication will be accomplished. It is entirely possible, however, that when man has discovered the secrets of his solar system and developed the methods for interplanetary and intergalactic travel and communication, he will then detect a multitude of planets which are comparable to earth and which could sustain human life.

To acquire a basis for further study of the solar system, there are certain fundamentals which should be understood:

1. The solar system is composed of the sun, nine planets and their moons, asteroids, comets, meteorites, micrometeorites, and dust.
2. The sun is the center star of the solar system.
3. All nine planets move around the sun in the same direction and in nearly circular paths.
4. All nine planets orbit around the sun on nearly the same plane but at different distances from the sun.
5. The four inner planets—Mercury, Venus, Earth, and Mars—are relatively small dense bodies known as "terrestial" planets.
6. The next four planets in distance from the sun—Jupiter, Saturn, Uranus, and Neptune—are called the major or giant planets and are principally composed of gases with solid ice and rock cores at unknown depths below the visible upper surfaces of their atmospheres.
7. Pluto, the most distant planet, is relatively unknown.
8. The diameter of the solar system is 79 astronomical units (a.u.) or 7,300,000,000,000 miles. One astronomical unit equals 92,900,000 miles, or the mean distance of the earth from the sun. (Figure 139.)

All around earth's solar system, i.e., the sun and the nine planets, lie the numberless other stars of this *galaxy*. A galaxy is a system of stars and can best be visualized as a disc standing on edge. (Figure 140.) Earth's solar system is located quite far down on the disc. Some idea of the tremendous size of earth's galaxy is obtained when it is understood that it takes four and one-half years for light from the sun to travel to its nearest neighbor, the star *Proxima Centauri*, and 26,080 years for sunlight to reach the center of the galaxy. These figures are more easily understood when it is remembered that it takes only eight minutes for the sun's light to reach the earth. In terms of these almost unbelievable times and distances, the sun's planetary system suddenly seems a smaller, friendlier place, and certainly worth closer examination.

The sun, in astronomical terms, is a "main sequence" star with a surface temperature of about $+ 11{,}000°$ F. Although classified as a medium-small star, it is over 300,000 times as massive as the earth. All useable forms of energy on the earth's surface, with the exception of atomic and thermonuclear energy, are directly or indirectly due to the storing or conversion of energy received from the sun.

Mercury, the planet closest to the sun, is difficult to observe because of its proximity to the sun. Mercury

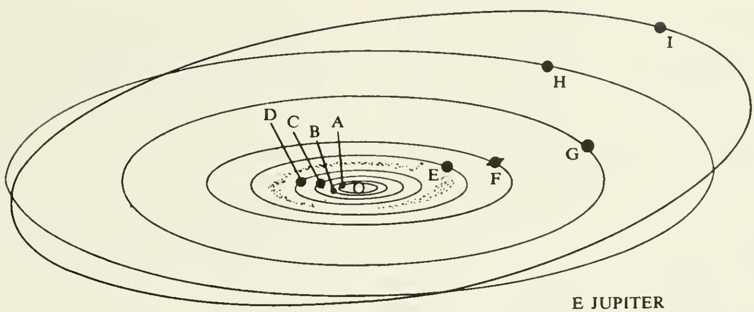


Figure 139—The Solar System

Planets of the Solar System

Planet	Mean distance from Sun (million miles)	length of year	Period of Rotation	Equatorial Diameter (miles)	Orbital Velocity (miles per second)	Escape Velocity (miles per second)	Gravity at Surface (earth=1)
Mercury	36.0	88.0 days	88 days	3,000	29.7	2.2	0.27
Venus	67.2	224.7 days	unknown	7,600	21.7	6.3	0.85
Earth	93.0	365.25 days	1 day	7,900	18.5	7.0	1.00
Mars	141.5	1.88 years	24 hr. 37 min	4,200	15.0	3.1	0.38
Jupiter	483.3	11.86 years	9 hr. 55 min.	88,700	8.1	37.0	2.64
Saturn	886.1	29.46 years	10 hr. 14 min.	75,100	6.0	22.0	1.17
Uranus	1,782.8	84.02 years	10 hr. 40 min.	30,900	4.2	13.0	0.92
Neptune	2,793.5	164.79 years	15 hr. 40 min.	33,900	3.4	14.0	1.12
Pluto	3,675.0	248.43 years	unknown	3,500	2.7?	6.5?	0.9?

has no moon and is about one-twentieth the size of the earth. It is a small, rocky sphere which always keeps the same side facing the sun. Mercury is not known to have any atmosphere.

Venus cannot be accurately judged since its dense and turbulent atmosphere denies a view of its solid surface to astronomers. On the basis of available evidence, it may be presumed that the surface of Venus is probably hot, dry, dusty, windy, and dark, beneath a continuous dust storm. The atmospheric pressure is perhaps several times the normal barometric pressure at the surface of the earth. Carbon dioxide is probably the major atmospheric gas, with nitrogen and argon being present in lesser amounts.

Mars is slightly more than one-half the size of the earth. The atmospheric pressure at the surface has been estimated at 8 to 12 per cent of the earth's sea level atmospheric pressure, and the atmosphere is believed to consist largely of nitrogen. Topographically, its surface is quite flat, with no abrupt changes in elevation and no prominent mountains. The climate would be similar to that of an eleven-mile high desert on earth, i.e., noon summer temperatures reaching a maximum of +80° to +90°, but falling rapidly during the night to reach a minimum of —100° F. Bleak and desertlike as Mars appears to be, with no free oxygen and little, if any, water, there is some evidence that indigenous life forms may exist.

Jupiter, Saturn, Uranus, and *Neptune* have so many characteristics in common that they may be treated together. They are all massive bodies of low density and high diameter. They all rotate rapidly and have a small dense rocky core surrounded by a thick shell of ice and are covered by thousands of miles of compressed hydrogen and helium gases. Temperatures at the visible upper atmospheric surfaces range from —200° F. to —300° F. Many of their moons are larger than the earth's moon. Although reliable physical data on these moons are lacking, it is possible that they may be more acceptable for space flight missions than the planets about which they orbit.

Pluto is the most distant planet of the solar system (3,675 million miles from the sun). Almost nothing is known about this most extreme member except its orbital characteristics, the fact that it is extremely cold, (light from the sun takes five and one-quarter hours to reach Pluto), and that it has a diameter less than one-half that of earth.

Asteroids are a group of substantial bodies more or less concentrated in the region between the orbits of Mars and Jupiter. It is possible that these chunks of material may be shattered remains of one or more planets. Quite a few of the asteroids are as much as 100 miles across, with the largest, Ceres, being nearly 500 miles in mean diameter.

Comets are very loose collections of orbital material that sweep into the inner regions of the solar system from the space beyond the orbit of Pluto. Some return periodically, e.g., Halley's Comet, and some never do. Their bodies consist of rarified gases and dust, and their heads are thought to be frozen gases or ices.

Meteorites enter the earth's atmosphere in the form of meteoritic particles, at velocities of 7 to 50 miles per second. Most of these particles are decomposed in the upper atmospheres but a few do reach the earth's surface. The range of meteoritic material entering the earth's atmosphere is from 25 tons to 1 million tons per day. The information concerning meteoritic input is very uncertain, as the estimated tonnage range suggests. The meteoritic content of other space regions is unknown.

Figure 140—This beautiful view of one of the disc-shaped galaxies in the southern hemisphere of the sky is similar to our own galaxy, the Milky Way system.

Micro-meteorites and *dust* originate as cometary refuse and are situated along the orbits of the comets with the highest concentration being in the *ecliptic*—the plane of the earth's orbit.

EARTH'S ATMOSPHERE

Before spaceman can come to grips with the physical requirements involved in space flight, he must first free himself from the barriers presently imposed by the earth's atmosphere. For a better understanding of the atmosphere, astronomers have divided it into sections. These are:

1. *Troposphere*—This air region extends from the earth's surface up about ten miles and encompasses the extreme altitude range of today's conventional aircraft. Only about 20 per cent of the troposphere is oxygen; the remainder is largely nitrogen.

2. *Stratosphere*—This air region extends from ten miles up to about sixteen miles up. In this area a reciprocating engine's power output is reduced to zero, since absolute pressure falls below 212 pounds per square foot. Temperatures average about —70° F. and due to the lack of air pressure at twelve miles and above, the airman's blood would boil unless he is protected.

3. *Mesosphere*—This air region extends from sixteen miles up to about fifty miles up. This is a rather unusual area because the temperature averages about 50 degrees above zero in comparison to the —70° F. in the next lower level and —104° F. in the next upper level. There is also a large concentration of ozone in this region, which absorbs much of the sun's ultraviolet rays, thereby shielding the earth from cosmic ray bombardment.

4. *Thermosphere*—This air region extends from fifty miles up to around 200-300 miles up. Here again the temperature is unusual in that it varies from —104° F. at its lowest boundary to +2200° F. at its upper limits. The thermosphere is also called the ionosphere because of its intense electrical activity. Atoms and molecules in this layer are bombarded by powerful electromagnetic waves from the sun and become electrified or ionized. The ionosphere has a strong influence on all radio transmission on the earth.

5. *Exosphere*—This air region extends from 200-300 miles up to about 1,000 miles up and begins to blend into outer space.

The three following classifications have been established only for purposes of clarifying scientific space terminology:

6. *Terrestrial Space* extends from 1,000 miles up to 10,000 miles up.

7. *Cislunar Space* extends from 10,000 miles up to 100,000 miles up.

8. *Translunar Space* extends from 100,000 miles up to 1,000,000,000 miles up.

Beyond the above designated categories of space, scientists have arbitrarily named the regions, in ascending order, (9) *interplanetary space*, (10) *interstellar space*, and (11) *intergalactic space*, without having specifically determined the lower and upper boundaries.

To conquer these giant distances in space and time from the earth to the edges of its solar system and beyond to the stars, man must develop new theories of propulsion, guidance, and physical existence. Just as aeronautics is the science of air travel, so astronautics is the science of space travel. Man has now discovered that neither the piston engine nor the jet engine used in air travel will be of assistance in his efforts to break the atmospheric barrier. For space travel, man has returned to an ancient propulsive device—the rocket.

The History of Rockets

The earliest authentic records show that in 1232 A.D. the Chinese used rockets—arrows of flying fire—against the Mongols during the siege of Kaifung-fu. The first mention of rockets being used in Europe appears in the Chronicle of Cologne in 1258 and again in 1379 when an Italian historian credited the rocket as being the decisive factor in the battle for the Isle of Chiozza.

There is an account, which was published in the late 18th century, which refers to the large number of rockets fired during a battle at Paniput, India. Records of the British campaign in India, particularly at the Battle of Mysore, relate the experiences with Indian rocket troops. The rockets were used primarily against the British cavalry and were cased in iron, 8 inches long by 1½ inches in diameter, with a spiked nose. They were balanced by a stick of bamboo or iron approximately 8 feet long and were launched by specially trained "rocketeer" troops. Rocket warfare was quite effective against the British forces until they, themselves, developed their own projectiles.

Up to this period the rocket's primary use had been as a weapon. In 1826, however, it was put to use as a life-saving device. Four rocket life-line stations were established on the Isle of Wight in the English Channel. Since that time, life-line rockets have been put into world-wide use and have helped to save over 15,000 lives around the coast of Great Britain alone. Continued experimentation and development of rocket capabilities proceeded during the latter part of the 19th century, with William Hale, an American, developing a rocket which rotated by offset exhaust nozzles, thereby establishing greater flight stability.

The first practical studies concerning rocket propulsion as a means of attaining space travel capability originated near the end of the 19th century and are generally credited to three men: Konstantin Ziolkowsky, a Russian mathematics teacher; Herman Ganswindt, a German law student; and Robert Esnault-Pelterie of France.

The first significant American contribution to rockets was made by Dr. Robert H. Goddard (1882-1945), a Clark University physicist. When Dr. Goddard started his experiments with rockets, little related technical information was available. Through his scientific studies he pointed the way to the development of rockets as they are known today. He discovered that a shaped, smooth, tapered nozzle would drive the rocket eight times faster and 64 times farther on the same amount of fuel. Dr. Goddard also found that the solid fuels of that time would not give the high power or the duration of power needed for a rocket capable of extreme altitudes. On March 16, 1926, after many trials, he successfully fired the first liquid fuel rocket, which attained an altitude of 184 feet and a speed of 60 mph. Later Dr. Goddard was the first to fire a rocket that reached a speed faster than the speed of sound.

Dr. Goddard was the first to develop a gyroscopic steering device for rockets and was the first to use vanes in the jet stream for stabilization. After proving on paper and in actual test that a rocket can operate in a vacuum, he developed the mathematical theory of rocket propulsion and rocket flight, including basic designs for long-range rockets. He was also the first to patent the idea of *step rockets*. A step rocket is one that is carried by another rocket, with the second igniting when the first has consumed its fuel load.

Professor Herman Oberth, a German, was conducting rocket research in the early 1920's. In 1923, he published a book, "The Rocket into Interplanetary Space," which pointed the direction for others to follow. In 1925, Dr. Walter Hohmann wrote a book called "The Attainability of the Celestial Bodies," which dealt with the conservation of energy in departure trajectories from the earth, return to earth, circular orbits to other planets, and landing on celestial bodies. These technical books were quickly followed by ones which were written for the general public.

The researches and writings of Oberth, Hohmann, Valier, and Ley established the foundation for German experiments. The first European liquid-fuel rocket was successfully tested in 1931. The following year Walter Dornberger secured approval from the German government to develop further liquid-fuel weapons, and in 1936, when the "Peenemunde Project" was organized, General Dornberger became the commander of this experimental missile test station. The majority of his research staff were former members of the German Rocket Society.

In the post World War II era, both the United States and Russia profited from the research accomplished by the Germans at Peenemunde and at other rocket research centers. Russia apparently concentrated from the start on long-range ballistic missiles, while the United States concentrated its efforts on rocket-powered air defense weapons. Today, there are many missile projects in various stages of progress, both offensive and defensive weapons, with rocket, turbojet, and ramjet engines. During this post World War II era, the United States was aided in rocket research by the many German scientists who came to this country and who later became naturalized citizens.

The guided missile emerged through an evolutionary rather than a revolutionary process. The development cycle of rockets and missiles has accelerated rapidly during the last 30 years. This increased activity is due in large part to the wealth of information on aerodynamics, propulsion, and guidance which has been obtained through the development of the airplane.

Current Space Problems

Rocket engines are often confused with jet engines. Both rockets and jets operate on the principle of action and reaction, both burn a fuel-oxygen mixture, and both exhaust the burning gases created by the fuel mixture. There is, however, one important difference. *A jet engine gets the oxygen it needs for combustion from the outside atmosphere whereas a rocket carries its own oxygen. A jet, therefore, can operate only within the earth's atmosphere but a rocket can operate anywhere.*

There is also a source of confusion in the difference between a missile and a rocket. *Basically, a missile is an object thrown at a target, i.e., a weapon.* In modern military language a missile is a powered vehicle designed to carry explosives to a target. There are at present two types of missiles: (1) the *guided missile,* which is capable of a change of direction by internal or external command at any time during its flight; and (2) the *ballistic missile,* which is powered and guided during the first part of its flight only, after which it proceeds like a thrown rock, without power or guidance.

Rocket refers only to the type of propulsion, i.e., an engine. Many missiles are rocket-powered and there is a tendency to call them all rockets, but a rocket can perform many other jobs—principally the propulsion of vehicles into space.

The projected probing of space is man's greatest challenge today. Research rockets have been successfully fired into space and much valuable information has thereby been acquired. The technological demands for a manned vehicle capable of making a space flight are many:

1. A propulsion system to sustain the initial speed for a long period must be developed.
2. A guidance system of incredible accuracy must be created.
3. An airframe far sturdier than any ever built, to protect the crew from the disastrous effects of hull puncture by space matter, must be designed.
4. A complete, built-in, earth-like environment for the crew must be devised.
5. A retrieving or re-entry into the earth's atmosphere must be conceived.

These are the major problems which industry and government, in a joint effort, are attempting to solve.

PROPULSION

Propulsion systems, i.e., rocket engines, are distinguished by the type of mechanism and propellant used to produce thrust. The most common type of rocket engine employs chemicals to produce, by chemical combustion, the hot exhaust gases required to propel the vehicle. The chemicals are of two types, fuel and oxidizer—similar to gasoline and oxygen in an automobile engine. Both are required for combustion, and both may be in either a solid or liquid form.

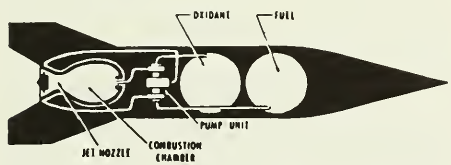
Solid chemical rocket engines combine the fuel and oxidizer into a solid mass called a *grain.* The propellant grain can be moulded into any desired shape, but it usually is cast with a hole down the center. This hole, called a *perforation,* may be shaped in many unique ways—a circle, a star, a gear. Its perforation shape and size affects the burning rate, or number of pounds of gas generated per second, and, thereby, affects the thrust of the engine.

The propellant grain, after being properly moulded with the desired perforation shape, is inserted into a metal or plastic case. When the entire missile has been assembled and is ready for flight, the propellant grain is ignited by a pyrotechnic device usually triggered by an electrical impulse. The propellant grain burns on the entire inside surface of the perforation, causing the hot combustion gases to pass down the grain and be ejected through the nozzle, thereby producing the needed thrust. (Figure 141.)

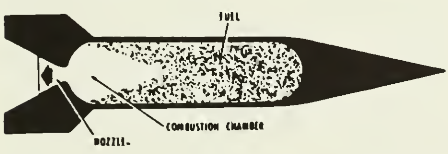
Liquid chemical rocket engines are bipropellant in that two separate propellants, a liquid fuel and a liquid oxidizer, are used. Each propellant is contained in a separate tank and is mixed with the other only upon injection into the combustion chamber. The two chemical propellants are fed into the combustion chamber either by pumps or by pressure inside the tank.

Typical fuels now used in the liquid chemical engine include kerosene, alcohol, hydrozine, and hydrogen. Oxidizers include nitric acid, nitrogen tetroxide, oxygen, and fluorine. Two of the best oxidizers are the liquefied gases, oxygen and fluorine, but these gases exist as liquids only at very low temperatures. This low temperature factor adds to the difficulty of their use in rockets. In general, the liquid propellants in common use today provide greater thrust capabilities than do presently available solid propellants. On the other hand, liquid fuels require more complex engine systems. (Figure 141.)

Nuclear rocket engines, as a source of missile propulsion, have not yet achieved operational capability. Present research indicates that the nuclear rocket will not utilize the combustion process which is typical of the solid and liquid fuel engines. Instead, the hot exhaust gases necessary to provide needed thrust will be developed by passing a liquid through a fission reactor. Liquid hydrogen is the propellant most often considered for a nuclear rocket because it yields the lightest possible exhaust gas. The liquid hydrogen would be stored in a single tank, forced into the reactor by a pump, heated and expanded by the reactor, then exhausted through a conventional rocket nozzle to obtain thrust.



LIQUID FUEL ROCKET



SOLID FUEL ROCKET

Figure 141—Schematic Diagram of Liquid and Solid Fuel Rocket Engines

Several other types of rocket engines have been proposed but exceedingly complex problems are still to be solved before they may be advantageously used. There is the *plasma rocket*, which would utilize electricity to heat the propellant directly by discharging a powerful arc through it. The restricting factor is that such a large amount of electrical power, about 150 kilowatts, is required to produce one pound of thrust.

A *photon rocket* would require light or some other radiation to be generated and then exhausted from the rocket in a focused beam. Such a system, however, would use energy very inefficiently unless matter could be completely converted into energy. A large searchlight, for example, is in a sense a photon rocket, but it yields less than one ten-thousandth of a pound of thrust for an electrical power consumption of 100 kilowatts.

An *ion rocket* would be propelled by causing each molecule of the propellant—usually conceived as being an alkali metal, probably cesium—to have an electrical charge, i.e., the propellant would be ionized. It would, theoretically, then be possible to accelerate the charged molecules, or ions, to very high velocities through a nozzle. However, the amount of electric power required to charge and accelerate the molecules is very high. For example, an ion rocket using cesium for the propellant would require about 2100 kilowatts of electric power to produce one pound of thrust.

There are two general measures of performance of a rocket engine: (1) the amount of thrust, which determines the amount of propellant that must be used to accomplish a given task, and (2) the fixed weight of the engine including the necessary tankage, power supply, and structure. At present, the chemical rocket engine, although a fairly lightweight device, cannot provide sufficient thrust to sustain flight for a long period. The principal obstruction to general use of a plasma, photon, or ion rocket engine is the lack of a lightweight electrical power system. The nuclear rocket engine, however, offers the greatest potential for space flight if temperature limitations on the walls of the missile airframe can be solved.

GUIDANCE

Many factors govern the choice of a specific guidance system for a guided missile, but the primary consideration is the range or distance which the missile must fly. In addition, the prescribed purpose of a missile may dictate that the missile be guided during any one or all of its flight phases, i.e., launching, midphase, and initial flight. The ballistic missiles are commonly guided only during their launching phase and initial flight, while a cruise-type missile uses mid-course guidance continually throughout its flight. Air-to-air missiles employ terminal guidance systems that lead the missile directly to the target.

Space flight missions in the near future will use ballistic rockets—those which are powered and guided only during the first part of their flight—and the guidance of such vehicles will be improved versions of current ballistic missile guidance techniques.

The major types of guidance systems now in use are (1) pre-set, (2) command, (3) target seeking, (4) inertial, and (5) celestial navigation. Each of the above-listed guidance systems must be able to measure the missile's position and velocity, compute the control actions which are needed to readjust the missile's position and velocity, and then deliver the necessary commands to the vehicle's control system so that the needed corrections can be made.

When *pre-set guidance* is used, a predetermined flight course is set into the missile's internal control system before the missile is launched. This preplanned flight course will have considered the predicted atmospheric conditions, the probable location of the target, and the performance capability of the missile. After the missile is launched, it will obey the pre-set control system's commands, going through all the motions which have been set into the mechanism. This guidance system is simple, reliable, inexpensive, and not vulnerable to countermeasures; however, once it has been fired, the launching crew no longer has control over it. Moreover, this guidance system is not considered to be highly accurate.

In the *command guidance* system the missile can be controlled throughout its entire flight path. Control of the missile's actions is achieved by using radio beams or some other electronic device which can send back information regarding the missile's position, direction, and speed to a computer on the ground. The computer swiftly compares the missile's present position with its desired position and then orders the necessary corrections made by sending radio impulses back to the weapon's control system.

There are several variations of the command guidance system currently being tested. One is the *Wire Rider*, in which a wire connects the missile control system and the command station. As the weapon flies toward its target, the wire unreels. Electrical impulses can then be sent through the wire to the control system to guide the weapon to the target. This type of guidance system is used for very short-range efforts such as anti-tank warfare.

A second type of command guidance is the *Beam Rider*, in which a radar beam remains fixed on the target and the missile rides the beam to its intended destination. An air-to-air missile, using the Beam Rider technique, is also provided with sensing instruments which determine the missile's position relative to the beam and make the needed adjustments. When a ground-to-air missile is launched, two beams are used. One beam tracks the target and the other beam tracks the missile. A ground computing system determines the error between the two beams and then corrects the missile's course until the two beams coincide at the target.

A third method of command guidance is to have in the nose of the missile a television camera and transmitter which send back to a ground operator a picture of what the missile is "seeing." The operator controls the flight of the missile and when the objective is sighted, he steers the missile into the target. The primary advantage of this system is that the remote-control operator can be hundreds of miles away from the missile and the target.

A missile using *target-seeking* or *homing* guidance is often referred to as "the most intelligent" of all missiles because it actually perceives the target and then computes its own control signals to guide itself to the target. If the missile is to "see" the target, the target must have some distinctive source of heat, light, magnetism, or radio impulse which the missile can accurately detect. Missiles which employ this method to find and destroy a target are called *passive seekers*. An *active seeker* is a missile which "illuminates" the target by radar signals and then guides itself toward the target by following the reflected signal.

Inertial guidance is fundamentally a pre-set guidance system with a course-and-distance measuring mechanism added. Basically, an inertial guidance system is composed of three accelerometers and a computer. An accelerometer is a small mechanical device which sensitively responds to any acceleration change of the missile. Each accelerometer measures acceleration in a single direction and can operate only during powered flight. The "weightlessness" of space completely nullifies the accelerometer's operation. The information acquired by the accelerometers during the period when they are measuring the sideways and the forward and backward movements of the missile is relayed to the missile's internal computer, which constantly measures velocity, distance traveled, and course. The computer compares the information concerning its present position, which it received from the accelerometers, with the position it "knows" it should maintain, and then makes corrections and necessary adjustments through the missile's autopilot.

Celestial navigation guidance is accomplished by an automatic sextant which takes continual sights on preselected stars—much in the same manner as does an airplane or ship navigator. The missile's automatic equipment measures the angle between the course of the missile and the course to the star. This information is relayed to the missile's computer system, which evaluates the report, prepares needed corrections in the missile's position, and then dispatches the new or revised knowledge to the missile's control system. When this guidance system is used alone, it is known as "Automatic Celestial Navigation (ACN)," but it is most often used in conjunction with and to double check the inertial guidance system. When celestial navigation is used in this manner, it is known as the "Stellar Supervised Inertial Auto-navigator (SSIA)."

ORBITS

Today's military intercontinental and intermediate-range ballistic missiles will be used as man's springboard into space. In fact, putting a satellite into orbit —once the necessary propulsion and guidance systems have been produced—is much simpler than putting a warhead on a target halfway around the world.

An orbit is a path in which a body moves in relation to its source of gravity. There are four types of orbits, all named after the conic sections, i.e., the four basic curves derived by intersecting a cone with a plane. (Figure 142.)

1. *Circle.* A body traveling around the earth at a constant speed and on a path which at all times is equidistant from the earth's center of gravity follows a circular orbit.

2. *Ellipse.* A body traveling a closed path which is longer than it is wide follows an elliptical orbit.

3. *Parabola.* A body traveling at such a high velocity that it no longer follows a closed path but escapes into space follows a parabolic orbit.

4. *Hyperbola.* A body traveling in essentially a parabolic orbit, but which has the ability to change its position with respect to the sun, follows a hyperbolic orbit. (Figure 142.)

Basically, a satellite is put into orbit by accelerating it to somewhere above 18,000 mph but less than 25,000 mph. This range of speed is known as *orbital velocity,* i.e., the satellite is projected far enough out and at a fast enough speed so that the earth's gravity does not pull it back, yet its velocity is not so great that it is released from the earth's gravity and flies on into space. Thus, satellites remain in orbit for the same reason that the moon and planets remain aloft. There is a state of balance between the earth's gravity and the satellite's centrifugal force. This state of balance is achieved, however, only when the orbiting satellite follows a nearly circular path.

At the present time the orbits of most artificial satellites are elliptical, i.e., egg-shaped; consequently the "balance of power" is constantly shifting from the earth's gravitational pull to the satellite's centrifugal force, with a consequent change in the speed of the satellite.

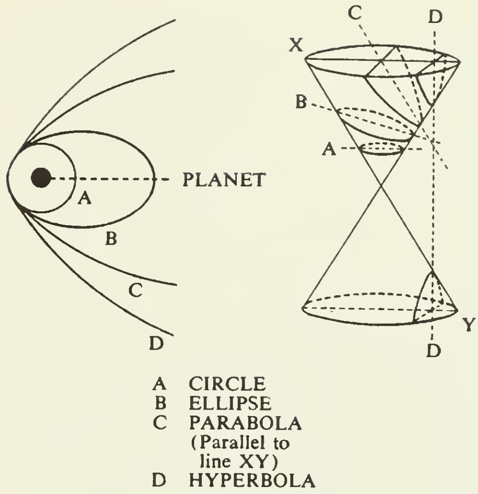


Figure 142—Conic Sections and Basic Orbits

There are two key points in the elliptical flight path of the satellite—the *apogee* and the *perigee.* (Figure 143.) The perigee is that point of the satellite's

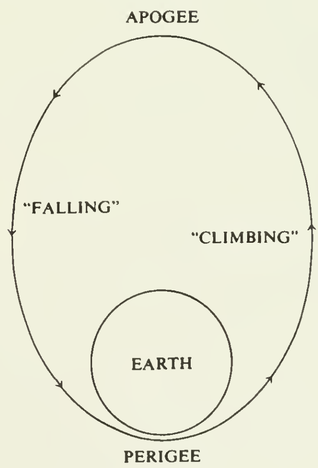


Figure 143—The Satellite Ellipse

orbit which is closest to the earth's surface; the apogee is that point of the satellite's elliptical flight path which is farthest from the earth's surface.

As the satellite flies toward apogee, it gradually loses its initial velocity because it is traveling away from earth and against earth's gravitational pull. When it reaches apogee, earth's gravitation overcomes the satellite's centrifugal force—velocity—and gravitation then draws the satellite back toward the earth's surface.

Throughout the next half revolution of the satellite around the earth, the satellite drops through a long arc, picking up the velocity it lost on its outward swing. At perigee the satellite is moving at maximum speed—the centrifugal force exceeds gravitational pull—and starts shooting off into space again. This process is repeated over and over again and if the elliptical flight path does not reenter the earth's atmosphere, the satellite will remain in orbit indefinitely.

Satellites are usually launched in an easterly direction in order to take advantage of the earth's west-to-east rotation. Maximum impetus for satellite launchings would be acquired if the missiles were launched from bases along the equator, where the surface rotational velocity is 1,000 mph, e.g., a rocket fired due east from the equator would have a 1,000 mph bonus toward its orbital or escape velocity.

There are two basic methods for achieving a lunar or interplanetary flight: (1) a launching from the earth's surface, and (2) a launching from an orbiting space station. While there would be little difference in the techniques used, there would be a major difference in the powerplant requirements, since a lunar or interplanetary trip starting from a satellite needs much less power.

In calculating a flight path to the moon, an astronautical engineer must estimate the following effects:

1. The gravitational fields of the earth, sun, and moon.
2. The earth's atmosphere.
3. The earth's rotation on its axis.
4. The moon's orbit around the earth.
5. The inclination of the earth's axis to the ecliptic—the plane of the earth's orbit.
6. The inclination of the moon's orbit to the ecliptic.
7. The performance capability of the space vehicle.

The moon will not be an easy target since its diameter is about one-fourth that of the earth; its orbital velocity is 2,268 mph, and its distance from earth alternates between 221,463 miles at perigee to 252,710 miles at apogee.

ATMOSPHERE REENTRY

In theory, recoverable satellites and spacecraft will begin their reentry into the earth's atmosphere at a tangent to the earth's surface. The upper atmosphere will be used as a drag brake to decelerate the vehicle's speed gradually from the approximately 19,000 mph initial entry speed. As the returning spacecraft progresses toward the earth's surface, its flight path will steepen and the decelerating vehicle will lose altitude more quickly. In contrast, the ballistic missile will begin entry at quite a steep angle, with an initial speed of about 15,000 mph.

This high-speed reentry point has caused another major roadblock to space travel. All types of entry vehicles will exchange their kinetic energy for heat energy during the entry process. The ballistic missile will make this transformation to heat energy in a very brief period, while the more carefully planned flight paths of satellites and other spacecraft extend the heating process over a longer period. In all cases, however, this aerodynamic heating caused by the enormous entry speed presents staggering engineering problems, with destruction of the vehicle being the penalty for unsatisfactory solutions.

At present there are several known methods for dealing with the intense heat of high-speed atmospheric entry. Recently a practical aerodynamic method for *dumping* a large fraction of the heat generated during reentry was developed by employing blunt nose cones.

A second method to keep the vehicle's skin temperature within tolerable limits is to use *aerodynamic lift* to keep the vehicle at higher altitudes for a longer period before slowly permitting it to enter denser portions of the earth's atmosphere.

Several fluid cooling systems have been designed, one of which pumps a cooling fluid through passages next to the vehicle's skin to absorb and carry away incoming heat.

Another method now being studied by the National Aeronautics and Space Administration (NASA) is called *ablation cooling*. The surface of the space vehicle would be coated with a substance which progressively vaporizes during heating. The vaporizing process would not only absorb heat but would also generate gases which would insulate the skin from heat penetration.

Radiation also provides cooling attributes during an entry flight. A moderate increase in a vehicle's surface temperatures in comparison to the cold, surrounding atmosphere will permit a sizeable increase in the quantity of heat which radiates away from the missile's skin. If the metal surface of the missile can withstand the exceedingly high temperatures which are created by air friction, radiation will supply all the cooling that is needed. Unfortunately the problem is intensified because the hot surface of the vehicle radiates *in* toward the cabin as well as *out* into the atmosphere.

Stability in flight is another major area still to be solved if reentry of spacecraft into the earth's atmosphere is to succeed. Research is presently being carried out to determine what kinds of stability are required by space vehicles and how much stability must be provided to make a given spacecraft design easily controlled. Without stability there can be no satisfactory, safe, successful return to the earth by satellites, ballistic missiles, or spacecraft.

PHYSICAL PROBLEMS

There are numerous physical problems to be solved before a manned missile can be launched into space. Those which are requiring the most attention from astronautical scientists at the present time are (1) acceleration, (2) weightlessness, and (3) physical needs.

Acceleration. To achieve escape velocity from the earth's atmosphere, a manned missile must acquire a speed in excess of 25,000 mph. This speed indicates that a tremendous amount of acceleration must be developed during the launching phase and for a short period during initial flight. As the missile's upward speed increases, the fuel tanks are rapidly drained, causing the mass of the missile to decrease, and as the mass decreases, the acceleration is increased even more.

Passengers in the missile will feel the direct impact of the astounding forces which move them upward. The inertia of their bodies will oppose the continuous, drastic change in speed and, as a result, they will be pressed against the bottom of their bunks by a sheer irresistible force. These tremendous "g-forces"—forces of gravity exerted on a body by the mass of the earth —will cause serious difficulties in blood circulation and in breathing.

Flight surgeons and other scientists have devoted a great deal of research effort to find solutions or remedial activities to nullify the greatly increased body weight during acceleration. The rigors of powered ascent which future spacemen must withstand touch the tolerance limits of the human organism; but by the careful selection and training of healthy and physically fit individuals, scientists are fairly certain a human body will be able to withstand this initial acceleration phase of space flight.

Weightlessness. Of all the phenomena that will be associated with space flight, weightlessness will be the strangest. The state of weightlessness is caused by an intricate interplay of the physical forces to which the ship and the men are subjected during their flight through space. The passengers will sustain the feeling of weightlessness as long as the rocket engines are out of operation. Weightlessness cannot be avoided since the theoretical mechanics of space flight entail travel by coasting. However, space technicians are presently searching for a method to impart rotating capabilities to the missile, i.e., revolving the vehicle at the same time that it travels forward. This rotation effect would tend to decrease the weightless condition.

Physical Needs. The scientific skills and experience which have been used in the past to create useful and livable physical conditions by artificial means will be urgently needed in order to equip man for his survival in space. Using only the spaceship and the satellite, astronautic technicians must create an artificial, though minute, earth. Primary consideration will be given to solving the vital breathing and food consumption problems.

Unlike a submarine, where the shell is built to keep water out, a spaceship must be designed to keep the air in. In addition, although the human organism does not require an excessive amount of oxygen, it does require some—about an ounce an hour—all the time. The net weight of the oxygen is small, about three pounds per day per man, but the weight of the storage containers is large. Therefore, space scientists are presently attempting to devise a method of reclaiming the oxygen which is exhaled during the breathing process. In conjunction with the problem of lack of oxygen, engineers must develop an air-conditioning system which will remove from the cabin air all substances released by man and his equipment which are potentially hazardous.

On extended trips through space, it would be desirable for the morale and health of the crew to provide food that is both varied and of high quality. Dieticians and food technologists are presently concerned with three new methods for food preservation: (1) Gamma irradiation, (2) Beta irradiation, and (3) freeze-drying. In the first two methods, gamma rays or electrons are used to extend the storage life of foods by stopping the sprouting process and by destroying microorganisms, parasites, and insects. In the case of freeze-drying, food is first frozen, then placed in a vacuum and subjected to an electromagnetic beam which causes the ice crystals to turn quickly into a gaseous state. The resulting product will have lost 90 per cent of its weight, and the bacterial and enzyme activities of the food will have been suspended.

Figure 144—The USAF Titan ICBM is launched from Cape Canaveral, Florida, on another successful 5,000 mile flight. Official USAF photo.

Summary

Since earth has been well explored, man has now turned his attention and efforts toward a new frontier —space. Through scientific research, man knows that the earth is only one of nine planets, plus a central star, the sun, which composes his solar system. He has learned that his solar system is but a small portion of a galactic star system, which, in turn, is but one galactic star system among the many that compose the universe.

Historically, rockets were first described and used by the Chinese in the 13th century. Rockets were intermittently employed during the next six centuries, generally as weapons or for pyrotechnic display. Near the end of the 19th century, the Russian, Ziolkowsky, the German, Ganswindt, and the Frenchman, Esnault-Pelterie, suggested that rockets could be developed as a method to propel man into space. In the early 1900's, Dr. Robert H. Goddard and Professor Herman Oberth contributed extensively to rocketry's scientific knowledge. The German government quickly realized the potential in rocket propulsion and established the "Peenemunde Project" in 1936 to permit further experimentation and research on missile design and propulsion.

Currently, space scientists are confronted with many complex problems which must be solved before manned space flight can become a reality. In the area of propulsion, engineering research and testing techniques have developed solid-fuel and liquid-fuel propellants to a fairly high degree of useability. In addition, astronautic engineers are attempting to develop practical nuclear, plasma, photon, and ion rocket engines which would increase the thrust and acceleration characteristics of the missile.

A missile's guidance system must be highly accurate while completing an exceptionally complicated task. The commonly used types of guidance systems in today's missiles are (1) pre-set, (2) command, (3) target seeking, (4) inertial, and (5) celestial navigation. The particular guidance system which is incorporated into a missile depends upon the missile's target, range, and speed.

There are four types of orbits, or flight paths, which a missile or satellite will follow during its travel through space: (1) circular; (2) elliptical; (3) parabolic; and (4) hyperbolic. To be put into a circular or elliptical orbit, the spacecraft must be accelerated to at least 18,000 mph but not more than 25,000 mph. Speeds in excess of 25,000 mph will free the spacecraft from the restrictions of the earth's atmosphere and cause it to fly out into space. Satellites are usually launched in an easterly direction to take advantage of the added impetus provided by the earth's west-to-east rotational velocity.

Reentry into the earth's atmosphere is still a difficult problem which must be solved prior to a manned space flight. Various cooling systems are now being studied to alleviate the exceedingly high temperatures which will build up on the surface of the spacecraft during its reentry phase. Closely allied to the high temperature problem are the requirements of control stability.

Among the many human physical problems now being tested, (1) acceleration, (2) weightlessness, and (3) physical needs concerning food and oxygen are of major importance. Each of these three activities require special attention by space scientists since an artificial earth must be re-created within a missile or satellite if man is to exist for the long periods required by interplanetary and intergalactic space flight.

Questions

1. Name the planets which revolve around the sun.
2. Who were the first three men to complete practical studies concerning the use of rocket propulsion as a means of space travel?
3. Name three of the many discoveries which are generally credited to Dr. Robert H. Goddard.
4. Why are rocket engines often confused with jet engines? How do they differ?
5. Discuss briefly the propulsion system of a nuclear rocket, a liquid chemical rocket, a photon rocket, and a solid chemical rocket.
6. What is meant by pre-set guidance, a beam rider, and an active seeker?
7. What is an astronomical unit, a galaxy, and an asteroid?
8. What is inertial guidance?
9. What is weightlessness and why is it important to space flight?
10. What are the two general measures of performance of a rocket engine?
11. What is a guided missile? A ballistic missile?
12. Why are satellites launched in an easterly direction?
13. What human problems occur during the initial acceleration of a manned space vehicle?
14. Define (1) apogee, (2) perigee, (3) orbital velocity, (4) troposphere, and (5) comet.
15. How will ablation cooling assist a spacecraft to reenter the earth's atmosphere?
16. What is the difference between a missile and a rocket?

Chapter 13 Space Exploration

Beginning with the successful launching of Explorer I in January 1958, the United States has embarked on a thrilling assault on a new frontier. Vast sums of money are being appropriated by the federal government for this exciting venture. Large numbers of the keenest brains in the country are working on solutions to its difficult and complex problems. Many of the nation's corporations are expending time, facilities, and manpower on space hardware. Colleges and universities are developing new curricula and research projects. Members of Congress and military commanders are searching for answers to the political and military problems generated by space activities. Radio, television, and newspapers are providing great amounts of broadcast time and printed pages to cover and explain space-age achievements.

With all this discussion, dialogue, and debate centering around the need to conquer space, it is desirable to review the reasons for its exploration.

Quest for Knowledge

The one reason most generally accepted by the public is the scientist's "need to know." Research gives the necessary impetus to progress. New knowledge now accruing from space research will be translated tomorrow into benefits for all mankind.

The quest-for-knowledge concept was defined by President Eisenhower when he stated:

"Scientific research has never been amenable to rigorous cost accounting in advance. Nor, for that matter, has exploration of any sort. But if we have learned one lesson, it is that research and exploration have a remarkable way of paying off—quite apart from the fact that they demonstrate that man is alive and insatiably curious. And we all feel richer for knowing what explorers and scientists have learned about the universe in which we live."

There have already been some practical gains, e.g., new metals and ceramics and better weather forecasting, but it is probable that the greatest advances from space research are still unseen and unknown.

Peaceful Uses

A second important reason for public acceptance of the responsibilities and sacrifices imposed by space exploration is the realization that the goals are fundamentally peaceful. Even though the nation is gaining knowledge essential to the national security, the peacetime benefits, present and potential, are tremendous.

Mr. James E. Webb, Administrator of the National Aeronautics and Space Administration (NASA) reports, "New knowledge is needed in almost every branch of science and technology. Outer space is our newest frontier and in this dawning era we can broaden man's horizons. Our Space Agency is a research and development organization, dedicated to the acquisition of knowledge and its dissemination for *peaceful and scientific* purposes to benefit all mankind."

To accomplish this goal of peaceful penetration of space, the United States shares much of its knowledge and information with scientists of approximately twenty friendly foreign countries. At the same time, NASA is entrusted with the task of supervising the expenditure of over one billion dollars a year. More than 85 per cent of this NASA budget is distributed in work and research contracts negotiated with industry and universities. There are now over 5,000 organizations engaged in the missile-space industry.

President Kennedy summed up the public view on this subject when he stated that the American efforts were planned "to invoke the wonders of science instead of the terrors . . ., to explore the stars, to conquer the deserts, eradicate disease, tap the ocean depths and encourage the arts and commerce."

National Security

Even though this nation's primary emphasis is on the peaceful products of space exploration, there can no longer be any doubt of the military implications of the "space race." One of the objectives in the Act which created NASA, passed by Congress in 1958, was "the making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary and space activities, of information as to discoveries which have value or significance to that agency."

No one can, at the present time, forecast all of the military applications of space technology. However, aerospace power of the United States is the Free World's key to future military security; consequently, the control of space becomes necessary to the future safety of the nation.

National Prestige

An added factor, but one difficult to measure, is that of national prestige. The Soviet Union has been exceptionally skillful in the exploitation of its space achievements for propaganda purposes. The successful orbital flights of the Cosmonauts Gagarin and Titov undoubtedly contributed greatly to Russian prestige throughout the world. Many in the United States believe that this country's space efforts are a gauge of its vitality and its capacity to counteract rival influences, as well as a criterion of the nation's ability to maintain a technological and scientific greatness worthy of the trust and confidence of other free nations.

Figure 145—The NASA Mercury-Redstone III is shown during the early morning hours of May 5, 1961, as it was being readied for flight. The booster placed Astronaut Alan B. Shepard, Jr., inside a Project Mercury spacecraft into a 5,100 mile per hour flight 302 miles downrange. (Courtesy National Aeronautics and Space Administration.)

In the international-prestige feature of the space race, at least its early stages, the United States was in a runner-up position. The Soviet successes have been spectacular, but when the following figures are studied and the exploits of Astronaut Glenn added, it is obvious that this nation has made notable gains and is now forging ahead. (See Figure 145.)

*SPACECRAFT TOTALS**

	Earth Satellites	*Lunar Impact*	*Solar Orbit*	*Total*
United States Spacecraft Orbited	156	1	5	162
Russian Spacecraft Orbited	39	1	3	43
U. S. Spacecraft Now in Orbit	69	0	5	73
Russian Spacecraft Now in Orbit	5	0	3	8

*As of November 15, 1963, *Space Log*, TRW Space Technology Laboratories, p. 40.

It can be understood both from the above figures and the following description of the many American space projects that this country's broad scientific endeavors have shown outstanding results.

Current Space Activities

EXPLORER SATELLITES

The Explorer series originated the space exploration program of the United States. The first Explorer, which was launched in January 1958, produced information leading to the discovery of the Inner Van Allen radiation belt and recorded the first micrometeorite observations in a satellite. Subsequent Explorer satellites have continued to investigate the Inner and Outer Van Allen radiation belts, micrometeorite energy, and, in addition, solar winds, interplanetary magnetic fields, and distant areas of the earth's magnetic field.

Explorer VII, which is one of the two satellites still active, was nicknamed the "Kitchen Sink" when it was launched in October 1959 because of the large number of scientific instruments it carried. Explorer VII has solar batteries which generate the necessary electricity for the satellite's operation.

Explorer XII, which was launched from Cape Canaveral in August 1961, has relayed information which is causing a reappraisal of the Inner and Outer Van Allen radiation belts discovered by earlier Explorer satellites. Scientists now feel that a single belt begins about 400 miles out from the equator and extends to a maximum of 24,000 to 28,000 miles. No definite outer boundary can be established as the solar winds constantly shift the radiation belt's frontier. Currently, the Van Allen belt is named the magentosphere. Through January 1, 1964, a total of 21 Explorer satellites had been successfully launched.

PIONEER SATELLITES

Beginning in October 1958, a total of five shots were made in the Pioneer series. Although Pioneers I, II, and III did not reach their objectives, i.e., earth-moon trajectories, they did provide much new scientific knowledge concerning radiation hazards, the density of micrometeorites, and measurements of the interplanetary magnetic field.

Pioneer IV, however, was considered a major achievement during the early years of space exploration. In March 1959, Pioneer IV was launched on an earth-moon trajectory. Although this space probe reached the vicinity of the moon, it did not come within the 20,000-mile range which would have permitted a photoelectric sensor to sample the moon's radiation. Pioneer IV passed within 37,300 miles of the moon and continued on into orbit around the sun, where it is expected to remain for millions of years. It is also noteworthy that Pioneer IV was tracked for a distance of 407,000 miles before contact was lost.

Pioneer V was considered an even more spectacular accomplishment. This space probe was launched in March 1960 and went into orbit around the sun where it, too, is expected to circle for millions of years. Pioneer V was designed to investigate space between orbits of earth and Venus, test extreme long-range communications, and study methods for checking the Astronomical Unit and other astronomical distances. At present, a total of seven launches are scheduled. Pioneer VI will probably be launched in 1965. To date, the Pioneer program has achieved all of its major projects and transmitted vast amounts of useful information. In addition, this interplanetary probe recorded the most distant radio transmission from the earth, more than 22 million miles.

PROJECT SCORE

In December 1958, another earth satellite with the code name Project Score was placed in orbit. Although the satellite remained in orbit only 34 days, it relayed a great amount of scientific information.

The objectives of Project Score were to test a variety of combinations of voices and teletype communications between ground and satellite stations and to confirm the feasibility of using courier satellites. Project Score is best remembered for the broadcast of President Eisenhower's Christmas message to the world. This particular transmission and reception was the first time a human voice had been received from outer space.

DISCOVERER SATELLITES

In February 1959, the first in a long series of Discoverer satellites was launched. As of February 1962, 38 Discoverer launchings had been attempted and 26 had been successful.

The primary mission of the Discoverer series has been to develop ability to launch satellites consistently into a precise, near circular, polar orbit; stabilize and control an object in orbit; maintain space-ground communications; and separate a capsule, bring it back to the earth, and recover it. This fourth mission has been highly successful. There have been 26 attempted capsule recoveries, of which eight have been successful mid-air recoveries and four successful ocean recoveries.

In December 1961, Discoverer XXXVI was launched from Vandenberg Air Force Base in California. This Discoverer carried something new—a ten-pound robot named Oscar. Oscar, a code name for Orbiting Satellite Carrying Radio, was built by amateur radio operators to broadcast transmissions to ham operators around the world. In January 1962, Discoverer XXXVII was launched but failed to orbit. However, Discoverer XXXVIII, launched the following month, did go into orbit. Following the launch of Discoverer XXXVIII, the Department of Defense adopted a policy of releasing only basic information on military launches. Consequently, Discoverer Satellites are no longer individually identified.

TRANSIT SATELLITES

The initial attempt to launch a Transit satellite occurred in September 1959. Although Transit 1A failed to achieve orbit, Transit 1B was successfully launched from Cape Canaveral in April 1960.

The primary purposes of the Transit satellites are to develop, test, and demonstrate navigational equipment which would reliably determine the position of all surface craft, aircraft, and submarines. In addition, they would provide for a more accurate, all-weather air and sea navigation system than is presently available.

Transit 2A was unique in that it carried, and placed into orbit, a "piggy back" satellite which has been named Greb, a slight code-name misspelling of Galactic Radiation and Beta. Transit 4A carried two piggyback satellites which, although successfully ejected, did not separate; nevertheless, they are still transmitting data on certain experiments. Transit 5A, an operational, navigational system for Polaris submarines was successfully launched on December 18, 1963.

TIROS SATELLITES

The Television and Infrared Observation Satellite (TIROS) was the first NASA meterological satellite project. In April 1960, the first of eight Tiros satellites was launched. Tiros I, a camera-carrying picture-taking satellite, provided the weatherman with a new dimension for weather prediction. The two television cameras have relayed over 22,000 pictures to weather scientists around the world.

Tiros II was placed into orbit in November 1960 and Tiros III in July 1961. (See Figure 146.) All three satellites are expected to remain in an earth orbit for many decades, and since the top and sides of these pill-box shaped satellites are covered with solar cells which transform sunlight into electricity, they will continue to measure the earth's cloud cover and to transmit pictures. Tiros IV, V, and VI were launched into an earth orbit during 1962. Eight Tiros satellites have now been successfully launched with a ninth scheduled for the summer of 1964.

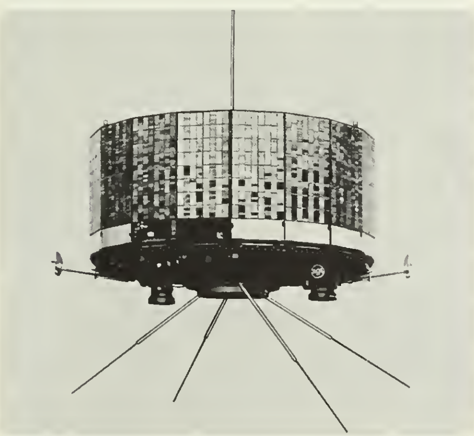


Figure 146—This is NASA's satellite TIROS III. This Tiros differs from earlier Tiros satellites in that it carries two wide-angle cameras and an additional infrared experiment. (Courtesy NASA.)

Although the Tiros series has been a highly successful experiment, the satellites are not in themselves operational weather systems. (See Future Space Projects.)

MIDAS SATELLITES

The Missile Defense Alarm System satellite (MIDAS) was designed to provide the United States with a military satellite system capable of detecting the launch of an aggressor ballistic missile within seconds after lift-off. Although Midas I, launched in February 1960, failed to orbit, Midas satellites II, III, and IV have since been successfully injected into a nearly circular earth orbit.

An interesting feature of the Midas satellite is that after attaining its 18,000 mph orbital speed, the attitude of the satellite is changed from the horizontal to a nose-down position. Its shape is basically a cylinder, with one end pointed. It is this pointed end which is continuously aimed at the earth and which contains the infrared sensors which detect the tremendous heat generated by missile boosters at the time of launch. The Midas satellites, weighing close to 3,500 pounds, are the largest objects to have been placed in orbit by the United States.

ECHO SATELLITE

A man-made star, given the code name Echo I, was launched in August 1960. It is an inflated sphere, 100 feet in diameter, made of mylar polyester plastic about one-half the thickness of the cellophane on a package of cigarettes, and is still in orbit. Because this communications satellite can be seen by the naked eye, it has probably created more public interest than any other unmanned shot.

Echo I was an experiment in a passive communications satellite, and its only mission was to serve as a relay point for bouncing messages from one point on the earth to another point. Except for two very tiny transmitters which are powered by solar cells, it was unique in that it carried no instruments. Echo II was launched in January 1964. It is being used as a passive reflecting sphere for joint US-USSR experiments.

SAMOS SATELLITES

From October 1960 to November 1961, three attempts were made to launch a Satellite and Missile Observation System (SAMOS). Only Samos II was successfully orbited. Its programmed life span was relatively short. Samos II was launched in January 1961 and its transmitters faded in March 1961.

The Samos satellites were designed to scan the entire surface of the earth, and, in addition, to study cosmic rays, the earth's electrical field, and micrometeorites. The details of the results of the various Samos II experiments have not been made public. It is known, however, that the picture-taking, worldwide reconnaissance satellite was sponsored as a military program and was a follow-up to the Midas satellite series. During 1964, NASA/DOD plan a joint effort to continue the Midas and Samos projects.

Lunar and Interplanetary Launchings

The next logical step in the effort to achieve space capability is, first, to probe the atmosphere surrounding the moon, then to make an impacted or "hard" landing followed by a controlled or "soft" landing, and finally, after an instrumented exploration of the moon's surface, to make a manned lunar landing. The attempt to reach the moon with unmanned satellites has been divided into three stages. These have been given the code names of Ranger, Surveyor, and Prospector.

RANGER SPACECRAFT

In August 1961, Ranger I, the initial effort of the United States in moon exploration, was launched from Cape Canaveral to flight test lunar spacecraft. Both Rangers I and II were designed to seek information concerning attitude control, solar and battery power supplies, communications equipment, estimates of the probable lifetime of equipment in a space operation, and data on the composition of materials and gases beyond the earth's atmosphere.

Ranger III was to have studied the possibilities of landing a package on the moon and to have developed studies of lunar environment. It was launched in January 1962, but, due to excess velocity given by the Atlas booster, the spacecraft missed the moon by over 22,000 miles and continued on into space to become a satellite of the sun. Rangers IV and V were launched in April and October of 1962. They were assigned the same program objectives and experiments as Ranger III.

Ranger VI was launched on January 30, 1964. It impacted on the surface of the moon; however, its TV system failed and consequently a great deal of invaluable data was not transmitted to the various earth receiving stations. A total of nine spacecraft launches are planned prior to an attempted manned lunar landing.

SURVEYOR SPACECRAFT

A launch schedule, beginning in 1965, or possibly late 1964, has been established for the Surveyor series Surveyor spacecraft will attempt a soft or controlled lunar landing. It is expected that Surveyors will carry 100 to 300 pounds of scientific instruments designed to examine the magnetic lunar field, the atmosphere of the moon, and its surface and subsurface characteristics. The spacecraft will carry a drill which will dig and analyze samples of the lunar surface. A successful Surveyor will also choose the eventual site for a manned landing, via television search and by depositing a radio beacon which future spacecraft can use as a "Moon approach beam." (See Figure 147.)

MARINER AND VOYAGER SPACECRAFT

During the same period that the moon was being explored, interplanetary probes by Mariner spacecraft were launched. A Mariner II spacecraft investigated interplanetary space between earth and Venus in 1962. The experiments which were carried out by this satellite determined the temperature on the planet's surface, the Venusian magnetic field, and the atmospheric composition. A total of twelve shots are planned.

The Voyager project is similar to the Surveyor series except that Voyager spacecraft will explore the planet Venus, first by orbit, then by placing a capsule on the surface of the planet Venus. While the capsule records measurements on the surface of the planet, the mother spaceship will continue to orbit it at an altitude of several hundred miles transmitting data

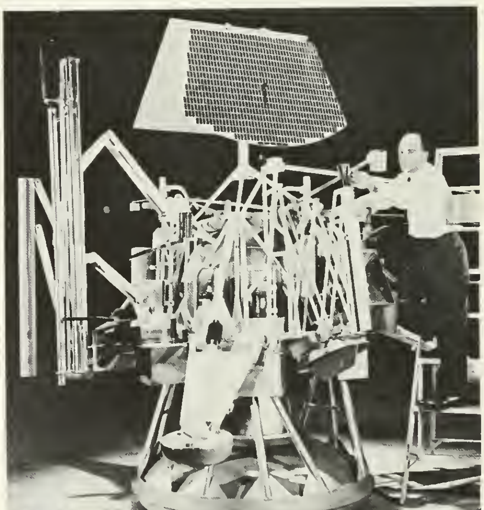


Figure 147—Full-scale model of Surveyor satellite. Surveyor is scheduled to make soft landing on the moon. (Courtesy NASA.)

on the atmosphere. The initial launch is scheduled for 1967.

Future Space Projects

METEOROLOGICAL SATELLITES

In the meteorological field, Nimbus and Aeros satellites are planned. Nimbus satellites, scheduled for an early 1964 launching, will be placed into a polar orbit and will be able to provide weather information from every point on the earth's surface every six hours. Aeros satellites will also be earth-oriented and will be placed in a circular stationary orbit. Three Aeros satellites, properly spaced around the surface of the earth, will be able to monitor global weather conditions continuously.

COMMUNICATIONS SATELLITES

In the field of world-wide communications, the United States has developed the Relay, Telstar and Syncom projects.

Relay was placed in orbit in 1962 and Relay II in 1964. These satellites will have as their primary mission the reception and transmission of television, telephone, and other wide-band forms of communication. Telstar I and II satellites are a commercially sponsored series which will also be used to develop new information on television, telephone, and radio transmissions. Both Relay and Telstar will be relatively low-altitude earth satellites.

Syncom II went into orbit at an estimated 22,000-mile altitude in July, 1963. Like the Relay and Telstar satellites, Syncom is an active-repeater satellite, unique in that its orbital pattern will follow a "figure-eight" conformation, constantly monitoring activities along the east coast of the United States only.

The Advent satellite will also be injected into orbit at approximately 22,000 miles but, unlike the Syncom which will orbit in a figure-eight path, it will be given a speed which will be synchronized with the earth's speed, thus permitting the satellite to remain in a stationary position. First flights are scheduled for the 1966-1968 period.

OBSERVATORY SATELLITES

The Orbiting Solar Observatory (OSO), Orbiting Astronomical Observatory (OAO), and Orbiting Geophysical Observatory (OGO) projects are developing a great deal of scientific interest. The first OSO satellite was successfully placed in orbit on March 7, 1962. A second launch is scheduled for 1964. This 458-pound laboratory will help to answer such questions as how the sun affects weather conditions, how radio and television communications are influenced by bombardment in the ionosphere, and the extent of the Van Allen belt.

OAO satellites will be of primary interest to astronomers. It is planned that the satellite will carry telescopes to aid the study of deep space not presently observable because ground observations are obscured by the earth's atmosphere. OAO satellites are scheduled for launch in 1965 and, in addition to telescopes, will carry large reflecting mirrors, solar batteries, and video tubes to test ultraviolet rays.

OGO satellites will be devised so that they can conduct up to 50 geophysical experiments in one flight. Planned experiments now include investigation of terrestrial phenomena, the physics of fields and energy in space, solar elements, gravitation, and micrometerorites. OGO will be positioned so that it always points at the earth; however, certain instruments located on the solar paddles will point toward the sun. A total of six flights are planned with the first launch to be in 1964.

Man in Space

Sometime prior to 1970, Phase III of the Apollo project will have been completed. This will land a lunar spacecraft, carrying three people, on the moon, conduct numerous experiments, and return to the earth.

Just as the unmanned satellites were a vital step in the progression to a manned lunar shot, so the X-15, Mercury, and Gemini projects are necessary preliminary requirements to the Apollo effort.

X-15 ROCKET PLANE

Beginning with the X-I rocket plane, which Major Charles Yeager, USAF, flew in 1947 faster than the speed of sound, much experimental and scientific data have been compiled which are of major assistance to the man-in-space program. The X-series of rocket planes, presently represented by the X-I5, have tested the higher altitudes where the air is so thin and cold that a man would die within a few seconds if he were not wearing a spacesuit. Information gained from friction and heat developed by high-speed craft have aided the Mercury Project designers and will be of valuable assistance to Gemini and Apollo scientists. G-load testing has given some indication of both pilot and aircraft operational control and proficiency. New ways to control the attitude of the rocket plane have been developed, since the plane was designed to fly at an altitude which would leave 99 per cent of the atmosphere behind.

The X-15, flying almost outside the earth's atmosphere, has provided a study of the effects of radiation on the human body, along with much useful information on the survival of man in space. In addition, air-conditioning systems have been tested, communications improved, and new instruments planned. The list of experiments attempted and the amount of knowledge acquired from X-15 flights has been substantial. Possibly the reentry information, physiological and psychological data, and improved rocket engine performance and fuel knowledge have been among the most significant experiments of the X-15 program.

The X-15 research program was started in 1952 when the National Advisory Committee for Aeronautics (NACA), the immediate predecessor of NASA, began laboratory studies on manned hypersonic flight at high altitudes. In 1954, NACA established the basic performance requirements for the research airplane and in 1955 North American Aviation, Inc. was awarded a contract to build three X-15's.

The X-15 is a comparatively small airplane, 50 feet long, with a 22-foot wing span. The outer body of the craft is made of a special metal, a nickel-chrome-iron alloy, named Inconel X, with an inner layer composed of a stainless-steel and titanium alloy. This special skin is not only strong but can protect the plane and the pilot in temperatures up to 1,200 degrees Fahrenheit. The vehicle is painted with an unusual chemically composed black paint which resists fire, absorbs heat, but still holds together at temperatures up to a thousand degrees. The rocket engine has been designed to generate more than 400,000 hp, and although it requires less than 1½ minutes to consume its fuel load, the X-15 has been able to achieve an altitude of approximately 354,000 feet and a speed of over 4,000 mph. The X-15's scientific contributions in the areas of aeromedicine, aerodynamics and structural heating, hypersonic stability and control, and piloting problems are a major factor in the successful suborbital and orbital flights programmed under the direction of Projects Mercury and Gemini. The X-15 and X-15A2 programs are expected to continue through 1968.

PROJECT MERCURY

Project Mercury became an official program in America's assault on space in October 1958. Its scientific objective was to determine what man's capabilities would be in a space environment and his reactions while being subjected to entering into and returning from space. To accomplish this scientific objective successfully, NASA decided it would be necessary to put a manned space capsule into orbital flight around the earth, recover the capsule and its occupant successfully, and analyze the scientific information resulting from this flight. The Project was terminated upon the successful completion of Maj. Gordon Cooper's 22-orbital flight. The general objectives were attained when Lt. Col. John H. Glenn, Jr., USMC, completed three orbits of the earth on February 20, 1962.

The initial flight of the man-in-space program was accomplished by Navy Lt. Com. Alan B. Shepard, Jr., when he completed a suborbital flight in May 1961. (See Figure 148.) His achievement was quickly followed by a similar one made by Capt. Virgil I. Grissom, USAF, in July 1961.

A first step in the Mercury Project was the selection of the Astronauts. Hundreds of applications were submitted and, following strenuous physical and psychological tests, seven former test pilots were chosen in April, 1959: Lt. Malcolm S. Carpenter, USN; Capt. Leroy G. Cooper, USAF; Lt. Col. John H. Glenn, Jr., USMC; Capt. Virgil I. Grissom, USAF; Lt. Cdr. Walter M. Schirra, USN; Lt. Cdr. Alan B. Shepard, Jr., USN; and Capt. Donald K. Slayton, USAF.

These men were chosen because of their exceedingly high intellectual ability and physical fitness. All seven Astronauts have considerable technical knowledge in astronomy, navigation, mechanics, and other basic sciences. Prior to being chosen, all were carefully checked on their ability to sustain stresses such as high altitude, pressure, motion, heat, and loneliness.

When the training program for the Astronauts was started, many difficulties had to be resolved since a similar training schedule did not previously exist. As the program developed, the training schedule was divided into five major categories: (1) academics, (2) static training devices, (3) dynamic training devices, (4) egress and survival training, and (5) specific mission training.

The academic phase consisted of lectures and studies in the scientific fields of mechanics, aerodynamics, astronomy, meteorology, astrophysics, geophysics, space trajectories, rocket engines, and physiology. In addition, there were many detailed briefings on the launch vehicle, the capsule, and their instruments.

The static training devices tested and improved the Astronauts' knowledge of retromaneuvers and reentry maneuvers. There was extensive instruction in the function and operation of the instrument panel. Their ability to control the flight attitude of the spacecraft was tested by a machine named ALFA (Air Lubricated Free Attitude) Trainer, and their navigational ability was improved by installing a Link Trainer in a planetarium so that they could practice navigation by the stars.

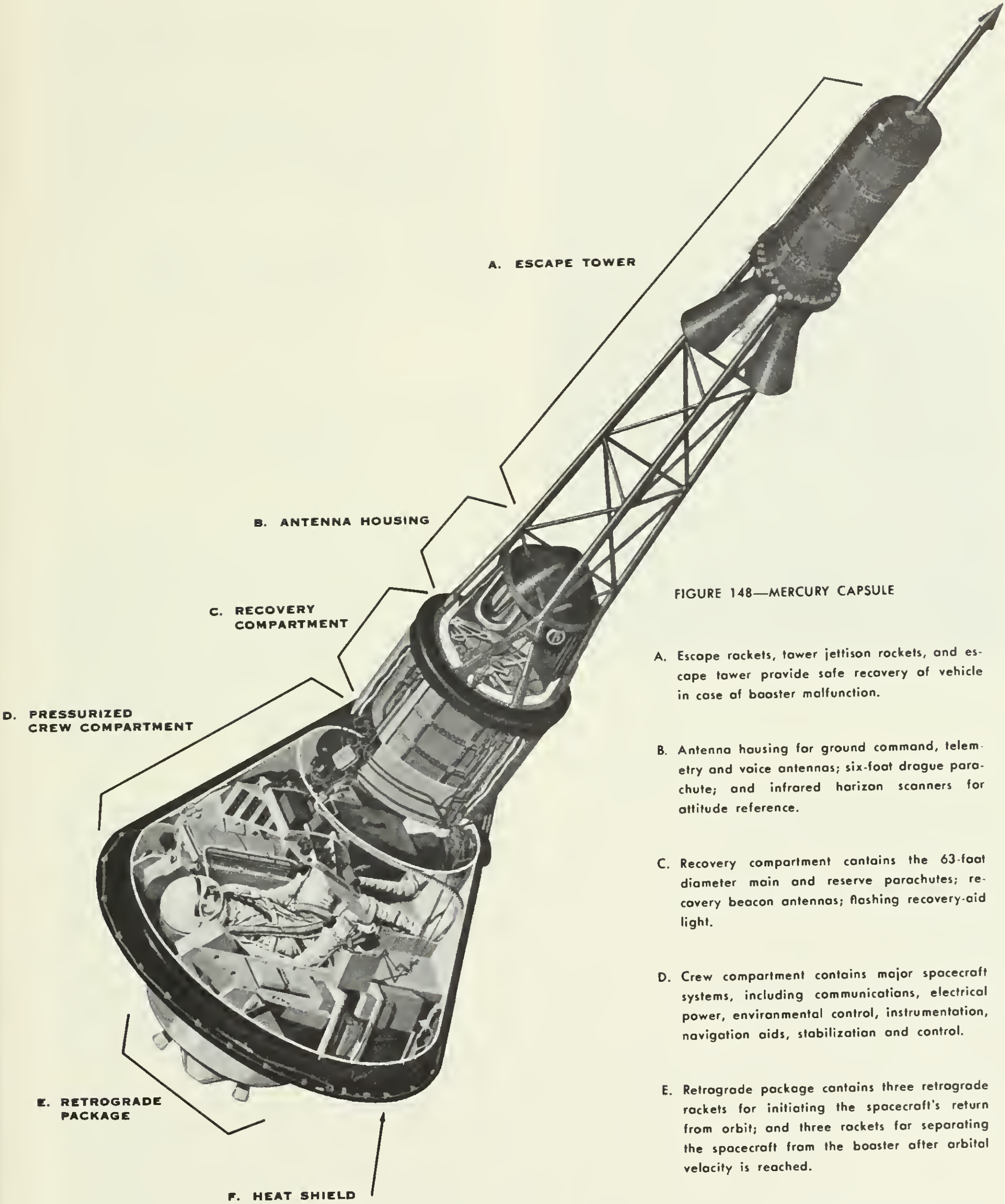


FIGURE 148—MERCURY CAPSULE

A. Escape rockets, tower jettison rockets, and escape tower provide safe recovery of vehicle in case of booster malfunction.

B. Antenna housing for ground command, telemetry and voice antennas; six-foot drogue parachute; and infrared horizon scanners for attitude reference.

C. Recovery compartment contains the 63-foot diameter main and reserve parachutes; recovery beacon antennas; flashing recovery-aid light.

D. Crew compartment contains major spacecraft systems, including communications, electrical power, environmental control, instrumentation, navigation aids, stabilization and control.

E. Retrograde package contains three retrograde rockets for initiating the spacecraft's return from orbit; and three rockets for separating the spacecraft from the booster after orbital velocity is reached.

F. Heat shield provides protection for the astronaut from the extreme temperatures experienced during re-entry.

The dynamic training devices gave the Astronauts some experience in weightlessness by flying aircraft through a parabolic trajectory. This instruction was followed by centrifuge training or high-g training, where several of the men were able to withstand accelerations up to 18g without apparent difficulty. Another interesting training device was the MASTIF (Multiaxis Spin Test Inertia Facility). The Mastif trainer revolved around all three axes, i.e., pitch, roll, and yaw. The Astronaut, by using an exact replica of the Mercury capsule control panel, was taught to control the flight path. (See Figure 149.) In addition,

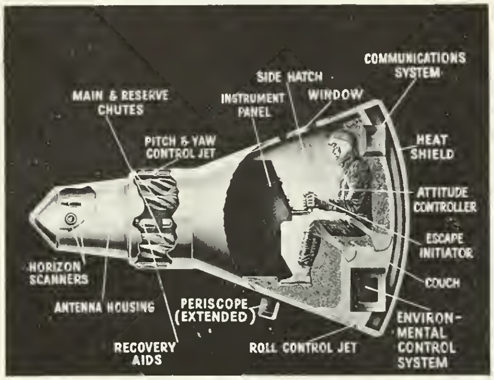


Figure 149—Project Mercury, Ballistic Missile. (Courtesy of NASA.)

since all of the men were qualified jet pilots, they felt that it was vital to continue their proficiency as pilots because they were then able to maintain their sharpness in making rapid judgments and reactions.

Egress and survival training provided an adequate amount of proficiency should the Astronaut not be rescued within a reasonable period. The space capsule was dropped into the ocean and both open sea and underwater egress were practiced. During this same period, both water survival and desert survival techniques were acquired.

Specific mission preparation consisted of special instruction for a particular mission in an indivdual spacecraft and launch vehicle. From the time that the spacecraft arrived at Cape Canaveral until it was launched, the Astronaut lived with it. He participated in all the check-out procedures, attended all meetings concerned with the check out and modification of the craft, and practiced his specific mission flight plan in a procedures trainer. When the spacecraft was moved to the launching pad, there were additional countdowns and radio checks to be made, and emergency rescue procedures to be practiced. This final training program took about eight weeks and was successfully completed when the man and the machine were launched from the earth's surface and were safely returned.

Since there was such a vast amount of knowledge to be learned, it is not possible for each Astronaut to be completely expert in every area. It was therefore necessary to have each Astronaut assume the responsibility for certain areas:

Carpenter	★ Navigation and navigational aids
Cooper	★ Redstone launch vehicle
Glenn	★ Crew space layout
Grissom	★ Automatic and manual attitude control system
Schirra	★ Life support system
Shepard	★ Range, tracking, and recovery operations
Slayton	★ Atlas launch vehicle

This new type of training program produced outstanding results. The suborbital flights of Shepard and Grissom, followed by the orbital flights of Glenn, Carpenter, Schirra and Cooper advanced the space flight capability of the United States to the point that manned lunar and interplanetary flight is now planned. Although the flights themselves were spectacular, the long-range values will stem from the scientific and research data which was obtained.

PROJECT GEMINI

In September 1962, the National Aeronautics and Space Administration (NASA) released the name of nine men who had been selected for Gemini and Apollo missions. The nine new "astronaut candidates" were: Neil A. Armstrong, a NASA test pilot; Maj. Frank Borman, USAF; Lt. Charles Conrad, Jr., USN; Lt. Com. James A. Lovell, USN; Capt. James A. McDivitt, USAF; Elliott M. See, flight test engineer; Capt. Thomas P. Stafford, USAF; Capt. Edward H. White, USAF; and Lt. Com. John W. Young, USN. These men were selected from over 200 military and civilian test pilots.

The first two-man space team was announced in April 1964. Astronaut V. I. (Gus) Grissom and Astronaut Candidate John W. Young were chosen as the first team and Astronaut Walter M. Schirra and Astronaut Candidate Thomas P. Stafford were selected as the backup crew.

In April 1964, Project Gemini became operational with the successful firing and orbiting of an unmanned

Gemini capsule. A second unmanned test flight was scheduled for August 1964.

After the two unmanned tests are completed, NASA plans an additional ten Gemini flights to test manned orbital flights and finally manned flights with rendezvous and docking missions.

The Gemini spacecraft will be similar in appearance to the Mercury capsule, although Gemini will weigh twice as much as Mercury and will be about one-fifth larger. (See Figure 150.) Gemini will also differ from Mercury in its reentry and landing methods. While the Mercury capsule, after reentering, was parachuted to the earth, Gemini spacecraft will have an inflatable, steerable device, resembling a bat's wing, to guide it to the ground.

PROJECT APOLLO

Project Apollo research and development is currently in the mock-up stage. Prior to the Project's final goal of a multi-manned landing on the moon and a safe return to earth, there will be several intermediate steps.

The first step will be to fly the three-man spacecraft in an earth orbit. This flight will permit the testing of the equipment and systems, the training of the crew, and the development of operational techniques. Following the earth orbital flights, the craft will be flown longer and longer distances from the earth.

The final step before a moon landing will be to make several orbits of the moon, conducting numerous scientific experiments pertaining to the guidance and control tasks that would be needed in the lunar landing mission.

Although the final Apollo spacecraft configuration has not been established, safety of flight will be of utmost importance and will be a major influence on the ultimate design. One of the most difficult problems still to be solved is the development of a powerful launch vehicle for the capsule. Saturn booster rockets are now being tested. Saturn launch vehicles will be capable of providing 1,500,000 pounds of thrust and will have the power to send a 90,000-pound payload to the moon.

Peaceful Applications of Space Research

One of the most obvious and continuing values of America's space effort is the economic benefit. A large percentage of the federal budget is being spent by contracting with industry for new research and new product development. The government's expenditures are not being limited to one field only. The entire industrial spectrum is used; e.g., electronics, metals, fuels, machinery, plastics, instruments, textiles, paints, and even foods. The economic benefit is a general one which improves the health and well-being of the nation's economy. But there are also some specific advantages to the individual.

Figure 150—Mockup of a Project Gemini spacecraft. (Courtesy of McDonnell Aircraft Corporation.)

COMMUNICATIONS

Although communications satellites are still in the research and development stage, the potential worldwide coverage of television, telephone, and radio is enormous. The experiments being conducted with the aid of Echo and Telstar Satellites presage successful and broadened broadcast ability.

Echos I and II have already proved that voice transmission can be extended to intercontinental ranges. Two-way telephone conversations have been held. In August 1960, the first transatlantic wireless-code was transmitted between the United States and France by bouncing the signal off the reflecting skin of Echo I. Wire photos have also been sent and received. When enough earth satellites have been properly positioned, world-wide transmissions will become a reality.

The advantages of a world-wide communications net are evident. The efficiency and effectiveness of transmissions would be improved, since atmospheric magnetic storms would not affect their operations.

On-the-spot news coverage and "live" programs would assist the nations of the world in a better understanding of the customs and habits of other countries. Educational TV would be available in a wider area and would not be dependent upon weather conditions. Hi-fidelity radio and long-distance phone calls would be available to everyone at much less cost.

WEATHER

Meteorologists have stated that their inability to predict weather conditions accurately stems from their lack of adequate data. With present equipment, about 20 per cent of the earth's surface is regularly observed. The Tiros satellites have greatly added to the amount of knowledge now available to scientists on cloud coverage. Many researchers feel that once accurate weather prediction becomes commonplace, then something can also be done to change the weather.

The benefits of long-range accurate forecasts could be immeasurable. Farmers would be able to take advantage of the best days for planting and harvesting—even determine the best crops to plant. Hurricanes and tornados might be dissipated before they became destructive. Vacations could be better planned. Floods and other natural disasters could be foreseen and necessary countermeasures thus prepared.

The significance of correct weather forecasting was outlined in a study by the House of Representatives Committee on Science and Astronautics. The report stated, "An improvement of only 10 per cent in accuracy could result in savings totalling hundreds of millions of dollars annually to farmers, builders, airlines, shipping, the tourist trade, and many other enterprises."

ADDITIONAL RESEARCH BENEFITS

In experimenting with foods for space use, nutritionists have discovered new methods for their preparation and preservation, particularly the development of synthetics and the infrared blanching of foods, which is an improved way to prepare them for freezing or canning.

The research on temperature control can lead to more economical and efficient home heating. For the housewife, scientists have developed a new material for pots and pans named Pyroceram. Pyroceram, which can be taken from the refrigerator and immediately placed over the hottest flame, was originally proposed for use as a nose-cone material.

Miniaturization of instruments, caused by the need to conserve both weight and space in the space capsule, may eventually provide the well-known two-way wrist watch radio of the "Dick Tracy" comic strip.

By evolving new ways to check the physical and mental health of the Astronauts, doctors and medical technicians have developed new techniques and instruments to measure heart action, brain waves, blood pressure, breathing rate, and other physiological responses. A new drug, which is a by-product of a missile propellant, is now being used to treat mental ills. In addition, a means to lower blood temperature during operations and a miniature heart stimulator and a small valve which could replace the valve in the human heart are now in the testing stage.

Industry is making use of new plastics and metal alloys to replace iron, steel, aluminum, etc. Newly discovered silicones, polyesters, resins, asbestos, graphite cloth, and glass fibres have proved to have far more mechanical strength than many common construction materials. New sources of power are being investigated. Scientists believe that it will eventually be possible to substitute solar batteries, gaseous fuel cells, and lightweight nuclear reactors for the present gas, oil, and coal power sources.

Transportation and navigation may soon progress to the point where they are not affected by the weather. Research data from both the Tiros and Transit series of satellites will make it possible for planes and ships to avoid inclement weather and to pinpoint exactly their geographic location.

The new products and the new developments of space research and technology are numerous and varied. The by-products and new incentives of the Aerospace Age, as Dr. Hugh L. Dryden, NASA's Deputy Administrator said, are "perhaps the greatest economic treasure . . . This new technology is advancing at a meteoric rate. Its benefits are spreading throughout our whole industrial and economic system." Many new jobs have been created. It is estimated that the aerospace industry is now the largest manufacturing industry in the United States. As an employer, it has approximately 1,200,000 employees.

Summary

The space program of the United States, which began with the successful launching of Explorer I in January 1958, has achieved many spectacular successes in a very short period of time. Although there have been many military applications and uses of space technology, the primary American emphasis has been on peaceful developments.

The United States has planned and carried out a variety of scientific experiments with its satellite program. Communications, weather, navigation, lunar and interplanetary probing, missile warning, missile recovery, mapping, and observation satellites have been launched. All of the satellite projects have added to the knowledge which will permit both lunar and interplanetary landings within the near future.

The X-series of experimental aircraft have provided much needed information to conclude successfully the Mercury flights. Knowledge concerning air conditioning, temperature control, and communications equipment is important. However, the greatest contributions of the X-15 project to the space program have been in the areas of physiological and psychological data, and in improved engine performance and fuel information.

Project Mercury was initiated in 1958. After selecting seven men to begin training as the nation's first Astronauts, a new training program was developed. Because it was impossible for the Astronauts to keep up to date with all of the information required for successful space flights, each man became an expert in one particular area. The next man-in-space project has received the code name of Project Gemini. Project Gemini will be followed by unmanned lunar and interplanetary launches. Project Apollo's goal is to land a manned spacecraft successfully on the moon and then have it return safely to earth.

The peaceful applications of space research are even now finding aceptance and use by the public. An entirely new industry has developed to deal with space technology and research. More than 5,000 companies are presently engaged in space research or production, and there are more than 3,000 useable by-products of missile-space science.

Questions

1. What are the five major categories of the Astronauts' training program?
2. What new information did Explorer XII ascertain concerning the Van Allen radiation belt?
3. Which unmanned earth satellite created the most public interest? Why?
4. What have been the contributions of the X-15 to manned space flight?
5. What were the two objectives of the Project Score satellite? Were they achieved, and, if so, how?
6. How many people were chosen for Project Mercury? Name them.
7. How can accurate weather prediction be of value? Which earth satellites assist the meteorologist in his forecasts?
8. What are the major differences between Project Mercury and Project Gemini?
9. What was the scientific objective of Project Mercury?
10. Did Ranger VI accomplish its launch objectives? What were those objectives?
11. What is an OAO satellite and what will it do?
12. What is Inconel X and what is its use?
13. Which satellite was nicknamed the "Kitchen Sink"?
14. What are Prospector spacecraft designed to accomplish?
15. What was unique about the Transit IIA satellite?
16. Why were Midas satellites launched?
17. Describe five different by-products of space technology?
18. What is the significance of the code name Gemini when used to describe the next United States man-in-space project?
19. What are the names of the Russian Cosmonauts who made orbital flights?
20. Which launch vehicles are now being tested for the Apollo program? What intermediate steps in the Apollo Project are planned before a manned lunar landing can be accomplished?

NASA'S PROPOSED 1964 LAUNCH PROGRAM*

Mission	Orbit (mi.)	Payload Wt. (lb.)	Purpose
MANNED FLIGHT:			
Gemini	186	7,000	First manned Gemini mission
MANNED FLIGHT DEVELOPMENT:			
Gemini	186	7,000	Vehicle-capsule compatibility
Gemini	Ballistic	7,000	Systems qualification
Apollo	Ballistic	22,500	Launch vehicle test
Apollo	Ballistic	22,500	Launch vehicle test
Apollo	200	22,500	Launch vehicle test
Apollo	200	22,500	Launch vehicle test
LUNAR, PLANETARY:			
Mariner C (2)	Mars	570	Flyby
Ranger (4)	Moon	804	Rough impact
Surveyor (2)	—	2,100	Vehicle-dynamic payload test
SCIENCE:			
Solar Observatory (2)	300	490	Study solar radiation
Ariel-2(UK-S-52)	174-939	165	Study space phenomena
Explorer (S-66)	575-851	110	Study ionosphere from above
Explorer (IMP-B)	126-172,500	135	Interplanetary monitoring platform
Explorer (S-3C)	173-10,350	100	Study energetic particles
COMMUNICATIONS:			
Syncom	22,300	75	Active relay experiments
Echo 2	641-816	650	Passive Sphere (launched 1/25/64)
Relay	1,298-4,606	172	Active Repeater (launched 1/21/64)
METEOROLOGY:			
Nimbus	575	650	First R&D flight
Tiros	400	285	Photograph cloud cover

*Aviation Week and Space Technology, McGraw-Hill, Vol. 80, No. 11, March 16, 1964, p. 110.

OFFICIAL WORLD RECORDS

Date	Competition	Country	Record
August 11-15, 1962	Duration with Earth Orbit Commandant A. G. Nikolaev; Spacecraft USSR Vostok 3; 63 orbits around earth.	USSR	94 hr. 09 min. 59 sec.
June 14, 1963	Duration with Earth Orbit (claimed) Lt. Col. Valeri Bikovsky; Spacecraft USSR Vostok 5; 81 orbits around earth	USSR	119 hr.
August 11-15, 1962	Distance with Earth Orbit Commandant A. G. Nikolaev; Spacecraft USSR Vostok 3	USSR	1,640,168 Mi.
June 14, 1963	Distance with Earth Orbit (claimed) Lt. Col. Valeri Bikovsky; Spacecraft USSR Vostok 5	USSR	2,050,521 Mi.
April 12, 1961	Greatest Altitude with Earth Orbit Maj. Yuri A. Gargarin; Spacecraft USSR Vostok	USSR	203.19 Mi.
April 12, 1961	Greatest Mass Lifted with Earth Orbit Maj. Yuri A. Gagarin; Spacecraft USSR Vostok	USSR	10,416,84 lb.
May 5, 1961	Greatest Altitude without Earth Orbit Cmdr. Alan B. Shepard, USN; Mercury Spacecraft, U.S. Freedom 7	U. S.	116.5 Mi.
May 5, 1961	Greatest Mass Lifted without Earth Orbit Cmdr. Alan B. Shepard, USN; U.S. Freedom 7	U. S.	4,040 lb.

Appendix

Glossary of Aerospace Terms

A

Ablation cooling—melting of nose cone materials during reentry of space ships or vehicles into the earth's atmosphere at hypersonic speeds.

Acceleration—the act of increasing speed.

Accelerometer—an instrument which measures and indicates the magnitude of accelerations of an aircraft or spacecraft in flight and is a direct indication of the forces applied to aircraft or spacecraft and their passengers.

Aerobatics—evolutions voluntarily performed with an aircraft other than those required for normal flight.

Aerodynamics—the science that treats of the motion of air and other gaseous fluids, and of the forces acting on bodies when the bodies move through such fluids, or when such fluids move against or around the bodies.

Aeronautics—the science and art of flight.

Aeronomy—the study of the upper regions of the atmosphere where physical and chemical reactions due to solar radiation take place.

Aerospace power—the entire aeronautical and astronautical capacity of a nation.

Afterburner—an auxiliary combustion attached to the tailpipe of certain jet engines in which additional fuel is mixed with unused oxygen in the air flowing from the jet and burned to increase the change in velocity of the gases, thus increasing total thrust.

Agonic line—an imaginary line over the surface of the earth joining all points along which there is no magnetic variation.

Aileron—a hinged or movable portion of the trailing edge of an airplane wing, used to control the motion of the airplane about its rolling or longitudinal axis.

Aircraft—any airborne vehicle supported either by buoyancy or by aerodynamic action.

Air density—the ratio of the mass of air to its volume, expressed as its weight per unit of volume, e.g., kilograms per cubic meter.

Airfoil—any surface, such as an airplane wing, aileron, rudder, or elevator designed so that air flowing around it produces useful motion.

Air mass—a large body of air within which the conditions of temperature and moisture in any horizontal plane are approximately the same.

Arctic or polar—an air mass formed in a cold northern region.

Cold—an air mass the temperature of which is colder than the surface over which it is moving.

Continental—an air mass formed over land areas in a temperate zone.

Maritime—an air mass formed over water.

Tropical—an air mass formed in or near a tropic region.

Warm—an air mass the temperature of which is warmer than the surface over which it is moving.

Airplane—a mechanically-driven, fixed-wing, heavier-than-air craft supported by the dynamic reaction of the air against its wings.

Pusher—an airplane with the propeller or propellers in back of the main supporting surfaces.

Tractor—an airplane with the propeller or propellers in front of the main supporting surfaces.

Airport—a tract of land or water adapted for the landing and takeoff of aircraft and providing facilities for shelter, supply, and repair.

Approach—an approach channel designated by the FAA administrator where adequate facilities are provided for instrument approach procedures.

Traffic—1. The flow of aircraft within a given airspace, or the traffic of aircraft on an airdrome, or a combination of these. 2. The passengers, cargo, mail, or baggage carried by aircraft.

Airspeed—the speed of an aircraft relative to the air through which it is moving.

Calibrated—the indicated airspeed rectified to compensate for error in the airspeed indicator or the Pitot-static system.

Indicated—the speed of the airplane passing through the air, uncorrected for instrumental errors or errors caused by temperature or barometric pressure.

Indicator—an instument for measuring the speed of an aircraft through the air.

True—the actual speed of an aircraft through the air, obtained by correcting the indicated airspeed for temperature and altitude.

Airway—an air route along which aids to air navigation, such as beacon lights, radio ranges and direction finding facilities, and landing fields are maintained.

Airworthiness—the quality of an aircraft denoting its fitness and safety for operation in the air under normal flying conditions.

Algae—unicellular and multicellular plants considered as a potential source of food and oxygen in a closed ecological system for space vehicles.

Altimeter—an aneroid instrument for measuring the height, in feet, of an aircraft above sea level or above an airport of either departure or destination.

Setting—the setting made on the barometric scale of an altimeter so that on landing the instrument pointers will indicate the approximate elevation of that airport above sea level.

Altitude—the vertical distance from a given level to an aircraft in flight.

Absolute—the height of an aircraft above the earth.

Corrected—the actual height of an aircraft above sea level.

Amphibian—an airplane designed to rise from and alight on either water or land.

Aneomometer—an instrument for measuring the speed of wind.

Angle—

Dihedral—the acute angle formed by the plane of the wing and the lateral axis of the aircraft.

Drift—the horizontal angle between the longitudinal axis of an aircraft and its path over the ground.

Of attack—the acute angle between the wing chord and the relative wind. This angle varies with the attitude of the aircraft.

Of incidence—the angle between the wing chord and the longitudinal axis of an airplane.

Wind correction—the angle between the track of an aircraft over the ground and the heading of the aircraft. (If intended track or course is being followed, wind correction angle and drift angle are equal.)

Anoxia—absence of oxygen in the blood, cells, or tissue, as would be the case if a person were at 50,000 feet or above without oxygen equipment.

Antigravity—a hypothetical effect upon masses, such as a rocket vehicle, by which some yet-to-be-discovered energy field would cancel or reduce the gravitational traction of the earth or other body.

Aphelion—the point at which a planet or other celestial object is farthest from the sun in its orbit about the sun.

Apogee—the point in an elliptical orbit around earth which is farthest from earth.

Arrester hook—a hook attached to an airplane for engaging an arresting wire; part of the complete arresting gear.

Asteroid—one of the many small celestial bodies revolving around the sun, most of the orbits being between those of Mars and Jupiter. Also called "planetoid", "minor planet".

Astro—a prefix meaning "star" or "stars" and, by extension, sometimes used as the equivalent of "celestial", as in astronautics.

Astrodynamics—the practical application of celestial mechanics, astroballistics, propulsion theory, and allied fields to the problem of planning and directing the trajectories of space vehicles.

Astronaut—a person who occupies a space vehicle. Specifically one of the test pilots selected to participate in Project Mercury, the first U.S. program for manned space flight.

Astronautics—the art, skill, or activity of operating space vehicles. In a broader sense, the science of space flight.

Astronomical Unit—mean distance of the earth from the sun, equal to 92,907,000 miles.

Astronomy—the oldest of the sciences; treats of the celestial bodies, their magnitudes, motions, constitution, and location.

Astrophysics—the study of the physical and chemical nature of celestial bodies and their environs.

Atmosphere—the envelope of air surrounding the earth; also the body of gases surrounding or comprising any planet or other celestial body.

Attitude—the position of an airplane as determined by the inclination of its axes to some reference, usually the earth or horizon.

Aurora borealis—a luminous phenomenon usually seen in this hemisphere in the northern sky when it does occur. It is due to electric discharges from the sun. In the southern hemisphere the same phenomenon is known as aurora australis.

Autogiro—a type of rotor plane in which lift is produced by revolving airfoils or blades hinged to a vertical shaft above the fuselage. Some forward speed, as provided by an engine that is fitted with a conventional propeller, is necessary for takeoff in contrast to the helicopter, which has no conventional propeller.

Axes of an aircraft—three fixed lines of reference perpendicular to each other and passing through the center of gravity of the airplane: longitudinal, running from nose to tail; lateral, parallel to a line drawn from wing tip to wing tip; and vertical, perpendicular to the other two.

Azimuth—the initial angle or direction between true North and a great circle course.

B

Ballistics—the science that deals with the motion, behavior, and effects of projectiles, especially bullets, aerial bombs, rockets, or the like; the science or art of designing and hurling projectiles so as to achieve a desired performance.

Ballistic trajectory—the trajectory followed by a body being acted upon only by gravitational forces and the resistance of the medium through which it passes.

Balloon—(1) a bag, usually spherical, made of silk or other light, tough, nonporous material filled with some gas which is lighter-than-air, (2) a term describing the tendency of an aircraft to float or maintain altitude at minimum speed.

Banking—(bank)—to incline an airplane laterally or roll it about its longitudinal axis; the position of an airplane when its lateral axis is inclined to the horizontal.

Barometer—

Aneroid—an instrument indicating atmospheric pressure by the action of a partially air-evacuated aneroid cell.

Mercurial—an instrument indicating atmospheric pressure in terms of the height in inches of a column of mercury supported by it in an air-evacuated glass tube.

Beaching gear—wheels and struts which can be fastened to the hull of a flying boat when at rest in the water, permitting the boat to be hauled up onto land.

Beacon—a light, group of lights or other signalling device, indicating a location or direction.

Beam—a comparatively narrow directional radio signal formed by interlocking and blending the A and N signals of a radio range station.

Bearing—the angle from one object to another, generally measured clockwise through 360° from a given reference.

Magnetic—the angle to an object, measured clockwise through 360° from the magnetic meridian (i.e., Magnetic North). (Magnetic bearing equals true bearing plus or minus magnetic variation.)

Relative—the angle to an object from the nose of an airplane (longitudinal axis), measured clockwise.

True—the angle to an object, measured clockwise through 360° from the true geographic meridian (i.e., True North, 0°).

Bioastronautics—astronautics considered for its effect upon animal or plant life.

Biplane—an airplane having two wings or supporting surfaces, one located above the other.

Bipropellant—a rocket propellant consisting of two unmixed or uncombined chemicals (fuel and oxidizer) fed to the combustion chamber separately.

Bird—a colloquial term for a rocket, satellite, or spacecraft.

Blades—

Compressor—revolving compressor blades pull air into the engine, forcing it back through diminishing passages to compress it. A modern gas turbine may have several hundred blades arranged in rows called stages.

Turbine—turbine blades extend into the stream of hot gases rushing through the engine. These gases, which were ignited in the combustion section, push against the turbine blades, causing the turbine shaft to rotate.

Blimps—a nonrigid dirigible; sometimes also a semirigid dirigible.

Blister—a dome made of Plexiglas or some other similar substance protruding from the fuselage of the airplane providing navigators, observers or gunners with better visibility.

Boat, flying—a type of aircraft in which the fuselage (hull) is especially designed, being both strong and waterproof, to permit water landing only.

Booster vehicle—the engine, or engines, on a rocket or guided missile that provides the initial thrust to get the unit into motion—or into the air. Usually, the booster operates for a very short time—a few seconds or minutes—and is then burned out or cut off. These engines provide a powerful thrust and expend a great amount of fuel. The entire section containing the booster is dropped to lighten the missile or rocket. The operation is comparable to the use of jet-assisted take-off on conventional aircraft.

Bucket—one of the blades or vanes attached to the turbine wheel in a jet engine or to the wheel of a gyroscope.

Bumpiness—an unstable condition of the air often resulting in minor vertical changes in an aircraft's flight path. A condition resulting from flight in rough air.

Burble—a term used to illustrate severe disturbances of the streamlined flow around an airfoil.

Burnout—an act or instance of the end of fuel and oxidizer burning in a rocket; the time at which this burnout occurs.

C

Calibrated Air Speed—(See Airspeed.)

Camber—the curvature of the upper or lower surface of an airfoil with respect to its chord.

Cantilever—

Full—a type of wing construction in which the internal construction is sufficiently strong to eliminate the necessity for external bracing.

Semi—a type of wing construction in which the internal construction is less strongly built, thereby requiring external short struts or braces.

Carburetor—an apparatus on an engine which mixes air and fuel in proper proportions to form a highly combustible mixture.

Heater—a device installed on a carburetor to prevent icing caused by refrigeration due to vaporization of the gasoline.

Capsule—a small, sealed, pressurized cabin with an acceptable environment, which contains a man or animal for extremely high-altitude flights, orbital space flight, or emergency escape.

Ceiling—the height above ground of the base of a cloud bank.

Absolute—maximum height above sea level that an airplane will reach under its own power.

Service—height above sea level beyond which the airplane is unable to climb 100 feet per minute.

Centrifugal force—a force which tends to force an object outward from a center of rotation.

Centrifuge—a large motor-driven apparatus with a long rotating arm at the end of which human and animal subjects or equipment can be revolved at various speeds to simulate very closely the prolonged accelerations encountered in high-performance aircraft, rockets, and manned missiles.

Centripetal force—a force which tends to force an object inward toward a center of rotation.

Chamber, cannular combustion—a tube, roughly cylindrical, between the compressor and turbine of a jet engine, in which fuel is injected into the airstream and burned.

Chart—an aeronautical navigation map showing lines of latitude and longitude, compass roses, topographical detail, prominent land marks and other aids and dangers to aerial navigation.

Check points—a known or designated point or feature, as a landmark, beacon, mountain, city, or the like, used as a reference in air navigation or for orientation in flying.

Chord—

Length—the projection of the airfoil on its chord length.

Line—the reference line of an airfoil by which curvatures are specified. It consists of a straight line extending roughly from the center of the leading edge backwards to the trailing edge.

Cislunar space—space between the earth and the orbit of the moon.

Clearance—the difference in diameters of closely fitting parts, such as piston and cylinder or bearings and journal.

Climate—the natural weather conditions of any region or portion of the earth.

Climb—the action of an airplane when ascending under power.

Clouds—

Alto-cumulus—a fleecy, middle-height cloud formation made up of large whitish or grayish cloudlets, often grouped in rows.

Alto-stratus—a middle-height sheet cloud similar to cirro-stratus but thicker and heavier.

Cirro-cumulus—small, white, rounded masses of high altitude clouds, referred to as mackerel sky.

Cirro-stratus—uniform layer of high altitude cloud, formed of ice particles.

Cirrus—a light, fleecy, filmy high altitude cloud (20,000 to 40,000 feet) formed of minute ice particles.

Cumulo-nimbus—a very turbulent, mountainous mass of condensed water vapor from which may fall rain, snow, or hail; commonly called a thunderhead.

Cumulus—a billowy, heaped-up cloud formation usually found between 5,000 and 15,000 feet and having a flat base.

Nimbo-stratus—a gray, layer-like type of rain cloud covering the entire sky.

Strato-cumulus—large billowy masses of low level, dark clouds which during the winter often cover the whole sky.

Stratus—flat layer-like clouds extending horizontally and lying at any height between the surface of the earth and an altitude of about 15,000 feet. Stratus clouds represent stable air conditions with very little vertical convection and quite usually associated with warm fronts. They occasionally occur at low altitudes in a warm air mass, in the form of fog.

Cold front—(See Front.)

Comet—a luminous member of the solar system composed of a head or coma at the center of which a presumably solid nucleus is sometimes situated, and often with a spectacular gaseous tail extending a great distance from the head.

Communications satellite—a satellite designed to reflect or relay radio or other communications waves.

Compass—

Card—a card graduated in degrees from 0° to 360° rigidly mounted to and actuated by the compass needle.

Correction card—a small card mounted near the airplane compass indicating the amount of deviation found on various headings.

Course—the true course corrected for variation and deviation but not for wind.

Heading—the true course corrected for variation, deviation, and wind.

Magnetic—an instrument in which strongly magnetized needles, affected by the earth's magnetic field, are used to determine direction of flight.

Rose—a circle, graduated in degrees from 0° to 360°, printed on aeronautical charts at convenient intervals and used for plotting directions.

Condenser—a device for storing electrical energy; a capacitor.

Configuration—a particular type of a specific aircraft rocket, etc., which differs from others of the same model by virtue of the arrangement of its components or by the addition or omission of auxiliary equipment as "long-range configuration", "cargo configuration".

Connecting rod—a rod in an aircraft engine which transmits the energy exerted by the piston to the crankshaft.

Contact flying—flight of an aircraft in which its attitude and flight path can at all times be determined by visual reference to the ground.

Contour line—a line connecting all points of equal elevation above sea level.

Control, balanced—(surface)—a control surface which extends on both sides of the hinge in such a manner that the wind force striking the surface aids the pilot in moving the controls.

Control—

Cable—any cable in an aircraft which transmits movement from the control levers to the control surfaces.

Column—a lever, corresponding to the control stick, having a rotatable wheel mounted at its upper end for operating the longitudinal and lateral control surfaces of an airplane.

Stick—the vertical lever by means of which the longitudinal and lateral control surfaces of an airplane are operated.

Surface—a movable airfoil designed to be moved by the pilot in order to change the attitude of an aircraft.

Controls—a general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.

Convection—the upward or downward movement, mechanically or thermally produced, of a limited portion of the atmosphere. Convection is essential to the formation of many clouds, especially of the cumulus type.

Convertiplane—an aircraft so built that it can perform, at the will of the operator, as any one of two or more different types of vehicles, especially an aircraft that can be adjusted to fly either as a fixed-wing airplane or as a helicopter or autogiro.

Corona—the faintly luminous outer envelope of the sun. Also called "solar corona".

Cosmonaut—Russian term for their astronaut Major Yuri Gagarin, the first man in space.

Countdown—a time-sequenced step-by-step process for final check-out and preparation of a missile for launch.

Counter rotating—propellers having two sets of blades mounted coaxially and revolving in opposite directions.

Course—the direction over the surface of the earth that an aircraft is intended to travel, sometimes referred to as intended track.

Compass—the angle in degrees between North on the compass and the desired course of the plane measured clockwise through 360°.

Line—the direction over the surface of the earth that an aircraft is intended to travel, sometimes referred to as intended track.

Magnetic—the angle in degrees between Magnetic North and the desired course of the plane measured clockwise from Magnetic North through 360°.

True—the angle in degrees between the nearest geographic meridian and the desired course of the plane measured clockwise from 0°—True North—through 360°.

Cowling—a removable covering over the engine.

Crankcase—that part of the aircraft engine which holds the bearings for the crankshaft, timing gear, cam shaft, etc., and which supports the oil pan and cylinders.

Crankshaft—a shaft in an aircraft engine which receives its rotation from off-set cranks and to which the propeller is attached.

Cultural features—a map-making term referring to works of man, that is cities, railroads, highways, airports, etc.

Cyclone—in meteorology an area of low barometric pressure called, on weather maps, a low.

Cylinder—a chamber in an aircraft engine of which the upper part serves as the combustion chamber and the lower part houses the sliding piston.

D

Deep space probes—spacecraft designed for exploring space in the vicinity of the moon and beyond. Deep space probes with specific missions may be referred to as "lunar probe", "Mars probe", "solar probe", etc.

Degree—a 360th part of the circumference of a circle, or a 90th part of a right angle.

De-icer boots—a rubber strip on the leading edge of an airfoil actuated pneumatically to break ice which has formed. Also a rubber strip on the base and the leading edge of a propeller blade over which alcohol is sprayed to prevent the formation of ice.

Depression—(See Cyclone.)

Destruct—the deliberate action of destroying a rocket vehicle after it has been launched, but before it has completed its course.

Deviation—

Card—the card usually placed near a compass giving the deviation correction for converting magnetic headings to compass headings.

Errors—the error of a magnetic compass caused by magnetic influences in the structure and the equipment of an aircraft.

Dew—moisture condensed on the ground as a result of a chilling of the earth's surfaces, i.e., the layer of air resting on the earth's surface.

Dew point—the temperature at which, under ordinary conditions, condensation begins in a cooling mass of air.

Diaphragm, nozzle—in a jet engine, a row of stator blades immediately preceding the turbine wheel, which has the dual purpose of increasing gas velocity and of directing it upon the turbine blades at the proper angle.

Dihedral—(See Angle.)

Discontinuity—the term applied in a special sense by meteorologists to a zone within which there is a comparatively rapid change of meteorological elements, as in a warm or cold front.

Distributor—an apparatus for directing the secondary current from the induction coil to the various spark plugs of a multicylinder engine.

Dive—a steep descent, with or without power, in which the airspeed is greater than the maximum speed in horizontal flight.

Docking—the process of bringing two spacecraft together while in space.

Dope—a compound, made of cellulose-nitrate or cellulose-acetate-butyrate, used on fabric surfaces of airplanes, making such surfaces taut and weather resistant.

Doppler navigator—navigation equipment contained in an aircraft which gives accurate position information but which operates independently of ground based radio aids.

Doppler shift—the change in frequency with which energy reaches a receiver when the source of radiation or a reflector of the radiation and the receiver are in motion relative to each other. The Doppler shift is used in many tracking and navigation systems.

Double drift—a wind force and direction-finding method in which the drift angle is observed on each of two successive headings at a known airspeed.

Downwash—the air deflected in a direction perpendicular to the direction of motion of the airfoil.

Drag—the component of the total air force on a body parallel to relative wind and opposite to thrust.

Induced—that component of drag which is induced by lift.

Parasite—that component of drag not including the induced drag of the wings.

Profile—the result of subtracting the induced drag from the total wing drag.

Drizzle—precipitation originating from stratus clouds consisting of numerous tiny droplets.

Duralumin—a very strong copper, aluminum, and manganese alloy which may or may not include magnesium, widely used in aircraft construction.

E

Ecliptic—the intersection of the plane of the earth's orbit with the celestial sphere.

Elevator—a movable auxiliary airfoil, usually hinged to the horizontal stabilizer and used to control the airplane's angle of attack.

Empennage—the tail assembly of the fuselage including the fixed and movable control surfaces, that is, the fin, rudder, stabilizer and elevator.

Equi-signal zone—a zone of equal signal strength of the "on course" signal of a radio range, where a steady tone is heard as the result of the reception of the energy from the two antenna systems being received with equal intensity.

Escape velocity—minimum velocity which will enable an object to escape from the surface of the earth without further propulsion. The escape velocity of the earth is just over seven miles per second, or 25,000 mph.

Estimated time of arrival (ETA)—the estimated time at which the pilot of an aircraft expects to arrive at a given destination as based on his calculations from known factors.

Exhaust port—the opening from which the burned gases escape from the cylinder after their combustion.

Exosphere—outermost region of the earth's atmosphere, where atoms and molecules move in dynamic orbits under the action of the gravitational field.

F

Fading—diminishing of signal strength due to increasing distance from a radio station or because of other radio phenomena.

Fairing—a drag-reducing auxiliary part of an aircraft, usually covering a part that would otherwise create a much greater parasite drag.

Feathered—a propeller whose blades' leading edges are turned parallel to the line of flight, thereby reducing drag and preventing windmilling in the case of engine failure.

Fin—an approximately vertical fixed or adjustable airfoil attached to the tail of an airplane to provide directional stability.

Fix—a definite geographic position of an aircraft determined by the intersection of two or more bearings or lines of position.

Fixed satellite—an earth satellite that orbits from west to east at such a speed as to remain constantly over a given place on the earth's equator.

Flaps—hinged or pivoted auxiliary airfoils forming part of the trailing edge of the wing and used to increase lift at reduced airspeeds.

Flight path—the flight path of the center of gravity of an aircraft with reference to the earth.

Floats—an enclosed water-tight structure attached to an aircraft to give it buoyancy and stability when in contact with water.

Float chamber—a chamber in a carburetor which contains the float and the proper supply of gasoline to feed the spray nozzle.

Fog—a cloud at the earth's surface.

Four cycle—(engine)—a four-stroke-cycle engine.

Free fall—the fall or drop of a body, such as a rocket, not guided, not under thrust, and not retarded by a parachute or other breaking device. Weightlessness.

Front—a surface of discontinuity between two overlapping air masses possessing different densities; also the boundary between two different air masses.

Cold—the border at the forward edge of an advancing cold air mass displacing warmer air in its path.

Stationary—a front along which neither air mass is displacing the other to any significant degree.

Warm—the line of discontinuity found at the forward edge of an advancing current of relatively warm air which is over-running a retreating mass of colder air.

Frost—atmospheric moisture deposited upon objects in the form of ice crystals.

Fuel pump—a small engine driven pump which makes gasoline available to the carburetor inlet from the fuel tank; used in cases where the fuel tanks are below the carburetor level.

Fuel system—all parts of an airplane having to do with the consumption of gasoline.

Fuselage—the approximately streamlined body to which the wings and tail unit of an airplane are attached.

G

Galaxy—the group of several billion suns, star clusters, etc. Most recognizable is our own galaxy, the Milky Way. Also refers to any groups of stars forming independent units.

Gantry—crane-type structure, with platforms on different levels, used to erect, assemble, and service large rockets or missiles; may be placed directly over the launching site and rolled away just before firing.

Gap—distance between the wings of a biplane as measured from the chord line of the upper wing to the chord line of the lower wing.

Garbage—miscellaneous objects in orbit, usually material ejected or broken away from a launch vehicle or satellite.

Gear pump—a type of oil pump which derives its pumping action from a set of meshed gears, the teeth of which are in close clearance to the inside wall of the pump housing.

Generator—machines used to transform mechanical energy into electric energy.

Geocentric—relating to or measured from the center of the earth; having, or relating to, the earth as a center.

Geodetic—pertaining to geodesy, the science which deals with the size and shape of the earth.

Geographic poles—the north and south poles through which pass all geographic meridians and around which the earth rotates.

Geophysics—the physics of the earth, or the science treating of the agencies which modify the earth.

Glaze—a U. S. Weather Bureau term for a smooth coating of ice on objects due to the freezing of rain.

Glide—a descent at a normal angle of attack with little or no power.

G-load—the force exerted on an object by gravity or by an acceleration. One G is the measure of the gravitational pull exerted on a body by earth at approximately sea level.

Gnomonic—a method of chart projection on which straight lines represent great circle courses.

Grain—a single piece of powder charge regardless of size or shape used in a rocket.

Granular snow—a form of precipitation consisting of small nontransparent grains of snow.

Gravity—the force which tends to draw all bodies toward the center of the earth.

Great circle—an imaginary circle on the earth's surface which is made by passing a plane through the center of the earth (e.g., any meridian or the Equator).

Bearing—the direction from one place to another which follows a great circle passing through both places.

Greenwich meridian—the meridian passing through the location of the principal British observatory near London and from which longitude is reckoned east or west.

Ground loop—an uncontrollable violent turn of an airplane while taxiing or during the landing or takeoff run.

Ground speed—the actual speed of the airplane over the ground.

Guidance—the process of directing the movements of an aeronautical vehicle or space vehicle, with particular reference to the selection of a flight path or trajectory.

Beam Rider—a system for guiding missiles in which the guided missile rides along a beam, usually a radar beam, to its target.

Command—a type of electronic guidance of guided missiles or other guided aircraft wherein signals or pulses sent out by an operator cause the guided object to fly a directed path.

Homing—the guidance given a guided missile or the like by built-in homing devices.

Pre-set—a type of guidance for guided aircraft rockets or other guided missiles in which the path of the missile is determined by controls set before launching.

Gust—a sudden brief increase in the force of the wind.

H

Hail—irregular lumps or balls of ice, often of considerable size and having a complex structure, falling almost exclusively in thunderstorms.

Halo—a name for a group of optical phenomena caused by ice crystals in the atmosphere.

Haze—a lack of transparency in the atmosphere caused by the presence of dust or of salt particles left by evaporated ocean spray. At a certain distance, depending on the density of the haze, all details of landscape and color disappear.

Heading—

Compass—the angle between north as indicated on the airplane compass and the direction in which the ship is headed.

Magnetic—the angle between magnetic north and the direction in which the ship is pointed.

True—the angle between True North and the direction in which the airplane is pointed.

Helicopter—a type of rotor plane whose support in the air is derived from airfoils mechanically rotated about an approximately vertical axis. It is capable of vertical flight or hovering at a given altitude.

Heliocentric—measured from the center of the sun; related to, or having the sun as a center.

High—an area of high barometric pressure.

Horn—a short lever which moves a control surface in response to the movement of the control wires.

Horizon—the line where the earth and sky seem to meet.

Hp (horse power)—unit by which rate of work is measured—one horsepower is the power necessary to lift 550 pounds one foot in one second.

Hull—the water-tight fuselage or body of a flying boat, which supplies the buoyancy necessary for operation from the water.

Humidity—the percentage of invisible moisture particles in a given parcel of air.

Relative—the ratio of the actual amount of vapor present in a given parcel of air to its saturation point at the same temperature.

Hydraulic—any force exerted by liquid pressure.

Hypersonic—velocities of five or more times the speed of sound.

Hypoxia—oxygen deficiency in the blood in high-altitude flight, impairing physical faculties. Occurs at about 20,000 feet.

I

ICBM—a ballistic missile with sufficient range to strike at strategic targets from one continent to another. ICBM minimum range is approximately 5,000 miles.

Ice needles—thin crystals or shafts of ice so light that they seem to be suspended in the air.

Ice rain—(1) a rain that causes a deposit of glaze, (2) falling pellets of clear ice, called sleet by the U.S. Weather Bureau.

IGY—International Geophysical Year.

Impact pressure—the pressure imposed by a moving object striking a relatively motionless body.

Incidence—(See Angle).

Inconel-x—a registered trade-name of The International Nickel Company, Inc. The name "Inconel" is applied to a nickel chromium-iron alloy. It contains approximately 80% nickel, 14% chromium and 6% iron. It has physical properties similar to stainless steel and is used in the X-15.

Indicated airspeed—(See Airspeed.)

Inertia—the tendency of a body to remain in a static state, state of rest, or a state of motion, until it is acted upon by a moving force.

Inertial force—the force produced by the reaction of a body to an accelerating force, equal in magnitude and opposite in direction to the accelerating force. Inertial force endures only as long as the accelerating force endures.

Inertial guidance—a pre-set guidance system with a course-and-distance measuring mechanism composed of three accelerometers and a computer. Primarily employed as a navigation and guidance device in missiles, space craft, and high altitude performance aircraft.

Infrared—pertaining to or designating those rays lying just beyond the red end of the visible spectrum, such as are emitted by a hot nonincandescent body. Their wave lengths are longer than those of visible light and shorter than those of radio waves.

In-line engine—an internal-combustion, reciprocating engine in which the cylinders are arranged in one or more straight rows.

Insolation—solar radiation as received by the earth or other planets.

Instrument flight—flight which is controlled solely by reference to instruments, i.e., without any reference to landmarks. Involves maintainance of definite altitudes and navigation by dead reckoning and radio.

Intake valve—a valve in an aircraft engine which is automatically opened on the intake stroke of the piston, for the proper length of time, to permit the charging of the cylinder with the fuel mixture.

Internal combustion—a term used to define an engine that receives driving force by the burning of fuel in its cylinders.

Ion—an atom or molecularly bound group of atoms having an electric charge. Sometimes also a free electron or other charged subatomic particle.

Ionosphere—region of the earth's atmosphere extending fifty to 500 miles above the earth, merging into the exosphere above.

IRBM—a ballistic missile with a range of 200 to 1,500 miles.

Isobar—a line on a weather chart drawn through places or points having the same barometric pressure.

Isogonic lines—imaginary lines on the surface of the earth at all points on which the magnetic variation is the same. The Agonic line is the line of no variation.

J

Jet, *Pulse*—a kind of jet engine of the athodyd group, having neither compressor nor turbine, but equipped with vanes in the front end which open and shut, taking in air, to create power, in rapid periodic bursts rather than by continuous inhaling.

Ram—a jet engine consisting essentially of a tube open at both ends in which fuel is burned continuously to create a jet thrust, and having neither a compressor nor turbine.

Turbo—a jet engine which obtains thrust from the increase in air velocity as it passes through the compressor, where its density is increased; the combustion section, where it is mixed with fuel and burned to obtain increased pressure; and the turbine and exhaust cone, where its velocity is further increased as its pressure drops. The turbine's single function is to drive the compressor to increase air pressure before it enters the combustion chambers.

Turboprop—a variation of the turbojet in which the turbine absorbs most of the energy of the flowing gases and transmits it through a shaft and reduction gears to a propeller.

K

Knot—a measure of speed. One knot being a speed of one nautical mile per hour.

L

Lambert projection—a method of projecting a portion of the curved surface of the earth on a flat chart with a minimum amount of distortion.

Landing—the act of terminating flight in which the aircraft is made to descend, lose flying speed, establish contact with the ground or water and finally come to rest.

Area—that portion of the field available for takeoffs and landings.

Gear—the understructure which supports the weight of an aircraft when in contact with the land or water and which usually contains a mechanism for reducing the shock of landing. Also called under carriage. Some landing gear is retractable or able to be drawn up into the wings or body of an airplane in flight to reduce parasitic drag.

Pancake—a landing in which the leveling-off process is carried out several feet above the ground, as a result of which the airplane settles rapidly on a steep flight path in normal attitude.

Three point—the act of contacting the ground simultaneously with the wheels and tail wheel or skid of the aircraft.

Lapse rate—the rate temperature decreases in relation to altitude decrease.

Laser—(from *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation) a device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal.

Lateral axis—(See Axis).

Latitude—the angular measurement north or south of the equator of any point on the earth measured in degrees, minutes, and seconds of arc from 0 to 90 degrees.

Launch—send forth a rocket or missile from its launcher under its own power.

Launching pad—launch stand upon which the missile will stand when ready for liftoff, plus the service tower that can be moved out of the way on tracks, the flame bucket, the ground-support equipment located nearby to control the countdown sequence, and the protective building or trailer housing the equipment.

Launch vehicle—any device which propels and guides a spacecraft into orbit about the earth or into a trajectory to another celestial body. Often called "booster".

Leading edge—the foremost edge of an airfoil or propeller blade.

Level-off—to make the flight path of an airplane horizontal after a climb, glide, or dive.

Lift—the nearly vertical reaction resulting from the passage of an airfoil through the air. Lift always acts approximately perpendicular to the relative wind.

Liftoff—the action of a rocket vehicle as it separates from its launch pad in a vertical ascent. A liftoff is applicable only to vertical ascent; a takeoff is applicable to ascent at any angle.

Lightning—a disruptive electrical discharge in the atmosphere or the luminous phenomena attending such a discharge.

Light-year—the distance light travels in one year at 186,000 miles per second.

Line squall—a more or less continuous line of squalls and thunderstorms marking the position of an advancing cold front.

Link Trainer and Link Simulator—a synthetic replica of an aircraft cockpit containing a complete panel of controls, radio aids, and computer-actuated flight and engine instruments. Used for training pilots and crews in instrument flying, emergency procedures, and, in some instances, complete tactical missions.

Liquid-propellant rocket engine—a rocket engine fueled with a propellant or propellants in liquid form. Rocket engines of this kind vary somewhat in complexity, but they consist essentially of one or more combustion chambers together with the necessary pipes, valves, pumps, injectors, etc.

Load—the force or pressure exerted upon an object under static or dynamic conditions, either by virtue of its own weight or by some imposed object or force.

Factor—(in flight maneuvers) the ratio of the aerodynamic load imposed upon the lifting surfaces in a specified maneuver to that imposed in normal level flight.

Full—empty weight plus useful load. Also called gross weight.

Pay—that part of the useful load from which revenue is derived.

Useful—the crew and passengers, oil and fuel, ballast, other than emergency, ordnance or portable equipment.

Loading—

Of aircraft—placing the useful load in an airplane so as not to disturb the normal level position of the airplane in flight.

Power—the result of dividing the gross weight of the airplane by the rated horsepower of the engine computed for air of standard density.

Wing—obtained by dividing the gross weight of the airplane by its wing area.

Log—a written record, either computed or observed, of navigational data; a record of a pilot's flying time; an operational record of an aircraft or its engine(s).

Longeron—any one of the principle longitudinal members of the internal construction of an airplane fuselage, usually continuous across a number of points of support.

Longitude—the angular measurement of any point on the earth's surface east or west of the Greenwich meridian, measured in degrees, minutes, and seconds of arc from 0 to 180 degrees along the parallel of latitude which passes through that point.

Longitudinal axis—(See Axis.)

Low—an area of low barometric pressure, with its attendant system of winds. Usually called a barometric depression or cyclone.

LOX—liquid oxygen used as an oxidizer.

Lubber line—a clearly defined, fixed index or reference line on an aircraft instrument.

Lunar—of or pertaining to the moon.

M

Mach number—a number expressing the ratio of the speed of a moving body or of air to the speed of sound, with Mach 1.0 equal to the speed of sound.

Mackerel sky—a portion of cirro-cumulus or alto-cumulus covered sky.

Magnetic north—the north of the earth's magnetic field, situated at about Lat. 71° N., Long. 96° W., more than 1,000 miles from the geographic north pole.

Magneto—a device for generating electricity, usually of high voltage, which is delivered to the spark plugs, in the proper order and at the proper time, by the distributor.

Map—a flat surface representation of a portion of the earth's curved surface, drawn to some convenient scale, and usually dealing with or showing more land than water. The unit of linear measurement of surface distance used in map making and map reading is the statute mile (5,280 feet).

Maser—an amplifier utilizing the principle of *m*icrowave *a*mplification by *s*timulated *e*mission of *r*adiation.

Mercator—the chart projection on which latitude and longitude lines are represented as straight lines intersecting at right angles. On this projection rhumb lines (or lines of constant course) are represented by straight lines and great circles by curved lines.

Meridian—a great circle on the earth's surface passing through the North and South Poles.

Meteor—in particular, the light phenomenon which results from the entry into the earth's atmosphere of a solid particle from space; more generally, any physical object or phenomenon associated with such an event.

Meteorite—a meteoroid which has reached the surface of the earth without being completely vaporized.

Meteoroid—a solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom or molecule.

Meteorology—the scientific study of the atmosphere.

Mid-meridian—a meridian passing through the halfway point between two places on the earth's surface.

Mile—

Nautical—the unit of 6,080.2 feet for measuring distances. For practical purposes one minute of latitude may be considered equal to a nautical mile.

Statute—the unit of 5,280 feet for measuring distances.

Millibar—a unit of pressure used in reporting weight of atmosphere on weather charts. One inch of mercury is equal to approximately 33.8 millibars. The standard atmospheric pressure of 29.92 inches of mercury equals approximately 1,013 millibars.

Minute of arc—60 minutes of arc are equal to one degree.

Missile, ballistic—any missile guided especially in the upward part of its trajectory, but becoming a free-falling body in the latter stages of its flight.

Guided—controlled or controllable as to direction by present mechanisms, radio commands, or built-in self-reacting devices.

Mist—a thin fog in which the horizontal visibility is greater than one kilometer or approximately 1,100 yards.

Module—a self-containued unit of a launch vehicle or spacecraft which serves as a building block for the overall structure. The module is usually designated by its primary function as "command module", "lunar landing module".

Monoplane—an airplane having but one wing or supporting surface.

Monopropellant—a rocket propellant in which the fuel and oxidizer are premixed ready for immediate use.

MPH—the standard abbreviation for "miles per hour."

Multiple courses—a number of narrow equi-signal zones resulting from the breaking up of a radio range course by mountainous topography or other causes.

Multipropellant—a propellant that consists of two or more liquid ingredients each separated from the others until introduced into the combustion chamber.

Multistage rocket—a vehicle having two or more rocket units, each unit firing after the one in back of it has exhausted its propellant. Normally, each unit, or stage, is jettisoned after completing its firing. Also called a "multiple-stage rocket" or, infrequently, a "step rocket".

N

NACA—National Advisory Committee for Aeronautics.

Nacelle—an enclosed shelter for personnel or for a power plant in an airplane, usually shorter than the fuselage and without a tail unit.

NASA—National Aeronautics and Space Administration.

Nautical mile (NM)—a measure of distance equal to 6,-076.103 feet or approximately 1.15 miles.

Navigation—

Celestial—the method of obtaining a fix by reference to the altitude or angular height above the horizon of celestial bodies at a given instant.

Dead reckoning—the fixing of position using known directions, ground speed, and elapsed time from a given point.

Pilotage (Map Reading Navigation)—directing an airplane with respect to visible landmarks.

Radio—the fixing of position by means of various radio aids, i.e., radio ranges, radio direction finding equipment, etc.

Nephoscope—an instrument for measuring the movement of clouds.

Non-rigid dirigible—a lighter-than-air craft having a gas bag, envelope, or skin that is not supported by any framework nor reinforced by stiffening. It maintains its shape by internal pressure of the gas with which it is filled.

Nosecone—assembly at the upper end of a ballistic missile from which it is separated after the end of propelled flight. The nosecone may contain an atomic bomb with an arming and fuzing system, and a means of decelerating the body as it speeds down into the atmosphere.

Nozzle diaphragm—(see Diaphragm, nozzle.)

Nozzle, filled—a duct through which a liquid or gas is directed, designed to increase the velocity of the liquid or gas; specifically, a jet nozzle for a jet engine or rocket.

O

Occluded front—a line along which a warm or cold front overtakes a slow moving cold or warm front, forcing aloft a parcel of the warmer air.

Oil pump—gear, vane, or plunger type of pump used to lift oil from the sump to the upper level tank and to provide pressure for the circulation of oil in an engine.

Oleo struts—a special kind of shock-absorbing strut used in certain landing gear, depending essentially on a hydraulic action. The oleo strut is a telescoping strut consisting of a hollow piston, which upon compression, forces a fluid through a small orifice in the piston, causing the piston to travel slowly so as to cushion the shock. Most types of oleo struts employ, in addition to the hydraulic device, compressed air, coil springs, or both.

Orbit—path in which a celestial body moves about the center of gravity of the system to which it belongs; every orbit is basically in the shape of a conic section with the center of gravity at one focus.

Orbital speed—velocity needed to keep a body moving in a closed orbit around a sun, planet, or satellite. May be circular velocity or elliptical velocity and can vary over wide limits depending on the distance from the attracting force center and upon the magnitude of the attracting force; orbital velocity of the Earth is 18,000 mph.

Orbital velocity—speed of body following closed or open orbit, most commonly applied to elliptical or near-circular orbits.

Ornithopter—an as yet unsuccessful type of aircraft theoretically achieving its chief support and propulsion from the bird-like flapping of its wings.

Over-the-top flying—flight of an aircraft above an overcast.

Overshoot—to fly beyond a designated mark or area, such as a landing field, while attempting to land.

P

Panel—a section of airplane wing separately constructed and fitted to the rest of the wing.

Paraglider—a flexible-winged, kite-like vehicle designed for use in a recovery system for launch vehicles or as a reentry vehicle.

Parallel (of latitude)—a circle on the earth's surface parallel to the plane of the equator at all points.

Payload—originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc., by extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle during its flight.

Perigee—the point in an elliptical orbit which is nearest earth.

Perihelion—the point in an elliptical orbit around the sun which is nearest the sun.

Photon engine—a projected type of reaction engine in which thrust would be obtained from a stream of electromagnetic radiation.

Piston—a closely fitting, plunger shaped part of an engine which slides within the cylinder.

Pin—anchors the piston to the connecting rod assembly.

Ring—an iron ring fitted into a groove in the piston head, the purpose of which is to provide a pressure seal between the piston and the cylinder wall, thus keeping oil from the combustion chamber and increasing the head compression characteristics. Also used as a heat-conducting medium from the piston head to the cylinder wall.

Pitch—an airplane's movement about its lateral axis.

Adjustable—a propeller, the blades of which are mounted to the hub in such a manner that the pitch may be changed only while the propeller is on the ground.

Constant speed—a propeller, the blades of which are attached to a pitch-changing mechanism that automatically keeps them at the optimum pitch during various flight conditions.

Controllable—a propeller, the blades of which are so mounted that the pilot may change the pitch at his discretion while the propeller is rotating.

Fixed—a propeller whose pitch cannot be changed.

Pusher—a propeller so mounted as to push the airplane through the air; a propeller mounted aft of its engine.

Reversible—a propeller that may be turned to reverse pitch so as to give reverse thrust. Used to slow an aircraft in flight or during the roll after landing.

Tractor—a propeller that pulls.

Planet—a celestial body of the solar system, revolving around the sun in a nearly circular orbit, or a similar body revolving around a star.

Planetarium—a room or building containing a model or representation of the planetary system, especially one using projectors to display the movement of celestial bodies on a hemispherical ceiling.

Plot—accurately marking the position and/or course of an aircraft or ship on a navigational chart.

Precipitation—any moisture reaching the earth's surface, such as rain, snow, hail, or dew, etc.

Pressurized—containing air, or other gas, at a pressure that is higher than the pressure outside the container.

Prime meridian—a meridian from which longitude is measured. In English-speaking countries and in many other countries, the Greenwich meridian is used as the prime meridian.

Projection—any of various methods for representing the surface of the earth or the celestial sphere upon a plane surface.

Protractor—an instrument for laying down and measuring angles on paper, used in drawing and plotting.

Psi—the standard abbreviation for "pounds per square inch."

Pylon—a rigid structure that protrudes from a wing, fuselage, or other surface of an aircraft to support a float, engine, drop tank, or the like.

Q

Quadrant—one of the four signal zones, which are 90° apart, identified by either the "N" or the "A" signal surrounding a Radio Range Station.

R

Radial—(engine) an aircraft engine with one or more stationary rows of cylinders arranged radially around a common crankshaft. (More in AF dict.)

Radials—any one of a number of lines of position radiating from an azimuthal radio-navigation facility, e.g., VHF omnidirectional radio range, identified in terms of the bearing of all points along that line from the facility.

Radiation—the emission from a body (per unit time per unit surface area), of an amount of energy which depends partly on the nature of the body but to a larger extent upon the temperature.

Radiation fog—fog resulting from the radiation cooling of air near the surface of the ground on calm, clear nights.

Radio—

Astronomy—the study of celestial objects through observation of radiofrequency waves emitted or reflected by these objects.

Compass—a radio receiver using a fixed or rotating loop antenna and a visual indicator, chiefly for "homing" of a flight directly toward or away from a radio station.

Direction finder—a radio receiver using a manually rotatable loop antenna for the purpose of determining the direction to or from the transmitting station. Detection is made aurally (through the ear) and/or visually (by reference to an instrument).

Automatic (ADF)—similar to the ordinary radio direction finder, except that the rotation of the loop is automatic and the indicator needle continuously indicates the bearing of the station.

Telescope—a device for receiving, amplifying, and measuring the intensity of radio waves originating outside the earth's atmosphere.

Radius of action—the distance, determined by fuel capacity and wind conditions, that an aircraft can safely fly in a given direction before returning to its base, without running out of fuel.

Reentry—entry of a ballistic missile, nose cone, space weapon, or bomb from a satellite bomber into the atmosphere. The reentry point is the portion of the terminal trajectory where thermal heating becomes critical.

Relief—unequal elevations of the earth's surface noted on charts by gradient tinting and by contour lines.

Retrorocket—a rocket fitted on or in a vehicle that discharges counter to the direction of flight, used to retard forward motion.

Rhumb line—a line on a chart or the surface of the earth that cuts all meridians at a constant angle.

Rib—a structural member of an aircraft wing which gives the wing its proper airfoil shape and which supports the wing covering.

Rigid—a dirigible having several gas bags or cells inclosed in an envelope supported by an interior framework. Distinguished especially from nonrigid and semi-rigid airships.

Rocket—a reaction engine which derives its thrust by expelling a mass at high velocity through its open end. It is distinguished from a jet in that it is entirely independent of the atmosphere.

Ion—a type of engine in which the thrust tu propel the missile or spacecraft is obtained from a stream of ionized atomic particles, generated by atomic fusion, fission, or solar energy.

Nuclear—a rocket engine in which the hot exhaust gases necessary to provide needed thrust will be developed by passing a liquid through a fission reactor.

Photon—a type of rocket or missile engine in which the thrust is derived from harnessing a stream of light rays.

Plasma—a rocket engine in which the propellant would be heated by discharging a powerful electrical charge through the propellant.

Roll—angular motion about the longitudinal axis accomplished by operating the ailerons.

RPM—the standard abbreviation for "revolutions per minute."

Rudder—a hinged or movable auxiliary airfoil on an aircraft, the function of which is to initiate a yawing or swinging motion on the aircraft.

Pedal—the foot pedals by means of which the controls leading to the rudder are operated.

S

Satellite—an attendant body that revolves around another body.

Saturation—the condition that exists in the atmosphere when the water vapor present is equal to the maximum amount of vapor that the air can hold at the prevailing temperature.

Selenocentric—relating to the center of the moon; referring to the moon as a center.

Selenographic—of or pertaining to the physical geography of the moon, specifically, referring to positions on the moon measured in latitude from the moon's equator and in longitude from a reference meridian.

Semi-rigid—a dirigible having its main envelope reinforced by some means other than a completely rigid framework.

Sextant—an instrument used in celestial navigation for determining the altitude or angle of a celestial body above the horizon.

Shock cords—a cord that absorbs shock, especially one that consists of a bundle of rubber strands that permits stretching.

Shower—a fall of rain, snow, sleet, or hail, of short duration but often of considerable intensity, falling from isolated clouds separated from one another by clear spaces.

Sideslip—motion of an aircraft in a direction downward and parallel to an inclined lateral axis. In a turn it is the opposite of skidding. Also used to lose altitude and airspeed in short landing.

Skid—sliding sideways away from the center of curvature when turning. It is caused by using excessive rudder control.

Skin—the covering of an airplane—either metal, fabric or plywood.

Sleet—frozen or partly frozen rain; frozen raindrops in the form of clear ice.

Slipstream—the current of air driven astern by a propeller.

Slots—a high lift device incorporated in the leading edge of an aircraft wing, the primary purpose of which is to improve the airflow about the wing at high angles of attack.

Snow—precipitation in the form of small ice crystals, falling either separately or in loosely coherent clusters (snowflakes).

Soar—the art of flying without engine power for prolonged periods of time by taking advantage of ascending currents of air.

Soft landing—a landing on the moon or other spatial body at such slow speed as to avoid a crash or destruction of the landing vehicle. Soft landings on the moon are anticipated by use of retrorockets for slow-down of the landing vehicle; soft landing on Mars may be accomplished by partial use of the Martian atmosphere.

Solar—of or pertaining to the sun.

Solar cell—an electronic device similar to a junction diode, in which photons of energy (radiant energy) from the sun cause an electron flow across a junction.

Solid propellant—specifically, a rocket propellant in solid form, usually containing both fuel and oxidizer combined or mixed and formed into a monolithic grain.

Sonic boom—a sonic boom sounds much like thunder. Sonic booms are caused by aircraft flying faster than sound. In supersonic flight, an aircraft will cause shock waves of compressed air to form. These air waves move to the ground and are heard as sonic booms.

Sonic speed—the speed of sound; by extension the speed of a body traveling at Mach 1.

Space—

Cislunar—space around the earth beyond the outermost reaches of the terrestrial atmosphere and within the orbit of the moon.

Intergalactic—that part of space conceived as having its lower limit at the upper limit of interstellar space, and extending to the limits of space.

Interplanetary—that part of space conceived, from the standpoint of the earth, to have its lower limit at the upper limit of translunar space, and extending beyond the limits of the solar system, some several billion miles. (This term is one of distance from earth, not one of planetary influence.)

Interstellar—that part of space conceived, from the standpoint of the earth, to have its lower limit at the upper limit of interplanetary space, and extending to the lower limits of intergalactic space. (From the standpoint of a detached observer, it is that part of space within the Galaxy.)

Translunar—interplanetary space beyond the orbit of the moon.

Spacecraft—a vehicle designed to fly in space.

Spacesuit—hermetically sealed enclosure for an individual, supplying him with a respirable atmosphere, suitable temperature, and permitting him mobility.

Space vehicle—an artificial body operating in outer space. May be a pilotless, instrumented vehicle, or a manned space vehicle.

Span—the maximum length of an airfoil from wing tip to wing tip measured parallel to the lateral axis.

Spark plug—in an internal combustion engine, a part fitting into the cylinder head, carrying two electrodes separated by an air gap across which the current from the ignition system discharges thereby forming the spark for combustion.

Speed—

Air—the speed of an airplane through the air.

Constant—a propeller, the blades of which are attached to a pitch-changing mechanism that automatically keeps them at the optimum pitch under various flight conditions.

Ground—the actual speed of the airplane over the ground, i.e., airspeed plus or minus wind velocity.

Landing—the minimum speed an airplane reaches as the airplane strikes the ground in normal landing attitude.

Speed of light—the speed at which light travels, 186,300 miles per second.

Speed of sound—the speed at which sound waves travel through a medium. In air at standard sea-level conditions, some 750 mph.

Spin—a maneuver in which an airplane descends along a helical path of large pitch and small radius while flying at a mean angle of attack greater than the angle of attack at maximum lift.

Spinner—a cap fitted over the propeller hub to increase the streamline properties of the aircraft.

Spiral—a maneuver in which an airplane descends in a helix of small pitch and large radius, the angle of attack being within the normal range of flight angles.

Spoiler—a small plate fitted to the upper surface of a wing, the purpose of which is to disturb the smooth airflow and create lack of lift and increase in drag.

Squall—(1) a sudden, brief storm, closely akin to a thunderstorm but not necessarily accompanied by thunder and lightning; (2) a sudden, brief blast of wind of longer duration than a gust.

Stability—that property of a body which causes it, when its equilibrium is disturbed, to develop forces or movements tending to restore the original condition.

Automatic—stability of an aircraft created by movable auxiliary control surfaces operated by automatic mechanical devices.

Directional—stability around the vertical or yawing axis.

Dynamic—that property which causes an airplane to return gradually to its normal flight position by damping out the restoring forces after its steady flight position has been disturbed.

Inherent—the property which causes an airplane to restore itself to normal flight position solely by the arrangement of its fixed parts and without help from the controls or other mechanical devices.

Lateral—stability around the longitudinal or rolling axis.

Longitudinal—stability around the lateral or pitching axis.

Stabilizer, horizontal—the stationary horizontal member of the tail assembly of an airplane to which the elevator is attached. It is responsible for longitudinal stability.

Stagger—a term referring to the position of the wings of a biplane. When the upper wing is placed slightly forward of the lower wing, stagger is positive. When the lower wing is placed forward of the upper wing, stagger is negative.

Stall—the condition of an airplane which is operating at an angle of attack greater than the angle of attack of maximum lift.

Standard atmosphere—the condition of the atmosphere when the barometric pressure reads 29.92 inches of mercury and the temperature is 59° Fahrenheit (15° centigrade) at sea level; used primarily as the accepted standard in calibrating aircraft instruments whose indications are affected by changes in barometric pressure.

Stationary orbit—also, in reference to earth, known as a twenty-four hour orbit; a circular orbit around a planet in the equatorial plane, having a rotation period equal to that of the planet.

Step rocket—a multistage rocket.

Straight and level—the adjustment and maintenance of an aircraft in three planes, vertical, lateral, and horizontal, i.e., (1) keeping the plane longitudinally level by use of the elevators, (2) keeping the plane laterally level by the use of ailerons, and (3) keeping the plane directionally straight by use of rudder. The movements and use of these three controls are later coordinated to fly the airplane properly.

Stratiform—a general term applied to all clouds which are arranged in unbroken horizontal layers or sheets.

Stratosphere—the upper region or external layer of the atmosphere, in which the temperature is practically constant in a vertical direction.

Streamlining—shaping of a part so as to create the least disturbance of air passing around it.

Stringers—longitudinal members connecting the bulkheads or rings in semi-monocoque construction. They act to keep these bulkheads and rings in place and to support the skin of the aircraft fuselage.

Strut—a rigid, streamlined member fastened to either the fuselage or landing gear to support the wings.

Subsonic—less than the speed of sound. A speed having a Mach number less than 1.

Supercharger—a centrifugal pump or blower which forces a greater volume of air into the cylinders of an aircraft engine than would normally be accomplished at the prevailing atmospheric pressure.

Supersonic—greater than the speed of sound. A speed having a Mach number greater than 1.

Sweepback—the tapering back of the wing of an airplane from the wing root to the tips.

Switch—a device for making, breaking, or changing the connections in an electric circuit.

Synchronous satellite—an equatorial west-to-east satellite orbiting the earth at an altitude of 22,300 statute miles at which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation.

T

Tab—an auxiliary airfoil attached to a surface to provide for aerodynamic control of that surface or for trimming of the aircraft for any normal attitude of flight.

Tachometer—an instrument that measures, in revolutions per minute, the rate at which an engine crankshaft turns.

Tail—(See Empennage.)

Takeoff—the handling of an airplane leading up to and at the instant of leaving the ground.

Tank, hopper—a separate compartment within an aircraft engine's oil tank, from which, during engine operation, the engine draws its oil. Also called a "hotwell".

Taper—a gradual change in chord-length of a wing, from the root to the tip. Chord-length usually decreases from root to tip.

Taxi—to operate an airplane under its own power, either on land or water, other than in actual takeoff or landing.

Telemetering—the technique of recording space data by radioing an instrument reading from a rocket to a recording machine on the ground.

Terrestrial—pertaining to the earth.

Three-point landing—the act of contacting the ground simultaneously with the front wheels and tail wheel or skid of the aircraft.

Throttle—a valve which regulates airflow through a carburetor and therefore controls the amount of fuel-air mixture available to the cylinders of an engine.

Throw—the displacement, or the amount of the displacement, of a control surface to either side of its neutral position, as in "rudder throw was measured by a rule."

Thrust—the amount of "push" developed by a rocket; measured in pounds.

Thrust augmenter—any contrivance used for thrust augmentation, as a venturi used in a rocket or an afterburner, etc.

Topographical features—the representation of the natural geographic detail of a charted region but not including cultural (man made) aids to navigation.

Torque—any force which produces or tends to produce rotation about the airplane's longitudinal axis.

Tracking—the process of following the movements of a satellite or rocket by radar, radio, and photographic observations.

Tracks—the actual path over the ground of an airplane in flight.

Trailing edge—the rear or following edge of an airplane wing or propeller blade.

Tricycle landing gear—a three-wheel landing gear in which no tail-wheel or tail skid is used, normally consisting of two main wheels with an auxiliary wheel forward. Also applied to landing gears of this type or other devices. Often shortened to "tricycle gear."

Trim tab—a small auxiliary hinged portion, inset into the trailing edge of an aileron, rudder, or elevator and independently controlled. The trimming tabs are an aerodynamic control for the surface to which they are affixed and serve to hold that surface at a position that will result in balancing or trimming the airplane for any normal attitude of flight, i.e., the airplane will fly hands off.

Troposphere—the lower region of the atmosphere from the ground to the stratosphere in which the average condition is typified by a more or less regular decrease of temperature with increasing altitude, storms, and irregular weather changes.

Truss—a rigid framework made up of such members as beams, struts, and bars (welded or bolted together to form triangles), and itself a structural member that resists deformation by applied loads.

Turbofan—a jet engine of the bypass, or ducted-fan, type in which part of the air taken in at the front by a compressor or fan bypasses the combustion chamber to give extra thrust; one type has a fan at the rear.

Turboprop—**(see jet, turboprop.)**

Turbo-supercharger—a supercharger utilizing an exhaust-driven turbine to operate the impeller.

Turbulence—irregular motion of the atmosphere produced when air flows over a comparatively uneven surface, or when two currents of air flow past or over each other in different directions or at different speeds.

Turn indicator—an instrument for indicating the direction and rate of turn of an airplane. It is usually combined with a "ball bank indicator" to show whether or not the controls are properly coordinated in making a turn, i.e., whether the airplane is slipping or skidding.

U

Ultrasonic—speeds between sonic and hypersonic.

Umbilical cord—any one of the servicing electrical or fluid lines between the ground and an uprighted rocket missile or vehicle before the launch.

V

Valve, butterfly—a valve operating in a tube or shaft which has a surface on each side of the valve axis.

Van Allen Belt—a doughnut-shaped belt of high-energy charge particles, trapped in the earth's magnetic field, which surrounds the earth. This belt, which forms an obstacle to interplanetary explorations, was first reported by Dr. A. Van Allen of Iowa State University. Scientists now feel that the belt begins about 400 miles out from the equator and extends to a maximum of 24,000 to 28,000 miles.

Variation—the angle at any given place between the true meridian and a line drawn to the magnetic North Pole. It is labeled East or West, depending on which side of the true meridian the magnetic North Pole lies.

Venturi tube—a short tube with a constricted throat which, when placed in a fluid flow and parallel to the flow, brings about an increase in flow velocity at the throat with a consequent diminished pressure within the fluid at the throat.

Visibility—the greatest distance toward the horizon at which prominent objects can be seen and recognized.

Visual Omni Range (VOR)—a type of ground-based radio aid used in navigation.

W

Wash—the disturbance in the air produced by the passage of an airfoil through the air.

Weightlessness—condition in free fall. May be physiologically unimportant but psychologically dangerous in space flight. Can be avoided by spinning the space vehicle and simulating the effects of gravity by providing a weight feeling with centripetal force.

Wind—moving air, especially a mass of air having a common direction of motion, generally limited to air moving horizontally or nearly so. Vertical streams of air are usually called convectional currents.

Angle—the angle between the true course and the direction from which the wind is blowing; measured from the true course, toward the right or left from 0° to 180°.

Correction angle—the angle between the track and the heading of the aircraft.

Wing—an airfoil or lifting surface so designed as to produce sufficient force when in motion as to lift the weight of the aircraft.

Bow—the internal construction of the wing tip that determines its shape.

Rib—a chordwise member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars.

Root—the end of an airplane wing which is attached to the fuselage.

Y

Yaws—an angular displacement or motion to the left or right about the vertical axis of an airplane.

Z

Zone "A" or "N"—the area in which, when flying near a low frequency radio range, the A(.—) or N(—.) is predominant.

Bi-signal area (or zone)—that area of a circle around a radio range station in which both the "A" and the "N" signal and two sets of identification letters can be heard. One signal predominates while the other is heard as a "background" sound.

Zoom—the climb for a short time at an angle greater than the normal climbing angle, the airplane being carried upward at the expense of airspeed.