DESIGN CHARACTERISTICS FOR MOST SUITABLE PURSUIT AIRPLANES

(AIRPLANE SECTION REPORT)

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OBJECT OF STUDY.

The selection of the most suitable engine, wing section and wing loading to obtain the most desirable performance for single-seater, low-altitude, water-cooled, pursuit airplanes.

SPECIFICATIONS.

General Mitchell, in a letter of July 10, 1922, proposed the following specifications:

- Military load: 450 pounds
- Fuel supply: 3½ hours
- Ceiling: 20,000 feet
- Velocity at 15,000 feet: 155 miles per hour

This analysis, however, was made on the basis of a military load of 525 pounds, corresponding to that previously used, and fuel supply sufficient for running one-half hour full speed at the ground and 3 hours full speed at an altitude of 15,000 feet.

CONCLUSIONS.

To increase the speed of the airplane (even at 15,000 feet) it is necessary to sacrifice a certain height of ceiling. The best compromise is obtained by use of minimum parasite area, light wing loading (less than 8 pounds per square foot) and thin wing sections. The Fokker D-8 tapered wing section, however, gives very good performance, and structural considerations might make the selection of this wing section more suitable. Thick untapered wing sections, contrary to the often expressed belief, do not give as good a performance as the thin wing sections. Likewise the tapered U. S. A. 35 did not give a satisfactory performance. The reason for this is that the thick wing sections have such a high minimum drag that it is much better to use strut and wire construction, and the consequent increase in parasite drag, than to increase the minimum drag of the wing by use of the thick wing section, because the additional parasite drag of struts and wires is not so great as the additional minimum drag of the thick wing section.

The Curtiss D-12 is theoretically the best engine if consideration is given the low parasite area demanded by this engine. A performance at altitude was assumed in the calculations of at least the same efficiency as the Wright H-2 motor. No altitude chamber tests have as yet been run for the Curtiss D-12, so exact figures are not obtainable.

The results are summarized in figure 1, where ceiling is plotted against velocity at 15,000 feet, for various wing loadings and wing sections. Calculations are based upon model results, no allowance being made for scale. However, in order to arrive at some idea of the performance to be expected, the performance of the MB-3 is calculated by the same method and plotted against actual performance, showing that the performances indicated by the chart are conservative for the parasite areas assumed (smaller than that of the MB-3) and may actually be obtained.

The conclusions above apply likewise to airplanes built about the Wright H-2 and Liberty engines.

ANALYSIS.

There have been many performance formula calculated for the selection of wing sections and wing loadings suitable for use in airplanes of different types, but they are all so approximate or difficult to apply that another method of attack seems to be desirable. Consequently, it was decided to make a study of the design characteristics most suitable for use with one special type of airplane, and the single-seater pursuit was selected. In order to arrive at some basis of attack, it was decided to compare airplanes built about three engines—the Liberty 12, Wright H-2, and Curtiss D-12. It is impossible to use these engines in airplanes of the same weight. Consequently, the weight of the structure was selected from types already in existence about the Wright H-2 motor and calculations made for use with airplanes built about the other two motors. It has been demonstrated that it is possible to build a structure weighing 550 pounds about the Wright H-2 motor. The weight of motor, water, radiator, and accessories is 950 pounds; the weight of gas and oil for the specified duration is 350 pounds; and the plane 2,380 pounds. It is assumed that the weight of the structure about the Liberty 12 and the Curtiss D-12 will be in proportion to the total weight of the airplane, and on this assumption the weight of the structure would be 593 and 572 pounds, respectively. The weight may be tabulated as follows:

<table>
<thead>
<tr>
<th>Engine</th>
<th>Weight of engine, radiator, and accessories, pounds</th>
<th>Gas and oil, pounds</th>
<th>Military load, including pilot, pounds</th>
<th>Weight of structure, pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wright H-2</td>
<td>450</td>
<td>350</td>
<td>350</td>
<td>2,300</td>
</tr>
<tr>
<td>Liberty 12</td>
<td>2,999</td>
<td>1,929</td>
<td>572</td>
<td>2,502</td>
</tr>
<tr>
<td>Curtiss D-12</td>
<td>1,020</td>
<td>380</td>
<td>693</td>
<td>2,599</td>
</tr>
</tbody>
</table>

In order to calculate the ceiling, it is necessary to determine the minimum horsepower required and the angle of attack at which this is obtained. The ordinary formula for horsepower required may be placed in this form

\[ 550 H_{P} = \sqrt{\rho \rho_{o} I_{e} Max. \left[ \frac{64 A_{P}}{L_{e}^{1/2}} + \frac{D A}{L_{e}} \right] \rho_{o} I_{e} Max. V_{L}^{3} } \]

where \( V_{L} \) is the landing speed in foot-seconds.
The angle of attack which makes this expression a minimum for a given wing section is that which makes the expression in the brackets a minimum and does not vary with altitude, although the minimum horsepower required does vary as the square root of $\frac{\rho_1}{\rho_0}$.

The expression in the bracket is a minimum when

$$[\frac{64 A_p W}{L_p^2} + \frac{(D)}{W}]$$

is a minimum, and consequently a value of the parasite area and wing loading must be assumed. It seems very probable that a parasite area of 4½ square feet may be used for an airplane built about the Curtiss D-12 motor and R. A. F. 15 wing section. Five and eight feet may be adopted as the parasite areas for airplanes built about the Liberty and Wright H-2, respectively. It is also assumed, to insure a fair basis of comparison for thick wings, that the Fokker D-8 wing section can be used with a reduction of parasite area of one-half square foot and that the Gottingen and U. S. A. 35 sections may be used with a reduction of parasite area of 1 square foot. The Slane is so thin that it will be necessary to add at least 75 pounds to the weight of the spars to give the requisite strength. These considerations make it necessary to make an estimate of the ceiling with variation in parasite area, wing loading, and weight. Having obtained by calculation the angle of attack for minimum horsepower and the horsepower required at the ground for this angle of attack, it is possible to assume a constant propeller efficiency at speed of minimum power required of, say, 62 per cent for the various engines and plot a curve of power available at various altitudes from the engine horsepower data given in Serial 1743. By using the chart of densities given on page 2, Appendix F, in Serial 1147, a ceiling may be determined by the equation of

$$HP_1 = HP_0$$

It was found that within the limits assigned to parasite area and wing loading the angle of attack for minimum horsepower required remains constant for a given wing section; and the calculation was thus much simplified, it being necessary only to compute the horsepower required at this angle for various parasite areas, wing loadings, and weights. These results are given in Figure 2 for a weight of 2,500 pounds and Figure 3 for weights of 2,500 and 2,700 pounds for the Curtiss D-12 motor. The Curtiss D-12 motor was selected because it gave the best ceiling with each wing section considered, namely, U. S. A. 27, R. A. F. 15, U. S. A. 35, and Gottingen 387, the values about the R. A. F. 15 being given in Figure 4.

In order to complete the study a calculation was made of the speed and rate of climb at 15,000 feet. In each case the Curtiss D-12 was found to give the best performance, the values of each for an airplane about the R. A. F. 15 with each engine being given in Figures 5 and 6. In making the calculations propeller efficiency of 81 per cent was assumed for each engine and the same power available curve was used in determining the ratio of climb, the propeller being supposed to give maximum efficiency at high speed.

In comparing results, it was found that three wing sections only need be considered—the Fokker D-8, R. A. F. 15, and Slane, the latter wing being added to the calculations when it was found that it gave a better performance than the other wings at first considered. Figures 7 and 8 give the results for maximum speed and rate of climb at 15,000 feet.

A final chart was made for the increase of ceiling obtainable with a 10 per cent increase in power, in order that the ceilings might be calculated with high compression engines or with propellers designed for their greatest efficiency at ceiling velocity. The results are given in Figure 9.

From those charts it is possible to calculate the increase in ceiling, speed, and rate of climb, with variations in parasite area, wing loading, weight, and power of the motor, or propeller efficiency.

The conclusions obtained, so far as they relate to the variations in performance with slight changes in design characteristics, will be quite accurate in spite of the fact that the scale effect has been neglected. The actual performance obtained may not be accurate. Neither can a method of obtaining accurate data be indicated until more data has been obtained with reference to the variation due to scale effect. The lift of the thick wing sections seems to increase up to a VL of 80 or 100 and then decrease, so that the final result for full scale is about the same as VL of 30 or 40. The drag decreases with VL in a similar manner. Thin wing sections, however, seem to have the peak of the curves at much higher VLS, so that the comparison without scale effect is more favorable to the thick wing sections, when made with model tests run at the low VLS here used.

One source of error was not considered, namely, the variation in parasite area with angle of attack, due to the projection of the fuselage on the front plan, making the ceiling predictions too optimistic were it not for the counterbalancing error due to neglect of scale effect. This error, however, has little weight, where the charts are used for purposes of comparison, unless there is considerable variation in fuselage lengths.
**Fig. 1**
Ceiling vs $V_{MAX}$ at 12000 ft.
Graph for various wing sections with least pressure area about Cessna D-12 Motor.

**Fig. 2**
Ceiling vs $\frac{V}{S}$ vs $P_E$
For various wing sections about Cessna D-12 Motor.
Weight = 2500 lbs.
Fig. 3.

Ceilings vs \( \frac{W}{A} \) for various wing sections about Coentis D-12 motor weight 2200 lbs 2700 lbs.

Fig. 4

Airplane with least profile area about RAF 13 wings
Ceilings vs weight for 32 ft with 3 different engines.
**Fig 5**

Airplane with least parasite area about RAF-15 wing with 3 different engines high speed vs weight per sq ft at 15000 ft

**Fig 6**

Airplane with least parasite area about RAF-15 wing with 3 different engines ratio of wings to weight per sq ft at 15000 feet
Fig. 9

Increase in ceiling for 10% increase in power for Curtiss D-12 motor or 10% increase in propeller efficiency.