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TREND IN AIRPLANE DESIGN
AS INDICATED BY
APPROVED TYPE CERTIFICATES

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TREND IN AIRPLANE DESIGN AS INDICATED BY APPROVED TYPE CERTIFICATES

INTRODUCTION

Many important changes in the trend of airplane and airplane engine design are represented by the approved type certificates issued by the Aeronautics Branch of the Department of Commerce. These changes are concerned chiefly with detail of design, rather than with fundamental principles of aircraft engineering, and, in general, the theory of flight as applied more than a quarter of a century ago by the Wright brothers has been followed faithfully.

But if the changes are not fundamental, they are, nevertheless, substantial. In fact, the modern airplane bears only a family resemblance to the historical Wright biplane, and even within the comparatively brief period of time during which the Aeronautics Branch has been issuing approved type certificates, there have been many improvements and refinements.

It has been noted particularly that the speed of airplanes has increased since the first approved type certificate was issued by the Aeronautics Branch and to attain higher speed, designers have had to alter other performance characteristics or make concessions along other lines. For example, higher speed frequently meant less pay load carried, and the study shows that the average pay load in proportion to horsepower has been decreasing steadily.

Other changes represented attempts to achieve other ends. In a series of mathematical studies of approved type airplanes, both high speed and landing speed were considered, also wing loading, power loading, pay load in its relation to gross weight and to engine horsepower, the trend followed as to gross weight in general, the proportion of land planes, seaplanes, amphibians, and flying boats introduced, the proportion of open and closed designs and the proportion of monoplanes and biplanes. A mathematical study of engines disclosed the proportion of radial air-cooled, in-line air-cooled, V-type water-cooled, and V-type air-cooled types introduced. In addition to the mathematical studies, which included preparation of graphs, general observations as to trends in design practice have been made.

BASIS OF THE INVESTIGATION

On January 1, 1931, the Aeronautics Branch had issued approved type certificates for 390 airplanes and 65 engines. The first A. T. C. issued for an airplane was dated in March, 1927, and the first for an engine was issued approximately a year later. The airplane data, therefore, represent a period of time of slightly less than four years, while those for airplane engines are for somewhat less than three years.

As many of the airplanes and engines approved were designed either partially or completely before the policy of issuing approved type certificates became effective, the study might well be regarded as covering a period even longer than the four years from 1927 to 1930, inclusive. However, the graphical curves which have been drawn to represent the various trends studied begin, for airplanes, with the second quarter of 1927, and for engines, with the second quarter of 1928. Most of the graphs have been compiled with points plotted for each three months of the period of the study, making a total of 15 divisions for airplanes and 11 for engines.

The investigation is an impartial survey of the data as a whole and is not concerned with improvements or deficiencies in individual designs. For this reason no account is taken of the number of craft built under any certificate or of the perseverance with or aban-

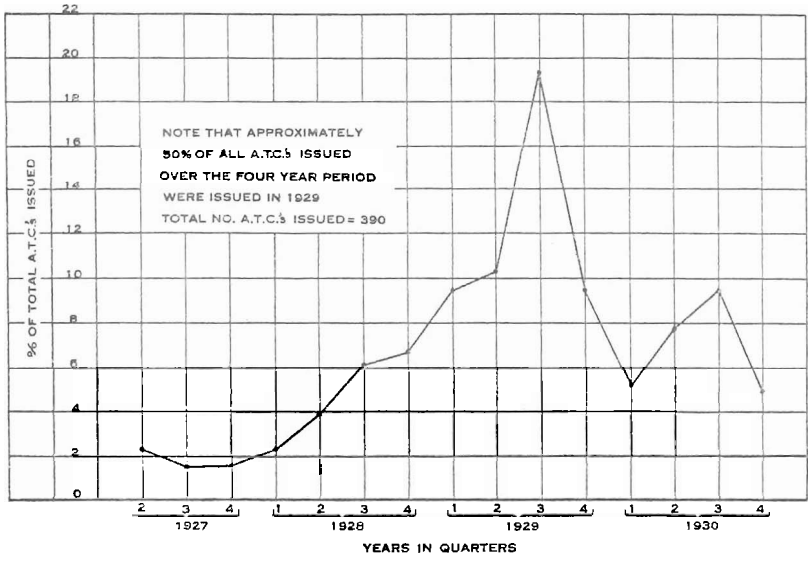

FIGURE 1.—Per cent of the total number of approved type certificates issued in each quarter of period studied

donment of any designs which have been approved. Instead, each approved type of airplane or engine is considered once with respect to each of the several phases of designing considered, and the study as a whole is believed to represent in a general way the ideas of all the engineers who contributed to the development of the types involved.

The various approved type airplanes and engines were introduced by 140 concerns. Many of the approved products no longer are manufactured, but in most cases the plans for discontinued types formed the basic files for other models approved subsequently.

AIRPLANES

There was a steady increase in the number of approved type certificates issued for airplanes up to the end of the second quarter of 1929. (See fig. 1.) In the third quarter of 1929 there was a marked increase,

and approximately 19.2 per cent of all approved type certificates issued during the period of the study were issued in this quarter. Following this peak there was a decrease in number of approvals as abrupt as the climb was steep. The curve in Figure 1 continues to drop until reaching the end of the first quarter of 1930, varies through the remainder of 1930, reaching a peak in the third quarter and dropping again in the fourth quarter. About 5 per cent of the total number of certificates were issued in the final quarter of 1930.

The curve reflects the reactions of the industry to general business conditions and events such as an important program of air races or an aircraft exposition. Under requirements for many of the races, entrants must fly airplanes manufactured in accordance with approved type certificate data. The data received preceding such events, and the approvals resulting therefrom invariably exceeded the number for other periods of the year.

The trend of volume of applications during the 4-year period is not a definite one. The curve of Figure 1 starts with about 2 per cent of the total issued in the second quarter of 1927, drops slightly, and then rises with some irregularities to the peak in the third quarter of 1929. After an abrupt drop in the fourth quarter of 1929 and the first quarter in 1930, the curve rises again, and then falls for the final three months of 1930.

This curve is of value chiefly as a supplementary index to the other mathematical studies, as a comparison of Figure 1 with any one of the subsequent graphs concerning airplane design will show the reader approximately how many models are involved in any particular section of one of the latter curves.

POWER LOADING AND WING LOADING

The average weight supported by each unit of horsepower of the airplane engine has decreased during the period of the study, and at the same time the average load carried by each square foot of wing surface has been increased steadily. (See fig. 2.) The curves representing these two trends are irregular, but nevertheless, the indications are definite. Also, both curves are remarkably like the curves for high speed and for landing speed in Figure 5. These resemblances are discussed under the heading Average Top Speed and Average Landing Speed.

The trend in power loading was downward in nearly all of the quarters. In only four quarters were there any increases, and in one the level remained constant. The tendency toward lower power loadings indicates the development of higher-powered engines, with resultant higher speeds and maneuverability. In terms of load factors, lower power loading means higher factors required, which in turn has called for careful design.

As an illustration of this trend in terms of the airplane market, it may be pointed out that many airplanes originally equipped with, say, 200-horsepower engines have been revised in design until the same models, with the same seating capacity and pay load, now are equipped with engines developing as much as 450 horsepower. For another airplane the increase may have been from 90 to 225 horsepower; the increases represent a number of different horsepower ratings.

While power loading was decreasing (because of the increase in power of engines), wing loading was increasing, and the two trend were directly opposed to each other. In quarters when the curve representing average power loading dropped, the corresponding curve for wing loading increased, and vice versa, with a few exceptions.

When engine horsepower has been increased, there always has been an increase in gross weight, but usually the wing area has remained the same. This has resulted in higher landing speeds and more highly stressed structures. In substantiating increases in gross weights, designers may increase the wing area, but this, of course

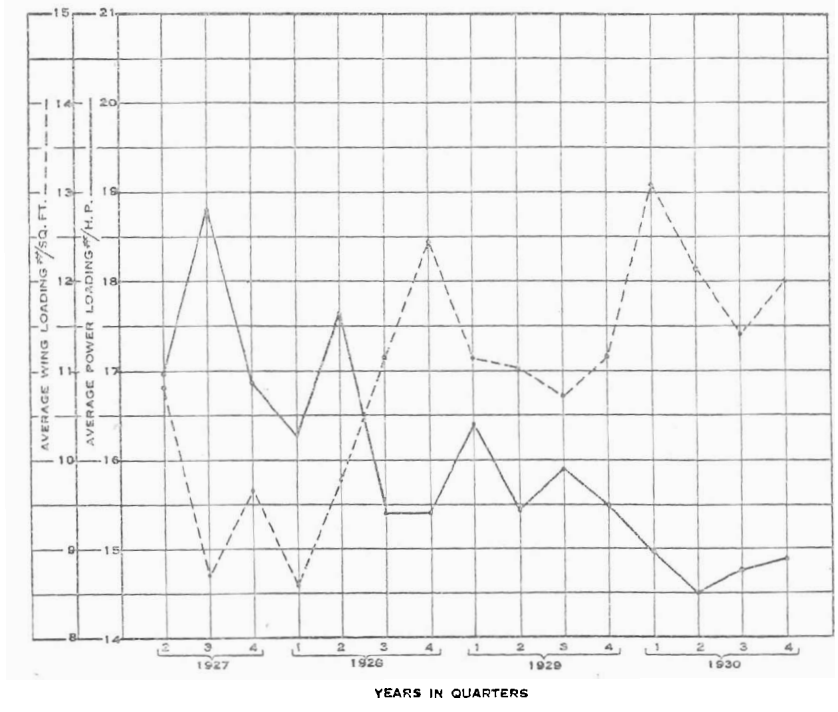

FIGURE 2.—The average wing loading of approved type airplanes increased while the average load carried by each unit of horsepower declined

would reduce the high speed. In most cases, therefore, engineers have kept the wing area constant under these circumstances, even at the expense of a somewhat higher landing speed, and higher wing loadings.

AVERAGE PAY LOAD IN PER CENT OF GROSS WEIGHT AND AVERAGE PAY LOAD PER HORSEPOWER

The ratio of pay load to engine horsepower is a measure of the economy of a design. An airplane owner can compute the purchase cost of his craft per engine horsepower, and the maintenance and operation cost per horsepower. The airplane's pay-load capacity, whether it represents actual or potential income, or merely seating space for pleasure flying, must be in reasonable relation to cost per

horsepower, or air transportation in the one case will prove to be a poor investment and in the other an overexpensive pastime.

For approved type airplanes, the average pay load carried has decreased steadily, in proportion to the horsepower. (See fig. 3.) The average was highest in the third quarter of 1927, soon after the beginning of the period covered by this survey, fell off sharply in the next two quarters, recovered slightly, and then continued downward until 1930. In the fourth quarter of 1930 there was a notable recovery.

Pay load in per cent of gross weight is a measure of efficiency of design, the most efficient design being that in which the greatest percentage of the gross weight represents pay load. This does not mean that an airplane built for very high speed with a small pay load is necessarily poorly designed, since such a craft may serve admirably

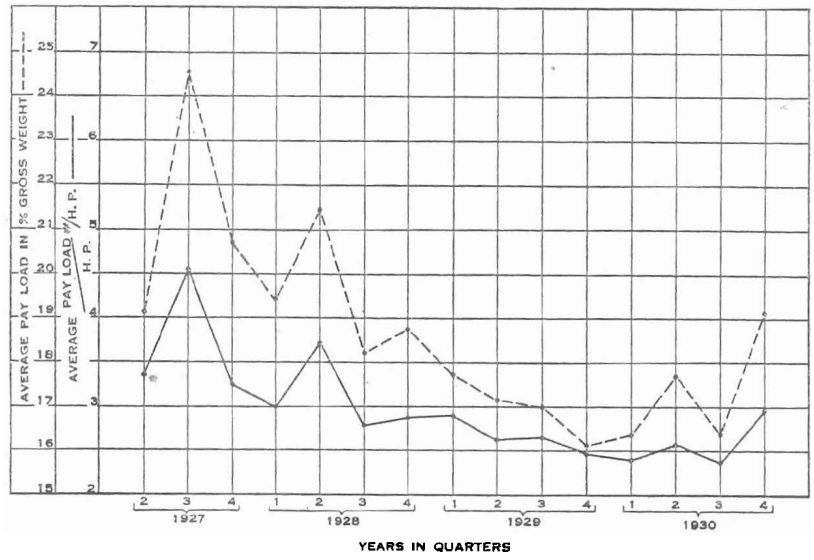

FIGURE 3.—Average pay load in per cent of gross weight and average pay load in proportion to horsepower both declined during the 4-year period

for its intended purpose, but at the same time it is not an efficient load carrier, and there is a practical limit to this type of designing even when it is conceded that speed is to be considered as more important than amount of load to be carried.

The curve in Figure 3 representing average pay load in per cent of gross weight shows that the trend in this phase of designing has been downward since the third quarter of 1927. The curve presents an appearance almost identical with that of the curve representing average pay load per horsepower, as was to be expected, and the recovery in the last quarter of 1930 for the latter trend was duplicated for average pay load in per cent of gross weight.

An additional study of these two trends with regard to their operation in airplanes of various weights between 1,500 and 24,500 pounds is illustrated by the curves in Figure 4 (*A* and *B*), plotted for airplanes of over 10,000 pounds approved in 1929 and 1930 and planes 10,000 pounds and under approved in 1930. In general, it

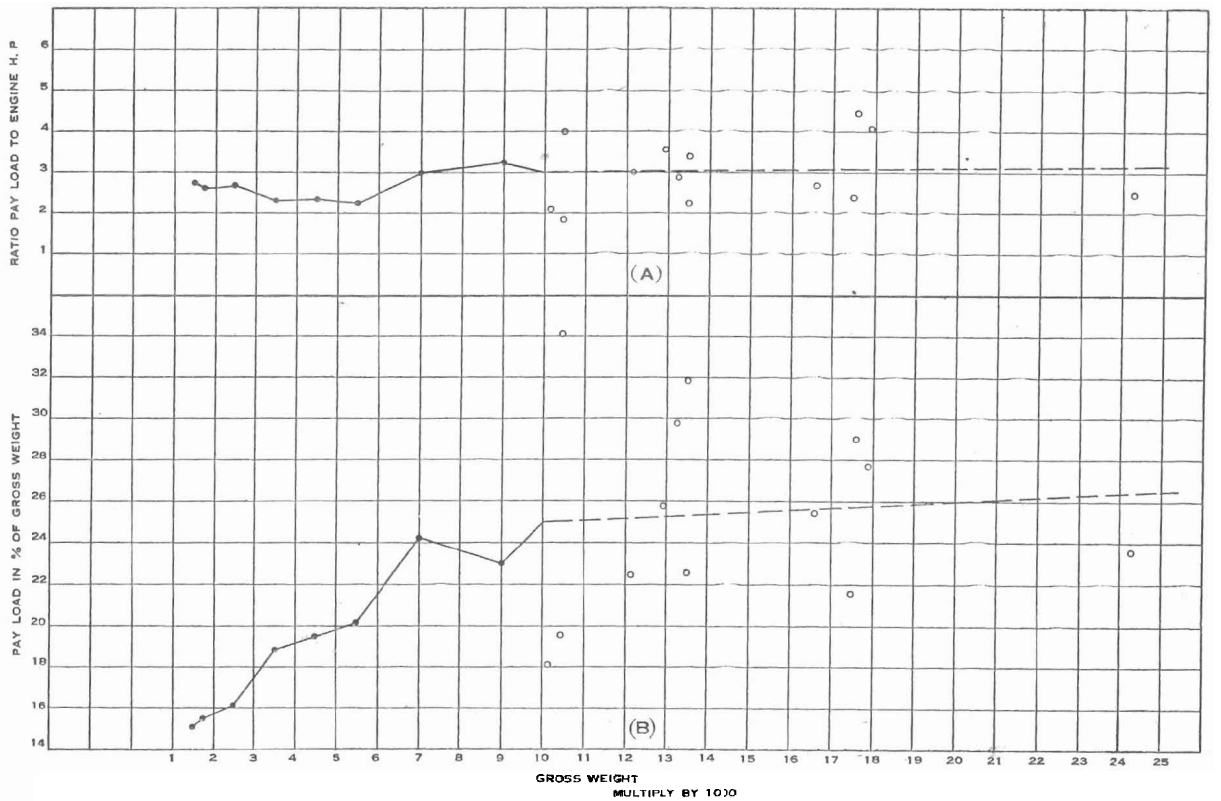

FIGURE 4.—Ratio of pay load to engine orsepower (*A*) and pay load in per cent of gross eight (*B*) for approved type airplanes of different sizes. Dots on the two curves represent averages for planes un r 10,000 pounds approved in 1930. Planes over 10,000 pounds approved in 1929 and 1930 were plotted directly and are represented by small circles. The broken lines indicate can lines fo nlanes over 10,000 pounds

was found that the larger airplanes were most economical and most efficient, with regard to the ratio of pay load to engine horsepower and pay load in per cent of gross weight.

The smallest types of airplanes were found to have the lowest average ratios for pay load as compared with engine horsepower. For airplanes of 5,000 pounds gross weight and upward the ratio is approximately 3, with a very slight increase upward as planes of larger weights are reached by the curve.

For pay load in per cent of gross weight, it was found that the smallest planes were the least efficient. For airplanes weighing up to 5,000 pounds, the average varied from 15 to 20 per cent, with the heavier planes rating as most efficient. Above 5,000 pounds there was less variation, but the percentage climbed gradually as planes of greater gross weight were considered.

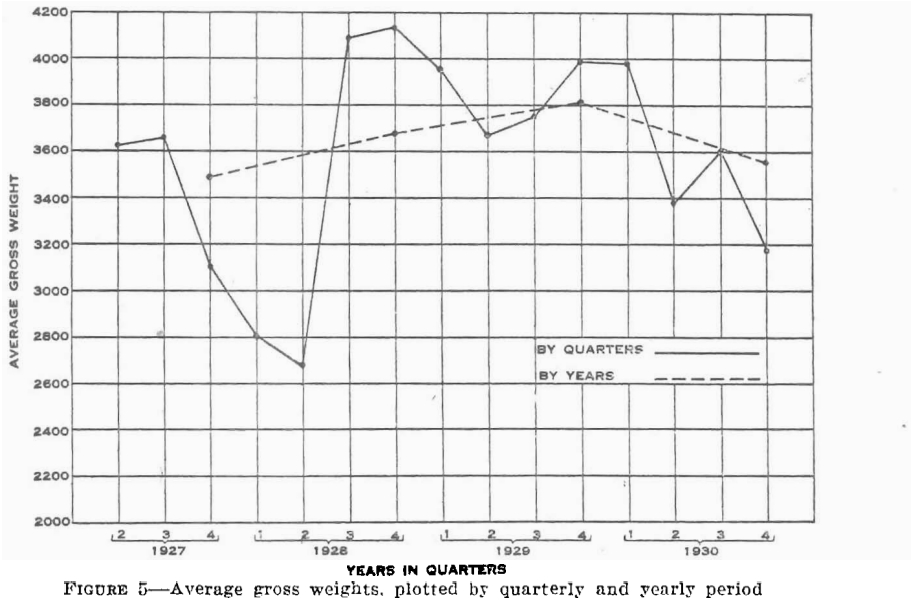

FIGURE 5—Average gross weights, plotted by quarterly and yearly period

These two trends probably are accounted for by the fact that the heavy planes are transport craft which are built primarily for carrying loads, while the smaller airplanes, designed to carry one or two passengers, are not built with so much attention to the amount of weight that may be carried. Nevertheless, the results of this phase of the investigation of approved type airplanes are interesting in view of the theory that the efficiency of heavier-than-air craft must necessarily decrease as their size is increased. While the conclusions drawn from the present survey may not disprove the theory, they do indicate that designers have not yet encountered the difficulties that it forecast.

GROSS WEIGHT

There was considerable variation in the gross weights of airplanes submitted for approved type certificates. There was a slight increase in the average gross weight until the end of 1929, after which the average dropped somewhat. In Figure 5 average gross weights

have been plotted by quarters, and by yearly periods, the trend revealing itself more clearly in the latter curve. The average weight at the beginning of the period was a little less than 3,600 pounds, dropped to less than 2,800 in the second quarter, advanced to more than 4,000 pounds, and then dropped irregularly to about 3,200. These are averages for quarterly periods, of course, and the averages represent some planes weighing less and more than the limits mentioned.

HIGH SPEED AND LANDING SPEED

The average high speeds of airplanes that were granted approved type certificates between 1927 and 1930 showed a steady increase within the approximate limits of 101 miles an hour and 137 miles an hour. (See fig. 6.) These limits, as well as other values for the curves in Figure 6, are referred to as approximate because of the

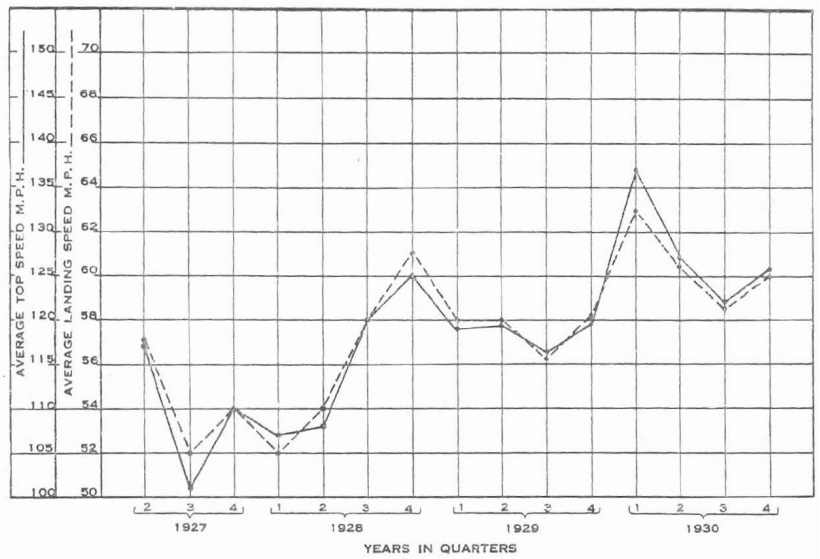

FIGURE 6.—Average high speed and average landing speed increased irregularly but persistently

fact that the averages were based upon approximate calculations of the speeds of individual airplanes. They are presented, therefore, only as indicating the general trend.

The trend in top speed during the years 1927–1930 was irregular, and the curve representing this increase has many fluctuations, but throughout the entire period there was a clearly defined tendency toward increased speed. The lowest point on the curve indicating this trend was plotted at 101 miles an hour and the highest at 137. At the beginning of the period the average top speed was 117 miles per hour. It dropped to 101 in the third quarter of 1927, climbed to a peak of 125 miles an hour in the fourth quarter of 1928, then dropped again and climbed to a high peak of 137 in the first quarter of 1930. At the end of the period the average top speed was 126.

Thus, it will be seen that the actual increase in average top speed from 1927 to 1930 for new airplanes that received approved type certificates was approximately 10 miles an hour, although the average varied during the period through more than 35 miles an hour. The

most interesting feature of this trend, however, is that it has been persistently upward. From the third quarter of 1928 to the end of 1930 there was never a time when the average top speed dropped below the level of 117 miles per hour that represented the average top speed at the beginning of the 4-year period.

Average landing speed took exactly the same trend as did average top speed, bearing out the established principle that these two performance characteristics are definitely related to each other, and that when top speed is increased, allowance must be made for a proportionate increase in landing speed, unless the additional top speed is gained by some means which do not affect the power loading and wing loading.

In the first quarter of the period studied the average landing speed was approximately 57 miles an hour. It dropped to about 50 in the next quarter and then climbed irregularly to a peak of approximately 63 miles an hour in the first quarter of 1930. At the end of 1930 the average landing speed was approximately 60 miles an hour.

A factor in airplane design that is related closely to top speed is average wing loading. In the types considered in this study the trend for wing loading and those for high speed and landing speed have been almost identical. A comparison of the two curves for speed in Figure 6 and the curve for average wing loading in Figure 2 will show that the three curves are almost exactly alike—descending and ascending in the same quarters. When designers have increased the speed of their planes, they have increased the load on each square foot of wing area, and when they have planned airplanes which were not to have so much speed, they have been able to put a lighter load on the wings.

The other curve in Figure 2 is interesting for its contrast with the speed curves. Not only has average power loading declined as speed has increased, but also minor variations in the speed curves appear inversely in the power-loading curve. Other factors were at work here, as there were some quarters in which speed and power loading increased or declined together, but, in general, the inverse principle held true.

Another comparison with the speed trend may be made with regard to average pay load in per cent of gross weight and average pay load per horsepower. A comparison of Figure 6 with Figure 3 shows that while speed was increasing, both pay load in per cent of gross weight and pay load per horsepower were decreasing. In this case there were more deviations than there were between the trends for speed and those for wing and power loading.

In the first part of 1929, while average speed of the new types was decreasing, the average pay load in per cent of gross weight and average pay load per horsepower also decreased. The decrease in the case of pay load was comparatively slight however, while the decrease in speed for those quarters was fairly substantial.

In the last quarter of 1930 there was an increase in speed, and at the same time a marked increase both in average pay load in per cent of gross weight and average pay load per horsepower. This would seem to indicate careful and efficient designing, since it is normal for an airplane design to lose some pay-load capacity in gaining speed.

LANDPLANES, SEAPLANES, AMPHIBIANS, AND FLYING BOATS

Landplane types predominated throughout the entire period, accounting for more than 80 per cent of the total number of certificates issued in each of the 15 quarters. (See fig. 7.) This is not to be taken as a reflection upon the value of aircraft built to operate from water, but at the same time the study of seaplane data showed that the number of seaplane types approved was about 10 per cent of the total and a similar study of amphibians revealed that about 5 per cent of the approved type certificates were for planes that were built to operate from land or water. The number of flying boats approved was so small that there is little basis for comparison. In Figure 7 only three points could be plotted for flying boats, one in 1928 and two in 1930.

Some of the craft approved were convertible—to be used as either landplanes or seaplanes—and therefore might have been considered

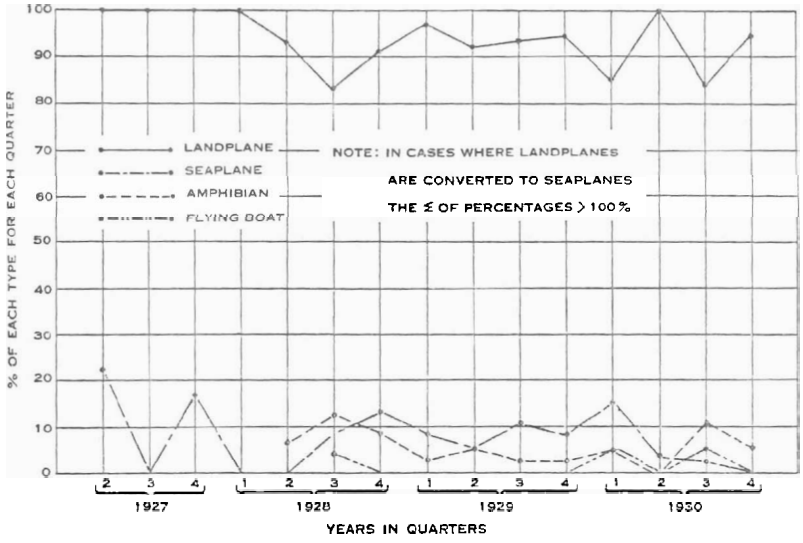

FIGURE 7.—Per cent of landplanes, seaplanes, amphibians and flying boats approved in each quarter

as being in either class. They were included in both curves, and when this was done it resulted in the sum of the percentages being greater than 100 per cent.

OPEN AND CLOSED AIRPLANES

At the beginning of the period open-cockpit planes led cabin planes by a large margin. About 80 per cent of the craft approved in the first quarter (the second three months of 1927) were open and 20 per cent closed. However, in the next quarter there was an even division between the two types, and during the remainder of the period the division was nearly equal, with open types leading by a small per cent in most quarters. The number of open types was exceeded by the number of closed types in only three quarters, the third and fourth in 1928 and the second of 1930. Throughout the period, the average percentage of open types was about 55 per cent and for closed types 45 per cent. (See fig. 8.)

MONOPLANES AND BIPLANES

Monoplanes have experienced a decided increase in popularity at the expense of biplane types among aircraft receiving approval by the Department of Commerce. In the second quarter of 1927

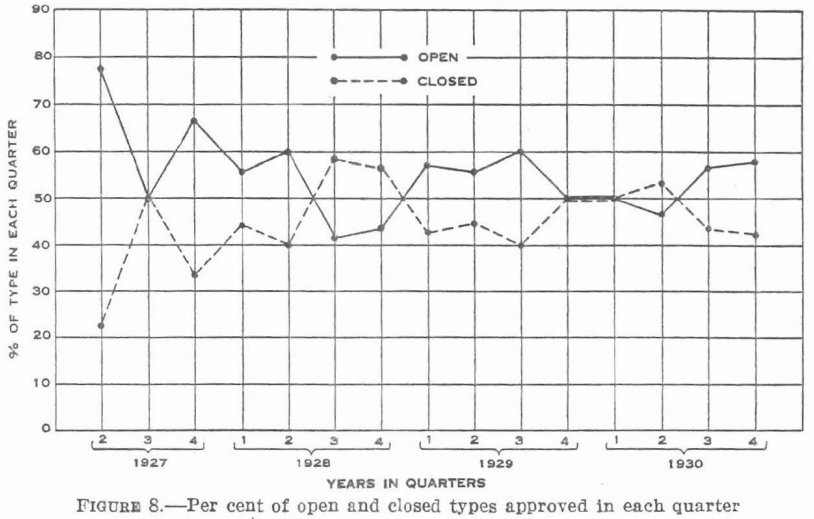

FIGURE 8.—Per cent of open and closed types approved in each quarter

about 80 per cent of the airplanes approved were biplanes, and in the following quarter all of them were biplanes. From then on

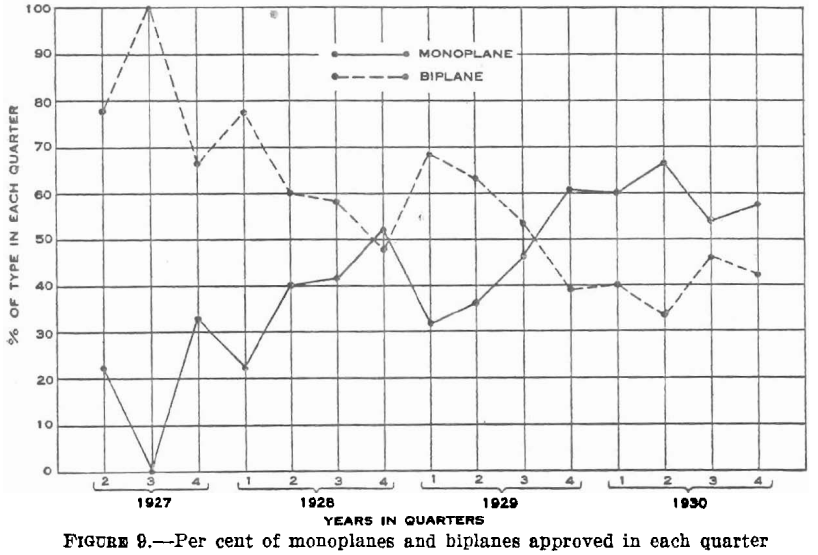

FIGURE 9.—Per cent of monoplanes and biplanes approved in each quarter

the percentage of biplanes decreased steadily, with slight recoveries in certain quarters, while the percentage of monoplanes mounted. (See fig. 9.)

The number of monoplane types approved exceeded the number of biplanes for the first time in the fourth quarter of 1928. Biplanes

then took the lead again and held it for three quarters, whereupon monoplanes again went ahead and remained the majority type until the end of the period under consideration. The greatest lead of monoplanes over biplanes was in the second quarter of 1930, when about 65 per cent of the approved types were monoplanes and about 35 per cent biplanes. In the final quarter of 1930, some 58 per cent of the total were monoplanes and about 42 per cent were biplanes.

ENGINES

The 65 types of engines approved by the Department of Commerce in 1928, 1929, and 1930 included radial air-cooled, in-line air-cooled, V-type water-cooled and V-type air-cooled. Radial air-cooled types were most numerous, and the others followed in the order named. Only one V air-cooled engine was approved, and this was in the fourth quarter of 1930. The curves representing the trends in engines are shown in Figure 10, and are based upon actual numbers of approvals, rather than percentages.

V-type water-cooled engines were in second place at the beginning of the period—the second quarter of 1928—but no engines of this type were added to the approved list after the first quarter of 1929. With the disappearance from the field of the V-type water-cooled engine, the in-line air-cooled type sprang into prominence, and this type was second in number to the radial air-cooled type for the remainder of the period. In two quarters—the second of 1929 and the third of 1930—there were more approvals for in-line types than for any other type.

The trend toward in-line types is significant in that it is indicative of the effort of designers to contribute to higher top speed by the reduction of frontal area. In many cases they have turned to the in-line engine with this object in view, and designers who continue to use the radial air-cooled engines are inclosing them with special cowling for the same purpose.

The approved type list includes engines ranging from a unit of 3 cylinders rated at 30 horsepower to one of 12 cylinders with a rating of 800 horsepower.

GENERAL OBSERVATIONS

Studies of the data submitted by manufacturers have revealed many tendencies that are not covered in the mathematical studies, because they either did not lend themselves to that type of survey or were so pronounced that such treatment was unnecessary to determine trends.

METAL CONSTRUCTION

Notable among these was the trend toward metal construction. Metal tubing has been used freely for fuselage construction and stamped metal parts have been employed less frequently for such parts as wing ribs. Other metals that are being adopted for use in airplanes include stainless steel and alloys of magnesium. The former is used chiefly for pontoons and hulls of seaplanes, flying boats and amphibians, and is favored because of its resistance to corrosion.

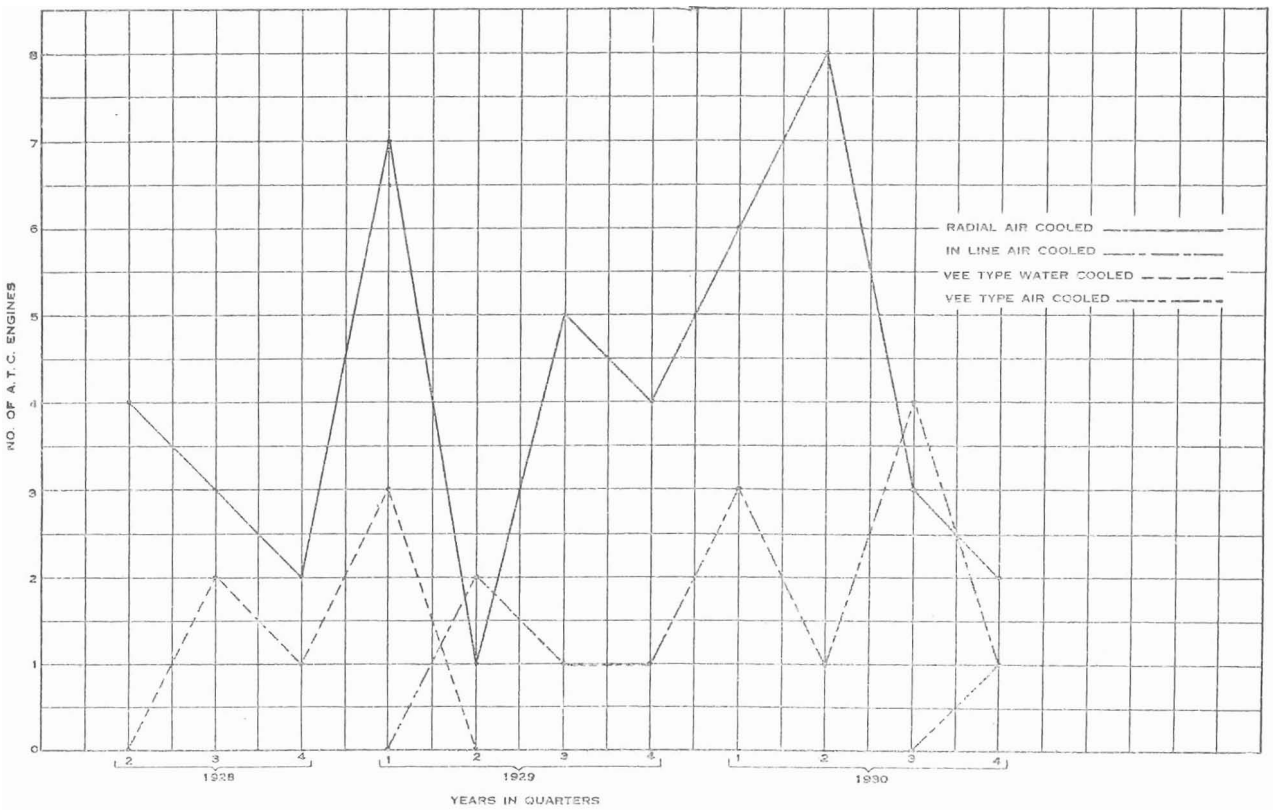

FIGURE 10.—Per cent of radial air-cooled, in-line air-cooled, V-type water-cooled, and V-type air-cooled engines approved in each quarter, from the second quarter of 1928 to the end of 1930

A type of construction that has appeared in several new designs is the metal monocoque fuselage—a fuselage built of metal framework with sheet-metal covering, and depending upon this covering for a part of its strength. This has been made possible by the adaptation of corrugated and flat sheet metal to use in aircraft.

LIGHT AIRPLANES

Toward the end of the period of the study, the Aeronautics Branch began to receive applications for approved type certificates for very light, low-powered airplanes—designed for production in quantity and sale at low prices. In the first month or so of 1931—after the end of the period of the study itself—the number of applications for craft of this type increased, pointing to an attempt by airplane builders to supply craft for pleasure flying by those who can not afford the more powerful and more expensive types of airplanes.

The Aeronautics Branch, in its Airworthiness Requirements of Air Commerce Regulations for Aircraft, has defined light airplanes for the purpose of licensing and inspection. The requirements say that these craft, "* * * when equipped with engines not of an approved type, are defined as heavier-than-air aircraft of less than 1,000 pounds gross weight, with a maximum wing loading of 5.5 pounds per square foot, and having at least 5 square feet of wing area per engine horsepower. When equipped with engines of an approved type, airplanes of less than 1,000 pounds gross weight may be classed as light airplanes if the wing loading does not exceed 6 pounds per square foot and the ratio of wing area to horsepower is not less than 4."

Several manufacturers have offered these light airplanes to the public, and others are preparing to do so as this is written. The light airplanes usually have large wing area, affording short runs for take-off and slow landing speeds and making it possible for their pilots to use small fields. Their economy of operation lies in part in their small size, and also in the fact that their engines are of low horsepower.

LANDING GEAR

A development of particular interest to airport managers is that tail skids are disappearing and are being replaced by landing wheels at the tails. This has been made possible by the success that has attended the use of brakes on the main landing wheels. Tail wheels are equipped either with hard or pneumatic tires.

Designers have turned almost universally to shock absorber units to replace the old assembly of wheel mounting wound around with rubber shock cord. The shock absorbers have compression units employing rubber, or they may be hydraulic, oil, or air shock absorbers.

The increased use of skis points to greater use of airplanes in winter when operations must be conducted over snow and ice. Combination wheels and skis, for use on airplanes that must take off from snow or ice and land on bare ground, or vice versa, have been introduced.

PROPELLERS

The trend in propeller construction has been toward metal types for large aircraft of great horsepower. For smaller airplanes,

particularly those having engines of less than 100 horsepower, the wooden propeller has been most favored. This situation is due, doubtless, to the fact that the large airplanes include the transport craft which are operated daily on frequent schedules, so that it is necessary for their owners to consider durability of propellers. For the smaller planes, which do not fly so regularly, the wooden propellers appear to have been chosen more frequently because of their lower cost.

Considerable research has been directed toward the development of controllable pitch propellers. These propellers are designed to provide varying angles of attack for the surfaces of the propeller for taking off, climbing, and cruising. Another line of research along which propeller designers have worked looks toward the development of hollow steel blades.

COMFORT AND CONVENIENCE OF PASSENGERS

The effort to achieve comfort and convenience in airplane cabins has been most marked in designs for air transport operations, but it has not been missing from designs of other types. Many ideas along this line were borrowed from automobile and railroad-car designers.

Large transport planes now have in their cabins comfortable reclining chairs, reading lights, lavatories, racks for coats and packages, adequate ventilating facilities, and sometimes kitchenettes. Their interior fittings have been designed by competent interior decorators so that they will be attractive as well as comfortable. Smaller cabin planes have as many of these things as may be practicable. Private owners frequently have their cabins decorated to suit individual tastes.

CONCLUSION

The trend of design in aircraft naturally follows lines suggested by operation and use of aircraft, for if designers neglected these suggestions they would find no market for the products of their talent and skill. Air transportation is sold primarily upon the basis of its speed and directness of route. These are the greatest advantages it has over other forms of transportation, whether one is thinking of transportation of passengers, mail, and express over scheduled lines, or of the other uses of airplanes such as aerial photography and surveying, emergency trips away from the airways and the like. In addition, flying is a sport, and in this phase of flying speed is one of the attributes that makes it attractive.

All this being true, it follows naturally that designers should seek for means of increasing the speed of aircraft built from their plans, and the results of this study indicate that they have done so. As has been seen, however, they have encountered a number of difficulties, one of their chief problems being that of pay load. Already designers have, in many cases, sacrificed pay-load capacity to attain greater speed.

The use of more powerful engines to achieve greater speed has resulted in a decrease in power loading, and at the same time wing loading, in general, has become greater. Pay load has become less in per cent of gross weight, and less in proportion to horse power.

The larger airplanes were found to be most efficient from the standpoint of pay load.

Gross weights varied widely throughout the period of the survey, but there was no decided trend upward or downward. Average high speed and average landing speed increased.

Landplanes were most numerous among designs submitted for approved type certificates, amounting to more than 80 per cent of the total. Next in order were seaplanes, followed by amphibians and flying boats.

Open-cockpit designs led in numbers by a large margin at the beginning of the period of the study, but cabin designs gained in popularity so that the open designs amounted to only slightly more than half of the total for the four years.

Biplanes were more numerous than monoplanes among early applications, but monoplane designs exceeded the others toward the end of the period.

Among engines, radial air-cooled types were submitted most frequently with in-line air-cooled, V-type water-cooled and V-type air-cooled following in the order named.

Other trends noted in the study were increased interest in metal monocoque fuselage construction, a leaning toward the light airplane as a product for the private owner market, increased use of wheel brakes with an accompanying replacement of tail skids by tail wheels, increased use of skis, and continued effort to augment the comfort and luxury of cabin interiors.

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