Significant Engineering Developments

IN AIRCRAFT DESIGN

By WARREN FURRY

JAMES RUSSELL LOWELL once said in effect that true scholarship consists in knowing not merely that things exist, but *what they mean.* This statement suggests that a summary of the salient points in the history of aircraft design might serve as an inventory of aircraft engineering accomplishments. We hope that it will also promote some thinking about the needs of the aircraft industry which must be supplied by engineering endeavor. To those of us who aspire to fruitful research and the rewards of inventive labor in this field, or related fields, such an inventory should be useful; and since modern history is the history of science and engineering, our discussion will be concerned with matters of historical importance.

The history of an industry usually may be written as the story of men; men who discovered the principles of the science involved; men who invented the industry's tools and devices; and those who otherwise engineered its technical and commercial development. In the case of the aircraft industry, however, no one man dominated any of these fields. Many men, working independently but concurrently, effected a development with a rapidity that is unique in industrial history.

It would be impossible, in one short article, even to enumerate all the individual engineering developments that have contributed to advancement in aeronautics. For this reason, our history of design will be condensed into an abstract of those groups of developments that we believe have had the greatest influence on design.

In selecting the divisions of engineering to be covered, we may ask, "What are the basic engineering considerations involved in the design and production of airplanes?" We might answer by stating an engineering definition of an airplane, as follows:

An airplane is a machine or craft that must be so shaped and devised as to fly spectacularly, if military, and economically, if commercial; it is a structure, the whole and each part of which must be designed to carry certain estimated loads imposed by gravity, air pressures and inertia; it is a vehicle that must be made self-propelling by a power plant; and it is a product that must be manufactured rapidly if military, and profitably if commercial. Summarizing: An airplane is a craft, a structure, a vehicle and a product.

From this definition then, our fields of engineering are aerodynamics, structures, power plant and production. It is interesting for us to note that the aerodynamics developments are the only ones that are purely aeronautical. The remainder are largely matters of mechanisms, power, structures and metallurgy. But, being directed toward the attainment of areonautical objectives, these matters have been subject to the necessity for constant compromise which characterizes aeronautical design.

AERODYNAMICS

Outstanding developments in aerodynamics include: 1. Airfoil and cowling shapes, 2. Wind tunnel techniques, and 3. Flight testing techniques. In speaking first of the airfoil, it may be well to consider that generally the term "airfoil" defines any surface that is designed to produce a reaction by deflecting an airstream. However, designers commonly use the term to mean the cross-sectional shape of an airfoil, or most often merely the cross section of a wing.

It was logical that improvement in airfoil shapes was among the first to be undertaken. Our earliest airplanes were nothing more than powered gliders and consisted of little more than sets of wings. These wings often were simply frameworks covered only on the lower side. But it was found by experiment that a covered convex upper surface produced a pressure differential contributing more to the lifting effect than the reaction produced by the lower surface. Experimental work involving closed airfoils took place in Germany, France and England before the first World War, and the United States air service conducted some investigations at about the same time.

In the 1920's the National Advisory Committee for

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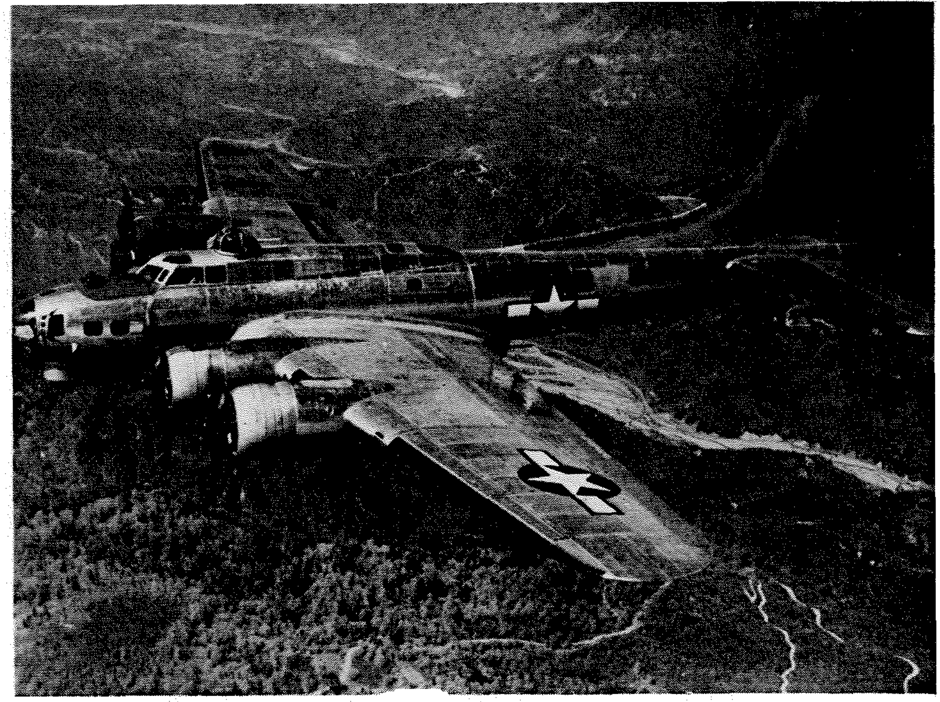
The Constellation. Lockheed high-altitude, long-range heavy transport; now used exclusively by the United States armed forces.



AT RIGHT:
The B-17 G Bomber, United States Army's standard "Heavy," now being produced in quantity by Lockheed.

Aeronautics, a Federal agency (NACA), began extensive research on airfoil shapes. A series of wind-tunnel tests was conducted on families of airfoils, *i.e.*, groups deriving their cross-sectional shape by regular variations of a basic outline. The results of these and similar tests enable designers to select an airfoil according to the wing-performance characteristics desired. Further tests led to the development of laminar-flow airfoils, so called because of near-absence of airstream turbulence at critical points on the surface. Undergoing experiment are even more advanced shapes that may render obsolete those that we now regard with highest favor. Without modern airfoils, aircraft speeds above the range of automobile speeds would be impossible. Without them, wings would need to be vastly greater in size to produce the required lifting force.

It would seem appropriate at this point to explain that the helicopter is omitted from this list for two reasons: first, because experiments with such devices were begun independently of other aeronautical endeavors at a very early date, and in one sense we may consider the helicopter as a separate and distinct invention; second, because the development of present-day rotating-wing aircraft has been largely founded on the results of aerodynamic research in connection with fixed-wing aircraft. In this latter sense, helicopters and autogiros may be considered as adaptations of the conventional airplane.

A somewhat similar development to that of airfoils is to be found in engine cowling shapes. Evolved by collaboration of aerodynamicists and power specialists, the NACA cowl for air-cooled engines has resulted. This familiar device smooths out the airstream that otherwise would be made violently turbulent by an "exposed" engine. In so doing, it assists also in controlling engine cooling.

These cowling shape developments share "high-speed honors" with the airfoils; they constitute one of the outstanding contributions made by this country in improvement of speed.

The primary proving ground of aerodynamics is of course the wind tunnel, and its steadily advancing technique is of first importance. It enables designers to secure, from models, data that would otherwise be obtainable only after flight testing of completed planes. The full value of the wind tunnel is best appreciated by aerodynamicists who have used it in solving complicated problems of flight stability.

Improvement in the aerodynamics phase of flight testing is closely correlated with advancement in wind-tunnel work. In fact, the results of its development have proved the value of both techniques.

The importance of advanced methods of flight testing is, however, independently significant, since such testing is concerned also with power plant operation, with structural efficiency and with vibration.

Early flight testing was performed by "wringing out" a new plane, *i.e.*, flying it in all feasible attitudes, and executing all known maneuvers. In such testing, the instruments consisted chiefly of the pilot's senses of sight, hearing and touch (in case of a hot engine, his sense of smell, also). But data thus obtained were not always quantitatively reliable. (At least no more so than the degree of sensitivity of the seat of the pilot's pants.)

Modern flight testing is accomplished with extensive instrumentation. Numerous engine, flight, strain-gauge and vibration instruments are installed and the readings frequently are recorded photographically to reduce the possibility of human error.

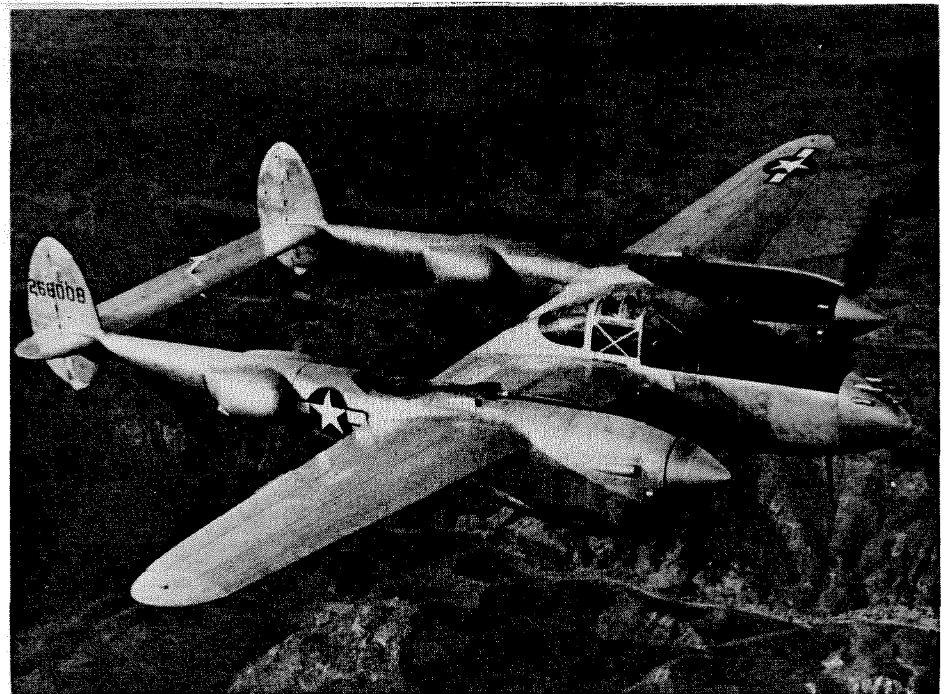
Without the information that can be gained only by the expert analysis of flight test data, the mistakes that are always made in the design of high-performance aircraft would be far more costly. They would certainly prolong the business of redesigning to remove "bugs" and they might often result in loss of life and airplanes.

STRUCTURES

In the field of structures (under which term we include both structural design and analysis), there are three classes of development which demand attention: materials, thin-sheet design and structural testing.

From the purely aircraft structural standpoint, a desirable material is one with a high strength-weight ratio. Our present popular high-strength alloys of aluminum, of magnesium, and of steel have this characteristic. Most of these alloys represent long years of metallurgical research and experiment. In some applications, these metals have already attained a practical limit in strength per unit weight; that is, higher unit strengths could not be practically utilized to make parts smaller, and therefore lighter, because of limitations imposed by handling and manufacturing requirements.

It is to be expected, however, that new materials will be developed that will be almost revolutionary in their effect on design. It is possible that improved bonding agents and fabrication methods may permit more exten-



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Lockheed P-38 Interceptor, the famed "Lightning" pursuit plane that has proved to be World War II's most versatile combat aircraft.

sive use of plywood. At present, however, the metals, which may be consistently manufactured with uniform strength, are in no danger of being supplanted as material for primary structure.

In the matter of structural design, the use of thin-sheet material may be said to have made the all-metal airplane possible. Thin-web beams, for instance, are comparatively easy to build. They can retain their rigidity in spite of local damage from gunfire. They are eminently adaptable to the type of construction usually associated with the cantilever monoplane.

Semi-monocoque design, which in one sense is an adaptation of thin-web beam design, utilizes the airplane's sheet-metal skin or covering to carry a considerable portion of the imposed shear and bending loads. This arrangement is in direct contrast to early designs in which the craft's covering was structurally parasitic.

Many of our early plane builders checked the strength of their structures by guess. Testing of wings and other major assemblies often was done only by determining their "feeling" of rigidity. This estimated rigidity was then compared with the required stiffness as evaluated by the pilots' observations of deflections in flight.

Designers now have data that enable them to predict the maximum loads that will be imposed upon each part of a plane. They have methods of analysis by which to compute, during the design stage, the strength of parts and assemblies; and they have developed methods of physical testing by which the predictions and computations may be substantiated.

Thus by means of new materials, refined designs and perfected testing, our modern, structurally-efficient aircraft have been evolved. These developments are factors that help to make operation of our airlines commercially feasible. They have produced the designs that make the performance of our military aircraft unparalleled.

POWER PLANT

The development of aircraft engines during the 40 years since Kitty Hawk is an achievement deserving of a volume. The Wright Brothers themselves built the nine-horse engine that was used in their first successful flight in 1903. Later engine designers worked quite independently of plane designers, frequently too independently. Sometimes airplane designs were otherwise completed before the selection of an engine was made. Even now, planes are designed "around" the chosen (or the available) power plant. The trend, however, is as it should be: toward co-design of plane and power plant.

Generally speaking, increases in airplane size and performance have followed in the wake of the development of engines. Weight-power ratio has been steadily reduced, and fuels have been as steadily improved. The fuel-injection principle and automatic oil coolers have marked important steps forward. The supercharger and the constant speed (controllable-pitch) propeller have made high altitude flying possible.

Like structural improvements, many engine developments have hinged on metallurgical discovery. But the needs for power plant advancement are confined to no one field. Diesels, gas turbines, jet propulsion and even atomic energy experiments are in our laboratories and on our test stands.

Although most so-called aircraft companies are technically airframe manufacturers, they are usually responsible for the complete airplane as delivered to the customer. They buy the bare engine from the engine manufacturer, plus accessories such as carburetor, starter, generator, etc., but then their own power-plant specialists are required to design, with the help of consultation with representatives of the engine builders, the complete fuel, exhaust and cooling systems necessary to produce the finished aircraft. These systems include air intake ducts for carburetor and oil cooler, exhaust collector rings and tail pipes, fuel and oil tanks and transmission lines, turbo-supercharger installations, cowling and nacelle enclosures and a vast hydraulic, electric and cable control system.

In the power-plant field designers need, among other things, a perfected automatic engine-control system. And in overall design, progress from 10 pounds per horsepower to one pound per horsepower is a tremendous advancement, but it isn't enough. We must go further, both toward reduction of weight-power ratio, and toward increase of engine efficiency.

PRODUCTION

Our first commercial airplanes were built somewhat laboriously with the extensive use of many hand tools. Usually they were constructed all in one piece. Repairs and replacements often involved actual destructive operations. Our production engineers have now broken down the fabrication process into component assemblies and sub-assemblies. Repair or replacement, and even final assembly on the factory line, may be accomplished without drills, files or other cutting tools, needing only "a wrench and a screwdriver."

Successful airplane production, like all modern machine manufacturing, depends upon the interchangeability of those parts and assemblies which are intended to be identical. This feature of interchangeability is achieved through the use of ingeniously coordinated jigs and fixtures. Designs then, are executed so that the fabrication process may be adapted to the use of such tooling.

Individual parts are manufactured rapidly and with precision by being designed for production on such machines as the punch press and turret lathe. These machines make possible the aircraft industry's closest approach to true mass production. Such methods of joining as spotwelding and metal stitching are also worthy of mention in this connection.

A large portion of aircraft design work is purely mechanical in aspect; it is the same kind of work that is done in designing a vacuum cleaner, a farm tractor and a Diesel-electric locomotive. Naturally, close attention is given to weight saving; in other respects, airplane design is simply product design.

It is therefore not difficult to perceive the importance of such "design for production" in our industry today. It makes possible the high rate of delivery that will provide the planes necessary to win the war. After victory, the same consideration will be an outstanding factor in controlling costs of commercial aircraft, and of the private planes which many of us will own or operate.

In conclusion, it is not intended to disregard the importance of the great number of inventions and developments that have advanced aviation—using the term aviation as distinguished from airplane design. Most of these applications, although not falling into the categories discussed, are of an engineering nature. Some of them have revolutionized certain phases of flying, and thereby have influenced design. De-icing mechanisms, for instance, have made operation possible in weather that otherwise would be prohibitory. Cabin pressurizing and improved oxygen apparatus have made flying practical at the high altitudes attainable with our supercharged engines. Auxiliary airfoils and high-lift devices such as wing slots and flaps permit operation from small landing areas. Blind-flying instruments and the automatic pilot so extend the range of permissible flying conditions that designs must be modified accordingly.

There are scores of other developments, all of them important; none of them perfected; any of them worthy of considerable effort toward improvement. And as new devices come into use, entire new fields frequently are opened for research.

For young engineers, these fields are tough and competitive, and will be increasingly so, but this condition should not be considered a limitation. The industry will continue to need men who appreciate as being unusual the opportunity for interesting engineering work in connection with aircraft and aviation development.

New Frontiers of the Mind

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nothing organically wrong with her, just a lot of hysterical symptoms, and I haven't time to bother with her." Sigmund Freud had time, and let the patient tell him her troubles day after day until, to their mutual surprise, she was cured of "neurosis." Freud then wrote an article describing the method of "mental catharsis." Beyond one or two caustic remarks by older and wiser physicians, however, few noticed the article and the world slumbered on, unaware that it was harboring in that drab Viennese office an *enfant terrible* who, in the words of Thomas Mann, was to exert an impact on the twentieth century comparable to that of Darwin on the nineteenth and of Galileo on the seventeenth. Much of modern literature, drama, and painting can be understood only in Freudian terms. James Joyce, Eugene O'Neill, Salvador Dali, to name only three, are saturated in psychoanalysis.

Freud is one of those people who are now pointed out with pride; now viewed with alarm. It is difficult to be neutral and objective about him. His admirers point out the wealth of helpful concepts which he developed—rationalization, sublimation, projection, repression—and a long glossary of others. His critics assert that many of his interpretations were wrong and much of his thinking fuzzy, that his generalizations were so sweeping that they can neither be proved nor disproved, that his methods were far from scientific, and that his emphases were logically untenable. As one wit has put it: "The sex drive is so very important that it is impossible to over-emphasize it—but Freud has succeeded in doing so."

Freud's preoccupation with the sex and death wishes blinded him to the other motives of men, but his critics have to admit that for all his errors Freud's influence was great enough to produce a radical change in the contours of the psychological frontier. He was the hair shirt which goaded us to activity; he was the red flannel underwear which made us scratch in new places. Freud forced us to consider genetic development, especially of the first three years of life; to recognize the existence of unconscious motives and their rationalization; and to attack the problems of frustration. He was frequently wrong, but his wrongness produced much rightness.

NERVOUS BREAKDOWN

Recent studies of "experimental neurosis" probably would never have been performed had it not been for the work of the great Russian, Pavlov, on conditioning. In the early years of this century, one of Pavlov's assistants reported that a laboratory dog had suffered a "nervous breakdown" when presented with a problem which he could not solve. Like many other important observations, this finding lay dormant for years. But in the 1930's in several laboratories, particularly that under the direction of Professor Maier of Michigan, a series of experiments was started to find out why that dog broke down. Maier uses Lashley's basic method—a rat on a pedestal learning to jump to one of two doors. When the rat has learned to go always to the door with the circle on it, Maier bends out the sides of the triangle so that it becomes more and more circular. Finally the rat can no longer discriminate between the two figures; when that happens he is frustrated between his hunger and his desire to avoid a fall into the net. Under stress, individual rat personalities emerge. Some—the Horatio Algers—keep on trying, getting approximately half of their trials correct by chance. Some appear to try—they jump, twist in the air, kick a glancing blow against the door, and land in the net; they get no food but they avoid the punishment. The shy rats refuse to jump. Some develop a "nervous breakdown." A few jump to the floor and rush blindly around the room; some jump hysterically up and down in one spot; some shiver and shake; others lie completely supine, so that they may be pushed or pulled into any position as though they were wax. We get exactly the same symptoms in a mental illness found in humans, catatonic schizophrenia, which is an attempt