HISTORY OF THE DEVELOPMENT OF THE AIRPLANE

THESIS FOR DEGREE OF M. E.

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HISTORY OF THE DEVELOPMENT OF THE AIRPLANE

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THESIS

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In writing this history of the development of the airplane, it is the aim to present only the events and changes that have become the structure landmarks between the old stick-and-wire airplanes and our modern stressed-skin designs. Much has been written on the airplane and related subjects from the layman's point of view. In this thesis the material will be presented in such a manner as to be of interest, it is hoped, to the professional engineer, to the engineering student, and to others concerned with the development of the machine that has reduced distance in terms of time and brought formerly remote and isolated parts of the earth, where other means of transportation have been impractical, if not impossible, into the path of world travel and commerce. For mountains and oceans are no obstacle to these man-made birds.

Records show that the first flight in a machine whose support depended on velocity and on no other means of buoyancy was made in the United States, on December 17, 1903. From this time until the outbreak of the World War in August, 1914, the development and advancement of the airplane was slow; because it was men with small capital, small shops, and in some cases, no shops at all, who had the desire to look down on this earth from a flying machine and to try their luck in exhibition work at various county and state fairs. The construction of the airplane during this period was possible only because of the materials used, which consisted of wood, piano wire, a few low-grade steel fittings for the supporting structure, and linen or a good grade of cotton for the covering. The use of these materials required few tools, making the building and repairing of the airplane in use during these years a comparatively simple matter. This was desirable, because repairs often had to be made quickly and on the landing field where the exhibition was being given. The biplane was the type most used by these flyers, which, with its low wing loading and low power loading, was a happy choice for this type of work. For, although these airplanes were not built to severe requirements, this low loading, together with the lack of either streamlining or cleanness of design, produced a low-speed airplane, whose strength requirements were adequately met by the type of construction then known. This and careful handling in the air are the only reasons why more of these airplanes did not fail in flight. With the earnings from exhibition flying at fairs, the pilot, who was his own mechanic in many cases, would prepare during the off season for the next year's work. Either he made changes in his existing airplane or he built a new one incorporating the ideas obtained from the period of flying. When an exhibition was over, the airplane was not flown to another, but was disassembled, boxed, and shipped by rail. Shipping airplanes by rail was practiced until after the summer of 1914, when, owing to the war, exhibition work was discontinued.

Prior to the entry of the United States into the World

War, there were a few aircraft companies, small in size, who contracted to produce airplanes for foreign countries. The work was done in American factories, but was under the supervision of representatives of the country buying the airplanes. At that time none of these countries knew much about requirements for military airplanes; but the United States knew even less. However, by the time this country entered the conflict, considerable information had been collected by the Allies, which they passed on to American government agencies. In the summer of 1917 the Airplane and Engine Sections of the U.S. Signal Corps were created in Washington, and in November of that year, they were moved to McCook Field, Dayton, Ohio, where they finally developed into the present Materiel Division of the U. S. Army Air Corps. This was the real beginning of a splendid work, but owing to the pressure that was necessary at this time, items of prime engineering importance were neglected.

Realizing that there was little basic design information which could be used, it was decided to conduct experiments in order to obtain the necessary information. Therefore, the Structures Branch of the Research Department was created.

It was the duty of this newly formed Branch to determine and approve the strength characteristics of all military airplanes. Little was known about calculating loads in the members of such flimsy structures; so the best method was to actually load the structural assembly to simulate air loads. The loads to be applied were calculated from the meager wind tunnel test data that existed at the time and from the acceleration values that might be expected in maneuvering the airplane. By means of this work, as well as through an increasing number of wind tunnel tests, new rules and methods for calculating the strength of structural members were formulated. The wind tunnel work consisted in placing in the tunnel small models of airfoils or airplanes mounted on a weighing device, then in forcing the air past the model while at the same time, weighing the forces caused by the air in passing over the model. The most common forces measured were lift, drag, and moments for the airfoil or airplane model, at all angles of attack within the flying range of the airplane. Model after model was tested in the wind tunnel, and the results used in the design of future airplanes. With these data the engineer's best effort was put forth to design a structure that would satisfy the strength requirements and yet be light in weight. This procedure was the best possible at that time. However, the static testing of complete airplanes was continued, each test furnishing a lesson and indicating where improvements could be made. It became customary for manufacturers building airplanes to specifications to furnish three full-scale models of a design. One of these models was used for the purpose of conducting flight tests, another for destructive structural tests to determine strength characteristics, and the third was stowed

for use as a working model, if needed. This procedure continued until the engineering departments of the different manufacturing companies could be improved and become well organized, which required no little time. Much of the improvement came about through the work of the different colleges and universities, who continually sent out men better qualified in aeronautical engineering work. Many of these institutions became interested enough to build and operate their own wind tunnels in order to obtain information and to check tests that had been made in other wind tunnels. In addition, structural problems were studied from the reports of actual structural tests. As a result of the interest shown by the different institutions of learning, a marked improvement took place in the engineering work submitted as early as 1924, when the proposed designs submitted to the Air Corps included all the calculations made and the methods used.

It was also around 1924 when the Post Office Department began letting contracts to private owners of airplanes for the carrying of the air mail, which until then had been carried in remodeled wartime airplanes operated by the Post Office Department itself. Manufacturers were thus rewarded for their efforts in producing airplanes that would carry more pay load at a greater speed.

As early as 1922, structural tests were conducted on all-metal, internally-braced monoplanes manufactured by Junker in Germany. The type of structural design incorporated in this airplane was new to this country, as was also the kind of metal used. The Junker wing structure was built with duralumin tubing and steel fittings to form the spars, and corrugated sheet duralumin to form the cover. Thus, the cover acted as a structural member of the wing, and resisted drag loads imposed upon it. As this was the first wing to be tested in the United States in which the covering was used to resist and transmit load, a new structural term, "stressed-skin" wing, was coined; this is the type of construction in common use today. Without a doubt, this construction is the result of the early work of Dr. Hugo Junker and Herr Dornier, of Germany, and Messieurs DeBoysson and Dewoitine, of France, all of whom have patents on some modified type of structure in which the load is transmitted by a reinforced skin. The work of these men dates back to 1915. However, because of the thinness of the sheet, difficulties were encountered in its application and manufacture. These difficulties were the result of the light wing loading in use at that time, which with the stressed skin type of construction, produced such a heavy airplane that it was several years before the type was generally adopted. When airplanes with greater wing loading began to appear, which was in 1927, a study was made by the Materiel Division of all types of metal construction that would have a high strength-weight ratio. From the results of this study it appeared that the logical way to resist a distributed load, such as an air load on the wing, was to keep the stresses distributed, which thought is sound; for, when a distributed load is concentrated, a premium in structural weight must be paid. With this in mind, a wing having two shear webs some distance apart and corrugated thin sheet between these webs, which formed a box, was built and tested. This wing had a span of 55 feet and an area of 423 square feet. The corrugations of the material, running spanwise and forming the flanges of the cantilever beam, resisted the moment, while the two webs resisted the shear. The tests conducted on this wing, during October and November, 1930, furnished some interesting and valuable data even though the wing was similar in construction to those patented in 1915. The principal lesson learned from these tests was how to distribute the material to produce the radius of gyration that prevents buckling while the wing is under load. This is a problem in itself, and the only secret is to keep the structural material where it is placed. This is not a difficult thing to do when one has done it many times. If structural members are removed, the stress in them is removed also; for this reason one of the two shear members has been eliminated in the box stressed-skin wing, leaving a wing with a single-shear web (which must be properly located) and with a reinforced nose section to resist the moments due to torque and bending. Several wings having a single-shear web have been built with much success. In using but one shear member, the thickness must be increased, which tends to reduce the possibility of failure due to fatigue caused by vibration, but it must be remembered that the single-shear web should be used in wings with airfoils having low moment coefficients or a constant center of pressure.

Stressed-skin construction has been used in fuselage or body structures much longer than in wing structures. During the war, when much wood was used, many fuselages were of this type of construction; but designing and constructing a stressed-skin fuselage is not as difficult as designing and constructing a wing of this type, on account of the depth and size and the much lower load it must support in comparison with the load the wing must support. If the sizes that structural design dictates were used in the fuselage, it would be undesirable in appearance and difficult to maintain. The design principles are the same, but it is much easier to design and build a fuselage for a reasonable weight; that is, provided it is not desired to have too many openings, which tend to lower the natural frequency of vibration in torsion and bending regardless of how reinforcing material is used around them. Vertical and horizontal tail surfaces may be of the same type of construction as the wing.

Several earlier attempts were made by the Air Corps to use all-metal construction in airplane design. Late in the year of 1922 tests were conducted on the first all-metal monoplane designed and built in the United States. This airplane was a corps observation type known as the CO-1. During the same year the Gallaudet day bomber was built by the Galladet Aircraft Corporation of East

Greenwich, Rhode Island, who used metal construction with fabric covered wings and tail surfaces. In both of these airplanes, much use was made of duralumin and highly heat-treated steels. The structure of the CO-1 was built of duralumin corrugated sheet, duralumin tubing, and steel tubing and fittings. The fuselage of this airplane was designed similarly to that of the Junker J.L.6, whereas the main structural members of the wing were definite members forming a space-frame structure. The duralumin cover of the fuselage, which had its corrugations running lengthwise, supported at intervals by bulkheads, resisted the shears and moments under the different loadings. These bulkheads stabilized the covering against buckling, thus permitting the cover to be stressed more highly before failure. The wing was constructed with steel and duralumin spars and a corrugated duralumin cover. The spars resisted the beam loads, whereas both the spars and cover resisted the torsional and drag loads. The structural design of this airplane followed the same thought as the older type of definite structure except that the fuselage was of the stressed-skin type and the wing was metal covered to resist shear due to drag loads and shear due to torque.

The Gallaudet day bombardment airplane was the first airplane to have its fuselage streamline in shape and to have an elliptical cross section. This was an advanced step in fuselage construction, and in order to build it, the services of silversmiths and coppersmiths were used. The internally-braced monoplane wing of this airplane was constructed of two truss-type spars having heat-treated shear and chord members; but the spars were stabilized by the usual drag wires, bulkheads, and ribs, which also resisted the drag and torsional loads. This airplane, although an outstanding achievement in construction and an advanced thought in design, never took the air, because of its excessive weight, most of which was built into the fuselage. The airplane was redesigned with fabric covering for the space-frame structure. When the redesigned airplane arrived, it showed a tendency during flight tests to roll to the right, even though the engine torque should have given it a tendency to roll to the left. Assuming that something was wrong with the structure, it was decided to conduct proof tests on the internally-braced wing; these were completed during the months of April and May, 1924. From the results of these tests it was found that the aileron, or lateral control system, was faulty and that a slightly greater angle of incidence was built into the left wing panel than was built into the right panel. This, without a doubt, caused the tendency of the airplane to roll to the right. On the first flight, when the rolling tendency was soon discovered, it was not certain whether the airplane could be landed safely. After the airplane was made to fly properly, it developed resonance vibration, or flutter, or both. The airplane was landed by skillful piloting in a badly damaged condition. Soon after this accident, further development of this type airplane was abandoned.

Discontinuing work on this type airplane was a mistake, because it was not long before a similarly constructed airplane was built by one of the aircraft companies and successfully flown in carrying the air mail over one of the air transport lines. This new all-metal monoplane was the forerunner of the present airline passenger and mail planes. Of course, airplanes have been improved greatly since this one was built, and much has been done to increase their size. The possibilities of large airplanes were considered as far back as 1921, and as a result, the first large outer wing panel was tested in March 1922. This wing panel was internally braced and had a span of 40 feet; the total span of the airplane was 97 feet 4 inches with a root chord of 26 feet, a tip chord of 13 feet, and a total of 2082 square feet lifting surface in the complete wing. The design, construction, and tests of this outer wing panel constituted a splendid experiment, but had such construction been put into service, it would have required a trained engineer to be one of the crew of each airplane in order to keep the proper amount of tension in the tie rods or tension members. The complete airplane for which this outer panel was designed was never built.

For all the thought given to the large airplane at this time, the small airplane was not neglected. From the close of the War and until 1925, encouragement was given by the Air Corps to the design and building of racing airplanes. The racing airplane, usually small and fast, furnished useful information because of the absence of equipment, in checking both the engineering data and the accuracy of the method used to obtain these data. As the result of the engineering data obtained in the flight of these small, fast, highly maneuverable airplanes, the strength requirements for the pursuit type were increased nearly 50 per cent. This change in the requirements of the pursuit airplane was made in 1923; there has been little change necessary in these requirements since. However, many new requirements have been added, and a change has been made in the presentation of the design requirements for aircraft. The first pursuit airplane to be tested under these new requirements was the small biplane known as the PW-9, weighing 2910 pounds. This airplane was designed and built during the summer of 1923, and was subjected to the usual structural tests in November and December of the same year. It was far in advance of its time, and many of its features have been incorporated in later designs. Contemporaneous with the arrival of this airplane at McCook Field, in Dayton, Ohio, was that of another pursuit practically the same in size and known as the PW-8. This airplane was also a biplane, but it was unlike the PW-9 in that it had two bays in its lift truss. During flight tests, while these two airplanes were diving down as straight as possible, the propeller on the PW-8 failed owing to the increase in its rotational speed. The failure was a lucky one, because it occurred at the hub, allowing both halves of the blade to fly off at the same time. One of the halves landed in Northwest Dayton, while the other came to earth in North Dayton, a distance of approximately two miles apart. This was a propitious occurrence, because much was learned, with no one hurt even though one-half of the propeller landed in a back yard where children were at play. Some of the propeller hub bolts fastening the hub to the engine crankshaft flange tore pieces out of some interplane struts, but the struts were not sufficiently weakened to cause a collapse of the entire wing structure. These two airplanes had the usual wood, wire-braced wings, and had welded-steel tubular, wire-braced fuselages. These airplanes gave way to the P-12 series pursuit airplanes, the first of which was designed in 1929 and tested for structural properties in January, 1930, just prior to the production status of the type. The P-12 airplane resulted in one of the largest production orders for airplanes since the close of the World War. No one was ever killed in this type on account of failure in a structural member. During the production period, the duralumin space-frame fuselage was changed to a stressed-skin design. This P-12 stressed skin type pursuit airplane, in which much wood was used in the wing cellule, was followed by one constructed entirely of metal and known as the P-26 airplane. All the structural members with the exception of a few steel fittings were of duralumin. One error made, which was no fault of the designer, was the use of external wire bracing in the lift truss. Many of these airplanes, after the addition of auxiliary lifting surfaces to the original design, are still giving good service.

While the pursuit airplane was having so much thought given to its design and performance, development of the bombardment type lagged behind, until 1929, when the B-9 airplane, entirely of metal, was designed and put under construction. The fuselage of the B-9 was so designed that the loads were resisted not only by the skin, but by four longerons, or heavy structural members, spaced as far apart as possible in the elliptical cross section. The wing was of the two-spar construction, with ribs and bulkheads to support the thin metal cover. The two spars resisted the shear and moments due to beam load, while both the spars and the thin metal cover resisted the shear due to the torsional moment. The two engines were mounted in nacelles on the wing and thus balanced some of the shear and moments due to beam load while adding to the torsional load to be resisted by the wing. Although only seven of these B-9 bombardment airplanes were constructed, much was learned from their use.

Early in 1932 the stressed-skin type wing, which had been in various stages of development prior to this time, was used in a biplace pursuit monoplane. The stressed-skin wing for this airplane was constructed of heavy flat sheet reinforced with stringer material having various cross-section shapes, which replaced the corrugated material and thin flat sheet previously used. This cantilever wing had a 44-foot span and a 297-square foot area. The air loading was 17.5 pounds per square foot; the design loading 210 pounds per square foot. The weight, including the reinforcement around the opening for the retractable landing gear, was 2.94 pounds per square foot. The use of heavier flat sheet with stringer reinforcing produces a smoother surface, which is also better aerodynamically under static and dynamic loading than can be expected with the corrugated reinforcing and thin flat sheet.

The resisting of load by means of a reinforced skin is not so problematical in the design of the fuselage and engine nacelles on account of their depth and comparative low loading. In the design of a wing, where high dynamic loading is to be resisted, the problem becomes more involved in the stressed-skin construction, particularly when many openings are necessary, such as those for the retraction of the landing gear, for the installation of various items, and for inspection purposes.

The first airplane to be submitted in which a smooth reinforced skin was incorporated in the design was the C-19, a single-engine transport or cargo airplane delivered in June, 1931. The methods of design for the corrugated construction and the smooth reinforced skin are practically the same, there being very little difference in the strength-weight ratio of the two types of construction. In the manufacturing process, more riveting is necessary with the reinforced flat sheet than with the corrugated and flat sheet. However, in the latter construction much difficulty is experienced in the spring back of the corrugations, both in the shearing and fitting operations. The excessive amount of riveting may be eliminated by electric spot-welding.

Duralumin or aluminum alloy, which contains aluminum and a varying amount of copper, together with small amounts of manganese, magnesium, and small amounts of certain impurities, is subject to inter-crystaline corrosion due to electrolytic action; this action is accelerated in sea water and sea air. However, even with this bad characteristic, it is suitable for aircraft construction, for, with an organic protective coating or with a coating of commercially pure aluminum rolled integrally with the alloyed metal sheet, excessive corrosion is retarded even though the copper and aluminum are of opposite polarities. Owing to the action of this metal in and around sea water, there was designed and built a corrosion-resistant steel wing for an amphibian airplane. With this airplane operating in and out of, or near, the sea, it was thought that it would be subjected to the most severe service conditions. When the use of this material for aircraft was first proposed, many considered it infeasible, meaning that it could not be done for a reasonable weight. Well, it proved practicable, but was delayed three years because many did not understand the problem. Since this material is denser than the aluminum alloy commonly used in aircraft construction, much more care must be exercised in its support and distribution and in the method of fabrication, in order to obtain a reasonable strength-weight ratio. The tensile strength of corrosion-resistant steel may be increased to more than 200,000 pounds per square inch by "cold work", not by heat-treatment. In the "cold worked" state it is impractical to drill or ream holes in it. Hence, much use has been made of electric spot-welding in making joints. This method of making joints is not new, for it was used when the automotive industry made fenders from many pieces. The automotive industry achieved satisfactory spot-welds, but when the welds were subjected to vibration, the metal adjacent to the weld would fail. The cause of these failures was thought to be a lack of proper timing and current; therefore, much time was spent in a study of timing devices and the proper current to use. This work had to be done before any attempt could be made toward a design. After many spot-welded sample joints were made and tested, reasonable allowable shearing and fatigue values of the welds were established. Upon completion of this work a wing having a 60-foot span and an area of 540 square feet was designed, built, and tested. The static test of this wing indicated that it had greater strength than the wood wing of like dimensions which it replaced and that it was somewhat lighter. This wing was subjected to a vibration test in the laboratory in order to test the spot-welds for fatigue strength. After 120 hours of mechanically vibrating the wing, there were no failures due to fatigue. At present, the destructive forces due to vibration under service conditions have not been investigated, but it is not thought that the amplitude of vibration under service conditions will be any greater than that to which the wing was subjected in the laboratory test.

A number of these wings are now under construction for service test purposes.

An investigation and study of the use of electric spot-welded aluminum alloys has been made. This problem is much more difficult than the electric spot-welding of steel because of the character of the metal. Although this study has been in progress five years or more, to date no electric spot-welding in main structural members of aluminum alloy has been given a service test. This method of making a mechanical joint in aluminum alloy will be perfected, but not in a short space of time or without disappointments. The use of electric spot-welding in airplane structures reduces the cost of building and eliminates rivet heads on the exposed surfaces of thin sheet, where countersinking for the use of countersunk head rivets is impractical and costly.

Much investigation has been done on the design of a metal wing in which the forces are resisted by a single-shear web and thin sheet, reinforced covering. This structure acts as a unit in resisting the shear in the beam direction; the moment due to shear in the beam direction; and the shear due to torque. Because of the less indeterminate features in single-shear web construction, it is superior to and more efficient than the multiple-shear web construction. The former type of construction was first used in an airplane four years ago, and is giving good service.

In the past the design of an airplane structure was based on tests of small models, conducted in the wind tunnel to obtain the forces such as lift, drag, and moments at different angles of attack. The most important of these forces for structural design purposes is the force due to moments. The scale of such models is often such that the results obtained are not sufficiently accurate to be used with satisfaction for structural design. Recently, the scale of models has been increased, with the result that more accurate measurements are obtained in a larger wind tunnel.

In the design and construction of large airplanes, it will be necessary to rely more and more on computations for the design of structural members, because of the smaller number of large airplanes to be built and the cost involved. It is desirable to test to destruction an airplane of each type selected for service, in order to prove whether the engineering work has been done properly and in accordance with the assumptions made, the quantity to be obtained may not always warrant such tests. This procedure will be appreciated more if it is considered that the design load is but 50 per cent greater than the expected load; in many cases, according to records obtained, the expected load has been exceeded. It is interesting to compare this increase of only 50 per cent in the design load over the expected load with the 300 per cent used in the design of other engineering projects.

To replace the destruction tests of large expensive airplanes, structural proof tests will be made in flight. This will be satisfactory so long as the proof test is not carried too far. It must be understood that any airplane can be disintegrated in the air by control forces. Furthermore, the design load for the large airplane is much lower than it is for the small airplane; therefore, any over control would be more effective on the design strength of the large airplane than it would be on the smaller airplane. Proof tests and load distribution tests should be carried on under the direction of an engineer with much experience. Many large airplanes are now being developed in the United States, in each of which a modification of some type of structure herein discussed is exemplified. The airplane will not be increased further in size when the wing weight becomes such that it is no longer economical to build larger airplanes.

Considering the efficiency of present lift sections, or airfoils, a 30-pound per square foot wing loading is about as high as is desirable if a reasonable landing speed, even with the present auxiliary lifting devices, is to be maintained. Again, considering the limit of loading to be 30 pounds per square foot, it is believed that, with the present commercially available construction material and with the efficiency of the present airfoils and auxiliary lifting devices, a wing weight of 6 pounds per square foot is the limit for dead weight. From data available on the weight of large airplane wing structures, it appears that a weight of 6 pounds per square foot will be required in a wing having a span of 250 feet. It must be remembered that the ratio of wing weight to span does not increase as the first power or straight line function, but is parabolic.

In the design of large airplane wings, advantage is taken of the distribution of the weights of fuel, oil, engines, and cargo, in order to reduce the shear and moment along the span, since the weights of these items act in opposition to the air loads. When a load of 25 tons of fuel is carried, such an item is not to be overlooked in counteracting air loads if the wing weight is to be kept to a minimum. Of course, the spanwise distribution of these weights can not be carried too far, because increasing the mass moment of inertia of the airplane about the vertical and longitudinal axes would result in unfavorable, if not dangerous, handling characteristics. When the distribution of these weights has been taken into consideration in the design, any change in their distribution while the airplane is in service will lead to difficulty and perhaps to failure of the structure.

The design requirements for each particular type of airplane, besides being based on the expected usage, should be based on records, collected over a long period of time, showing the accelerations to which similar airplanes have been subjected. Such records are obtained by using a velocity-acceleration recorder, the instrument commonly called a V-G recorder. This instrument is a development of the National Advisory Committee for Aeronautics and is designed with a system of links connected to an operating a stylus that draws a diagram on a smoked glass. An accelerometer mass damped by a spring in either direction produces the vertical motion of the stylus, whereas the airspeed diaphragm, which is operated by the pressure in the pitot tube, furnishes the forces for the horizontal motion of the stylus. The V-G recorder is a valuable instrument for collecting data for research, but it is of no value as a guide in flying the airplane in which it is mounted because it is non-visual and is usually located at the center of gravity of the airplane. In many installations it is located out of reach of the pilot. The many V-G records collected during a period of several years show that the design requirements used prior to obtaining these records were not far wrong. Although the present military airplane has sufficient strength, as shown by these records, it is an easy matter to effect a complete collapse of the present-day airplane by rough handling of the controls. In fact, because of the different physical effects on the human body, it is very easy to misjudge the deceleration to which an airplane is being subjected. In one experiment in which the airplane was to be subjected to a deceleration of 8 g., it was by accident decelerated to 10.5 g. The over-controlling of this airplane shows how easy it is for the pilot to make an error in judgment because of the physical effects of accelerated forces upon him. It also indicates the urgent necessity for a visual type accelerometer to be mounted in the airplane so that the pilot will not need to depend upon his physical reactions. These instruments are more important in the larger airplanes, because of the lower load factors to which they are designed. Moreover, in the larger airplane there are more lives and a greater investment to protect.

With the increase in speed of the airplane came the annoying troubles of flutter and buffeting, which cause great concern. Flutter and buffeting are two subjects that are of first importance in the design of aircraft. Flutter may be defined as a force resulting from some mechanical or aerodynamic force, or from a combination of both these forces, and matching the natural frequencies of the different assemblies or parts of the airplane. Some of the common causes of flutter are rough engines; dynamically unbalanced propellers; and loose vertical, lateral, and horizontal control systems. In order for the designer to avoid flutter, the natural frequency of the different assemblies or parts of the airplane should be widely separated, the movable control surfaces should be dynamically balanced, and initial loads should be maintained in the control system. The maintenance of initial load in the control system will prevent any looseness in the system that might be effected by deformation of the structural members, which is caused by load and temperature changes.

Buffeting may be defined as a force caused by impulses set in motion by a disturbed airflow whose frequency matches the frequency of that assembly or part of the airplane in its path. The parts of the airplane usually affected by buffeting are the wing, tail surfaces, and, in some cases, the fuselage.

In order to avoid buffeting, the airflow should leave the surface undisturbed, and this may be accomplished by eliminating abrupt changes in section, unfaired projections, and aerodynamically unstable airfoils.

Forces caused by either flutter or buffeting are destructive if allowed to continue. Since the frequency of an engine or a propeller, or a combination of the two, as well as the disturbed airflow, will change with airplane speed, the engine speed should be reduced in order not to create destructive forces should flutter or buffeting occur and should it be recognized in sufficient time.

During the year of 1920 experiments were first undertaken to determine the possibility of supercharging an airplane cabin in order to maintain low altitude temperature and pressure conditions during flights at high altitudes. By 1922 sufficient flights had been made to establish the fact that airplanes carrying passengers and crew under pressure were entirely feasible, provided the mechanical details could be properly designed to operate under all conditions encountered during such flights. When these facts were established, the work on supercharged cabins was discontinued because of more urgent work. During the summer of 1935 it was decided to make an extensive study of cabin supercharging for high-altitude flying. When flying above 12,000 feet without supercharging, the occupants of the airplane should take oxygen into the lungs through a hose connected to an oxygen bottle and the mouth. To supply the lungs with oxygen in low pressure air by this method tends to lower both the physical and mental efficiency of the occupants. For this reason it was desired to undertake further research work on the supercharging of cabins. Another reason, directly connected with high altitude flying on the commercial airlines, was added when it was reported that a number of deaths of passengers had occurred in flight. It is not known whether all these deaths were caused from the lack of pressure. In order to avoid any accidents in supercharged cabin airplanes such as have occurred in foreign countries, many problems had to be considered. Most of these problems had already been investigated, but not with the thought of applying them to such an airplane. Some of these problems are: the effect on the structure of stresses due to pressure change, temperature change, flying stresses, bullet punctures, vibration, explosions, fogging or frosting of windows, frosting of regulating and safety valves, and failure of the exhaust-driven supercharger supplying air to the cabin. Many of these problems had not only to be studied, but experiments had to be conducted at both room temperature and room pressure, at higher pressures, and in cold chambers to check these details as they apply to the supercharged cabin airplane. The physiological investigations carried on were the most interesting, because little work had been done and much less had been written on this work. Some of these investigations were: the air required per passenger; pressure, temperature, and humidity control; ventilation; rate of discharge of air permissible; and oxygen spray in an emergency.

From experiments it was found that air contains the same amount of oxygen as far away from the earth as man has traveled as it does at the earth's surface. At sea level under standard conditions, oxygen enters the lungs of a man at a partial pressure of 159 mm. Hg., and the effect of the partial pressure of oxygen depends on the individual and the altitude. If sufficient altitude is reached there will be produced in any individual oxygen-want (anoxemia), unconsciousness, and finally death. If an altitude of 67,500 feet, where the pressure is reduced to 47 mm. Hg., could be reached without a supercharged cabin, the fluids of the body would begin to boil and, of course, the results would be fatal. In the supercharged cabin there will be gases, dangerous and annoying, to be either eliminated or controlled. The air inlet to the cabin supercharger, which is driven by engine exhaust, will be located far from the engine to avoid any carbon monoxide entering the cabin, and there will be no exhaust heater used. A carbon monoxide indicating instrument, similar to those used in mines, will be installed to determine the quantity of this gas at all times in case of a leak. This gas should never exceed the maximum allowable concentration of .005 per cent. Exhaust heaters will not be needed, because the heat of compression due to supercharging will be sufficient with the proper insulation of the cabin. The carbon dioxide may be eliminated from the cabin by ventilation or by chemical absorption, or by both of these methods.

A factor of importance is the sudden or instantaneous drop in pressure caused by a structural seam failure, the blowing out of a window, or the opening of the air-tight door. From such failures there is evidence that brain hemorrhages have resulted, and probably there would be marked disturbances of the lungs, intestines, and heart.

A multi-engined airplane with a supercharged cabin will be completed in April, 1937. It will be officially known as the XC-35 airplane, but unofficially, as the flying laboratory. When experiments are conducted with this airplane, there will be an increased demand for human guinea-pigs.

At the close of the War most people thought there would be no further use for the airplane. These people had good reasons for such thoughts after completing a study of the airplane at that time.

The efficiency of American-built airplanes has steadily increased, making them desirable for purchase by foreign countries. Today these countries would purchase, if such were possible, more commercial transport airplanes and fighting airplanes than this country is capable of building with its present facilities. The reason for the desire to obtain American-built airplanes is that they are second to none in performance, efficiency, and adaptability to production.

Some estimation of the advancement in the development of the airplane may be made when considering the high speed of 127 miles per hour for the pursuit airplane at the close of the War as compared to more than 300 miles per hour for this type airplane today. In making such a comparison, it must not be forgotten that the power required varies approximately as the cube of the speed, whereas the required strength varies as the square of the speed. Not only has the speed been increased, but the flying range has been increased also. This increase in performance came about as a result of research and development work, from which better design conditions and requirements were formulated.

Much credit should be given to the men who set such an ideal standard many years ago and whose work has resulted in this vast improvement in airplane design.

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